# Pinto Abalone (*Haliotis kamtschatkana)*

# *Bibliography*

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## Background & Scope

The National Marine Fisheries Service Alaska Region is interested in establishing a Habitat Focus Area in southern Alaska. One aspect of this Habitat Focus Area is an emphasis on the conservation of Alaska's only native abalone species, *Haliotis kamtschatkana*, also known as pinto or northern abalone. *H. kamtschatkana* is not currently an ESA-listed species, though it is on the IUCN Red List of Threatened Species and the Canadian government lists it as a "Species at Risk".

The NOAA Central Library has collaborated with NMFS to produce this bibliography, which covers traditional and grey scientific literature on *H. kamtschatkana* from the beginning of the twentieth century. The earliest reference is from 1921, though the majority of the literature was published between 1970 and the present.

This bibliography has been divided into the following sections. Some references are included in more than one section as applicable.

**Section I – Biology**

**Section II – Conservation and Management**

**Section III – Ecology**

**Section IV – Population**

**Section V – Threats**

**Section VI – Abalone Fisheries and Aquaculture**

**Section VII – Abalone and Sea Otters**

**Section VIII - Abalone and Indigenous Cultures**

## Sources Reviewed

Along with a web search for relevant grey literature materials, the following online databases were used to identify sources: Dimensions, Lens.org, Clarivate Analytics' Web of Science: Science Citation Index Expanded, Wiley Online Library, ProQuest's Earth-Atmospheric & Aquatic Science Database, Science Direct, BioOne Complete, Google Scholar, the Biodiversity Heritage Library, and JSTOR. Only English language materials were considered.

## Section I: Biology

Ahmed, F., Koike, Y., Strüssmann, C. A., & Watanabe, S. (2013). Effect of density on growth and feed consumption of the abalones *Haliotis discus discus*, *H. gigantea*, *H. madaka* and their hybrids. *Aquaculture International,* 21(5), 969-986. https://doi.org/10.1007/s10499-012-9606-5

Effect of stocking density was studied in three abalone species *Haliotis discus discus* (HDD), *H. gigantea* (HG), and *H. madaka* (HM) and their hybrids [HDD × HM, HM × HG and HG × HM, mother first] by rearing individually marked abalones for 217 days at low (22 % of available surface area; LD), medium (53 %; MD), and high (126 %; HD) densities. Feeding rate (FR) and feed conversion rate were observed by measuring the amount of feed ingested at an interval of 2-3 days. Reduction of growth rate with the increment of density was found in all three species [Specific growth rate in weight (G ^sub W^) HDD, LD: 0.121, MD: 0.093, HD: 0.069; HM: 0.12, 0.082, 0.061; HG: 0.254, 0.222, and 0.131] and the hybrids HDD × HM (0.18, 0.109, 0.108). The medium density produced the highest growth rates in HM × HG and HG × HM hybrids (0.284, 0.342, 0.28). A growth spurt was observed in all three species and hybrids in the last 44 days of rearing. FR varied from 0.72 to 7.97 % body weight and decreased with the increase in density in all species and hybrids. The results indicate differences in density thresholds for the three abalone species and their hybrids suggesting requirement of different aquaculture management strategies for them.

Alaska Department of Fish and Game. (2021). Commercial Abalone Harvest, Effort, Value, and Season Length. Retrieved from https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareasoutheast.dive_harvest_abalone

Table summarizing the following for the commercial abalone fishery: guideline harvest ranges (lb x 1000); Southern Southeast harvest (lbs); District 13 harvest (lbs); total Southeast Harvest (lbs); number of divers; exvessel value; and season length (days).

Allende Ladoux, G. M. (1993). *Fine structure events in mantle tissues of the pinto abalone (Haliotis kamtschatkana J.H. Jonas, 1845) which are associated with the culture of Mabe pearls.* (Master of Science Thesis), Simon Fraser University, Burnaby, BC. Retrieved from https://summit.sfu.ca/item/7927

The purpose of this research was to study the formation of nacre. The secretory system involved in shell mineralization was activated by the implantation of a nucleus between the mantle and the shell of northern abalone, *Haliotis kamtschatkana* Jonas 1845 (Gastropoda: Haliotidae). Histological and ultrastructural studies of the outer mantle epithelium of H. kamtschatkana were observed at intervals of various weeks.

The mantle epithelial cells secreted first the conchiolin in the formation of nacre. When the implanted nucleus was totally covered with conchiolin deposits, aragonite crystals which comprise the prismatic layer were deposited on the implanted nucleus. Subsequently, irregular nacre deposits which form the nacreous layer were secreted on the prismatic layer. The results suggest that during this deposition

process, two different secretory cells types are responsible for producing and releasing conchiolin and nacre.

Bartsch, P. (1940). The West American Haliotis. *Proceedings of the United States National Museum,* 89(3094), 49-58. Retrieved from https://www.biodiversitylibrary.org/page/7611462

Several interesting sendings of sea-ears from California by A. Sorensen made it necessary to subject the West American members of the genus Haliotis to a critical examination. The results are noted below.

Bower, S. M. (1987). Artificial culture of *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a pathogenic parasite of abalone. *Canadian Journal of Zoology,* 65(8), 2013-2020. https://doi.org/10.1139/z87-306

*Labyrinthuloides haliotidis* was isolated from infected abalone (*Haliotis kamtschatkana*) and successfully cultured in minimum essential medium with 10% fetal calf serum at 10 °C for at least 1 year. On transfer to sea water, some subcultures produced numerous motile biflagellate zoospores while zoospore production of other subcultures was poor. On return to minimum essential medium, zoospores transformed into rapidly dividing vegetative forms. *Labyrinthuloides haliotidis* was not fastidious in its nutrient requirements and vegetative forms grew well in several different liquid media, on agar containing 10% bovine serum, and on pine pollen (Pinus contorta) in sea water. The mean diameter of the round vegetative forms often varied significantly (Student's t-test, $P < 0.05$) but the overall range in diameter (3.1 to 16.2 μm) observed in the various media was similar. Best growth occurred at 10 °C and in media made up with 30% sea water. No growth occurred at 28 °C or above, or in thioglycollate culture medium at 10 °C. Although *L. haliotidis* grew on pine pollen in sea water, zoosporoblasts and zoospores were not produced. The disappearance of precipitated proteins in agar medium around colonies of *L. haliotidis* and the destruction of host tissue around the parasite in infected abalone suggest that extracellular digestion occurs with this organism.

Bower, S. M. (1987). *Labyrinthuloides haliotidis* n.sp. (Protozoa: Labyrinthomorpha), a pathogenic parasite of small juvenile abalone in a British Columbia mariculture facility. *Canadian Journal of Zoology,* 65(8), 1996-2007. https://doi.org/10.1139/z87-304

*Labyrinthuloides haliotidis* n.sp. is an achlorophyllous eucaryotic protist that is pathogenic to juvenile abalone *(Haliotis kamtschatkana* and *Haliotis rufescens*) less than 190 days of age (postsetting). Within the muscle and nervous tissue of the head and foot of susceptible abalone and in axenic nutrient culture media at 10 °C, vegetative stages of L. haliotidis proliferated by binary fission and produced ectoplasmic nets from sagenogenetosomes located on the cell periphery. When the abalone died and the parasites were released from the decaying tissue or when culture forms were washed free of nutrient medium and placed in sea water, internal multiple fission (sporulation) occurred within some cells, producing zoosporoblasts. After 24 to 72 h of incubation at 10 °C, the zoosporoblasts ruptured to release from 3 to about 10 infective biflagellated zoospores. After about 24 h of active swimming, or on contact with a glass surface, the zoospores shed their flagella. Ultrastructure of vegetative stages and zoospores related this species more closely to the thraustochytrids than to the labyrinthulids. Confusion still prevails concerning the higher taxonomic affinities of this group of organisms. In keeping with recent

publications on the taxonomy of the kingdom Protozoa, L. haliotidis was considered to be a protozoan of the phylum Labyrinthomorpha and not allied with the fungi.

Bower, S. M. (1987). Pathogenicity and host specificity of *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a parasite of juvenile abalone. *Canadian Journal of Zoology,* 65(8), 2008-2012. https://doi.org/10.1139/z87-305

Infections with Labyrinthuloides haliotidis, an achlorophyllous, eucaryotic protist, were lethal to almost all juvenile abalone (*Haliotis kamtschatkana* and *Haliotis rufescens*) less than 6 months of age in an abalone mariculture facility in British Columbia, Canada. In laboratory experiments, L. haliotidis isolated from infected abalone or grown in axenic nutrient medium was infective for abalone (H. kamtschatkana) less than 4.0 mm in shell length and 140 days of age. Ten days after exposure to at least 104 parasites in 20 mL of sea water, about 90% of these abalone died with numerous parasites throughout the tissues of the head and foot. By about 190 days of age, regardless of shell size, abalone mortalities were reduced to less than 50% after exposure to about 105 parasites. Finally, by about 340 days of age, most juvenile abalone (4.0 to 10.5 mm in shell length) did not succumb after three consecutive exposures, 13 days apart, to between 2 × 105 and 5 × 106L. haliotidis. Larger abalone (15 to 25 mm in shell length) did not become infected following intramuscular injections of about 1.5 × 104L. haliotidis. Small juvenile scallops (Patinopecten yessoensis) and juvenile oysters (Crassostrea gigas), both less than 8 months of age, were also resistant to infection. However, two of the oysters with badly cracked shells became infected. This suggests that if L. haliotidis can gain access, it is capable of using living oyster tissue as a source of nutrients for growth and multiplication.

Bower, S. M. (1988). *Abalone disease research*. Aquaculture Update (28). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/337853.pdf

Scientists at the Pacific Biological Station have recently investigated a previously unknown organism which has caused high mortalities of juvenile abalone cultured at a mariculture facility in British Colurrbia. The cause of the hicjl mortality rates is a microscopic parasite that is new to science. The parasite belongs to a group of single-celled organisms historically studied by mycologists and therefore known as fungi. About 5 years ago, this group of organisms was transferred to the protozoan kingdom and placed in their own phylum called Labyrinthomorpha.

Bower, S. M. (1996). *Disease risks associated with the transplantation of abalone, geoducks, sea urchins and spot prawns in British Columbia*.Aquaculture Update (76). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/280586.pdf

A few examples of infectious agents that cause disease problems in shellfish currently under consideration for culture in B.C.

Bower, S. M., McLean, N., & Whitaker, D. J. (1989). Mechanism of infection by *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a parasite of abalone (*Haliotis kamtschatkana*) (Mollusca: Gastropoda). *Journal of Invertebrate Pathology,* 53(3), 401-409. https://doi.org/10.1016/0022-2011(89)90106-7

Biflagellated zoospores of the thraustochytrid *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a pathogenic parasite of juvenile abalone (*Haliotis kamtschatkana*), lost their flagella on contact with the abalone host. Within 4 hr, and prior to the complete development of the ectoplasmic net, sagenogenetosomes were produced and extracellular lytic activity disrupted the plasmalemma layer of host epithelial cells adjacent to the parasite. The damaged epithelial cells were lysed and the parasites entered into the resulting lesion. The ectoplasmic nets extending from the sagenogenetosomes were well developed within 24 hr and may have released lytic agents since net elements were observed deep within the cytoplasm of host cells. Nevertheless, the ectoplasmic net enabled the parasite to move into and within the head and foot tissues of the abalone. As demonstrated by their ultrastructural morphology, the motile zoospores were transformed to vegetative cells within 4 hr and binary fission was observed in the resulting vegetative cells within 24 hr.

Bower, S. M., Whitaker, D. J., & Elston, R. A. (1989). Detection of the abalone parasite *Labyrinthuloides haliotidis* by a direct fluorescent antibody technique. *Journal of Invertebrate Pathology,* 53(2), 281-283. https://doi.org/10.1016/0022-2011(89)90021-9

*Labyrinthuloides haliotidis* (Thraustochytriaceae) is an achlorophyllous eukaryotic protist that is pathogenic to juvenile abalone (*Haliotis kamtschatkana* and *Haliotis rufescens*) (S. M. Bower, Canad. J. Zool. 65, 2008-2012, 1987). Unfortunately, without determining its pathogenicity for small abalone or observing its morphological and growth characteristics in axenic cultures, this parasite has no distinctive taxonomic features (S. M. Bower, Canad. J. 2001. 65, 1996-2007, 1987). In order to facilitate identification of this pathogen, a fluorescein conjugated antiserum was produced so that a direct fluorescent antibody technique could be developed and its specificity was tested.

Breen, P. A., & Adkins, B. E. (1980). Spawning in a British Columbia population of northern abalone, Haliotis kamtschatkana. *The Veliger,* 23(2), 177-179. Retrieved from https://www.biodiversitylibrary.org/page/42412398

The northern abalone (Haliotis kamtschatkana Jonas, 1845) has supported a commercial fishery of 500,000-1,000,000 pounds (225-450 t) annually in British Columbia since 1976. Because of the interest in both management problems and artificial culture, the reproductive biology of abalones worldwide has been well studied (see Mottet, 1978 for review). However, the spawning behavior and season of H. kamtschatkana are not well described either in British Columbia or elsewhere. The season of spawning is of direct interest in regulating the fishery, especially if abalone are less valuable as a product or are more vulnerable to damage near spawning. Spawning behaviour also has some implications for management, which will be discussed below.

Quayle (1971) studied reproduction in this species by examining gonad sections from at least 25 individuals per month, taken from several British Columbia locations. Although his study lasted several years, he could find no demonstrable cycle, and he found ripe abalone throughout the year. Some recovering gonads were observed from April through June, and a spontaneous spawning was observed

in May among individuals held in the laboratory; both suggesting natural spawning in that part of the year. Hahn (unpublished M.S.) studied seasonal changes in gonad index and spawning phase in this species at a California site, and found that spawning occurred in March or April of three consecutive years. As Quayle had observed, there was considerable variation around the seasonal pattern, and partially spawned individuals were found throughout the year.

Campbell, A. (1997). *Possible criteria for re-opening the northern abalone fishery in British Columbia*.Canadian Stock Assessment Secretariat Research Document (97/64). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/243183.pdf

This paper reviews the literature for relevant biological and fishery characteristics of different abalone species, makes yield and egg per recruit calculations and suggests biological reference points, criteria for reopening a potential fishery, and possible rehabilitation and management actions for the northern abalone, Haliotis kamtschatkana, in British Columbia. The biology of the H. kamtschatkana makes this species vulnerable to over exploitation. The northern abalone is slow growing, relatively long lived and sedentary, and has low or sporadic recruitment with accumulations of older individuals distributed in shallow water locations easily accessible to harvesters. The high market value, reduced availability, and the difficulty of enforcing the fishery closure since 1990 in a large mostly uninhabited coastal area, has encouraged illegal harvesting of northern abalone populations, hampering attempts to rebuild stocks to a level that would allow a sustainable legal harvest. Evidence to date, from surveys in the central coast of British Columbia and Queen Charlotte Islands, indicate that there has been insufficient recruitment during the last two decades to maintain estimated fishing rates (F) during 1976-90 when the legal fishery was open (mean F about 0.5) and during the closure 1990-94 (F ranged from 0.1 to 0.7 in some locations). Samples from abalone illegally harvested during 1995 suggested that poachers removed all sizes of available abalone with no regard to the minimum size limit of 100 mm shell length that was in force during the legal fishery. Without size and fishing rate controls, egg per recruit (EPR) analyses suggested that egg production, during the closed fishery, could probably be at or less ( 50%EPR have been sustained; other fisheries that conserved lower egg production have suffered poor recruitment, stocks have declined and many fisheries closed. However, because of the difficulties of showing a stock-recruitment relation, predicting how environmental / ecosystem changes influence abalone stock dynamics, and ongoing poaching problems, there are no guarantees that various rebuilding / rehabilitation strategies will work.

Campbell, A., Lessard, J., & Jamieson, G. S. (2003). Fecundity and seasonal reproduction of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, Canada. *Journal of Shellfish Research,* 22(3), 811-818. Retrieved from https://www.biodiversitylibrary.org/page/3105535

Fecundity, size at maturity and seasonal reproduction of northern or "pinto" abalone, Haliotis kamtschatkana, from exposed "surf" areas and more sheltered, productive abalone habitat were investigated in Barkley Sound. Examination of histologic sections of gonads indicated that size at maturity occurred at a smaller size for the stunted 'surf' abalone than for abalone from more sheltered areas. Gonad index and stages showed that gonads were mainly ripe and that most abalone spawned during April to July. Although there were smaller abalone with ripe eggs from the "surf" area than those from the sheltered area, abalone females of comparable size from both areas had similar egg numbers. However, there were larger females with considerably higher fecundity from the sheltered areas than

from the "surf" areas. Implications of transplanting "surf" abalone to productive habitats to increase growth and fecundity rates are discussed in the context of population rebuilding attempts for H. kamtschatkana, which is listed by the Committee on the Status of Endangered Wildlife in Canada as a "threatened" species in Canada.

Campbell, A., Withler, R. E., & Supernault, K. J. (2010). Occurrence of the Red Abalone *Haliotis rufescens* in British Columbia, Canada. *American Malacological Bulletin,* 28(2), 185-188. https://doi.org/10.4003/006.028.0213

We document the first occurrence of a live red abalone, *Haliotis rufescens* Swainson, 1822, found on the central coast of British Columbia. The initial identification was based on morphological characteristics. Previously, the northern or “pinto” abalone *Haliotis kamtschatkana* kamtschatkana Jonas, 1845 has been the only abalone species considered to naturally occur in the coastal waters of British Columbia. Since hybridization of H. kamtschatkana with H. rufescens was known to occur, genetic analysis of tissue samples was undertaken to confirm the morphological identification as a purebred red abalone.

Carefoot, T. H., Qian, P.-Y., Taylor, B. E., West, T., & Osborne, J. (1993). Effect of starvation on energy reserves and metabolism in the Northern abalone, *Haliotis kamtschatkana*. *Aquaculture,* 118(3), 315-325. https://doi.org/10.1016/0044-8486(93)90466-C

The effects of starvation on levels of tissue glycogen, blood glucose, and oxygen consumption, as well as on condition index and meat palatability were investigated in the Northern abalone, Haliotis kamtschatkana. Glycogen reserves were depleted within 6 days of starvation in the digestive gland and after 27 days of starvation in the foot muscle, but were spared, at least in relative concentration, in the gonad. Blood glucose titre dropped to about half of the normal (control) level of 23–27 μg·ml−1 by 6 days of starvation. Oxygen consumption appeared to be maintained at normal, or even slightly enhanced, levels during the starvation period, and feeding of starved animals after 3.5 weeks resulted in a quick return to normal rates. Change in condition index was insignificant over the 27-day period. Finally, meat quality was unaffected over 27 days of starvation, as appraised by a taste-testing panel. It is concluded that 27 days of starvation led to no debilitating illness or excessive weight loss, nor to loss in meat quality in the abalone.

Carefoot, T. H., Taylor, B. E., & Donovan, D. A. (1998). Seasonality in digestive-gland size and metabolism in relation to reproduction in *Haliotis kamtschatkana*. *Journal of Shellfish Research,* 17(3), 713-716. Retrieved from https://www.biodiversitylibrary.org/page/2151942

A novel method of isolating digestive grand cells in abalone was used to provide information on the metabolic activity of this gland in Haliotis kamtschatkana. Activity, expressed as percent change in Vo(2) of isolated cells before and after the addition of glucose and amino acid substrates, was studied in relation to sex and to seasonal changes in gonad and digestive gland indices. At 3- to 4-mo intervals between May 1995 and July 1996, five collections of 10 adult abalone (equal sexes) were made from the West Coast of Vancouver Island, British Columbia. Each animal's live mass (without shell) was recorded, and its gonad was aspirated from the digestive gland into a known volume land mass) of seawater. The digestive gland was sliced free of its attachment, weighed, and related to shelf-less body mass as percent digestive gland index (DGI). The gonad live mass was determined from the mass of aspirated

mix of gonad and seawater, and related to shell-less body mass to give a percent gonad index (GI). Digestive gland cells were prepared and maintained in a special buffer, and their Vo(2)'s measured in microrespirometers. There was no sex effect on seasonal DGI, but significant seasonal differences in DGIs correlated perfectly with metabolic activity of digestive-gland cells with glucose substrate. Thus, when digestive glands were largest relative to body size, metabolic activity of their cells was greatest. GIs were significantly higher for males than females. There was a significant seasonal effect on GIs, with Values being high in springtime before spawning (April to May, 10-11%) and low in winter (December, 6%), but with statistical overlap between these and summer values (July to August, 7-8%). Metabolic response of the digestive gland cells was highest with glucose substrate (75% increase over presubstrate resting levels as compared with 4% for amino acid substrate), reflecting the carbohydrate-based metabolism of abalone.

Carefoot, T. H., Taylor, B. E., & Land, S. (2000). Use of isolated digestive-gland cells in the study of biochemical and physiological processes in gastropod molluscs. *Comparative Biochemistry and Physiology a-Molecular and Integrative Physiology,* 125(4), 497-502. https://doi.org/10.1016/s1095-6433(00)00181-1

We describe a method for preparation and maintenance of isolated digestive-grand cells in the abalone, Haliotis kamtschatakana. Viability of the isolated cells was confirmed by the fact that 18 h after preparation the cells exhibited less than 5% staining with trypan blue and actively synthesized glycogen following the addition of glucose substrate. Use of the method in a 15-month study of metabolic activity of the digestive gland of H. kamtschatkana showed significant differences in oxygen consumption of isolated-cell preparations correlated with seasonal differences in somatic and gametogenetic growth, and with relative size of the digestive gland.

Carson, H. S., Morin, D. J., Bouma, J. V., Ulrich, M., & Sizemore, R. (2019). The survival of hatchery-origin pinto abalone *Haliotis kamtschatkana* released into Washington waters. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 29(3), 424-441. https://doi.org/10.1002/aqc.3004

Wild populations of pinto abalone (Haliotis kamtschatkana) in Washington State have declined by 97% since 1992, despite a fishery closure since 1994. No recruitment has been detected recently, indicating probable reproductive failure due to low densities. A pilot programme placed a total of over 11,000 hatchery-origin juveniles, age 18-22months, at 10 sites in the San Juan Islands. Observed (naive) year1 survival averaged 10.2% (0-23% range) and was most influenced by site compared with lineage or size-at-outplant. Families survived in the approximate proportions that they were outplanted, and there was little support for an effect of size-at-outplant on survival. etection was low due to the small chance of sighting individuals on complex substrate. When derived from repeated sampling, an upper bound on naive detection rate averaged 0.38 and increased with size. When derived from a closed capture-recapture model, average detection was estimated at 0.19. Growth was highly variable and confounded with detection, but an average 3.4% of detected outplants across all sites (0-7.5% range) had reached reproductive size in 2017. A state-space model of exponential population growth was modified to account for imperfect detection and yielded an estimated density of abalone for each survey. Seven out of eight sites included in the model remained above a target abalone density of 0.3m(-2) throughout the project. The majority of tagged abalone made little net movement over weekly and annual timescales, although some emigration likely reduced survival estimates. The restoration programme is transitioning from a pilot phase to a production phase, including optimization of hatchery and outplant processes.

Existing well-performing sites will receive additional cohorts every 4-5years to maintain aggregation densities. New sites will replace poorly performing ones, although this is hampered by a poor understanding of the mechanisms behind site performance.

Carson, H. S., Ulrich, M., & Bouma, J. (2018, 2018/05/18). *Survival of hatchery-origin juvenile pinto abalone (*Haliotis kamtschatkana*) outplanted to restoration sites in the San Juan Islands.* Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/544/

The Washington Department of Fish and Wildlife, Puget Sound Restoration Fund, and other project partners have outplanted thousands of hatchery-reared pinto abalone in annual cohorts to ten sites in the San Juan Archipelago since 2009. We measured the “success” of each outplant site by the proportion of total juveniles placed that survived to a reproductive size. In winter 2017 surveys we observed a range of successes, from 0% at the worst site to 5.6% at the best. When nearby individuals are included, this success ranges as high as 7.5%. These percentages do not account for the probability of detection for a given abalone, which available information from tagged abalone suggests is between 20 – 40%. They also do not account for emigration from the sites, which has not been quantified. I’ll discuss these results, their implications for on-site reproduction, and their incorporation into an integrated population model describing the survival and growth of outplanted juveniles. I’ll also discuss the future of pinto abalone recovery, including our new strategy to “repeal and replace” low performing sites, optimize outplant efficiency, and scale-up restoration efforts to achieve population-wide recovery.

Collin, R., & Voltzow, J. (1998). Initiation, calcification, and form of larval ''archaeogastropod'' shells. *Journal of Morphology,* 235(1), 77-89. https://doi.org/10.1002/(SICI)1097-4687(199801)235:1<77::AID-JMOR6>3.0.CO;2-L

The coiled shell of gastropods begins as a cap-shaped lens of organic and calcified material that covers the posterior dorsal side of the larva. During development the cap enlarges to cover the larval visceral mass. Marginal growth then produces the characteristic coiled shell. One model of the initiation of shell coiling in ''archaeogastropods'' requires that the shell remains flexible and uncalcified until after torsion, and that muscle contraction during torsion deforms the shell. We describe early shell calcification and tested this requirement of the model for the patellogastropod limpets Tectura scutum and Lottia digitalis, the trochids Calliostoma ligatum and Margarites pupillus and the abalone Haliotis kamtschatkana. We determined the stage of initial calcification by staining larvae with the fluorescent calcium marker calcein and observing them with bright field, crossed polarizing filter, and fluorescence microscopy. In T. scutum the earliest observable shell was calcified and calcium was sometimes detected even before the initial shell was visible. Larvae of the other species deposited a noncalcified matrix that was subsequently calcified, and in C. ligatum and M. pupillus this initial calcification was distinctly spotty. Shells of both patellogastropods and the abalone were demonstrably rigid prior to torsion while the shells of the trochids were not. These results suggest that shell coiling in patellogastropods and abalone is not initiated by contraction of the larval. retractor muscle during torsion; in trochids this mechanism is possible. However, analysis of camera lucida drawings of pre- and post-torsional shells of T. scutum and C. ligatum did not detect shell shape changes during torsion.

COSEWIC. (2009). *COSEWIC Assessment and Update Status Report on the Northern Abalone Haliotis kamtschatkana in Canada.* Ottawa, ON. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_northern_abalone_0809_e.pdf

Highly valued for its meat, this marine mollusc is patchily distributed along the west coast of Canada. Despite a total moratorium on harvest in 1990, the species was designated as Threatened in 2000. Poaching is the most serious threat and continues to reduce population abundance, particularly the larger, more fecund component; however, all size classes have declined significantly over the past three generations (i.e. since 1978) with mature individuals declining an estimated 88-89%. Low densities may further exacerbate the problem by reducing fertilization success in this broadcast spawner (the Allee effect). Although predators such as the recovering Sea Otter population are not responsible for recently observed declines, they may ultimately influence future abundance of abalone populations.

Cox, K. W. (1960). Review of the Abalone in California. *California Fish and Game,* 46(4), 380-406. Retrieved from https://www.biodiversitylibrary.org/page/18552511

In 1951 the Department of Fish and Game was directed by the State Legislature to expand its abalone investigation which had been in progress since 1939. Activities, at first concentrated in the area north of San Francisco, were later extended to include a major part of the central and southern California coastline and the Channel Islands. A preliminary report on the findings was presented to the Assembly Interim Committee on Fish and Game in August 1955; an article containing information on parts of the program was featured in Outdoor California, May 1957; Notes on the California Abalone Fishery were printed in Proceedings of the National Shellfish Association, 1958; a summary report was submitted to the Director of the Department of Fish and Game in November 1958; and, a detailed report on the investigation's findings in the coastal area north of San Francisco was presented to the State Legislature in March 1959.

In the course of the investigation a considerable amount of new information has been gathered and this report, which redescribes the species of abalone found in California, is based on some of these findings. Many conservationists, biologists, wardens and others who are charged with management and law enforcement are not able to identify all of the different species of abalone. Of the thousands of sportsmen who fish abalone, less than one percent know all of the species they take; and, many engaged in the commercial fishery are not familiar with all the abalone they encounter. Since most of the laws and regulations governing the fishery are different for each species, proper identification is of the greatest importance for all concerned. In most instances the identity of an abalone can be determined by comparing it with written descriptions, shells or photographs of known species. Because of great variations in shell form, sculpture and color, a number of abnormal and atypical individuals have been erroneously described as new. With few exceptions, descriptions of abalone have been confined to shell characteristics. Only rarely has the apprearance of the living animal been mentioned. This report includes a brief description of the distinguishing parts of the body and epipodium of the live animal. These structures usually are characteristic for each species and have the added advantage of being easily recognized. In addition to presenting descriptive information and notes on distribution, habitat and economic importance, a brief outline of the general life history of abalone and a field key (Table 1) for the identification of the eight California species are included.

Crim, R. N. (2010). *Effects of ocean acidification on different life history stages of northern abalone (Haliotis kamtschatkana).* (Master of Science Thesis), University of British Columbia, Vancouver, BC. Retrieved from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071410

Anthropogenic atmospheric $CO_2$ levels are rapidly increasing; however, much of this $CO_2$ (ca. 30%) dissolves into the surface ocean (upper 200 m) where it reacts with seawater and disrupts both ocean pH and carbonate chemistry, a process termed ocean acidification. Average pH of the surface ocean has already decreased by 0.1 units since the beginning of the Industrial Revolution and is expected to drop another 0.2 to 0.4 units by the end of this century. Of primary concern is the potential for ocean acidification to dramatically disrupt biological processes, especially biogenic calcification. Different life history stages may also be affected in different ways. Furthermore, interactions between ocean acidification and other environmental perturbations are often non-additive and thus result in non-predictive outcomes. Here, I investigate the effects of ocean acidification on different life history stages of an endangered abalone, Haliotis kamtschatkana. I reared larvae and adults under elevated $CO_2$ conditions (800 and 1800 ppm), representing levels expected by the end of this century and beyond. Adults were also reared under two temperatures (9 and 12°C) to investigate interactions between $CO_2$ and temperature. Larval survival, shell size and shell morphology were negatively affected by elevated $CO_2$. At 1800 ppm, almost all larvae completely lacked a shell. Adults seem more tolerant of elevated $CO_2$. Survival, growth and feeding rates were unaffected by elevated $CO_2$, at either temperature. Early life history stages may be more sensitive due to differences in calcification processes. Near future levels of ocean acidification may dramatically impair early development of H. kamtschatkana but later life history stages may be more tolerant. Since H. kamtschatkana population growth is thought to be currently limited by successful fertilization, decreases in larval survival may have severe consequences for the recovery of this endangered species. Efforts to mitigate the dramatic population decline of H. kamtschatkana will need to consider the potential repercussions of ocean acidification.

Crim, R. N., Sunday, J. M., & Harley, C. D. G. (2011). Elevated seawater CO2 concentrations impair larval development and reduce larval survival in endangered northern abalone (*Haliotis kamtschatkana*). *Journal of Experimental Marine Biology and Ecology,* 400(1-2), 272-277. https://doi.org/10.1016/j.jembe.2011.02.002

Increasing levels of anthropogenic carbon dioxide in the world's oceans are resulting in a decrease in the availability of carbonate ions and a drop in seawater pH. This process, known as ocean acidification, is a potential threat to marine populations via alterations in survival and development. To date, however, little research has examined the effects of ocean acidification on rare or endangered species. To begin to assess the impacts of acidification on endangered northern abalone (Haliotis kamtschatkana) populations, we exposed H. kamtschatkana larvae to various levels of CO2 [400 ppm (ambient), 800 ppm, and 1800 ppm CO2] and measured survival, settlement, shell size, and shell development. larval survival decreased by ca. 40% in elevated CO2 treatments relative to the 400 ppm control. However, CO2 had no effect on the proportion of surviving larvae that metamorphosed at the end of the experiment. Larval shell abnormalities became apparent in approximately 40% of larvae reared at 800 ppm CO2, and almost all larvae reared at 1800 ppm CO2 either developed an abnormal shell or lacked a shell completely. Of the larvae that did not show shell abnormalities, shell size was reduced by 5% at 800 ppm compared to the control. Overall, larval development of H. kamtschatkana was found to be sensitive to ocean acidification. Near future levels of CO2 will likely pose a significant additional threat to

this species, which is already endangered with extinction due in part to limited reproductive output and larval recruitment.

Crosson, L. M. (2020). *Withering Syndrome Disease Dynamics in Wild and Cultured Northeastern Pacific Abalones.* (Ph.D. Thesis), University of Washington, Seattle, WA. Retrieved from http://hdl.handle.net/1773/46008

Withering syndrome (WS) is a chronic bacterial disease of abalones, Haliotis spp., caused by a Rickettsia-like organism (WS-RLO). The etiological agent, Candidatus Xenohaliotis californiensis, occurs along the eastern Pacific margin of North America in California, US and Baja California, Mexico. However, as infected abalones have been transported to Chile, China, Taiwan, Iceland, Ireland, Israel, Spain, Thailand, and Japan, the geographic range of the bacterium is likely broad especially where California red abalone (Haliotis rufescens) are cultured or in areas where native species have been exposed to red abalone. Disease susceptibility varies among abalones with up to 99% losses of black abalone (H. cracherodii) in lab and field studies in the US, to no losses among the small abalone (H. diversicolor supertexta) in Thailand. Some abalone populations that have suffered severe WS mortality events have developed resistance to the disease. In addition, a newly identified phage hyperparasite of the WS-RLO may reduce pathogenicity and dampen associated losses. Proper diagnosis of WS requires the identification of infection with the pathogen (WS-RLO detected via in situ hybridization or histology coupled with PCR and sequence analysis) accompanied by morphological changes that characterize this disease (e.g. digestive gland metaplasia and pedal atrophy). A quantitative PCR (qPCR) assay was recently developed and validated for the detection of WS-RLO DNA in abalone tissues, feces, and seawater. While confirmation of infection cannot be done by PCR-based assays alone, they can be used as proxies for infection in areas where the WS-RLO is established and are recommended for inclusion in all abalone health examinations. Avoidance of WS is best accomplished by the establishment of a health history, good husbandry practices, and multiple health examinations prior to the movement of animals. Population declines in wild and cultured abalones due to WS have been well documented along the northeastern Pacific Ocean. However, observed differences in species susceptibility to the disease are not well understood. The first objective of my dissertation was to examine the susceptibility of three temperate abalone species, the cool water (4-14°C) pinto or northern abalone (H. kamtschatkana), the intermediate water (8-18°C) red abalone, and the warm water (12-23°C) pink abalone (H. corrugata), to experimental WS infection at temperatures facilitating disease proliferation. Mortality data paired with histological and molecular detection of the WS pathogen confirmed that these abalone species exhibit different levels of susceptibility to infection and resistance to WS development ranging from high susceptibility and low resistance in pinto abalone to moderate/low susceptibility and resistance in red and pink abalones. The temperature associated with WS induced mortalities also varied among species: pinto abalone died at the lowest experimental temperature (17.32 ± 0.09°C), while red abalone died at an intermediate temperature (17.96 ± 0.16°C), and pink abalone required the highest temperature (18.84 ± 0.16°C). When data from the current and previous studies were examined, susceptibility to WS was inversely related to phylogenetic distance from white abalone (H. sorenseni), which had the highest susceptibility and lowest resistance of all abalone species tested prior to the current study. These results provide further evidence that an abalone's thermal optima and phylogenetic relationship can determine its susceptibility to WS; species with cool water evolutionary histories are most susceptible to WS and the most susceptible species appear to be closely related. Differences among the thermal ranges of abalone species have broad implications for WS disease dynamics and highlight the importance of understanding the mechanisms governing the abalone-WS relationship in order to properly manage declining abalone populations. My second dissertation objective was to elucidate important

epidemiological information on the WS-RLO. The bacterium remains unculturable thereby limiting our understanding of WS disease dynamics. My goals were to: (1) determine the temporal stability of WS-RLO DNA outside of its abalone host in 14°C and 18°C seawater, (2) develop a standardized protocol for exposing abalones to known concentrations of WS-RLO DNA and (3) calculate the dose of WS-RLO DNA required to generate 50% infection prevalence (ID50) in the highly cultured red abalone. WS-RLO stability trials were conducted in October 2016, February 2017, and June 2017 during which qPCR analysis was used to quantify bacterial DNA for 7 days in seawater collected at an abalone farm in southern California where the pathogen is endemic. For all trials and temperature treatments, WS-RLO DNA was not stable in seawater longer than 2 days. To determine an ID50, groups of uninfected juvenile red abalone were subjected to 3-hour bath exposures of WS-RLO at four concentrations: 0, 103, 104, and 105 DNA copies/mL. Abalone feces were monitored bi-weekly for the presence of WS-RLO DNA and abalone tissues were sampled 9 weeks after dosing for histology and qPCR examination. Results from the ID50 indicated that our protocol was successful in generating WS-RLO infections and a pathogen dose of 2.3 x 103 DNA copies/mL was required to generate 50% infection prevalence in the tissue of red abalone as assessed by qPCR. The WS-RLO is considered an established bacterial pathogen in coastal CA seawaters and is of great concern to coastal managers and local abalone aquaculture facilities (AFs) conducting open or flow-through seawater culture methods. California AFs are at high risk for spillback (wild to farm) and spillover (farm to wild) disease transmission due to high abalone host densities and the use and release of coastal seawater that may contain the WS-RLO and its associated novel phage. To address these concerns, my third and final dissertation objective was to sample nearshore surface seawater from nine established wild black abalone sites and four red abalone AFs from Bodega Bay, Sonoma County, CA, US to Ventura County, CA, US including the Channel Islands over two consecutive summers to determine the presence and amount of WS-RLO and phage DNA via qPCR. In July 2010, WS-RLO DNA was detected as far north as Andrew Molera State Park, Big Sur, CA and as far south as San Nicolas Island (SNI). Phage DNA was detected from Monterey Bay, CA to SNI. In July 2011, WS-RLO DNA was detected as far north as Davenport, CA and as far south as SNI. The phage DNA detection range remained the same as the 2010 survey. Phage DNA loads did not vary by year at AF or wild sites. However, WS-RLO DNA loads were greater in 2011 than 2010 at wild sites, while those at AFs did not vary by year. In October 2013, surface seawater surveys were conducted at the two southern-most AFs in Cayucos and Goleta, CA to assess fine-scale WS-RLO DNA dilution potential from a point-source discharge. In the 2013 samples, WS-RLO DNA loads in seawater directly adjacent to the AFs were less than the mean levels detected at all wild black abalone sites previously surveyed within 50 to 500 m of the AFs effluent outfalls. While these findings present management concerns for both wild and cultured California abalones, it is important to acknowledge that PCR-based assays do not indicate the presence of viable pathogen or active infection and serve as a proxy for WS exposure. In order to fully assess the potential for wild and cultured abalone disease interactions, additional experiments should be conducted to determine the longevity and infectivity of the WS-RLO and novel phage in seawater. Collectively, these findings are critical components of disease dynamics that will help assess WS transmission risk within and among abalone populations and facilitate appropriate management and restoration strategies for both wild and cultured abalone species in WS-endemic areas.

Crosson, L. M., & Friedman, C. S. (2018). Withering syndrome susceptibility of northeastern Pacific abalones: A complex relationship with phylogeny and thermal experience. *Journal of Invertebrate Pathology,* 151, 91-101. https://doi.org/10.1016/j.jip.2017.11.005

Population declines in wild and cultured abalones (Haliotis spp.) due to a bacterial disease called withering syndrome (WS) have been documented along the northeastern Pacific Ocean. However,

observed differences in species susceptibility to the disease are not well understood. Here, we examined the susceptibility of three temperate abalone species, the cool water (4-14 degrees C) pinto or northern abalone (Haliotis kamtschatkana), the intermediate water (8-18 degrees C) red abalone (H. rufescens), and the warm water (12-23 degrees C) pink abalone (H. corrugata), to experimental WS infection at temperatures facilitating disease proliferation. Mortality data paired with histological and molecular detection of the WS pathogen confirmed that these abalone species exhibit different levels of susceptibility to infection and resistance to WS development ranging from high susceptibility and low resistance in pinto abalone to moderate/low susceptibility and resistance in red and pink abalones. The temperature associated with WS induced mortalities also varied among species: pinto abalone died at the lowest experimental temperature (17.32 +/- 0.09 degrees C), while red abalone died at an intermediate temperature (17.96 +/- 0.16 degrees C), and pink abalone required the highest temperature (18.84 +/- 0.16 degrees C). When data from the current and previous studies were examined, susceptibility to WS was inversely related to phylogenetic distance from white abalone (H. sorenseni), which had the highest susceptibility and lowest resistance of all abalone species tested prior to the current study. These results provide further evidence that an abalone's thermal optima and phylogenetic relationship can determine its susceptibility to WS; species with cool water evolutionary histories are most susceptible to WS and the most susceptible species appear to be closely related. Differences among the thermal ranges of abalone species have broad implications for WS disease dynamics and highlight the importance of understanding the mechanisms governing the abalone-WS relationship in order to properly manage declining abalone populations.

Crosson, L. M., Wight, N., VanBlaricom, G. R., Kiryu, I., Moore, J. D., & Friedman, C. S. (2013). *Abalone Withering Syndrome: Distribution, Impacts, Current Diagnostic Methods, and New Findings.* Paper presented at the 40th U.S.-Japan Aquaculture Panel Symposium, Honolulu, Hawaii. Retrieved from https://repository.library.noaa.gov/view/noaa/4598

Withering syndrome (WS) is a fatal disease of abalone caused by a Rickettsiales-like organism (WS-RLO). The causative agent, “Candidatus Xenohaliotis californiensis,”occurs along the eastern Pacific margin of North America in California, USA and Baja California, Mexico. However, as infected abalones have been transported to Chile, China (People’s Rep. of), Taiwan, Iceland, Ireland, Israel, Spain, Thailand, and most recently Japan, and possibly other countries, the geographical range of the etiological agent is suspected to be broad, especially where California red abalones, Haliotis rufescens, are cultured or in areas where native species have been exposed to this species. Susceptibility varies among species with up to 99% losses of black abalone, H. cracherodii, in lab and field studies in the USA, to no losses among the small abalone, H. diversicolor supertexta, in Thailand. Some populations that have suffered catastrophic losses due to WS have developed resistance to the disease. In addition, a newly identified phage hyperparasite of the WS-RLO may reduce pathogenicity and dampen losses from the WS-RLO. Diagnosis of WS requires the identification of infection with the pathogen (WS-RLO detected via in situ hybridization or histology coupled with PCR and sequence analysis) accompanied by morphological changes that characterize this disease (e.g. pedal and digestive gland atrophy, and digestive gland metaplasia). A quantitative PCR (qPCR) assay was developed and may be useful in quantifying amounts of pathogen DNA. Confirmation of infection by the WS-RLO cannot be done by PCR analysis alone as this method only detects pathogen DNA, but can be used as a proxy for infection in areas where the agent is established. Control measures include avoidance, culling infected animals, cooler temperature and, as per federal regulations, oral or bath treatment with oxytetracycline. Avoidance is best accomplished by the establishment of a health history and multiple health examinations prior to movement of animals.

Although histology or in situ hybridization are required to confirm infection, PCR is able to detect small amounts of pathogen DNA and is recommended for inclusion in health examinations.

Curtis, L. J. F., Swan, K. D., & Lessard, J. (2021). *Northern abalone,* Haliotis kamtschatkana*, juvenile sampling techniques: a summary of methods tested in the Broken Group Islands, Barkley Sound, British Columbia*. Canadian technical report of fisheries and aquatic sciences (3420). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.896896/publication.html

The Northern Abalone (*Haliotis kamtschatkana*) is Canada's only abalone species and is currently listed as Endangered under the Species at Risk Act. Despite the closure of the abalone fishery in British Columbia (BC) in 1990, the species remains at risk of extinction. In 2002, Fisheries and Oceans Canada (DFO) and Parks Canada embarked on a multi-year study to test aggregation of adult abalone as a population rebuilding method. Abalone are slow growing and methods to sample juveniles efficiently were needed to detect the effects of these aggregations in a relatively short time span, to study population dynamics and to reduce the potential cost of this field experiment. However, juvenile abalone are difficult to sample, in part due to their cryptic nature. Consequently, DFO conducted a series of experiments to evaluate different methods for sampling juvenile abalone. These included two passive sampling methods (post-larval collectors and artificial habitats) and five active sampling methods (rock removal, Venturi suction, magnified searches, cryptic searches, and day/night surveys). Due to logistical constraints, not all methods were tested concurrently or in the same habitat. Here we review the efficacy,challenges, and limitations of each sampling technique. Most methods did not provide aconsistent and/or efficient means of sampling post-larval or juvenile abalone. The inclusion ofcryptic searches in abalone surveys is likely the best means to improve the detection of juvenilesin coastal BC. However, all of the methods we tested have limitations which need to beaddressed before they may be implemented in a widespread fashion.

Dahlhoff, E. P., & Somero, G. N. (1993). Kinetic and structural adaptations of cytoplasmic malate dehydrogenases of eastern Pacific abalone (genus haliotis) from different thermal habitats: biochemical correlates of biogeographical patterning. *Journal of Experimental Biology,* 185(1), 137-150. https://doi.org/10.1242/jeb.185.1.137

We measured the effects of temperature on cytosolic malate dehydrogenases (cMDHs) from the shell muscle of five species of eastern Pacific abalone, genus Haliotis, found at different latitudes and/or tidal heights. The apparent Michaelis-Menten constant (Km) of coenzyme (nicotinamide adenine dinucleotide, NADH) was conserved within a narrow range (11–21 micromolar) at physiological temperatures for all species. However, elevated temperatures perturbed the Km of NADH for cMDHs of the two species living at higher latitudes and/or lower tidal heights [Haliotis rufesens (red) and H. kamtschatkana kamtschatkana (pinto)] to a much greater extent than for cMDHs of congeners from lower latitudes and/or higher tidal heights [H. fulgens (green), H. corregata (pink) and H. cracherodii (black)]. The apparent Arrhenius activation energies for the cMDHs of these five species showed a similar interspecific divergence. Furthermore, green, pink and black abalone have cMDHs that are more resistant to thermal denaturation than are cMDHs of red and pinto abalone. Native gel electrophoresis showed that cMDHs of red and pinto abalone had identical mobilities, whereas cMDHs of green, pink and black abalone are distinct both from each other and from that of the two cold-adapted species. These data suggest that cMDHs from the abalone species living in warm habitats are adapted to function

optimally at higher temperatures than are the cMDHs of the two species living in cooler habitats. The relationships suggested by these criteria are in agreement with other studies that used morphological and molecular indices to predict abalone phylogeny. These results therefore provide further evidence that interspecific variation in protein structure and function may be driven by natural selection based on only small (i.e. several degrees Celsius) differences in average body temperature, and that such selection is an important element of the mechanisms of species formation and the maintenance of biogeographic patterning.

de la Cruz, F. L., Amar-Basulto, G., del Rio-Portilla, M. A., & Gallardo-Escarate, C. (2010). Genetic analysis of an artificially produced hybrid abalone (*Haliotis rufescens* x *Haliotis discus* Hannai) in Chile. *Journal of Shellfish Research,* 29(3), 717-724. Retrieved from https://bioone.org/journalArticle/Download?urlId=10.2983%2F035.029.0324

The Chilean abalone aquaculture industry is only supported with two species introduced during the late 1970s: red abalone Haliotis rufescens and Japanese abalone H. discus hannai. At the moment, red abalone accounts for 97% of total production due to its adaptability for full-cycle culture and faster growing than the Japanese species. However, Japanese abalone has a better acceptance and higher prices in Asian markets. These dualities have been merged by the successful hybridization between red and Japanese abalone. The goal of this study was to carry out a genetic analysis on red and Japanese abalone populations and their interspecific hybrids. Microsatellite markers were applied in three hatchery populations (HRed, HJap, and HHyb) to assess the genetic diversity and to certificate hybrid status. Allelic diversity was similar between HRed and HHyb populations (12 alleles), whereas for HJap it was significantly lower (7.8 alleles). Mean observed and expected heterozygosity (H-o, H-e) were 0.533 (0.045) and 0.786 (0.031), with no significant differences among populations (P <= 0.05). In most cases, H-o values were lower than H-e, indicating significant deviations from Hardy-Weinberg equilibrium. Comparison among populations showed that the hybrids are comparatively more similar to H. rufescens than H. discus hannai. Furthermore, hybrid status was confirmed by the presence of species-specific bands for each parental species of microsatellite locus Hco97. This work is the first approach to characterize genetically hybrids of H. rufescens x H. discus hannai produced in Chile.

DeFreitas, B. A. (2005). *Manipulations of adult density and juvenile habitat quality in Northern Abalone stock restoration.* (Master of Science Thesis), Simon Fraser University, Burnaby, BC. Retrieved from https://summit.sfu.ca/item/8465

Wild abalone populations throughout the world have declined dramatically over the past 40 years due primarily to market demands for the mollusc's edible foot. Northern abalone (Haliotis kamtschatkana), the only abalone species occurring in British Columbia (B.C.), is widely thought to be threatened by potential population collapse as a result of low adult densities that impair reproductive potential. This study examined the hypothesis that the abundance of wild northern abalone populations are below a critical density required for successful reproduction and assessed two techniques that may aid the 'recovery' of northern abalone in B.C. In the first study, I created dense aggregations of mature abalone during the reproductive period to test whether abalone preferred high density spawning aggregations that theoretically enhance reproductive potential. Twelve weeks following the manipulations, transplanted abalone had dispersed from enhanced densities at different rates and one year later, abalone densities had returned to pre-treatment levels. Slower rates of transplanted abalone dispersal at specific locations indicated that artificially aggregated abalone may have an enhanced theoretical

reproductive potential. However, transplanted abalone dispersing to pre-treatment densities indicated that wild populations do not necessarily suffer from impaired reproductive potential. In the second study, I installed artificial habitats that provided standardized surrogate habitat for juvenile abalone and surveyed surrounding natural habitats to determine an index of juvenile abalone abundance. Juvenile abalone used artificial structures at greater mean densities than nearby natural habitat and juvenile abalone abundance was significantly different between sites but not within sites, suggesting artificial structures showed promise in their ability to detect area specific differences in recruitment and to easily measure juvenile abalone abundance. Benefits of these studies in relation to abalone stock restoration are discussed.

Dewees, C., & Davies, L. T. (1992). *Sea urchins, abalone, and kelp: their biology, enhancement, and management: summary of an international conference sponsored by the California Sea Grant College and the Director's Sea Urchin Advisory Committee, California Department of Fish and Game.* California Sea Grant College, La Jolla, CA. Retrieved from https://nsgl.gso.uri.edu/cuimr/cuimrw92003.pdf

Valuable sea urchin, kelp, and abalone resources occur throughout the world. In California these resources are especially important. The nearshore kelp beds are also important habitat for many other marine organisms. In recent years, utilization of kelp bed resources has intensified, with the rapid expansion of the sea urchin fishery to 40 to 50 million pounds annually worth over $30 million to fishermen! serving as a prime example. Urgent kelp bed resource inanagement and research issues need to be addressed in California.

Fishery managers, researchers, the fishing industry, and others are aware of wide gaps in our knowledge about he biology, population dynamics, enhancement potential, and management of these resources. Similar resources and fisheries exist in all Pacific Coast states, Maine, Canada, Chile, Japan, and other nations. The Ca1ifornia Sea Grant College, in cooperation with the California Department of Fish and Game Director's Sea Urchin Advisory Committee, funded this Sea Urchin, Kelp, Abalone Conference to bring together academics, agency personnel, and resource users from throughout the world to identify research needs, management alternatives, and enhancement potential. The conference took place March 19-21, 1992, at Bodega Bay, California. It was organized by Professor Wallis Clark of the University of California, Davis, and myself, with the assistance of the individuals named in the acknowledgments. The 148 participants carne from the Pacific and Atlantic coasts, Canada, Mexico, Japan, Australia, and New Zealand.

Sea urchins were the primary focus because ofthe explosive growth in the fishery and urgency of management issues. Kelp and abalone discussions tended to focus on the interactions between these resources and sea urchins. In addition, abalone had been discussed thoroughly at the recent World Conference on Abalone held in Mexico.

With the help of a multidisciplinary planning committee, we designed the conference to be highly interactive by integrating discussion sessions into the program. The conference covered three primary topics: biology, enhancement, and management. We started with a series of papers on the status of biological knowledge about these organisms. Participants from industry, agencies, and academia were assigned todiscussion groups to identify research issues and needs. The trained discussion leaders then concisely summarized the discussion results for the entire conference audience. The process was

repeated for the enhancement and management topics. This approach greatly facilitated the sharing of diverse viewpoints and full participation by attendees.

These proceedings are organized into the three main topics of biology, enhancement, and management. In each section, abstracts of the presented papers are followed by a surnrnary ofthe group discussions and a list of recommendations. We have noted on the presentation abstracts when a full copy of the paper is available. A set of these papers can be obtained for $5 (checks payable to "UC Regents" ) from: Communications Department, California Sea Grant College, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232, Phone 619-534-4444. Please request publication T-CSGCP-028, The Management and Enhancement' of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective.

The conference results will be used by 1) the California Sea Grant College to help guide future research and extension activities; 2) the Department of Fish and Garne for resource managernent; 3) the fishing industry in its enhancement research and fishery manageinent discussions; and 4) by researchers, fishermen and fishery managers in other states and nations who are interested in these and similar organisms. Three days of papers and discussions identified many knowledge gaps and complex management issues surrounding sea urchin, kelp, and abalone resources. These are summarized in this publication. In addition, a need for a worldwide communication network for sharing research, enhancement, and management information was identified as highly desirable to transform the momentum of this conference into action and progress. The desire for cooperative agency/university/industry research was expressed by many participants. Fishermen were especially eager to share their underwater experience and skills. The first step would be the development of and training in data collection methods to assure unbiased data. Finally, and most importantly, the format of this conference seemed to open new cornrnunication channels among agencies, fishing industry, and academics that will facilitate creative approaches to sea urchin, kelp, and abalone issues.

Diaz-Viloria, N., Perez-Enriquez, R., Fiore-Amaral, G., Burton, R. S., & Cruz, P. (2008). Isolation and cross-amplification of microsatellites in pink abalone (*Haliotis corrugata*). *Molecular Ecology Resources,* 8(3), 701-703. https://doi.org/10.1111/j.1471-8286.2007.02054.x

Ten novel microsatellite loci were isolated in pink abalone, Haliotis corrugata, using (GT)(15) and (CT)(15) enriched genomic libraries. Two previously reported Haliotis kamtschatkana microsatellites cross-amplified in H. corrugata. A set of 12 polymorphic microsatellites were evaluated in a wild population sample (N = 49). The number of alleles ranged from two to 55, and the observed and expected heterozygosities ranged from 0.104 to 0.939 and from 0.213 to 0.982, respectively. Significant deviations from Hardy-Weinberg equilibrium at three loci and no linkage disequilibrium were observed. Haliotis corrugata microsatellites cross-amplified in other abalone species, two in H. fulgens, and seven in H. rufescens.

Dodou, D., Breedveld, P., de Winter, J. C. F., Dankelman, J., & van Leeuwen, J. L. (2010). Mechanisms of temporary adhesion in benthic animals. *Biological reviews of the Cambridge Philosophical Society,* 86(1), 15-32. https://doi.org/10.1111/j.1469-185x.2010.00132.x

Adhesive systems are ubiquitous in benthic animals and play a key role in diverse functions such as locomotion, food capture, mating, burrow building, and defence. For benthic animals that release

adhesives, surface and material properties and external morphology have received little attention compared to the biochemical content of the adhesives. We address temporary adhesion of benthic animals from the following three structural levels: (a) the biochemical content of the adhesive secretions, (b) the micro- and mesoscopic surface geometry and material properties of the adhesive organs, and (c) the macroscopic external morphology of the adhesive organs. We show that temporary adhesion of benthic animals is affected by three structural levels: the adhesive secretions provide binding to the substratum at a molecular scale, whereas surface geometry and external morphology increase the contact area with the irregular and unpredictable profile of the substratum from micro- to macroscales. The biochemical content of the adhesive secretions differs between abiotic and biotic substrata. The biochemistry of the adhesives suitable for biotic substrata differentiates further according to whether adhesion must be activated quickly (e.g. as a defensive mechanism) or more slowly (e.g. during adhesion of parasites). De-adhesion is controlled by additional secretions, enzymes, or mechanically. Due to deformability, the adhesive organs achieve intimate contact by adapting their surface profile to the roughness of the substratum. Surface projections, namely cilia, cuticular villi, papillae, and papulae increase the contact area or penetrate through the secreted adhesive to provide direct contact with the substratum. We expect that the same three structural levels investigated here will also affect the performance of artificial adhesive systems.

Donovan, D., Baldwin, J., & Carefoot, T. (1999). The contribution of anaerobic energy to gastropod crawling and a re-estimation of minimum cost of transport in the abalone, *Haliotis kamtschatkana* (Jonas). *Journal of Experimental Marine Biology and Ecology,* 235(2), 273-284. https://doi.org/10.1016/s0022-0981(98)00174-9

The contribution of anaerobic metabolism to the minimum cost of transport (COTmin; energy required to transport a unit mass over a unit distance, excluding maintenance and postural costs) was determined for the abalone Haliotis kamtschatkana. Abalone were induced to crawl in water for 6 m at speeds up to 9.9 shell lengths . min(-1). Changes in the concentrations of the anaerobic metabolites tauropine, D-lactate, arginine phosphate, and arginine occurred in foot muscle, but only at speeds at or above five shell lengths . min(-1). These metabolites did not change significantly in the shell adductor muscle. The amount of anaerobically derived ATP used during crawling was calculated and the values were compared with data for aerobic ATP production. Anaerobic metabolism accounted for 54% of COTmin, and the aerobic COTmin estimated by Donovan and Carefoot (1997) [Donovan, D.A., Carefoot, T.H., 1997. Locomotion in the abalone Haliotis kamtschatkana: pedal morphology and cost of transport. J. Exp. Biol; 200, 1145-1153] was thus adjusted from 20.3 J . kg(-1) m(-1) to 44.1 J . kg(-1) m(-1). This new value places abalone above the regression line of log(10)COT(min) on log(10)mass for sunning vertebrates, indicating that transport costs for abalone are more expensive than for the average similar-sized runner. The contribution of anaerobic metabolism was also determined for prolonged air exposure and whole animal righting behavior to allow comparisons to be made with other abalone species for which these data, but not data on anaerobic metabolism during crawling, were available in the literature. On this basis, we suggest that in comparison to H. kamtschatkana, Haliotis lamellosa and Haliotis iris may have lower aerobic scopes during crawling, while that of Haliotis asinina may be considerably higher.

Donovan, D. A. (1998). *Energetics of activity in the abalone: haliotis kamtschatkana.* (Ph.D. Dissertation), University of British Columbia, Vancouver, BC. https://doi.org/10.14288/1.0088703

The purpose of this thesis was to investigate several aspects of the energetic costs of activity in the Northern abalone, Haliotis kamtschatkana. The percentage of daily consumed energy partitioned to activity was calculated by first measuring summer and winter energy budgets in which abalone were inactive during measurements of respiration and mucus secretion, then by measuring respiration and mucus-secretion for active animals by integrating summer and winter activity budgets with energy equivalents for each activity. Energy expenditure due to metabolic changes during exposure to environmental stressors, measured as increases in blood-glucose levels and oxygen consumption, was also related to the summer energy budget. Abalone locomotion was investigated in several ways. Cost of transport was determined for a range of speeds and sizes by inducing abalone to locomote in respirometers and measuring oxygen consumption at known speeds. Relative contributions of aerobic and anaerobic metabolism were measured by analyzing muscle tissues for anaerobic metabolites after locomotion had occurred and comparing amounts of accumulated metabolites to amount of oxygen consumed during locomotion. Pedal morphology during locomotion was also investigated to detennine if possible energy-saving changes occur. This was accomplished by videotaping the pedal soles of locomoting abalone and measuring various foot morphometries. Activity, in the form of increased respiration and mucus secretion, accounted for a substantial portion of daily consumed energy during both seasons. Exposure to predatory seastars significantly increased blood-glucose titers and oxygen consumption, resulting in a metabolic increase equivalent to 0.3% of daily summer energy consumption. Cost of transport for abalone was less than that of other gastropods, possibly due to its larger relative size. Mucus secretion during locomotion did not vary with speed, but was less than the amount needed for substratum adherence. During locomotion, tauropine and D-lactate levels increased significantly in foot muscle while arginine decreased. Morphological analyses of pedal waves showed that the pedal sole area decreased with increasing speed, and the area of the foot incorporated into pedal waves increased. Together, these changes translated into a decrease pedal sole area in contact with the substratum.

Donovan, D. A., & Carefoot, T. H. (1997). Locomotion in the abalone *Haliotis kamtschatkana*: Pedal morphology and cost of transport. *Journal of Experimental Biology,* 200(7), 1145-1153. Retrieved from https://fire.biol.wwu.edu/donovan/papers/DonovanCarefoot1997.pdf

Morphological analyses of pedal sole area and pedal waves were conducted for a range of speeds and body sizes in the abalone Haliotis kamtschatkana. The pedal sole of resting abalone increased in size disproportionately with animal volume (slope of log(10)-transformed data, b=0.83; expected slope for isometry, b(0)=0.67) and length (b=2.51; b(0)=2.0). Pedal wave frequency increased linearly with speed, confirming that abalone increase speed by increasing the velocity of pedal waves. Total area of the pedal sole decreased by 2.1% for each shell length per minute increase in speed. Likewise, the area of the foot incorporated into pedal waves increased by 1.8% for each shell length per minute increase in speed. Together, these changes translated into a 50% decrease in the pedal sole area in contact with the substratum at a maximum escape speed of 15 shell lengths min(-1), relative to the pedal sole at rest. The amount of mucus secreted by resting animals during adhesion to the substratum increased isometrically with foot area (slope of log(10)-transformed data, b=1.08). The amount of mucus secreted during locomotion did not vary with speed, but was less than the amount needed for adhesion. We suggest that these morphological and physiological changes reduce the energy expenditure during locomotion. Cost of transport was investigated for a range of speeds and abalone sizes. The rate of

oxygen consumption (V) over dot(O2) (in mu l O-2 g(-1) h(-1)) increased linearly with increasing absolute speed nu (in cm min(-1)): (V) over dot(O2)=40.1+0.58 nu-0.15m (r(2)=0.35, P=0.04), where m is body mass (in g). Minimum cost of transport, calculated from the slope of absolute speed on (V) over dot(O2), was 20.3 J kg(-1) m(-1). Total cost of transport (COTT) and net cost of transport (COTN) were high at low speeds and decreased as speed increased, to minima of 86.0 J kg(-1) m(-1) and 29.7 J kg(-1) m(-1), respectively, at speeds measured in the respirometer. Log(10)-transformation of both cost of transport and speed data yielded linear relationships with the following regression equations: log(10)COT(T)=3.35-0.90log(10)nu-0.21log(10)m (r(2)=0.89; P<0.006) and log(10)COT(N)=2.29-0.69log(10)nu-0.09log(10)m (r(2)=0.48; P<0.006), respectively.

Donovan, D. A., & Carefoot, T. H. (1998). Effect of activity on energy allocation in the northern abalone, *Haliotis kamtschatkana* (Jonas). *Journal of Shellfish Research,* 17(3), 729-736. Retrieved from https://www.biodiversitylibrary.org/page/2151960

The effect of activity, in the form of increased respiratory energy expenditure and secretion of mucus, on the summer and winter energy budgets of Haliotis kamtschatkana was assessed. Abalone exhibited seasonal variations in field activity with 20% of all individuals observed crawling during June to October, compared with <5% during December to February. In the laboratory, abalone exhibited diurnal as well as seasonal variation in activity. The laboratory activity budget showed that an average abalone spends 9.8 h day(-1) quiescent, 12.0 h day(-1) alert, 0.7 h day(-1) feeding, and 1.5 h day(-1) crawling during the summer, and 15.8 h day(-1) quiescent, 5.5 h day(-1) alert, 2.3 h day(-1) feeding, and 0.4 h day(-1) crawling during the winter. Videotapes of abalone made over 24-h periods revealed that abalone usually crawl at a rate of one shell length min(-1). Locomotion is not continuous; rather, abalone stop and then start again, on average twice per meter. Components of the energy budget, C = F + U + P-g + P-r + R + M were measured during summer and winter months. None of the slopes of regressions of log(10)energy (J day(-1)) on log,,mass (g) was significantly different between summer and winter for any of the energy budget components, except those of somatic growth on mass. Summer y-intercepts were all significantly higher than winter y-intercepts, indicating that energy consumption and expenditure were higher during the summer. Respiratory energy expenditure was the largest component of both summer and winter budgets. Activity accounted for 23% of total consumed energy during the summer and 13% during the winter.

Emmett, B., & Jamieson, G. S. (1989). An experimental transplant of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, British Columbia. *Fishery Bulletin,* 87(1), 95-104. Retrieved from https://spo.nmfs.noaa.gov/content/experimental-transplant-northern-abalone-haliotis-kamtschatkana-barkley-sound-british

The biological and economic feasibilities of transplanting northern abalone. Haliotis kamtschatkana Jonas 1845, from exposed beds to two sites in sheltered, productive abalone habitat were investigated. After nine months, 39% and 72% of transplanted abalone were recovered at the two replicate sites. Recovery of tagged abalone at a control site, situated in the exposed source area, was 32%. Growth in shell length of transplanted abalone over the nine months averaged 7.8% whereas the average growth of nontransplanted controls was 3.7%, significantly less. There was little emigration of abalone from the transplant sites.

The study concludes that it is feasible to transplant 50-100 mm H. kamtschatkana in order to enhance growth. The economic feasibility of transplants is dependent on site-specific recovery rates and the costs of harvesting seed abalone. The population dynamics of abalone in exposed beds and the long-term potential for enhancing abalone settlement by introducing broodstock to depleted areas are two aspects which now require investigation.

Farlinger, S., & Campbell, A. (1992). Fisheries management and biology of northern abalone, *Haliotis kamtschatkana*, in the northeast Pacific. In *Abalone of the world: biology, fisheries, and culture.* S. A. Shepherd, M. J. Tegner, & S. A. Guzman del Proo (Eds.). Oxford: Fishing News Books Retrieved from https://www.worldcat.org/title/abalone-of-the-world-biology-fisheries-and-culture/oclc/24694338

Northern abalone are harvested in commercial dive, native food and sports fisheries in the northeast Pacific. Commercial abalone landings in Alaska and British Columbia (BC) increased rapidly in the late 1970s, but have since declined to low levels. Catch per unit effort has generally declined in BC during 1977-86 and stabilized at low levels. For Washington State there are only recreational and native food fisheries for which few landing data are available. Fishery management in BC is conservative and includes vessel quotas, whereas in Alaska area quotas are used. The total annual quota has been reduced to the present 47t for BC and 15-26t for Alaska. The reductions in landings and quota in BC have decreased the number of vessels and increased the unit price ($/kg) at a greater rate than the consumer price index, making the fishery lucrative for both legal and illegal participants. Abalone stock assessment in BC invovles bi- or triennial dive surveys to provide indices of abundance from which quotas can be adjusted. A 1989 resurvey of a major fishing area in BC suggested a further decline in both legal and pre-recruit abundance indices. Future research should focus on factors affecting recruitment and an evaluation of the survey methodology and size limit.

Fedorenko, A. Y., & Sprout, P. E. (1982). *Abalone biology, fishery regulations, commercial catch (1952-1980), and current state of resource in British Columbia*.Canadian manuscript report of fisheries and aquatic sciences (1658). Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/454836/publication.html

Landings of northern abalone (Haliotis kamtschatkana) in British Columbia have expanded greatly since 1976, with 1,474 m.t. harvested during 1976 to 1980. By late 1970's, the abundance of legal-sized abalone has declined by 60 - 85%. This report reviews the biology of northern abalone, world-wide production and trading of abalone, and its aquaculture; examines the development of commercial abalone fishery in B.C.; reviews management strategies in B.C., especially from 1976 to 1980; summarizes the annual landings by Statistical Area during 1952-1980, emphasizing catch trends and fishing effort in the last five years; examines biological studies in fishery management of abalone; and makes recommendations for a more viable abalone fishery in B.C.

Fisheries and Oceans Canada. (2004). *Northern Abalone*. Stock Status Report (2004/053). Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/331887.pdf

Densities of northern abalone have continued to decrease despite a total ban on harvest since 1990. There is no current evidence of population recovery in BC. Low recruitment levels and continued harvest

despite the fisheries closure are considered to be the most significant threats to northern abalone recovery. Expansion of the sea otter population and near shore marine development may also contribute to the decline of abalone in BC.

Fournier, D. A., & Breen, P. A. (1983). Estimation of Abalone Mortality Rates with Growth Analysis. *Transactions of the American Fisheries Society,* 112(3), 403-411. https://doi.org/10.1577/1548-8659(1983)112<403:eoamrw>2.0.co;2

We describe a maximum-likelihood procedure for obtaining simultaneous estimates of growth and total-mortality rates from size-frequency distributions. The method is applied to size data from simulations and from two populations of northern abalone Haliotis kamtschatkana in British Columbia. Total-mortality-rate estimates varied with the assumed number of age classes and other model variables, but this variation was satisfyingly small.

Frederick, A. R., Freidman, C. S., & German, D. P. (2018). Withering-syndrome induced gene expression changes in pinto abalone, Haliotis kamtschatkana. *Integrative and Comparative Biology,* 58, E69-E69. https://doi.org/10.1016/j.cbd.2021.100930

In the abalone and Candidatus Xenohaliotis californiensis (Ca. Xc) system, the Ca. Xc bacterium infects abalone digestive tissues and leads to extreme starvation and a characteristic “withering” of the gastropod foot. First identified in black abalone in California after an El Niño event, withering syndrome (WS) has caused large declines in wild black and captive white abalones on the northeastern Pacific coast, but disease resistance levels are species-, and possibly population-specific. This study compared gene expression patterns in the digestive gland of Ca. Xc-exposed and unexposed (control) Pinto abalone (Haliotis kamtschatkana), a particularly susceptible species. Lab-induced Ca. Xc infections were followed over 7 months and RNAseq to identify differential gene expression (DEG). Exposed Pinto abalone showed distinct changes in expression of 68 genes at 3 and 7 months post-infection relative to those in control animals. Upregulation of an orexin-like receptor (which is involved in feeding signaling) and a zinc peptidase-like region (many amino peptidases are zinc peptidases) in animals infected for 7 months indicates that animals with Ca. Xc infection may be starving and upregulating processes associated with feeding and digestion. Other groups of differentially expressed genes were upregulated or downregulated across control and exposed individuals over the 7-month experiment, including DEG groups that likely correspond to early disease state and to general stress response of being held in captivity. No patterns emerged in genes known to involved in molluscan immune response, despite this being an expectation during a 7-month infection; immune genes and unannotated DEGs were identified as targets for future research on immune response to WS in abalone.

Frederick, A. R., Heras, J., Friedman, C. S., & German, D. P. (2021). Withering syndrome induced gene expression changes and a de-novo transcriptome for the Pinto abalone, *Haliotis kamtschatkana*. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, 100930. https://doi.org/10.1016/j.cbd.2021.100930

In the abalone and Candidatus Xenohaliotis californiensis (Ca. Xc) system, the Ca. Xc bacterium infects abalone digestive tissues and leads to extreme starvation and a characteristic “withering” of the gastropod foot. First identified in black abalone in California after an El Niño event, withering syndrome

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Friedman, C. S., Roberts, W., Kismohandaka, G., & Hedrick, R. P. (1993). Transmissibility of a coccidian parasite of abalone, Haliotis spp. *Journal of Shellfish Research,* 12(2), 201-205. Retrieved from https://www.biodiversitylibrary.org/page/3446917

Renal coccidian infections developed in seed red abalone, Haliotis rufescens, after 5-7 mo of exposure to infective waters at the Fish and Game Marine Culture Laboratory in Monterey County, California. Similar infections developed in cohort seed abalone after 3 mo of exposure to infective waters in a barrel culture system located in an embayment near Pt. Hueneme, California. In the experimental trials the coccidian was directly transmitted from red abalone to pinto abalone after 10.5 mo of cohabitation. One hundred percent of the pinto abalone that shared aquaria with infected red abalone had coccidian infections after 17 mo of cohabitation, while no control abalone developed infections with coccidia. No change in the condition of the abalone or mortality resulted from natural or experimental infections with coccidia.

Fuller, A. M. (2017). *Transmission Dynamics of the Withering Syndrome Rickettsia-like Organism to Abalone in California.* (Master of Science Thesis), University of Washington, Seattle, WA. Retrieved from http://hdl.handle.net/1773/40574

A sentinel study was conducted to investigate the distribution of the withering syndrome (WS) pathogen by deploying modules containing live red abalone at two different field sites, one near an onshore commercial abalone farm and one in proximity to wild aggregations of abalone, both in Southern California. A newly validated quantitative polymerase chain reaction (qPCR) assay was used to quantify the withering syndrome rickettsia like organism (WS-RLO) DNA in water, tissue and fecal samples. In addition, histological screenings were conducted on tissues from all surviving abalone to understand clinical infections of the pathogen. WS-RLO DNA copies were detected in modules at the wild site but not at the site off of the abalone farm (even though WS-RLO DNA was detected in the farm's effluent; $p > 0.05$). Overall, proportions of clinical infections and WS-RLO DNA at both sites were very low and similar between sites ($p > 0.05$). Abalone infection prevalence and intensity of the WS-RLO was independent of WS-RLO DNA copy density in seawater. This study demonstrated the use of caged

sentinel abalone to monitor RLO transmission in the field. The results of this study will help managers better understand the risk of infection of abalone exposed to the WS-RLO in situ.

Green, J. L. (1993). *An investigation into pearl culture in the pinto abalone Haliotis kamtschatkana (Jonas) by examining its repaired shell and factors that influence its repair rate.* (Master of Science Thesis), Simon Fraser University, Burnaby, BC. Retrieved from https://summit.sfu.ca/item/5784

Development of blister pearls in molluscs imitates the natural process of shell repair. Therefore, an understanding of shell repair and factors influencing it will provide insights into the production of pearls in molluscs. In this study, the repaired shell of the pinto abalone (Haliotis kamtschatkana) is described and the influences of photoperiod, seasonality and site of damage are investigated for their influence on the rate of repair. As well, the effects on growth rates of implanting abalone with semi-spherical pearl nuclei was investigated.

Griffiths, A. M. (2009). *Investigations into mortality in juvenile Haliotis kamtschatkana (northern abalone) and factors that affect outplanting.* (Master of Science Thesis), University of Victoria, Victoria, BC. Retrieved from http://hdl.handle.net/1828/1828

The predation pressures on juvenile Haliotis kamtschatkana, northern abalone, in Barkley Sound. British Columbia, were investigated. Thirty-seven potential predators were tested in the laboratory to determine if they would consume juvenile abalone 1- 25 mm shell length (SL). Six of these potential predators consumed > 10 % of the abalone offered to them and were considered major predators. Natural mortality for juvenile H. kanntschatkana was then estimated by outplanting calcein marked and bee tagged hatchery-reared abalone at field sites. Calcein concentrations between 20 40 mg/L produced clear fluorescent marks for 3- 5 mm SL abalone when exposed to a double calcein marking procedure and abalone > 15 mm SL immersed in calcein for 72 h showed the most distinct marks. Recoveries of outplanted abalone were highest (24%) for 15.1- 20 mm juvenile abalone. I recommend outplanting juvenile abalone larger than 12 mm to increase chances of survivorship in the wild.

Gurney, L. J., & Mundy, C. N. (2004). *Reproductive Biology: Identifying Spawning Cycles in the Genus Haliotis.* Technical Report Series 23. Tasmanian Aquaculture and Fisheries Institute, Hobart, Tasmania, AU. Retrieved from http://web.rainbowcreative.co.nz/firefly-websites/nzafa.org.nz/pdfs/Tech_Review.pdf

The reproductive biology and patterns of spawning in the blacklip abalone Haliotis rubra in Tasmania are poorly understood. Anecdotal evidence suggests there is a seasonal peak to spawning activity, although gravid animals can be found in every month of the year. Knowledge of the reproductive biology and spawning patterns of a commercial species is essential to ensure that spawner biomass is not depleted to unsustainable levels. While there is abundant data on size at reproductive maturity, there is no data available on fecundity, or timing and frequency of spawning. A sampling program conducted by abalone researchers at the Department of Sea Fisheries generated histological sections, gonad indices and morphometric at monthly intervals from a population at George III Rock Reef between 1988 and 1992. This review is the first stage in a project to analyse the historic samples and report the findings of that historical study.

Prior to analysis of the samples, a brief inspection of the literature revealed a broad range of techniques and approaches had been used to calculate gonad indices and assess histological sections of gonad. Because there appeared to be some debate over the most appropriate techniques to employ, a full review of literature relating to investigations of spawning periodicity and the methods employed was required before commencing reanalysis of the DSF data.

Three different data types have been collected in studies of haliotid spawning periodicity, with many studies collecting only one data type. In particular the formulae and methods for calculating Gonad Indices have undergone significant evolution, although not all modifications have resulted in improvements. The utility and success of the three data types - Gonad Indices, Gonad maturation, and Oocyte based data - are reviewed here, with recommendations on the approach most likely to be successful in identifying spawning periodicity in haliotids.

Hahn, K. O. (1981). The reproductive cycle and gonadal histology of the pinto abalone, *Haliotis kamtschkatkam*a Jonas, and the flat abalone, *Haliotis walallensis* Stearns. In *Advances in invertebrate reproduction: proceedings of the second international symposium of the International Society of Invertebrate Reproduction (ISIR) held in Davis, California on August 27-31, 1979.* W. H. Clark & T. S. Adams (Eds.), (Vol. 11, pp. 387). New York: Elsevier Retrieved from https://science-catalogue.canada.ca/record=3842399~S6

Two abalone species, Haliotis kamtschatkana and Haliotis walallensis, found near Mendocino, California, were studied during 1974, 1975, 1977 and 1978. The reproductive cycle and spawning season were determined by studying the gonadal histology and using a gonad bulk index. The gonad bulk index (gonad area/total conical organ area x 100) was found to correlate significantly with the gonadal histology. During the years studied both species spawned in early spring (March arid April). Three specimen types were found: Type I, total spawner; Type II, partial spawner; and Type III, non-spawner. Five histological stages occurred during the reproductive cycle: ripe phase, partially spawned phase, spent phase, active phase and necrotic phase.

Hansen, S. C., & Gosselin, L. A. (2013). Do predators, handling stress or field acclimation periods influence the survivorship of hatchery-reared abalone *Haliotis kamtschatkana* outplanted into natural habitats? *Aquatic Conservation-Marine and Freshwater Ecosystems,* 23(2), 246-253. https://doi.org/10.1002/aqc.2315

Northern abalone (Haliotis kamtschatkana) in British Columbia, Canada, are listed as endangered and are protected from fishing, yet their populations continue to decline. It is suspected that supplementation of wild populations with hatchery-reared abalone will be necessary for the recovery of this species. This study examines the magnitude, timing, and causes of post-outplanting mortality of hatchery-reared late-juvenile northern abalone. Abalone survivorship declined precipitously following outplanting, with 83% of abalone surviving 24 h after release and only 34% surviving 2 weeks in the wild. Handling, tagging, and temperature variations experienced during the outplanting procedure did not cause mortality. The majority of the abalone mortality in this study was attributable to predators. Additional factors accounted for only 12% mortality over 7 d. A 1-week acclimatization period within predator exclosures did not improve subsequent survival of outplants. These results demonstrate that the ouplanting of hatchery-reared abalone as a method of restoring wild populations of this endangered

species is primarily constrained by high mortality during the first few days after outplanting, and that almost all of this early mortality is caused by predation. Predation mortality will therefore have to be overcome if outplanting of hatchery-reared juvenile abalone is to be an effective restoration strategy.

Hernandez-Ibarra, N. K., Morelos, R. M., Cruz, P., Galindo-Sanchez, C. E., Avila, S., Ramirez, J. L., & Ibarra, A. M. (2010). Allotriploid Genotypic Assignment in Abalone Larvae by Detection of Microsatellite-Recombinant Genotypes. *Journal of Heredity,* 101(4), 476-490. https://doi.org/10.1093/jhered/esq027

Abalone species are different from most mollusks utilized in aquaculture as they are known to hybridize in laboratory-induced matings. Allotriploidization of hybrid abalone has not yet been studied, and methodology useful in verifying the genotypic condition of such allotriploids do not exist. Genotypic verification of hybridization and allotriploidization in a cross of Haliotis fulgens and Haliotis rufescens was performed utilizing 6 crossamplifying microsatellite loci. Five H. rufescens spawns were used in this experiment, dividing each spawn into control and experimental hybrid groups and further into diploids and triploids. Two microsatellite loci developed for H. fulgens and H. rufescens allowed for the genotypic identification of hybrids within diploid and triploids. To further verify the percentage of allotriploids within the genotypic hybrids in the triploid hybrid groups, microsatellite loci originally developed in Haliotis corrugata and Haliotis kamtschatkana were tested for crossamplification in H. fulgens and H. rufescens. Of 21 loci, 4 were chosen for this study based on their crossamplification, heterozygosity in the females, and centromere recombination frequencies. Allotriploids in triploidhybrid larvae were then detected by identifying larvae with recombinant genotypes at any of those loci. One family had low success verification associated with reduced recombination frequencies for all loci in that family. These results demonstrate that allotriploid verification at larval stages is feasible but depends on the number of loci available, their crossamplification in the species, and their recombination frequencies.

Hickman, C. S., & Hadfield, M. G. (2001). Larval muscle contraction fails to produce torsion in a Trochoidean gastropod. *The Biological bulletin,* 200(3), 257-260. Retrieved from https://www.biodiversitylibrary.org/page/1519713

The causes and effects of ontogenetic torsion in gastropods have been debated intensely for more than a century (1-19). Occurring rapidly and very early in development, torsion figures prominently in shaping both the larval and adult body plans.

Hoshikawa, H., Sakai, Y., & Kijima, A. (1998). Growth characteristics of the hybrid between pinto abalone, *Haliotis kamtschatkana* Jonas, and exo abalone, H-discus hannai Ino, under high and low temperature. *Journal of Shellfish Research,* 17(3), 673-677. Retrieved from https://www.biodiversitylibrary.org/page/2151917

Rearing experiments have been done to compare growth rates in pinto abalone, Haliotis kamtschatkana Jonas, and ezo abalone, H. discus hannai Ino. The growth rate in shell length of juvenile pinto abalone was superior to that of ezo abalone at water temperatures below 7 degrees C. However, the growth rate declined above 17 degrees C and was lower than that of ezo abalone. The hybrid cross between the female of ezo abalone and the male of pinto abalone was obtained but with low fertilization (20%). The reciprocal cross was never successful. The growth rate of the hybrid was superior to the parental species

below 18 degrees C and moderate between parental species under 8 degrees C. Isozymic analysis confirmed that genetic hybridization occurred in this cross, on the basis of the results of electropherograms of the hybrid and its parental species.

Kikuchi, S., & Uki, N. (1981). Technical Study on Artificial Spawning of Abalone, Genus Haliotis VII : comparative examination of rearing apparatus for conditioning adult of abalone. [Awabi-zoku no sairan-gijutsu ni kansuru kenkyu. Dai 7 ho Bokai -shiiku-sochi no hikaku kento ]. *Tohoku-Ku Suisan Kenkyusho Kenkyu Hokoku*(43), 47-51. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/88977.pdf

Several types of rearing apparatus for conditioning adult abalone, Halintis discus hannai INci were discussed in their structures and function. 1. Similar growth of live abalone in natural habitat was achieved in a tank of Type 1 which was designed for rapid discharge of animal excretions. This apparatus could be employed also for other species like 11. discus and H. gigantea. 2. Apparatus of Type II might be useful for rearing the shellfish under high density condition. 3. Type III is not considered suitable a.pparatus for conditioning adult abalone. 4. The shell growth rate of adult .Haliotis (standard 50 prn/day) could be proposed as an indicator for the suitability of rearing conditions. 5. Growth rate of adult 11. discus hannai was not disturbed if the flow rate was maintained, which keeps the oxygen saturation of sea water at 80% in a rearing tank, used as a basis of changing rate of water, calculated from the oxygen consumption rate of 11. discus hannai. 6. Air bubbling is considered to have no influence on growth rate.of adult abalone.

Krajniak, K. G., & Bourne, G. B. (1987). Effects of FMRFamide on the intact and isolated circulatory system of the pinto abalone, *Haliotis kamtschatkana*. *Journal of Experimental Zoology,* 241(3), 389-392. https://doi.org/10.1002/jez.1402410315

The in vivo and in vitro effects of the molluscan tetrapeptide, FMRFamide, were examined on the circulatory system of the pinto abalone, Haliotis kamtschatkana. When perfused through isolated hearts, FMRFamide caused a dose-dependent increase in heart rate. Injected into the circulation of intact, unrestrained animals, the peptide initially enhanced the rate of beating, augmented the aortic diastolic and pulse pressures, and raised the arteriovenous (AV) pressure difference; but at higher doses, this initial enhancement was followed by a decrease in aortic blood pressure, an increase in efferent ctenidial pressure, and a substantially reduced heart rate. Therefore, FMRFamide could have a role in controlling the circulation of H. kamtschatkana.

Krajniak, K. G., & Bourne, G. B. (1988). Aortic and venous blood pressures in the intact pinto abalone, *Haliotis kamtschatkana*. *Comparative Biochemistry and Physiology a-Physiology,* 89(3), 405-407. https://doi.org/10.1016/0300-9629(88)91048-1

1. At -12 C, strain gauge manometers were used to measure resting blood pressures in the ventricle, aorta, and left efferent ctenidial vein of unrestrained specimens of the pinto abalone, Haliotis kamtschatkana.
2. All pressures were pulsatile with an aortic systolic pressure of 0.53 kPa and a mean efferent ctenidial pressure of 0.13 kPa.

3. Peak aortic pressure occurred slightly after that of the ventricular pressure and was 180 out of phase with that of the efferent ctenidial vein.
4. The resting heart rate was 18 bpm.
5. The pressure wave forms were similar to those recorded in the larger Haliotis corrugata from a warmer environment; however, the magnitudes of the pressures were dissimilar to those of H. corrugata, suggesting that either body size or temperature or both may cause differences in heart rate and blood pressure.

Krajniak, K. G., & Bourne, G. B. (1989). The effects of 5-hydroxytryptamine on the isolated and intact circulatory system of the pinto abalone, *Haliotis kamtschatkana*, and its presence in cardiac and non-cardiac tissues. *Comparative Biochemistry and Physiology C-Pharmacology Toxicology & Endocrinology,* 94(2), 561-566. https://doi.org/10.1016/0742-8413(89)90113-8

1. The in vivo and in vitro effects of 5-hydroxytryptamine (5-HT) on the circulatory system of the pinto abalone, Haliotis kamtschatkana, were examined.
2. In the isolated heart, 5-HT caused a dose-dependent increase in beat frequency.
3. In the intact animal, however, this effect was accompanied by increases in aortic systolic, diastolic, and pulse pressures, and, at very high doses, efferent ctenidial pressure.
4. The effects of 5-HT were inhibited by several antagonists.
5. Furthermore, high levels of 5-HT were found in the tissue samples taken from the auricles, and ventricle and in the hemolymph, and pericardial fluid.
6. Therefore, 5-HT may have a role as an excitatory neurotransmitter in the control of circulation in H. kamtschatkana.

Kuehl, L. M., & Donovan, D. A. (2021). Survival, growth, and radula morphology of *Haliotis kamtschatkana* postlarvae fed six species of benthic diatoms. *Aquaculture,* 533. https://doi.org/10.1016/j.aquaculture.2020.736136

Haliotis kamtschatkana is the only abalone native to the Pacific Northwest of North America. Haliotis kamtschatkana populations are in decline, and current restoration efforts in Washington State rely on out-planting hatchery-produced juveniles. Hatchery personnel report highest mortalities in the postlarval stage of H. kamtschatkana, mainly during the first 3 to 6 months. Postlarvae feed on films of benthic diatoms, and the purpose of this study was to test six diatom species (Achnanthes brevipes, Amphora sauna, Amphiprora paludosa, Cylindrotheca closterium, Navicula incerta, and Nitzschia laevis) as suitable diets for H. kamtschatkana. Diatom diet suitability might rely on several factors, including diatom characteristics as well as the postlarva's ability to ingest the diatoms. The radula is a crucial feeding structure for gastropods and may display morphological plasticity, but this has never been characterized in H. kamtschatkana. We investigated survival, growth, and radula morphology of H. kamtschatkana postlarvae when fed one of six benthic diatom species for 61 days post-settlement. Amphora sauna yielded the highest survival, in a statistically homogenous subgroup with N. incerta, A. paludosa, and C. closterium. Achnanthes brevipes yielded exceptionally low survival, on par with a starvation control. Cylindrotheca closterium yielded significantly better growth than all other diets except A. sauna. Radula development was similar to that of other abalone species. The shape and size of the radula did not explain success or failure of any of the diatom diets since the radula morphology of H. kamtschatkana was comparable to other abalone that have succeeded when fed these same diets. We found no relationship between diatom diet and radula morphology. We recommend A. sauna as a

suitable diet for newly settled H. kamtschatkana postlarvae, and that a combination of A. sauna and C. closterium be used to supplement feeding on naturally occurring biofilms.

Kurita, Y., & Wada, H. (2011). Evidence that gastropod torsion is driven by asymmetric cell proliferation activated by TGF-β signalling. *Biology letters,* 7(5), 759-762. https://doi.org/10.1098/rsbl.2011.0263

Gastropods are characterized by their asymmetric bodyplan, which develops through a unique ontogenetic process called 'torsion'. Despite several intensive studies, the driving force of torsion remains to be determined. Although torsion was traditionally believed to be driven by contraction of the retractor muscle connecting the foot and the shell, some recent reports cast doubt on that idea. Here, we report that torsion is accompanied by left–right asymmetric cell proliferation in the mantle epithelium in the limpet Nipponacmea fuscoviridis. Furthermore, we found that pharmacological inhibition of the transforming growth factor-β (TGF-β) signalling pathway, including that of Nodal, blocked torsion. We confirmed that the blocking was brought about through failure of the activation of cell proliferation in the right-hand side of the mantle epithelium, while the retractor muscle apparently developed normally. These results suggest that limpet torsion is driven by left–right asymmetric cell proliferation in the mantle epithelium, induced by the TGF-β pathway.

Lemay, M. A. (2007). *Reduced genetic diversity and high variance in reproductive success in captive-bred pinto abalone, Haliotis kamtschatkana.* (Master of Science Thesis), University of Guelph, Guelph, ON. Retrieved from https://hdl.handle.net/10214/23636

To mitigate the decline of threatened species, captive breeding programs are often used to augment diminishing populations. Success of these programs depends on introducing captive-bred animals to their historical range without altering wild genetic diversity or patterns of local adaptation. I tested for differences in genetic diversity between three captive-spawned and one wild population of the threatened pinto abalone, Haliotis kamtschatkana, and found a significant reduction in allelic richness among captive-bred groups. DNA-based pedigree reconstruction was used to test the hypothesis that variance in reproductive success is in part responsible for the observed reduction in genetic diversity. I found that several abalone released gametes during spawning, but failed to produce any offspring. Even among abalone that had successful fertilization, there was high variance in the number of offspring produced. Elucidating factors responsible for altered genetic structure and reduced genetic diversity will directly aid the conservation of this threatened species.

Lemay, M. A., & Boulding, E. G. (2009). Microsatellite pedigree analysis reveals high variance in reproductive success and reduced genetic diversity in hatchery-spawned northern abalone. *Aquaculture,* 295(1-2), 22-29. https://doi.org/10.1016/j.aquaculture.2009.06.029

The northern (or pinto) abalone, Haliotis kamtschatkana, is a broadcast-spawning marine gastropod that was recently listed as endangered in Canada. To aid in species recovery, a captive-breeding and supplementation program is underway in Barkley Sound, British Columbia. We genotyped first generation progeny for five microsatellite loci and used a pedigree reconstruction program (PEDIGREE 2.2) to identify their genealogical relationships in the absence of information on parental genotypes. We analyzed progeny from three separate group-spawning events and inferred considerable variation in the

number of offspring produced by each parent; in the most severe case a single male sired all the progeny produced during one spawning event. After only one generation of captive-breeding we found a 55-60% reduction in allelic richness and a 17-18% reduction in heterozygosity relative to the diverse wild source population. This study illustrates the difficulty of managing genetic diversity in hatchery populations of a broadcast-spawning species, even when gametes are collected separately from each individual broodstock.

Lesoway, M. P., & Page, L. R. (2008). Growth and differentiation during delayed metamorphosis of feeding gastropod larvae: signatures of ancestry and innovation. *Marine Biology,* 153(4), 723-734. https://doi.org/10.1007/s00227-007-0849-z

Extent of larval growth among marine invertebrates has potentially profound implications for performance by benthic recruits because body size influences many biological processes. Among gastropods, feeding larvae often attain larger size at metamorphic competence than non-feeding larvae of basal gastropod clades. Delay of metamorphosis can further influence size at recruitment if larvae continue to grow during the delay. Some caenogastopod larvae grow during delayed metamorphosis, but opisthobranch larvae do not. Data on larval growth of neritimorph gastropods are needed to help determine which of these growth patterns for planktotrophic gastropod larvae is more derived. We cultured planktotrophic larvae from all three major gastropod clades with feeding larvae through delays of metamorphosis of 3-10 weeks. Larvae of the caenogastropod Euspira lewisii and the euthyneurans Haminoea vesicula (Opisthobranchia) and Siphonaria denticulata (Pulmonata) conformed to previously described growth patterns for their respective major clades. Furthermore, the caenogastropod continued to lengthen the prototroch (ciliary band for swimming and feeding) and to differentiate prospective post-metamorphic structures (gill filaments and radular teeth) during delayed metamorphosis. Larvae of the neritimorph Nerita atramentosa arrested shell growth during delayed metamorphosis but the radula continued to elongate, a pattern most similar to that of non-feeding larvae of Haliotis, a vetigastropod genus. Character mapping on a phylogenetic hypothesis suggests that large larval size and capacity for continued growth during delayed metamorphosis, as exhibited by some caenogastropods, is a derived innovation among feeding gastropod larvae. This novelty may have facilitated post-metamorphic evolution of predatory feeding using a long proboscis.

Lloyd, M. J., & Bates, A. E. (2008). Influence of density-dependent food consumption, foraging and stacking behaviour on the growth rate of the Northern abalone, *Haliotis kamtschatkana*. *Aquaculture,* 277(1-2), 24-29. https://doi.org/10.1016/j.aquaculture.2008.01.039

Growth of abalone in the wild and hatchery is density-dependent in response to intraspecific competition for food and/or space. To determine if a candidate aquaculture species, Haliotis kamtschatkana, exhibits density-dependent growth we raised animals at three density levels and two food treatments: unlimited (ad libitum) and rationed (individual portions were the same among density treatments). We also tested for differences in food consumption, foraging patterns and stacking behaviour among the density levels. We observed density-dependent growth in the rationed treatments, indicating that relatively high growth rates at lower densities are driven, in part, by factors other than differences in food consumption. However, overall the quantity of food consumed related directly to growth; treatments fed ad libitum had higher growth rates. Furthermore, even when food was provided in excess, foraging was restricted to similar to 2 h after sunset in all treatments and the amount consumed per abalone was significantly lower at high densities. This is probably because high

density animals could not access the food provided: fewer were observed foraging and they had to move from prominent stacks. Our results indicate that both temporal and spatial access to food are critical and that managers can observe foraging and stacking by abalone in tanks to determine if a specific design will limit food consumption, and ultimately growth.

MacCallum, G. S., Blackbourn, J., McGladdery, S. E., Bower, S. M., & Davidson, J. T. (2001). Disease issues relevant to the culture of shellfish in Atlantic and Pacific Canada. *Bulletin of the Aquaculture Association of Canada,* 101(3), 5-12. Retrieved from http://aquacultureassociation.ca/wp-content/uploads/bsk-pdf-manager/2017/10/Bulletin-101-3.pdf

A project initiated in October, 2000 at the Atlantic Veterinary College and Pacific Biological Station (PBS) assessed the health /disease issues relevant to the culture of indigenous shellfish species. This project included a thorough geographic survey of infections affecting the Stimpson's bar clam (Mactromeris polynyma), European oyster (Ostrea edulis), green sea urchin (Strongylocentrotus droebachiensis), orange-footed sea cucumber (Cucumaria frondosa), and northern shrimp (Pandalus borealis) on the east coast, and the green and red sea urchin (S. droebachiensis, S. franciscanus), California sea cucumber (Parastichopus californicus), cockle (Clinocardium nuttali), varnish clam (Nutallia obscurata) and pinto abalone (Haliotis kamtschatkana) on the west coast. All species are currently under culture development, or of culture interest, on their respective coasts. Gross observations found the presence of the boring sponge (Cliona vastifica) in the shells of O. edulis and Clinoa sp., and Polydora sp. in such as Trichodina sp., unidentified intestinal ciliates, Rickettsia - like organisms, unidentified copepods, Nematopsis - like gregarine spores, and digenean metacercarian cysts in or near tissues in the bivalves, echinoderms and crustaceans. It is essential to establish baseline information on what is "normal" for species going into culture production to: 1) accurately assess disease risks, and 2) differentiate true pathogens from opportunists taking advantage of sub-optimal culture conditions. This proactive research approach sets a precedent for the development of shellfish culture species, since health research rarely occurs before a disease crisis occurs.

Maguire, A. K., & Rogers-Bennett, L. (2013). An ectoparasitic snail (*Evalea tenuisculpta*) infects red abalone (*Haliotis rufescens*) in northern California. *California Fish and Game,* 99(2), 80-89. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=69452

We document the presence of the ectoparasitic fine-sculptured odostome snail (Evalea tenuisculpta) on red abalone (Haliotis rufescens) in northern California. Red abalone form the basis for an important recreational fishery north of San Francisco. We found that 82% of the red abalone examined from three sites (n=73) in Sonoma County had these small snail parasites. We document that the parasitic snails also infects northern abalone (H. kamtschatkana). Infected red abalone had an average of 12 parasitic snails, averaging 4.8mm in length (range 1.0 to 8.8 mm) on their shell. In the laboratory, starved parasitic snails presented with live abalone elongated their proboscis to feed. Over three days, parasitic snails (85%) laid at least one egg mass, with larger snails laying more egg masses (containing more eggs) than smaller snails. Egg masses averaged 360 eggs per mass. More work is needed on the biology of this parasitic snail to determine its impacts on abalone, abalone populations, and the abalone fishery.

McDougall, P. T., Ploss, J., & Tuthill, J. (2006). *Haliotis kamtschatkana.* The IUCN Red List of Threatened Species International Union for the Conservation of Nature, https://doi.org/10.2305/IUCN.UK.2006.RLTS.T61743A12552981.en

The global status of the pinto abalone Haliotis kamtschatkana Jonas, 1845 is assessed as EN A2abd based on an observed population size reduction of 50%. We report on declines of 89.7% and 41.4% observed in catch per unit effort (CPUE) for both the Alaskan and British Columbian fisheries respectively. These data are comparable to declines in population densities of 88.6% and 85.5%, as measured at index sites in two regions on the coast of British Columbia. Although the observed declines support a classification of CR A2a (an observed population size reduction of 80%), we judge that the historical elimination of a chief predator led to abnormally large pre-exploitation levels. Due to the observed declines, all commercial harvests of the pinto abalone were closed by the year 1996. Current population numbers are stable, but potential for further decline still exists due to incomplete knowledge, an increase in sea otter populations, and continued poaching.

Miller, K. M., Laberee, K., Kaukinen, K. H., Li, S., & Withler, R. E. (2001). Development of microsatellite loci in pinto abalone (Haliotis kamtschatkana). *Molecular Ecology Notes,* 1(4), 315-317. https://doi.org/10.1046/j.1471-8278.2001.00122.x

Twelve novel di-, tri- and tetranucleotide microsatellite loci to the pinto abalone (Haliotis kamtschatkana) are described. Over 400 individuals were analysed at each microsatellite locus. Observed heterozygosities ranged from 0.44 to 0.93, and numbers of alleles from 20 to 63. Six of the loci contained excesses in homozygosity indicative of inbreeding, nonrandom mating, population admixture, or null alleles.

Mills-Orcutt, K. (2019). *Optimizing abalone outplant strategies using larval* Haliotis kamtschatkana *in the San Juan Archipelago, Washington.* (Master of Science Thesis), University of Western Washington, Bellingham, WA. Retrieved from https://cedar.wwu.edu/wwuet/905/

Prior studies testing the use of Haliotis kamtschatkana larvae as a means of stock enhancement in the San Juan archipelago have shown no success in inducing larvae to settle in densities required for successful reproduction. I conducted an experiment to test the effectiveness of new methods for outplanting larval abalone in hopes of creating a protocol Puget Sound Restoration Fund could use to restore wild populations. Using two sites within the San Juan archipelago, I outplanted abalone into pre-constructed larval abalone modules (LAMs) and sampled over four months, testing retention strategies. Three types of LAMs were used at each site to determine whether 125µm Nitex tenting was necessary for retention of larvae after outplanting. In total, nine LAMs were placed at each site: three with Nitex tenting (tented LAMs), three without tenting (open LAMs), and three which received no larval abalone (control LAMs). All larval abalone were treated with 5µM of settlement cue gamma-aminobutyric acid (GABA) at time of outplanting to stimulate metamorphosis into their benthic life phase. Larvae of the same families that were outplanted were also reared in LAMs at Shannon Point Marine Center so that survival could be compared to survival in field LAMs and so that emigration could be estimated. Shell lengths of field abalone were measured four months after outplanting and were compared to hatchery reared individuals of the same families to better understand if hatchery life compromises early growth. Four months after outplanting abundance counts of settled pinto abalone were significantly greater ($p < 0.001$) in LAMs with 125µm Nitex tents encasing the LAMs for 24 hours after seeding, compared to open

and control LAMs. Open LAMs had some settlement (0-12 abalone), while tented LAMs all contained settled juveniles (16-35 abalone). Control LAMs (which had not been seeded during outplanting) remained unsettled by any abalone, suggesting no adult reproductive abalone were present at my study sites. Emigration measurements from laboratory LAMs showed 8% (tented) and 14% (open) of total seeding densities settled on aquarium walls during final sampling, often clustered together. Shell length measurements during final sampling showed no size difference in outplanted abalone compared to hatchery controls suggesting hatchery conditions do not stunt growth rates of newly settled pinto abalone, however, more research needs to be done in order to better understand if behavioral differences exist between hatchery-reared juveniles and juveniles that were outplanted as larvae. In conclusion, I believe outplanting pinto abalone as larvae has significant potential to supplement current wild stocks in the San Juan archipelago as a cost-effective alternative to traditional juvenile outplanting.

Minchin, D. (1975). The righting response in haliotids. *The Veliger,* 17(3), 249-251. Retrieved from https://www.biodiversitylibrary.org/page/42520426

The author describes the importance of the righting response in haliotids when they become dislodged from the substrate or washed ashore. 16 Haliotis kamtschatkana from Salt Spring Island, British Columbia, Canada, were inverted in trays of 12{degree}C sea water, and their righting response was observed as follows: (1) The foot stretches over the lip of the shell and the posterior edge unfolds as the collumellar muscle rotates slowly to one side. (2) The posterior tip of the foot contacts the substrate and the sole becomes more exposed. (3) The columellar muscle contracts with an accompanying rotation of the shell, causing the animal to right itself. (4) The lateral edge of the foot folds back to expose the full sole to the substrate. 17 H. cracherodii and 7 H. rufescens, all from Montana de Oro State Park, California, USA, also showed the same righting pattern. Occasionally H. rufescens was able to right itself by extending the anterior portion of the foot over the edge of the shell. None of the inverted abalones were able to right themselves on level sand, but all were able to move across the sand.

Miyake, Y., Kimura, S., Horii, T., & Kawamura, T. (2017). Larval Dispersal of Abalone and Its Three Modes: a Review. *Journal of Shellfish Research,* 36(1), 157-167. https://doi.org/10.2983/035.036.0116

Abalone are planktonic larvae in their early life history stages, and their dispersal predominantly takes place during these stages. Abalone stocks rely on the natural supply of larvae in self-recruiting populations, larval connectivity in metapopulations, and artificial hatchery—produced larvae in regions where larval restoration is needed. Larval dispersal is, therefore, one of the key factors in the management of wild populations as well as in the establishment of resilient and genetically viable populations during restoration. In this review of abalone larval dispersal studies conducted in different regions of the world, evidence is found for three modes of larval dispersal; (1) short distance, (2) long distance, and (3) both short and long distance (dual mode). Four biological factors (spawning, larval duration, vertical behaviors, and presettlement mortality) are proposed to influence larval dispersal. Consideration of larval dispersal mode, influential biological factors, and their interactions may improve estimation of connectivity in metapopulations for establishment of effective marine protected areas, which could help the recovery of declining populations and the conservation of endangered abalone species.

Morse, D. E. (1992). Molecular mechanisms controlling metamorphosis and recruitment in abalone larvae. In *Abalone of the world: biology, fisheries and culture.* (pp. 107-119). Oxford: Fishing News Books. Retrieved from https://www.wiley.com/en-us/Abalone+of+the+World%3A+Biology%2C+Fisheries+and+Culture-p-9780852381816

Abalone larvae have proved especially useful for experimentally resolving the molecular mechanisms controlling the settlement and metamorphoosis of marine invertebrate larvae in response to chemical signals from the environment. Recent studies in vitro have confirmed the existence of two separate families of chemosensory receptors and signal transduction pathways that process such chemical information from the environment to control metamorphosis in abalone larvae. A variety of chemical stimuli have been found to induce larval settlement, or enhance the sensitivity of the larvae to settlement inducers, by interacting directly with the signal transducers. The receptors and signal transducers of the regulatory (amplifier) pathway have been characterized in vitro, on cilia purified from the larval epithelium; results of these analyses confirm conclusions from earlier experiments in vivo. Properties of the receptors of the regulatory and morphogenetic pathways suggest how these may interact to control settlement in response to two different classes of chemical signals (in the water column and on surfaces) in the natural environment. At last count, 13 Haliotis species (including H. discus hannai) have been found to respond similarly to chemical inducers of settlement and metamorphosis. We have begun to clone genes expressed in the abalone early after metamorphosis, to facilitate analysis of the machanisms controlling their develpmental activation and their contribution to early growth.

Noisette, F., Comtet, T., Legrand, E., Bordeyne, F., Davoult, D., & Martin, S. G. (2014). Does encapsulation protect embryos from the effects of ocean acidification? The example of *Crepidula fornicata*. *PloS one,* 9(3), e93021. https://doi.org/10.1371/journal.pone.0093021

Early life history stages of marine organisms are generally thought to be more sensitive to environmental stress than adults. Although most marine invertebrates are broadcast spawners, some species are brooders and/or protect their embryos in egg or capsules. Brooding and encapsulation strategies are typically assumed to confer greater safety and protection to embryos, although little is known about the physico-chemical conditions within egg capsules. In the context of ocean acidification, the protective role of encapsulation remains to be investigated. To address this issue, we conducted experiments on the gastropod Crepidula fornicata. This species broods its embryos within capsules located under the female and veliger larvae are released directly into the water column. C. fornicata adults were reared at the current level of CO2 partial pressure (pCO2) (390 µatm) and at elevated levels (750 and 1400 µatm) before and after fertilization and until larval release, such that larval development occurred entirely at a given pCO2. The pCO2 effects on shell morphology, the frequency of abnormalities and mineralization level were investigated on released larvae. Shell length decreased by 6% and shell surface area by 11% at elevated pCO2 (1400 µatm). The percentage of abnormalities was 1.5- to 4-fold higher at 750 µatm and 1400 µatm pCO2, respectively, than at 390 µatm. The intensity of birefringence, used as a proxy for the mineralization level of the larval shell, also decreased with increasing pCO2. These negative results are likely explained by increased intracapsular acidosis due to elevated pCO2 in extracapsular seawater. The encapsulation of C. fornicata embryos did not protect them against the deleterious effects of a predicted pCO2 increase. Nevertheless, C. fornicata larvae seemed less affected than other mollusk species. Further studies are needed to identify the critical points of the life cycle in this species in light of future ocean acidification.

Norman-Boudreau, K., Burns, D., Cooke, C. A., & Austin, A. (1986). A simple technique for detection of feeding in newly metamorphosed abalone. *Aquaculture,* 51(3-4), 313-317. https://doi.org/10.1016/0044-8486(86)90322-4

The digestive tracts of newly metamorphosed juvenile abalone (Haliotis kamtschatkana X H. kamtschatkana or H. kamtschatkana X H. rufenscens) were examined, every 2 days after settlement on plates, for the presence of ingested diatoms. Samples of five juveniles were rinsed with filtered seawater, immersed in a saturated EDTA disodium salt solution to decalcify the shell, and tissue was disolved with 6% sodium hypochlorite to reveal gut contents. The presence of diatoms was first noted 2 to 6 days after settlement. All diatoms found within abalone digestive tracts were of the Order Pennales and usually smaller than 10 mu m. This technique contributes to the examination of certain aspects of feeding in larval and juvenile molluscan species.

O'Brien, C. (2019). *Development of cryopreservation methods for sperm of pinto abalone (*Haliotis kamtschatkana*) for conservation aquaculture.* (Master of Science Thesis), Western Washington University, Bellingham, WA. Retrieved from https://cedar.wwu.edu/wwuet/859/

The pinto abalone, Haliotis kamtschatkana, is an ecosystem engineer with cultural and ecological significance. Due to the dramatic 98% decline in populations, a ten-year recovery plan was enacted to bring levels of pinto abalone back from the brink of extirpation in the San Juan Archipelago, Washington. The focus of this study was to assist restoration efforts in creating self-sustaining populations by developing methods of cryopreservation for male pinto abalone sperm. My study evaluated three commonly used cryoprotectants, a series of freeze/thaw temperatures, and developed methods of quality assessment specific to pinto abalone. Animals were provided and cared for by Puget Sound Restoration Fund and all experiments were done at the NOAA Research Station in Manchester, WA. I evaluated sperm quality with a computer-assisted sperm analysis (CASA) system, for which I developed parameters to track pinto abalone sperm motility. I used sperm motility to analyze sperm quality in a series of experiments culminating in a final experiment to test the optimized cryopreservation methods by fertilizing pinto abalone eggs. Toxic effects of commonly used cryoprotectants, di-methyl sulfoxide (DMSO), glycerol (GLY), and propylene glycol (PG), were tested at concentrations from 5%-20%. DMSO at 5% was the least toxic, yielding the highest percent motile sperm after an exposure time of 10 minutes. Using a programmable freezer, a series of freezing rates and endpoint temperatures were evaluated for cryopreservation of sperm in 0.5 mL freezing straws at a density of 1.8 x 108 sperm mL-1. A freezing rate of -3 ℃ min-1 to an endpoint temperature of -60 ℃, preservation in liquid nitrogen (-196℃), then thawing in a 40℃ water-bath for 8 seconds yielded the highest sperm motility. Cryopreserved sperm successfully fertilized eggs, but with lower success than with untreated sperm. The highest percent fertilized was 12.2% using a concentration of 1 x 106 sperm mL-1 with 14.2% post-thaw motility. Through this study, I have outlined the first attempt into cryopreservation of pinto abalone sperm and provided a foundation for future research to optimize the methods developed. Developing cryopreservation methods will allow hatchery managers to build a genetic library to improve production and maintain genetic diversity of this vanishing species.

Page, L. R. (1997). Larval shell muscles in the abalone *Haliotis kamtschatkana*. *Biological Bulletin,* 193(1), 30-46. https://doi.org/10.2307/1542734

I used light and electron microscopy to investigate shell-attached muscles in larvae of Haliotis kamtschatkana Jonas, 1845, because an early description of these muscles in H. tuberculata by Crofts (1937, 1955) has featured prominently in theories about gastropod evolution. Larval shell muscles in N. kamtschatkana can be grouped into two categories. The first category consists of the larval retractor muscle (LRM) and the accessory larval retractor muscle (ACC); these are striated muscles in which myofilaments begin differentiating before the head and foot rotate relative to the protoconch (this rotation is known as ontogenetic torsion). Collectively, these muscles ultimately insert on tissues within the larval head and mantle, but the ACC and mantle fibers of the LRM degenerate as metamorphic competence is achieved. The second category consists of two nonstriated pedal muscles that differentiate after cephalopodial rotation. The left pedal muscle is anchored on the back of the protoconch, to the left of the shell-attachment plaque for the LRM. It projects into the foot primarily, but also gives rise to muscle slips extending into the mantle fold. The right pedal muscle is anchored on a calcareous septum secreted along the visceral rim of the protoconch. The new data force a reconsideration of the ancestral homologues of larval shell muscles in abalone, because Crofts may have misidentified the accessory larval retractor muscle as a precursor of one of the later pedal muscles.

Page, L. R. (1997). Ontogenetic torsion and protoconch form in the archaeogastropod *Haliotis kamtschatkana*: Evolutionary implications. *Acta Zoologica,* 78(3), 227-245. https://doi.org/10.1111/j.1463-6395.1997.tb01009.x

Ontogenetic torsion in archaeogastropods has strongly influenced theories about early gastropod evolution, but the seminal studies by Crofts (1937, 1955) remain the major source of information about tissue movements during this developmental process. Computer-generated reconstructions of histological sections indicate that the cephalopodium of Haliotis kamtschatkana Jonas, 1845 rotates by a full 180 degrees relative to the shell and visceral lobe during the first quarter of pre-metamorphic development. However, a portion of pallial epithelium, including some of the shell field, accompanies the rotating cephalopodium; a process facilitated by detachment of the pallium from the apertural rim of the protoconch. Transmission electron microscopy indicates that a tract of the larval retractor muscle, which Crofts (1955) implicated in the mechanism of torsion, inserts on both pedal and pallial cells. A deep invagination of shelf held epithelium is a major focus of rotational torque. As a result of pallial deformation during cephalopodial rotation, the anus and gill rudiment are restricted to the right half of the larval body for 2 days after cephalopodial rotation by 180 degrees has been completed. Scanning and transmission electron microscopy indicate that grooves in the lateral flanks of the protoconch correspond to the deep invagination of shell field epithelium. The grooves are not created by a coiling type of accretionary shell growth or by flexion of the protoconch. A calcareous shelf is secondarily added to the periostracal template of the protoconch along its visceral apertural rim. Morphogenetic movements during ontogenetic torsion in this species are more complex than a simple rotation between cephalopodium and visceropallium and the protoconch shows no evidence of exogastric coiling.

Page, L. R. (1998). Sequential developmental programmes for retractor muscles of a caenogastropod: reappraisal of evolutionary homologues. *Proceedings of the Royal Society B-Biological Sciences,* 265(1412), 2243-2250. https://doi.org/10.1098/rspb.1998.0566

Evolutionary changes in the development of shell-attached retractor muscles in gastropods are of fundamental importance to theories about the early evolution and subsequent diversification of this molluscan class. Development of the shell-attached retractor muscle (columellar muscle) in a caenogastropod has been studied at the ultrastructural level to test the hypothesis of homology with the post-torsional left retractor muscle (larval velar retractor) in vetigastropod larvae. The vetigastropod muscle has been implicated in the generation of ontogenetic torsion, a morphogenetic twist between body regions that is important to theories about early gastropod evolution. Two shell-attached retractor muscles develop sequentially in the caenogastropod, Polinices lewisii, which is a pattern that has been also identified in previous ultrastructural studies on a vetigastropod and several nudibranch gastropods. The pattern may be a basal and conserved characteristic of gastropods. I found that the first-formed retractor in larvae of P. lewisii is comparable to the larval velar retractor that exists at the time of ontogenetic torsion in the vetigastropod, Haliotis kamtschatkana. However, the post-metamorphic columellar muscle of P lewisii is derived exclusively from part of the second-formed muscle, which is comparable to the second-formed pedal muscle system in the vetigastropod. I conclude that the post-metamorphic columellar muscle of P. lewisii, is not homologous to the larval velar retractor of the vetigastropod, H. kamtschatkana.

Page, L. R. (2003). Gastropod ontogenetic torsion: Developmental remnants of an ancient evolutionary change in body plan. *Journal of Experimental Zoology Part B-Molecular and Developmental Evolution,* 297B(1), 11-26. https://doi.org/10.1002/jez.b.00012

A dramatic morphogenetic movement ('ontogenetic torsion') during the development of gastropods has been proposed as a recapitulation of the original developmental departure that established the novel gastropod body plan. Nevertheless, speculative literature about ontogenetic torsion and its evolutionary significance has far outstripped empirical observations and recent results suggest that the developmental process may be somewhat different than the traditional description. I used scanning electron microscopy, immunohistochemistry, phalloidin labeling, and histological sections to monitor displacements of five components of the visceropallium with respect to axial coordinates of the cephalopodium in developing embryos of the caenogastropod, Trichotropis cancellata. Embryos of this species achieve a transient stage of anatomical organization that also arises during development of a vetigastropod (Haliotis kamtschatkana), although morphogenetic processes that generate this stage are different in these two species. At the stage of similarity, the embryonic shell has achieved its definitive orientation with respect to the cephalopodium, but the developing mantle cavity, sensory osphradium., and anus are confined to the right side. I also show that this stage of anatomical organization is recognizable during the development of other gastropods, which collectively represent three major gastropod clades. I propose that ontogenetic torsion should be viewed as a conserved stage of anatomical organization during development, rather than a conserved process of 180degrees rotation between the visceropallium and cephalopodium. The results lead to the suggestion that the mantle cavity of extant gastropods evolved by enlargement of the right side of the mantle cavity in a monoplacophoran-like ancestor. Under this interpretation, there is no need for a hypothetical pre-gastropod with a mantle cavity that was restricted to the posterior end.

Page, L. R. (2006). Early differentiating neuron in larval abalone (*Haliotis kamtschatkana*) reveals the relationship between ontogenetic torsion and crossing of the pleurovisceral nerve cords. *Evolution & Development,* 8(5), 458-467. https://doi.org/10.1111/j.1525-142X.2006.00119.x

Crossing of the pleurovisceral nerve cords in gastropods has supported the view that gastropods evolved by 180 degrees rotation between the ventral and dorsal body regions. Indeed, a rotation of this type occurs as a dramatic morphogenetic movement ("ontogenetic torsion") during the development of basal gastropods. According to a long-standing hypothesis, ontogenetic torsion in basal gastropods preserves an ancient developmental aberration that generated the contorted gastropod body plan. It follows from this reasoning that crossing of the pleurovisceral nerve cords during gastropod development should be mechanically coupled to ontogenetic torsion. The predicted mechanical coupling can now be examined because of the discovery of an early differentiating neuron in Haliotis kamtschatkana (Vetigastropoda) that expresses 5-hydroxytryptamine-like immunoreactivity. The neuron appeared to delineate the trajectory of the pleurovisceral nerve cords beginning before ontogenetic torsion. Before torsion, the neuronal soma is embedded in mantle epithelium at the ventral midline and two neurites extend anteriorly toward the apical sensory organ. Contrary to expectation, the two neurites of this cell did not cross-over during ontogenetic torsion because the soma of this mantle neuron shifted in the same direction as the rotating head and foot. Full crossing of the pleurovisceral nerve cords occurred gradually during later development as the mantle cavity deepened and expanded leftward. These results are consistent with a generalization emerging from comparative studies indicating a conserved developmental stage for gastropods in which the mantle cavity is localized to one side, despite a fully "post-torsional" orientation for other body components. Developmental morphology before this stage is much more variable among different gastropod clades.

Parkhaev, P. Y. (2017). Origin and the Early Evolution of the Phylum Mollusca. *Paleontological Journal,* 51(6), 663-686. https://doi.org/10.1134/S003103011706003X

The paper gives an overview of the modern hypotheses on the origin of the phylum Mollusca and the formation of its main classes. The Cambrian stage of molluscan evolution is characterized based on the paleontological material. The doubtfulness of assignment of the Precambrian (Vendian) soft-bodied fossil Kimberella to mollusks is argued. Judging from the interpretation of the morphologically diverse Cambrian fossils, it is suggested that the classes Polyplacophora, Monoplacophora, Gastropoda and Bivalvia formed already near the Precambrian–Cambrian boundary, i.e., from the beginning of the paleontologically documented evolutionary history of the phylum, whereas the assumption of the later origin of these taxa is unconvincing. The remaining classes of mollusks arose later, i.e., Cephalopoda, in the Late Cambrian; Scaphopoda, in the Ordovician; and Aplacophora, in the Silurian.

Paul, A. J., & Paul, J. M. (1981). Temperature and Growth of Maturing *Haliotis kamtschatkana* Jonas. *The Veliger,* 23(4), 321-324. Retrieved from https://www.biodiversitylibrary.org/page/42412612

The pinto abalone, H. kamtschatkana Jonas, 1845, supports a small commercial fishery along the outer coast of southeast Alaska, but its restricted distribution and low population densities preclude large-scale expansion of the fishery. Currently, little information is available on the relationship of temperature and the various biological functions of pinto abalone. This species spawns in the spring when the water temperature reaches approximately 9 degree C (Quayle, 1971; Paul et al ., 1977) and thermal death occurs if individuals are kept at 16 degree C to 17 degree C (unpublished data). The

objective of this study was to observe shell growth of maturing pinto abalone at different temperatures. Maturing individuals were selected because they grow rapidly and individual differences in growth are pronounced. The temperatures examined are typical of southeastern Alaska during the spring and summer growth period.

Paul, A. J., & Paul, J. M. (1998). Respiration rate and thermal tolerances of pinto abalone *Haliotis kamtschatkana*. *Journal of Shellfish Research,* 17(3), 743-745. Retrieved from https://www.biodiversitylibrary.org/page/2151861

Oxygen consumption rates were measured for pinto abalone, Haliotis kamtschatkana, held at 0.5-26.5 degrees C. Thermal tolerances were inferred from respiration data, behavior, and survival at the test temperatures. At 0.5 and 26.5 degrees C, pinto abalone were unable to maintain their attachment to surfaces and mortalities occurred. At 0.5 degrees C, the first mortality occurred after 13 days, and by the end of 6 wk. 75% of the test animals had died. At 26.5 degrees C, the first death was on Day 6, and by Day 10, all animals were dead. Between 2 and 24 degrees C, no evidence of respiratory stress was evident and a linear relationship between oxygen consumption rate and temperature was observed.

Paul, A. J., & Paul, J. M. (2000). Longevity of Captive Pinto Abalones *Haliotis kamtschatkana*. *Alaska Fishery Research Bulletin,* 7, 51-53. Retrieved from https://www.adfg.alaska.gov/static/home/library/PDFs/afrb/paul_v7.pdf

Ten pinto abalones Haliotis kamtschatkana were captured in Sitka Sound in 1979 and held in captivity at the Seward Marine Center Laboratory. The first of them died in 1985, and 3 were still alive in 2000 when this note was written. Their shell lengths at capture ranged from 48 to 53 mm. At death 7 individuals had shell lengths ranging from 91 to 102 mm. The 3 live individuals had shell lengths of 81, 96, and 98 mm. These observations indicate pinto abalones have the capacity to live for periods exceeding 20 years in captivity.

Paul, A. J., Paul, J. M., Hood, D. W., & Neve, R. A. (1977). Observations on food preferences, daily ration requirements and growth of *Haliotis kamtschatkana* Jonas in captivity. *The Veliger,* 19, 303-309. Retrieved from https://www.biodiversitylibrary.org/part/93678

Haliotis kamtschatkana Jonas, 1845, commonly called the pinto abalone, is found along the outside coastal waters of southeastern Alaska from Dixon Entrance to Icy Straits (Parker, 1973). It is also encountered in British Columbia and occurs as far south as Point Conception, California (Cox, 1962). The flesh of the pinto abalone has an excellent flavor and is especially tender. Therefore, this animal is eagerly sought by Alaskans for home consumption (Livingstone, 1952). This abalone is commercially harvested on a small scale and recovered meats retailed at approximately $4 per pound (ca. 450 g) in 1975. In Alaska, however, Haliotis kamtschatkana is encountered primarily in patchy aggregations (Livingstone, op. cit.); therefore, its fishery potential is probably limited. This is also the case for pinto abalone in British Columbia (Quayle, 1962).

Considering the extensive distribution of Haliotis kamtschatkana along the Pacific coast of North America, few papers on the basic biology of the species are available. The most extensive paper is that of Quayle (1971) which primarily provides information on morphometry and estimated growth rates for

pinto abalone in British Columbia. A general, but brief, review of distribution and feeding habits can be found in Cox (1962). Livingstone (1952) provides some data on size-weight relations and the percent meat recovery for pinto abalone from the Prince of Wales and Baranof Islands, southeast Alaska. Parker (1973) reported additional information on size-weight relations and determined that sexual maturity in Alaskan H. kamtschatkana was reached at a shell length of approximately 65 mm. No published data are available on feeding and growth of the pinto abalone in Alaskan waters.

Recent interest in the southeastern and southcentral Alaskan coastline as aquacultural areas has prompted the examination of the suitability of several native organisms, including Haliotis kamtschatkana, for culture. The major purpose of this investigation was to study the feeding and resulting growth of H. kamtschatkana in captivity.

Pennington, J. T., & Chia, F.-S. (1985). Gastropod torsion: a test of Garstang's hypothesis. *The Biological bulletin,* 169(2), 391-396. https://doi.org/10.2307/1541490

Torsion occurs in gastropod molluscs as a 180° twisting of the shell and viscera relative to the head and foot of the veliger larva. Garstang (1928, 1929) proposed, and it has since become widely accepted, that torsion functions as a larval defense by allowing veligers to first pull the head into the shell, then sealing the aperture with the foot and operculum. However, when we offered pre-torsional and torted larvae of the abalone Haliotis kamtschatkana Jonas as prey to seven planktonic predator species from four phyla, in only one case was rate of predation reduced on torted larvae. It therefore appears that torsion does not function defensively, indicating that other selective pressures probably maintained this trait in primitive gastropods.

Price, R. J. (2000). Biology of certain commercial mollusk species: Abalone. In *Marine and Freshwater Products Handbook.* R. E. Martin, E. P. Carter, G. J. Flick, & L. M. Davis (Eds.), (pp. 111-116). Lancaster PA: Technomic Publishing Co. Retrieved from https://www.routledge.com/Marine-and-Freshwater-Products-Handbook/Martin-Carter-Flick-Jr-Davis/p/book/9781566768894

Abalones are members of a large class (Gastropoda) of mollusks having one-piece shells. They belong to the family Haliotidae and the genus Haliotis, which means sea ear, referring to the flattened shape of the shell (Haaker et al., 1986). Abalone shells are rounded or oval with a large dome towards one end. The shell has a row of respiratory pores. The muscular foot has strong suction power, permitting the abalone to clamp tightly to rocky surfaces. An epipodium, a sensory structure and extension of the foot that bears tentacles, circles the foot and projects beyond the shell edge in the living abalone (Haaker et al., 1986). Nine species of abalone occur in North America: black (H. cracherodii, flat (H. walallensis), green (H. fulgens), pink (H. corrugata), pinto (H. kamtschatkana), red (H. rufescens), threaded (H. assimilis), western Atlantic (H. pourtalesii), and white (H. sorenseni) abalone.

Price, R. M. (2003). Columellar Muscle of Neogastropods: Muscle Attachment and the Function of Columellar Folds. *The Biological bulletin,* 205(3), 351-366. Retrieved from https://www.biodiversitylibrary.org/page/1533614

Malacologists often assume that ornamentation on snail shells is functional, and therefore adaptive. I conducted the first comprehensive test of the widely accepted hypothesis that columellar folds, a type

of internal ornamentation, enhance the performance of the columellar muscle, which attaches the snail to its shell. Careful dissections of live, non-relaxed specimens reveal that the physical attachment between the columellar muscle and the columella is not restricted to a small, circular patch located deep within the shell. Instead, the attachment is long and narrow, extending approximately a full whorl along the length of the columella. I developed a novel technique for preparing three-dimensional reconstructions from photographs documenting the dissections. These reconstructions were then used to measure four parameters that describe the muscle: (1) the surface area of the physical attachment between the muscle and columella, (2) the total contact area between the muscle and the columella, (3) the depth of attachment, and (4) the length of attachment. None of these parameters differed significantly between species with and without folds. In light of the biomechanics of muscular hydrostats, values of the first parameter indicate that columellar folds probably do not guide the columellar muscle as the animal moves in and out of its shell. Values of the other parameters indicate that columellar folds neither increase an animal's ability to maneuver its shell nor facilitate deeper withdrawal. These results, and the fact that folds have evolved convergently several times, might indicate that folds are an easily evolvable solution to many functional problems, none of which are currently understood.

Quayle, D. B. (1971). *Growth, morphometry and breeding in the British Columbia abalone (*Haliotis kamtschatkan*a Jonas)*.Technical report (Fisheries Research Board of Canada): Fisheries Research Board, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/26748.pdf

This report deals with some aspects of the results of a continuing study which included a tagging program whose primary purpose was to determine rate of growth and secondarily to indicate the degree of movement. Some information was obtained on time of breeding.

Read, K. D., Lemay, M. A., Acheson, S., & Boulding, E. G. (2012). Using molecular pedigree reconstruction to evaluate the long-term survival of outplanted hatchery-reared larval and juvenile northern abalone *(Haliotis kamtschatkana)*. *Conservation Genetics,* 13(3), 801-810. https://doi.org/10.1007/s10592-012-0330-5

The restoration of abalone (Haliotis spp.) populations through supplementation with the offspring of hatchery-spawned wild parents has been attempted in several species, with variable results. Between 2002 and 2005, the Bamfield Huu-ay-aht Community Abalone Project released 4.5 million larvae and 152,000 juveniles of the northern abalone (Haliotis kamtschatkana) into Barkley Sound, BC. The purpose of this study was to estimate the long-term survival of outplanted abalone 3-7 years after their release and thus determine their contribution to local population densities at three different outplanting sites. We identified outplanted abalone by genotyping epipodal tentacles sampled from wild-caught abalone for seven microsatellite loci. We then used three different pedigree reconstruction programs: one that used genotypes from hatchery-reared siblings (pedigree 2.2), one that used the wild parent genotypes that were available (cervus 3.0), and one that used both sources of information (colony 2.0). Each program identified different but partially overlapping subsets of hatchery-outplanted offspring. From this we inferred that up to 26% of the individuals sampled at the main outplanting site were from hatchery spawnings. Despite this large contribution of hatchery-reared stock, the density of mature abalone at each site was below the level required for successful fertilization. More intensive outplanting efforts might increase population densities of this broadcast spawner above this minimum sustainable level. However, for supplementation to be successful, other factors that could reduce outplanted

juvenile survival, including the low genetic diversity of hatchery-produced offspring and the low habitat quality of some outplanting sites, need to be monitored.

Rogers-Bennett, L., Allen, B. L., & Davis, G. E. (2004). Measuring abalone (*Haliotis Spp.*) recruitment in California to examine recruitment overfishing and recovery criteria. *Journal of Shellfish Research,* 23(4), 1201-1207. Retrieved from https://www.biodiversitylibrary.org/page/3063519

Abalone populations in southern California have declined dramatically since the 1950s when they supported a multispecies, commercial, and recreational fishery producing more than 3,000 t per year. Today the commercial fishery is closed statewide and the recreational fishery is closed south of San Francisco. In contrast, red abalone, Haliotis rufescens (Swainson, 1822), populations in northern California continue to sustain a 1,100 1 per year free-diving recreational fishery. We used standardized Abalone Recruitment Modules (ARMs) made of half cinder blocks (area = 2.6 m(2)) to compare the recruitment of juvenile abalone in northern California. where stocks are abundant, with southern California where stocks have declined. We compared the abundance of abalone inside ARMs (n = 12) in Van Damme State Park (VDSP). northern California with abalone inside ARMs (n - 82) in the Channel Islands National Park from 2001 to 2003. Abalone densities on the reefs Surrounding the ARMs at VDSP, averaged 8300/ha compared with abalone densities of 30/ha on reefs in three of the northern Channel Islands. Red, flat abalone, H. walallensis and pinto abalone. H. kamstchatkana kamstchatkana were found in the northern ARMs, whereas in the south red, pink, H. corrugata, threaded, H. kamtchatkana assimilis, and the endangered white abalone, H. sorenseni, were rare in the southern ARMs. Abalone were 30 times more abundant inside the ARMs in the north (5.30/ARM) compared with the south (0.18/ARM). Similar numbers of abalone were found in all 3 years in the ARMs in northern (69, 69, and 53 abalone) and southern California (14, 11, and 20 abalone). The majority of abalone in both the north and the south were less then 100 mm in shell length. Ironically, the rare flat abalone was more abundant in the north, than pink abalone were in the south, a species which once supported a major fishery. Clearly. abalone stocks in southern California are so low that recruitment is failing, despite their potential high fecundity and the fishery closure. These results demonstrate that ARMs call be used to monitor recruitment in the northern fishery, as well as establish quantitative recovery criteria to assess abalone restoration efforts that are desperately needed in the south.

Ross, P. M., Parker, L., O'Connor, W. A., & Bailey, E. A. (2011). The Impact of Ocean Acidification on Reproduction, Early Development and Settlement of Marine Organisms. *Water,* 3(4), 1005-1030. https://doi.org/10.3390/w3041005

Predicting the impact of warming and acidifying on oceans on the early development life history stages of invertebrates although difficult, is essential in order to anticipate the severity and consequences of future climate change. This review summarises the current literature and meta-analyses on the early life-history stages of invertebrates including fertilisation, larval development and the implications for dispersal and settlement of populations. Although fertilisation appears robust to near future predictions of ocean acidification, larval development is much more vulnerable and across invertebrate groups, evidence indicates that the impacts may be severe. This is especially for those many marine organisms which start to calcify in their larval and/or juvenile stages. Species-specificity and variability in responses and current gaps in the literature are highlighted, including the need for studies to investigate the total effects of climate change including the synergistic impact of temperature, and the need for long-term

multigenerational experiments to determine whether vulnerable invertebrate species have the capacity to adapt to elevations in atmospheric CO2 over the next century.

Seamone, C. B., & Boulding, E. G. (2011). Aggregation of the Northern Abalone *Haliotis kamtschatkana* with Respect to Sex and Spawning Condition. *Journal of Shellfish Research,* 30(3), 881-888. https://doi.org/10.2983/035.030.0329

Current low densities of the northern abalone Haliotis kamtschatkana may be affecting the fertilization success of this endangered broadcast spawner, thus preventing its populations from recovering to historical levels. This study attempted to determine whether the northern abalone were significantly aggregated during the period just before spawning because this may compensate in part for their low densities. We used scuba to map the spatial distribution, sex, and spawning condition of tagged abalone within grids at three different sites close to Bamfield Marine Sciences Center on the west coast of Canada. Underwater tagging methods were then used to monitor individuals over a 3-wk period during the 2009 spawning season. We found that the populations at all sites had nearest neighbor R ratios significantly less than 1.0, which indicates an aggregated distribution. Within the range of densities observed for our 3 sites (0.12-0.64 adults/m(2)), the mean distances to the nearest neighbor (1) of either sex, (2) of the opposite sex, and (3) of the opposite sex with ripe gonads were always less than 1.00 m except in one case. Individual abalone aggregated independently of sex; therefore, the probability of finding both a ripe male and a ripe female within an aggregation increased linearly with density. We estimated that the northern abalone populations observed were sufficiently aggregated to make successful fertilization more likely at low densities. This is the first study to map abalone sex and degree of gonad development that allow the analysis of nearest neighbor measurements with respect to gender and spawning condition.

Shepherd, S. A., & Breen, P. A. (1992). Mortality in abalone: its estimation, variability and causes. In *Abalone of the world: biology, fisheries and culture.* S. A. Shepherd, M. J. Tegner, & S. A. Guzman del Proo (Eds.), (pp. 276-304). Oxford, U.K.: Fishing News Books Retrieved from https://www.wiley.com/en-us/Abalone+of+the+World%3A+Biology%2C+Fisheries+and+Culture-p-9780852381816

The principal methods of measuring natural mortality (M) are: analysis of age- and size-freqeuncy distributions, mark-recapture experiments, examination of death assemblage, population models and the use of correlations between M and other life parameters. The methods are described and compared. Estimates of M for abalone range from about 0.05 to more than 1:00. There is a weak trend for M to increase with decreasing latitutde (i.e. from cold to warm temperature waters). Seasonal and inter-annual variations in M have rarely been examined. One study has shown wide variations of both kinds, suggesting that M may be much more variable than has been assumed. The predators, parasites and environmental hazards of abalone are also reviewed.

Shepherd, S. A., Woodby, D., Rumble, J. M., & Avalos-Borja, M. (2000). Microstructure, chronology and growth of the pinto abalone, *Haliotis kamtschatkana*, in Alaska. *Journal of Shellfish Research,* 19(1), 219-228. Retrieved from https://www.biodiversitylibrary.org/page/5727675

The microstructure, deposition of rings, and growth checks in the pinto abalone, Haliotis kamtschatkana Jonas, were examined at seven sites in southeast Alaska. Rings were of calcium carbonate with prismatic or block-like structure or were of organic material (called brown rings); sometimes both types were juxtaposed in a compound ring. Rings alternated with nacreous layers having a brick-like or laminar structure. Laminar thickness was correlated with ambient sea temperatures and provided internal evidence of periodicity of ring deposition. One ring a year appears to be deposited in the spire of this abalone in about mid-sumner, and a growth check is laid down at the growing edge of the shell in about mid-winter. Rates of deposition of the rings and growth checks were validated by comparison with known growth rates from mark-recapture experiments at one site, and modal analysis of length frequency data at others. Examination of a sample of shells of known age confirmed a deposition rate of one ring a year. Brown rings appear to be laid down adventitiously and were excluded from ring counts for aging purposes. The three independent techniques, rings, growth checks. and modal analysis, gave consistent juvenile growth rates at 7 sites of 14-18 mm/y during the first 4 y. Thereafter, growth rates followed a declining exponential curve. Growth rates differed little between sites, and mean parameters of fitted von Bertalanffy growth parameters for seven sites were: K = 0.20: L-infinity, = 125.9 mm.

Sloan, N. A., & Breen, P. A. (1988). *Northern abalone,* Haliotis kamtschatkana*, in British Columbia: fisheries and synopsis of life history information*.Canadian Special Publication of Fisheries and Aquatic Sciences (103). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.816448/publication.html

A comprehensive review of the life history and fisheries for the northern abalone, Haliotis kamtschatkana Jonas 1845, is presented with special emphasis on British Columbia populations. The literature on northern abalone throughout its range is discussed and compared with the literature on life histories of other Haliotis species worldwide. The exploitation (commercial/recreational/native) and management of northern abalone resources are described. The commercial northern abalone fishery is a minor one in British Columbia with populations fully exploited. There is some evidence that the a recent history of declining population abundance may be abating. Local commercial exploitation by divers expanded rapidly in the late 1970s (peaking at 433 t in 1978), but is now conducted at a much reduced level (quota of 47.2 t in 1987). Reasons for population decline are discussed and key gaps in life history data are identified. We conclude that the highest research priority for northern abalone should be to determine factors affecting recruitment.

Sorenson, A. (1947). Our West Coast marine fauna. *The Nautilus,* 60(3), 88-93. Retrieved from https://www.biodiversitylibrary.org/page/8523770

No abstract available.

Standley, C. S. (1987). *Temperature and salinity effects on gamete viability and early development of pinto abalone, red sea urchins and green sea urchins.* (Master of Science Thesis), Univeristy of Alaska, Juneau, AK. Retrieved from https://www.worldcat.org/title/temperature-and-salinity-effects-on-gamete-viability-and-early-development-of-pinto-abalone-red-sea-urchins-and-green-sea-urchins/oclc/39248472&referer=brief_results

No abstract available.

Stekoll, M. S., & Shirley, T. C. (1993). In situ spawning behavior of an Alaskan population of pinto abalone, *Haliotis kamtschatkana* Jonas, 1845. *The Veliger,* 36(1), 95-97. Retrieved from https://www.biodiversitylibrary.org/page/42465699

The pinto abalone (Haliotis kamtschatkana Jonas, 1845) supports a small commercial fishery in southeastern Alaska, but few studies have addressed its biology in the Alaskan part of its range (Livingstone, 1952; Paul et al., 1977; Paul & Paul, 1981; Standley, 1987). In British Columbia the species supported a much larger fishery until its closure in 1990 and has been the subject of many studies (Breen, 1980, 1986; Breen & Adkins, 1979, 1980; Quayle, 1962, 1971; Sloan & Breen, 1988). Knowledge of the reproductive biology of the species is important for management, as fishery openings might be timed to permit reproduction prior to harvest. No clearly defined reproductive cycle was evident in gonadal sections from British Columbia specimens; however, spontaneous spawning by pinto abalone in laboratory cultures was observed (Quayle, 1971). An in situ spawning of pinto abalone was observed in mid-July in the Queen Charlotte Islands; but, because approximately 500 abalone had been handled and aerially exposed while being tagged with plastic spaghetti tags before their return to the water, a strong possibility existed that handling had induced the spawning (Breen & Adkins, 1980). Standley (1987) extensively studied the reproductive biology of pinto abalone from Sitka Sound; she observed spontaneous laboratory spawning of pinto abalone (primarily in early summer) and was able to induce spawning by a variety of methods, but did not observe in situ spawning. The lack of observations of in situ spawning of pinto abalone is not unusual, as observations of any species of abalone spawning are rare (Hahn, 1989).

Steven, R., & Emma, T.-S. (2013). Transcriptome characterization of the Olympia oyster and pinto abalone. In *Figshare*. Retrieved from https://figshare.com/articles/Transcriptome_characterization_of_the_Olympia_oyster_and_pinto_abalone/156431

Transcriptome information for the Olympia oyster and pinto abalone.

Taylor, B. E. (1998). *Protein utilization, hormone treatment and nutrient metabolism as they apply to culture of abalone* Haliotis kamtschatkana*.* (Ph.D. Dissertation), University of British Columbia, Vancouver, BC. https://doi.org/10.14288/1.0088764

Development of formulated diets for use in abalone culture demands knowledge of the animal's nutritional requirements, growth, and metabolism. This thesis addresses some important aspects of these issues with regard to the abalone Haliotis kamtschatkana. Protein requirement was investigated from the standpoint of how protein utilization is affected by dietary protein content, amino acid

balance, and protein sparing, together with the possible amelioration of the last through enzymatic adaptation to diet. Focus on protein utilization stems from the fact that protein is a costly dietary ingredient and is an essential nutrient for protein growth. With respect to abalone growth, I assessed the efficacy of administering vertebrate growth hormones which enhance growth in other cultured aquatic animals. I also investigated metabolism of cells isolated from the abalone digestive gland (a primary site of metabolic conversions) from the standpoints of seasonal variation in metabolic activity, and relationships between digestive gland and gonad activity during the reproductive cycle. My data show that optimal utilization of dietary protein in Haliotis kamtschatkana occurs when diets are formulated with about 20 % dry mass of protein, and with carbohydrates, rather than fats, comprising the energy source since enzymatic adaptation to diet does not alter protein-sparing effects. With respect to growth, I found no enhancement from treatment with recombinant bovine or porcine somatotropin, or somatostatin (vertebrate growth hormones). Furthermore, I found that metabolism in these animals is seasonal and possibly inter-related with the competitive needs of reproduction and somatic growth. These findings contribute to the general understanding of abalone biology and provide information useful for culture of abalone.

Taylor, B. E., Donovan, D. A., McLean, E., Donaldson, E. M., & Carefoot, T. H. (1996). Effect of recombinant vertebrate growth hormones on growth of adult abalone, *Haliotis kamtschatkana*. *Aquaculture,* 140(1-2), 153-158. https://doi.org/10.1016/0044-8486(96)80444-3

Enhancement of cultivar growth through hormone treatment is of interest in aquaculture research owing to its potential for increasing production, In this study, injection of exogenous growth hormones was investigated as a means of enhancing growth in adult abalone, Haliotis kamtschatkana. Fifty individually caged abalone were held in a common aquarium tank with a constant flow of fresh ambient seawater and fed ad libitum on kelp (Nereocystis leutkeana). The abalone were divided into five groups of ten animals each. Every group had a similar mean weight (78 g) and length (7 cm). Four groups received weekly intramuscular injections (5 mu g g(-1) body weight) of either (1) recombinant bovine growth hormone, (2) recombinant porcine growth hormone, (3) somatostatin, or (4) bovine serum albumin. The fifth group served as an uninjected control. The abalone were weighed biweekly throughout the 10 week experiment. Water content and gonad index were assessed for each group at the end of the experimental. period, There were no significant differences in weight gain, water content, or gonad index among the five groups.

Terwilliger, R. C., & Read, K. R. H. (1970). The radular muscle myoglobins of the gastropod molluscs, *Acmaea testudinalis sutum* Eschscholtz, *Haliotis kamtschatkana* Jonas, *Tegula funebralis* Adams, *Fusitriton oregonensis* Redfield, and *Thais lamellosa* Gmelin. *International Journal of Biochemistry,* 1(4), 445-+. https://doi.org/10.1016/0020-711x(70)90058-3

1. The radular muscle myoglobin of the gastropod mollusc Fusitriton oregonensis has been purified.
2. Fusitriton carbonmonoxymyoglobin has a molecular weight of about 35,400 and is cleaved by p-hydroxymercuribenzoate into subunits of apparent molecular weight approximately 17,000.
3. The amino-acid composition of the half molecule of Fusitriton radular muscle myoglobin is: Lys16.5, His3, Arg3, 1/2Cys2, Asp17, Thr8, Ser8, Glu9, Pro4, Gly14.5, Ala24, Val6.5, Ileu5, Met6.5, Leu14.5, Tyr2.5, Phe13.5, Trppresent.
4. The radular muscle myoglobins of Acmaea testudinalis scutum, Haliotis kamtschatkana, Thais lamellosa, and TEgula funebralis all have apparent molecular weights of about 34,000.

5. The radular muscle myoglobins of the gastropod molluscs are compared.

Thompson, J. T., Lowe, A. D., & Kier, W. M. (1998). The columellar muscle of prosobranch gastropods: morphological zonation and its functional implications. *Invertebrate Biology,* 117(1), 45-56. https://doi.org/10.2307/3226851

The arrangement of muscle and connective tissue fibers in the columellar muscle of three prosobranch gastropods, Calliostoma euglyptum, Littorina littorea, and Ilyanassa obsoleta, was analyzed. The columellar muscle in the three snails is a flat, sheet-like muscle that originates on the columella of the shell and inserts on the operculum. The muscle was found to comprise a densely packed three-dimensional array of muscular and connective tissue fibers, supporting the hypotheses of previous authors that it functions as a muscular hydrostat. The fiber arrangement is not uniform throughout the entire muscle; instead it includes three regions that grade into one another. Nearest its origin, the muscle consists primarily of longitudinal muscle fibers with few dorsoventral or transverse fibers, and no oblique fibers. The middle portion of the columellar muscle in the region posterior to the head consists of longitudinal, dorsoventral, and transverse fibers wrapped by two opposed layers of oblique fibers. The third region of the columellar muscle extends through the foot and includes longitudinal, transverse, and dorsoventral fibers with a layer of oblique fibers on the dorsal surface. A narrow band of spherical spaces divides the columellar muscle into dorsal and ventral halves in this region. The morphological zonation within the muscle suggests that different regions perform different functions. In addition, compared to a muscle that is circular in cross section, the elliptical cross-sectional shape may increase the muscular force necessary to twist the foot relative to the shell and may decrease the resistance to buckling.

Vadopalas, B., Bouma, J. V., Jackels, C. R., & Friedman, C. S. (2006). Application of real-time PCR for simultaneous identification and quantification of larval abalone. *Journal of Experimental Marine Biology and Ecology,* 334(2), 219-228. https://doi.org/10.1016/j.jembe.2006.02.005

A paucity of direct studies of marine invertebrate larval dispersal motivated the development of a high-throughput method for identification and quantification of pinto abalone (Haliotis kamtschatkana) larvae in seawater. DNA extracted from sample retentate provided template to screen for species-specific cytochrome oxidase I (COI) mitochondrial DNA sequence via quantitative PCR (QPCR) technology. Primers and a dual-labeled probe were designed and used to identify and quantify DNA from the target species in blind tests of unknown samples alongside a standard template quantity series. Quantity estimates derived from QPCR standard curves were verified via direct enumeration of larvae using light microscopy. Multiplex reactions containing an internal positive control minimized underestimation of quantity and false negatives via partial or full PCR inhibition, respectively. Planned controlled field release and collection experiments to examine larval dispersion patterns via sampling over short and long postrelease times anticipate similar QPCR assays for other marine invertebrate species to aid investigations of larval dispersal in the marine environment.

Voltzow, J. (1983). Flow through and around the abalone *Haliotis kamtschatkana*. *The Veliger,* 26(1), 18-21. Retrieved from https://www.biodiversitylibrary.org/page/42412725

Flourescein dye streams released along the shell and at the shell openings of living and dead abalones revealed the lines of water flow around and through the shell. Regardless of ambient flow speed, water entered the shell of live abalones at a region to the left of the left cephalic tentacle and also through othe one or two most anterior shell openings and exited through the two or three most posterior openings. An identical flow pattern occurred through the shell of dead, intact animals when placed in an ambient flow of 6 cm/s, regardless of whether the anterior end faced upstream or downstream. Since the exhalent openings occur at the site of the shell at which the ambient streamlines are maximally compressed, they experience a reduction in pressure relative to the anterior, inhalent ones. Thus, the design of its shell may enable the abalone to take advantage of an induced flow to move water more efficiently through its mantle cavity.

Voltzow, J. (1986). Changes in pedal intramuscular pressure corresponding to behavior and locomotion in the marine gastropods *Busycon contrarium* and *Haliotis kamtschatkana*. *Canadian Journal of Zoology,* 64(10), 2288-2293. https://doi.org/10.1139/z86-343

Pedal intramuscular pressure recordings from the marine gastropods Busycon contrarium and Haliotis kamtschatkana were made using a wick catheter. Patterns of pressure fluctuations corresponded to a range of behavioral modes and locomotor speeds and reflected the morphological differences between the two regions of the foot, the columellar muscle and tarsos. Recordings from stationary specimens of both species showed sinusoidal pressure fluctuations corresponding to the heart beat. Pressure fluctuations in the foot of crawling Busycon were irregular and corresponded to the muscle action of its indistinct locomotor wave. Those from crawling Haliotis were characterized by regularly spaced, larger pressure peaks ascribable to the localized increase in pressure caused by the passing locomotor wave. The frequency and amplitude of these peaks increased with the speed at which Haliotis crawled. Additional large pressure pulses of over 3.4 kPa were recorded when snails twisted or lifted their shells, or brought their shells closer to the substratum, movements that are caused by the contraction of the columellar muscle.

Voltzow, J. (1990). The functional morphology of the pedal musculature of the marine gastropods *Busycon contrarium* and *Haliotis kamtschatkana*. *The Veliger,* 33(1), 1-19. Retrieved from https://www.biodiversitylibrary.org/page/42465161

The gastropod foot shows a high degree of morphological complexity and behavioral plasticity. This study describes the arrangement of the muscle fibers and connective tissue in the feed of Busycon contrarium and Haliotis kamtschatkana and analyzes the functional roles of the various muscle groups in wave propagation and other pedal actions. In addition, it presents the role of the connective tissue as an essential element in pedal function. The prosobranch foot is primarily solid muscle: it consists of two structurally and functionally distinct regions, the columellar muscle and the tarsos. The region of the columellar muscle consists of thick bundles of muscle fibers wrapped in connective-tissue sheaths and arranged in an orthogonal latticework. The muscle fibers of this region perform the gross shell-foot movements: protrusion, retraction, shell elevation, and twisting. The tarsos also consists of bundles of muscle fibers wrapped in connective-tissue sheaths. In this region, however, large bundles from the dorsal portion of the region divide into finer and finer branches as they approach the sole and sides of

the foot, forming a network of small groups of muscle fibers embedded in a dense connective-tissue matrix. This muscle system is responsible for the finer movements of the foot, including propagation of locomotor waves, manipulation of prey, and formation of egg capsules. In both regions, the connective tissue, by transmitting compressive and tensile forces, probably provides the mechanism by which one set of muscle fibers can directly antagonize another.

Wanninger, A., & Haszprunar, G. (2002). Chiton myogenesis: Perspectives for the development and evolution of larval and adult muscle systems in molluscs. *Journal of Morphology,* 251(2), 103-113. https://doi.org/10.1002/jmor.1077

We investigated muscle development in two chiton species, Mopalia muscosa and Chiton olivaceus, from embryo hatching until 10 days after metamorphosis. The anlagen of the dorsal longitudinal rectus muscle and a larval prototroch muscle ring are the first detectable muscle structures in the early trochophore-like larva. Slightly later, a ventrolaterally situated pair of longitudinal muscles appears, which persists through metamorphosis. In addition, the anlagen of the putative dorsoventral shell musculature and the first fibers of a muscular grid, which is restricted to the pretrochal region and consists of outer ring and inner diagonal muscle fibers, are generated. Subsequently, transversal muscle fibers form underneath each future shell plate and the ventrolateral enrolling muscle is established. At metamorphic competence, the dorsoventral shell musculature consists of numerous serially repeated, intercrossing muscle fibers. Their concentration into seven (and later eight) functional shell plate muscle bundles starts after the completion of metamorphosis. The larval prototroch ring and the pretrochal muscle grid are lost at metamorphosis. The structure of the apical grid and its atrophy during metamorphosis suggests ontogenetic repetition of (parts of) the original body-wall musculature of a proposed worm-shaped molluscan ancestor. Moreover, our data show that the "segmented" character of the polyplacophoran shell musculature is a secondary condition, thus contradicting earlier theories that regarded the Polyplacophora (and thus the entire phylum Mollusca) as primarily eumetameric (annelid-like). Instead, we propose an unsegmented trochozoan ancestor at the base of molluscan evolution.

Withler, R. E., Campbell, A., Li, S., Miller, K. M., Brouwer, D., & Lucas, B. G. (2001). *High Levels of Genetic Variation in Northern Abalone,* Haliotis kamtschatkana*, of British Columbia*.Canadian Science Advisory Secretariat Research Document (2001/097). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/261748.pdf

Northern abalone (Haliotis kamtschatkana), from 18 sites in British Columbia and one site in southeastern Alaska, were surveyed for variation at 12 polymorphic microsatellite loci. In all samples, levels of observed heterozygosity were high (Ho = 0.64-0.74) but lower than values expected (He = 0.88-0.90) under conditions of Hardy Weinberg equilibrium (HWE), due to heterozygote deficiencies at all 12 loci. Levels of excess homozygosity varied more among loci (fis = 0.02-0.55) than among samples (fis = 0.16-0.28), indicating that inbreeding alone did not account for the large homozygote excess observed at some loci. Based on the six loci at which genotypic frequencies were closest to HWE expectations, the estimated level of inbreeding in northern abalone aggregations was 0.06. The high level of He characterizing all samples resulted in a large estimated effective population size for northern abalone (420,000), consistent with a high estimate for the historical average number of migrants entering abalone aggregations each generation (20). Hierarchical analysis of gene diversity revealed that 99.6% of genetic variation was contained within abalone samples and only 0.4% partitioned among samples.

Approximately 0.2% of variation was accounted for by differentiation between abalone of the Queen Charlotte Islands and Alaska and those found in central and southern British Columbia, and the remaining 0.2% was due to differences among samples within each of those two regions. The results indicate that, historically, northern abalone aggregations did not represent isolated breeding units and any disruption of gene flow that may have been caused by recent low abundance levels cannot yet be detected in non-size-structured samples of adult abalone.

Withler, R. E., Campbell, A., Li, S. R., Brouwer, D., Supernault, K. J., & Miller, K. M. (2003). Implications of high levels of genetic diversity and weak population structure for the rebuilding of northern abalone in British Columbia, Canada. *Journal of Shellfish Research,* 22(3), 839-847. Retrieved from https://www.biodiversitylibrary.org/page/3105541

In the past 25 years, the abundance of northern abalone (Haliotis kamtschatkana) has declined by 80% in British Columbia (BC), leading to concern over a possible loss of genetic diversity and fragmentation of breeding aggregates in the species. Abalone from 31 sites in BC and one site in southeastern Alaska were surveyed for variation at eight polymorphic microsatellite loci. The high level of H-E characterizing all samples resulted in a large estimated effective population size for northern abalone (>350,000), consistent with high estimates for the historical average number of migrants entering abalone aggregations each generation (similar to20-125). Hierarchical analysis of gene diversity revealed that 99.6% of genetic variation was contained within abalone samples and only 0.4% partitioned among samples. Approximately half of the variation was accounted for by differences between abalone of the Queen Charlotte Islands, Alaska and those from central, southern British Columbia while the other half was caused by differences among samples within the two regions. Little allele frequency variation was observed among size classes or between repeat samples from sites sampled in more than 1 year. The results indicated that, historically, northern abalone aggregations did not represent isolated breeding units and any disruption of gene flow that may have been caused by recent low abundance levels cannot yet be detected. These results are discussed with respect to rebuilding efforts to be undertaken for northern abalone within BC.

Zhang, Z. N., Lessard, J., & Campbell, A. (2009). Use of Bayesian hierarchical models to estimate northern abalone, *Haliotis kamtschatkana*, growth parameters from tag-recapture data. *Fisheries Research,* 95(2-3), 289-295. https://doi.org/10.1016/j.fishres.2008.09.035

Bayesian hierarchical models were developed to estimate the growth parameters of northern abalone, Haliotis kamtschatkana, using tag-recapture data with a mixture of single and multiple recaptures. Individual variability in the growth parameters L-infinity and k of the von Bertalanffy model was incorporated in the analyses. The models developed fit the data well based on the Bayesian p-values. Variability in L-infinity for individuals was high relative to the variability in L. for the population, and variability in k for individuals was about the same as the variability in k for the population. Simulations showed that estimates of the growth parameters were accurate (relative biases <5%), when variability in both L-infinity and k or just in L. was accounted for. The "true" values of the parameters, L-infinity and k, were contained in the estimated 95% credibility intervals in 90-94 out of 100 simulation runs on 100 simulated data sets. Overall, allowing for variability for both L-infinity and k resulted in moderately more accurate estimates than allowing for just L-infinity On the contrary, estimates were unreliable when variability in just k was considered. Using the WinBUGS software program, the calculation procedure was rather simple irrespective of which growth parameter was modeled with variability.

## Section II – Conservation and Management

Alaska Department of Fish and Game. (2020). *2020-2021 Subsistence and Personal Use Statewide Fishing Regulations.* Retrieved from http://www.adfg.alaska.gov/static/regulations/fishregulations/pdfs/commercial/2020_2021_subsistence_pu_regs.pdf

This booklet contains regulations regarding Statewide Subsistence and Personal Use Fishing Regulations based on the official regulations on file with the Lieutenant Governor. This booklet covers the period May 2020 through April 2021 or until a new book is available following the Board of Fisheries meetings.

Bastien-Daigle, S., Vanderlinden, J. P., & Chouinard, O. (2008). Learning the ropes: Lessons in integrated management of coastal resources in Canada's Maritime Provinces. *Ocean and Coastal Management,* 51, 96-125. https://doi.org/10.1016/j.ocecoaman.2007.04.006

This article summarizes the findings of a research project to measure the progress made in managing coastal resources in Canada's Maritime Provinces using an integrated management (IM) approach. From a Canadian perspective, this region has a considerable breadth of experience in various forms of community-based and integrated processes of resource management. Data were obtained by conducting quantitative and qualitative surveys with existing IM groups and government agencies. Results indicate that actors are communicating, building new networks and trust, as a result of being involved in IM projects. A solid constituency is being built with individual commitment and motivation. There are however few indications that actors have moved beyond this threshold to solidify sustainable practices. The research identified several obstacles to the continuing progress of IM in the region.

Benkendorff, K., & Przeslawski, R. (2008). Multiple measures are necessary to assess rarity in macro-molluscs: a case study from southeastern Australia. *Biodiversity & Conservation,* 17(10), 2455-2478. https://doi.org/10.1007/s10531-008-9392-6

Our knowledge of suitable criteria to determine rarity in most marine invertebrates is lacking, thus hindering targeted impact studies, long-term monitoring programs, and associated conservation strategies. Standardized definitions of rarity are required to enable comparisons of different assemblages and taxa. Gaston (Rarity, Chapman and Hall, Melbourne, 1994) has recommended that rare species are defined as the lowest quartile of species in the assemblage. In this study, the 25% 'cut-off' was applied to intertidal macro-molluscs along the Illawarra Coast, Australia from 200 surveys of 13 reefs, using three measures of population structure; (1) local abundance (numerical rarity); (2) number of locations (spatial rarity) and; (3) percent of surveys (temporal rarity). Rare species were consequently defined as those species with no more than; (1) a local abundance of two individuals; (2) a regional occurrence at two reefs and/or; (3) a temporal occurrence in 2% of all surveys. These cut-off values increased when only intertidal specialists were analysed. Using a combination of all three measures, 62 species (42%) were classified as regionally rare, but only four of these were true intertidal specialists. Most species were rare by only one or two definitions of rarity; illustrating the importance of considering multiple measures of rarity and the need to design specifically targeted survey methods for future monitoring. Many species that are rare by all three definitions are likely to be temporary

immigrants, as subtidal species were significantly more likely to be classified as rare. Clearly many factors can influence the rarity of marine invertebrates on intertidal reefs, and these must all be considered to set appropriate conservation priorities.

Berkes, F., Berkes, M. K., & Fast, H. (2007). Collaborative integrated management in Canada's North: The role of local and traditional knowledge and community-based monitoring. *Coastal Management,* 35, 143-162. https://doi.org/10.1080/08920750600970487

The objective of this article is to take stock of integrated management in the Canadian North, assessing its contribution to the advancement of knowledge and practice regarding the role of indigenous knowledge and community-based monitoring. This is done in three steps. ( 1) The Beaufort Sea, designated a Large Ocean Management Area under Canada's Oceans Action Plan, is used as an example of a consultative planning process, with special attention to indigenous peoples. ( 2) How specifically can indigenous knowledge contribute to integrated management? The problem of Arctic marine food web contamination is used to illustrate the strengths and limitations of traditional ecological knowledge and its relationship to science. ( 3) The discussion of community-based monitoring relies on Voices From The Bay study involving the Inuit and Cree of Hudson and James Bay, and Inuit observations of climate change study in the Canadian western Arctic. The examples together address integrated coastal management and the health of ocean ecosystems, showing how stakeholder participation and knowledge to understand and help monitor environmental change.

California Department of Fish and Game Marine Region. (2005). *Abalone recovery and management plan*. California Fish and Game Commission. Retrieved from https://wildlife.ca.gov/Conservation/Marine/ARMP

The Abalone Recovery and Management Plan provides a cohesive framework for the recovery of depleted abalone populations in southern California, and for the management of the northern California fishery and future fisheries. All of California's abalone species are included in this plan: red abalone, Haliotis rufescens; green abalone, H. fulgens; pink abalone, H. corrugata; white abalone, H. sorenseni; pinto abalone, H. kamtschatkana (including H.k. assimilis); black abalone, H. cracherodii; and flat abalone, H. walallensis. A recovery and management plan for these species is needed to manage abalone fisheries and prevent further population declines throughout California, and to ensure that current and future populations will be sustainable

Campbell, A., & Hiemstra, L. D. (2003). *Proceedings of the workshop on rebuilding techniques for abalone in British Columbia*.Canadian technical report of fisheries and aquatic sciences (2482). Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/428654/publication.html

An international workshop on rebuilding techniques for abalone in British Columbia was held at Nanaimo, British Columbia, Canada, 14-16 January 2003. The objective of the workshop was to examine past, present and future research on aquacultural, biological and ecological studies, which were relevant

to future rebuilding efforts on northern (pinto) abalone, Haliotis kamtschatkana, stocks in British Columbia. The workshop was attended by 50 individuals representing First Nations, local communities, international (Australia, Canada, new Zealand, South Africa, and the U.S.A.) abalone research, management and aquaculture interests. Presentations and discussions at the workshop centred on community stewardship, enforcement, aquaculture, field research and rebuilding methods such as hatchery rearing, out-planting and restocking, wild stock manipulations, monitoring tools and evaluation performance indicators. There are four peer-reviewed papers and 13 abstracts in the Proceedings.

Campbell, A., Lucas, B. G., & Parker, G. (2000). *Discussion on an experimental approach for northern abalone stock rebuilding in British Columbia*.Canadian Stock Assessment Secretariat research document (2000/047). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.805845/publication.html

This paper reviews published reports on rebuilding and restocking attempts for abalone stocks. Pilot experiments are proposed that potentially may provide base-line information on large-scale methods to rebuild northern abalone stocks in British Columbia. These include (1) establishing 3 or 4 experimental marine reserves throughout British Columbia to allow experimental manipulation of wild abalone adult densities for increasing abalone recruitment, (2) experimental outplanting of hatchery-reared northern abalone juveniles, on a small scale, to determine optimal size and density for release and probability of success in increasing juvenile and adult abalone densities. An ecosystem approach is recommended in which habitat parameters, algae and invertebrates are monitored. Manipulation of red sea urchins abundance to determine the effects on abalone survival and growth is suggested. Maintaining the northern abalone fishery closure indefinitely and continued large scale index site surveys every 4-5 years to monitor long-term trends in northern abalone populations are also important. Enforcement for the prevention of poaching northern abalone and partnerships between local communities and government agencies will be critical to the success of any rehabilitation attempts and long-term experiments.

Carson, H. S., & Ulrich, M. (2019). *Status Report for the Pinto Abalone in Washington*.Olympia, WA Retrieved from https://wdfw.wa.gov/publications/02031

The pinto abalone (Haliotis kamtschatkana) is a shallow-water marine mollusk native to the marine waters of Washington State, particularly the San Juan Islands and Strait of Juan de Fuca. It is a grazer, feeding on diatoms and kelp, living on bedrock or boulder reefs. Juveniles are cryptic but emerge as adults around the reproductive size of 40 – 70 mm shell length. Males and females spawn gametes directly into the water in spring and summer; fertilization occurs outside the body. After a relatively short drifting larval phase of 7 – 10 days, abalone settle into appropriate habitat, often bull kelp beds and on rock covered in crustose coralline algae.

Likely harvested for subsistence by early inhabitants of the Pacific Northwest for centuries, the Department authorized the state recreational harvest of abalone in 1959. In 1992, managers grew concerned about observed abundance trends and established ten fixed monitoring sites in the San Juan Islands. Upon a resurvey of those stations in 1994 that showed a decline in abundance, and evidence of significant illegal harvest, managers closed the fishery. The population on these sites continued to decline despite the fishery closure. The most recent survey in 2017 found 12 total abalone remaining

from an original tally of 359 in 1992 – a 97% decline. Furthermore, the average size of abalone has increased over time, and juveniles have not been sighted during Department surveys since 2008.

Available evidence suggests that the Washington population is aging and has experienced widespread reproductive failure. Since the animals spawn directly into the water, males and females must be in close proximity for fertilization to occur. Adults maintain a small home range and may not migrate long distances to spawn with other individuals. Therefore, when legal or illegal fishing reduces the density of adults below some fertilization threshold, successful reproduction is reduced and remnant populations are unlikely to recover naturally. In addition to a low density of adults, pinto abalone populations in Washington face threats from changing ocean conditions, illegal harvest, reduced genetic diversity, disease, contaminants, and native or introduced predators.

A captive breeding and reintroduction partnership was formed between the Department, Puget Sound Restoration Fund, the National Oceanic and Atmospheric Administration, treaty tribes, universities and others. Since 2009 the partnership has outplanted groups of hatchery-origin juveniles onto sites in the San Juan Islands. The growth and survival of these individuals suggests that this restoration strategy is a viable one. However, pinto abalone would have to be produced and outplanted in significantly greater numbers to achieve population-scale recovery.

Due to the dwindling numbers of wild individuals, their apparent lack of natural reproduction, and a number of identified threats, it is recommended that the pinto abalone be listed as endangered in the state of Washington.

Chadès, I. (2013). Conservation of Biodiversity. In *Markov Decision Processes in Artificial Intelligence.* O. Sigaud & O. Buffet (Eds.), (pp. 375-394) https://doi.org/10.1002/9781118557426.ch12

This chapter examines two biodiversity conservation applications of Markov decision problems. First, it examines the problem of managing an endangered species, the Sumatran Tiger (Panthera tigris sumatrae), which is difficult to observe. Second, the chapter investigates the problem of how to recover two endangered species which interact as predator and prey. Northern abalone (Haliotis kamtschatkana) are the preferred prey of sea otters (Enhydra lutris), both co-habiting along the pacific northwestern coast of Canada and United States. It provides for the first time an optimal recovery strategy for these two species which takes into account their functional relationship using two types of reinforcement learning algorithms over a finite-time horizon. Finally, the chapter discusses the need for further research development in the MDP community to solve challenging optimization problems in conservation biology.

Chades, I., Curtis, J. M. R., & Martin, T. G. (2012). Setting Realistic Recovery Targets for Two Interacting Endangered Species, Sea Otter and Northern Abalone. *Conservation Biology,* 26(6), 1016-1025. https://doi.org/10.1111/j.1523-1739.2012.01951.x

Failure to account for interactions between endangered species may lead to unexpected population dynamics, inefficient management strategies, waste of scarce resources, and, at worst, increased extinction risk. The importance of species interactions is undisputed, yet recovery targets generally do not account for such interactions. This shortcoming is a consequence of species-centered legislation, but

also of uncertainty surrounding the dynamics of species interactions and the complexity of modeling such interactions. The northern sea otter (Enhydra lutris kenyoni) and one of its preferred prey, northern abalone (Haliotis kamtschatkana), are endangered species for which recovery strategies have been developed without consideration of their strong predator-prey interactions. Using simulation-based optimization procedures from artificial intelligence, namely reinforcement learning and stochastic dynamic programming, we combined sea otter and northern abalone population models with functional-response models and examined how different management actions affect population dynamics and the likelihood of achieving recovery targets for each species through time. Recovery targets for these interacting species were difficult to achieve simultaneously in the absence of management. Although sea otters were predicted to recover, achieving abalone recovery targets failed even when threats to abalone such as predation and poaching were reduced. A management strategy entailing a 50% reduction in the poaching of northern abalone was a minimum requirement to reach short-term recovery goals for northern abalone when sea otters were present. Removing sea otters had a marginally positive effect on the abalone population but only when we assumed a functional response with strong predation pressure. Our optimization method could be applied more generally to any interacting threatened or invasive species for which there are multiple conservation objectives.

Critical Habitat of the Northern Abalone (Haliotis kamtschatkana) Order, SOR/2017-266 C.F.R. (2017). Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2017-266/FullText.html

Whereas the Northern Abalone (Haliotis kamtschatkana) is a wildlife species that is listed as an endangered species in Part 2 of Schedule 1 to the Species at Risk Act;

Whereas the Minister of Fisheries and Oceans and the Minister responsible for the Parks Canada Agency, namely the Minister of the Environment, are the competent ministers in respect of the critical habitat of that species for the purposes of the annexed Order and have together prepared an action plan for that species;

Whereas the action plan that identified the critical habitat of that species has been included in the Species at Risk Public Registry;

Whereas no portion of the critical habitat of that species that is specified in the annexed Order is in a place referred to in subsection 58(2)b of that Act;

And whereas the Minister of Fisheries and Oceans and the Minister of the Environment are of the opinion that the annexed Order would affect areas in respect of which wildlife management boards are authorized by lands claims agreements to perform functions in respect of wildlife species and, pursuant to subsection 58(8) of that Act, have consulted the wildlife management boards in question with respect to the Order;

Therefore, the Minister of Fisheries and Oceans and the Minister of the Environment, pursuant to subsections 58(4) and (5) of the Species at Risk Acta, make the annexed Critical Habitat of the Northern Abalone (Haliotis kamtschatkana) Order.

Dovetail Consulting Inc. (1999). *A strategy for rebuilding abalone stocks in British Columbia: report on the workshop on rebuilding abalone stocks in British Columbia, Nanaimo, B.C., February 23-26,*

*1999*.Vancouver, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/264396.pdf

This strategy to rebuild abalone stocks in British Columbia is based on discussions during a four-day workshop held at the Coast Bastion Hotel in Nanaimo, British Columbia, from February 23rd to 26th, 1999. The workshop participants were people with an interest in abalone, including First Nations, commercial and recreational harvesters, environmentalists and the provincial and federal government. Participants also included scientists and managers knowledgeable about abalone who made presentations during the first two days of the workshop.

Fisheries and Oceans Canada. (1989). *Management plan for the 1990 abalone fishery, Pacific Region*. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40685986.pdf

Before the mid 1970s abalone landings from British Columbia waters were low. With the use of SCUBA gear becoming commonplace, the advent of freezer vessels and an eager market in Japan, the fishery increased rapidly to a maximum landing of 450t in 1977. At that time active management of the fishery began with a quota of 250t and limited entry added to the existing size limit . By 1980 a vessel quota was established after shortened seasons and gear restrictions failed to slow the fishery. Estimates of production on which the original quota was based proved high and the total allowable catch dropped steadily from 250t to 47t in 1985 where it remains to 1990, based on biannual surveys of major fishing areas. The fishery is highly regulated, with reporting of fishing activities, harvest logs, and validation of catch weights required. The level of illegal harvest is uncertain; however both fishermen and managers agree it is substantial.

Fisheries and Oceans Canada. (2004). *Abalone recovery: an update on the recovery of Abalone in British Columbia*. Vancouver, BC Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40743251.pdf

This newsletter provides an update on recent abalone recovery activities since August 2003. Fisheries & Oceans Canada (DFO) and Parks Canada Agency scientists, with funding in part from the Interdepartmental Recovery Fund, are continuing their cooperative study in and around Pacific Rim National Park Reserve, exploring methods and factors that improve abalone reproduction and recruitment in selected locations.

Fisheries and Oceans Canada. (2004). *National recovery strategy for the northern abalone (*Haliotis kamtschatkana*) in Canada*. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/317369.pdf

The northern or pinto abalone has been declining in numbers and distribution in surveyed areas of British Columbia (B.C.), Canada, as documented by regular surveys since the late 1970s. The northern abalone fisheries in B.C. were closed to all harvest in 1990. Northern abalone were assigned a threatened status by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in April

1999. A recovery team was formed in November, 2001, to assist Fisheries and Oceans Canada to prepare this National Recovery Strategy for the Northern Abalone in Canada.

The decline of the northern abalone may be attributed to many factors, which include illegal harvest and low recruitment. It is unclear whether disease may have had a role in the decline of this species in the wild. Future threats may also include habitat loss due to developments in, on, and under the water, as well as previously unstudied interactions with predators and competitors.

The recovery team considers illegal harvest to be the most significant threat to northern abalone. The northern abalone is especially vulnerable to over-exploitation because this species has a patchy distribution, a short larval period, is slow growing, relatively long-lived, has low or sporadic recruitment, and mature individuals, which tend to accumulate in shallow water, are easily accessible to harvesters.

The immediate recovery goal is to halt the decline of the existing wild northern abalone population in order to reduce the risk of northern abalone becoming endangered.

The long-term recovery goal is to increase the number and densities of wild northern abalone to levels where the population becomes self-sustainable within 5 biogeographic zones: Haida Gwaii (Queen Charlotte Islands), Queen Charlotte and Johnstone Straits, North and Central Coast, Georgia Basin, West Coast of Vancouver Island, in order to remove northern abalone from threatened status.

Fisheries and Oceans Canada. (2007). *Recovery Strategy for Northern Abalone (*Haliotis kamtschatkana*) in Canada*. Species at Risk Act Recovery Strategy Series Vancouver, BC. Retrieved from https://species-registry.canada.ca/index-en.html#/consultations/1342

The northern or pinto abalone has been declining in numbers and distribution in surveyed areas of coastal British Columbia (B.C.), Canada, as documented by regular surveys since the late 1970s. The northern abalone fisheries in B.C. were closed to all harvest in 1990 to protect the remaining population. Despite the complete ban on harvest, the population continued to decline and showed no sign of recovery. As a result, northern abalone were assigned a threatened status by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in April 1999. In June 2003, northern abalone were legally listed and protected as threatened under the Species at Risk Act (SARA).

Fisheries and Oceans Canada. (2012). *Action Plan for the Northern Abalone (*Haliotis kamtschatkana*) in Canada*. Species at Risk Act Action Plan Series Ottawa, ON Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/ap_haliotide_pie_n_abalone_0412_e.pdf

Northern Abalone is a marine species at risk. The Minister of Fisheries and Oceans is a “competent minister” for aquatic species under the Species at Risk Act (SARA). Since Northern Abalone are known to occur in the Gwaii Haanas National Marine Conservation Area and the Pacific Rim National Park Reserve, the Minister responsible for Parks Canada Agency is also a “competent minister” for this species. SARA (Section 47) requires the competent minister to prepare action plans for listed extirpated, endangered or threatened species. The Northern Abalone was listed as threatened under SARA in June 2003.

First Nations along the B.C. coast are playing a lead role in abalone stewardship and recovery within their claimed traditional territories, in collaboration with federal agencies and community partners (see Section 2.6). Although Northern Abalone are not specifically identified within the Nisga'a Treaty, the Nisga'a Fisheries Program is interested in abalone recovery and they participate in the recovery program.

Under the Canada National Marine Conservation Areas Act, and the Canada National Parks Act, Parks Canada Agency is involved in abalone management and protection in National Marine Conservation Areas (NMCAs), NMCA Reserves, and national parks with marine components (e.g. Pacific Rim and Gulf Islands National Park Reserves). Kelp harvesting is subject to licensing under the B.C. Fisheries Act.

Artificial movements of Northern Abalone into and within coastal waters and to aquaculture facilities are subject to review and licensing by the federal-provincial Introductions and Transfers Committee and SARA.

Success in the recovery of Northern Abalone depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this plan and will not be achieved by Fisheries and Oceans Canada, Parks Canada Agency or any other party alone. This action plan provides advice to jurisdictions and organizations that are involved in, or wish to become involved in, activities to conserve this species. In the spirit of the Accord for the Protection of Species at Risk, the Minister of Fisheries and Oceans and the Minister responsible for Parks Canada Agency invite all Canadians to join Fisheries and Oceans Canada and Parks Canada Agency in supporting and implementing this plan for the benefit of Northern Abalone and Canadian society as a whole. Fisheries and Oceans Canada and Parks Canada Agency will support the implementation of this action plan based on available resources and varying species at risk conservation priorities.

Fisheries and Oceans Canada. (2015). *Report on the Progress of Recovery Strategy Implementation for Northern Abalone (*Haliotis kamtschatkana*) in Canada for the Period 2007- 2012*. Species at Risk Act Recovery Strategy Report Series Ottawa, ON Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/Pr-NorthernAbalone-v01-2015Jul13-Eng.pdf

This report documents the progress of recovery strategy implementation for the Northern Abalone in Canada for the period 2007-2012. It summarizes progress that Fisheries and Oceans Canada (DFO) and the broader scientific community have made towards achieving the goals and objectives set out in the Recovery Strategy.

Hale, J. R., Bouma, J. V., Vadopalas, B., & Friedman, C. S. (2012). Evaluation of Passive Integrated Transponders for Abalone: Tag Placement, Retention, and Effect on Survival. *Journal of Shellfish Research,* 31(3), 789-794. https://doi.org/10.2983/035.031.0324

Since 1969, abalone populations have declined globally more than 50%, with many species now recognized as threatened, endangered, or species of concern. As monitoring progresses and restoration efforts evolve to include population supplementation, a reliable and robust method of tagging individual abalone is needed. Current abalone tagging methods are unsatisfactory, particularly for long-term

studies as a result of tag loss, shell erosion, and encrustation. Observing tag numbers of cryptically positioned abalone can be difficult. To obviate these issues, we evaluated passive integrated transponders (PITs) as tags for pinto abalone (Haliotis kamtschatkana kamtschatkana). We applied 9-mm PITs with cyanoacrylate glue to the dorsal exterior of the shell and to the ventral anterior of the shell, and by injection into the foot muscle of small adults (trial I), and applied PITs to the ventral anterior of the shell of juveniles (trial 2). We subsequently tracked growth, survival, and tag retention over 15 mo in trial I and 6 mo in trial 2 in captivity. Among small adults (trial 1), differences in relative growth rate and survival were not significant. PIT retention by adhesion to the ventral anterior and dorsal exterior was significantly greater than injection into the foot in trial I. Between controls and tagged animals in trial 2, differences in survival were not significant. There was no significant difference in ventral anterior tag retention between trial 1 and trial 2. Gluing PITs on the ventral anterior of the shell is a promising method because abalone quickly formed nacre over the tags, incorporating them into the shell, which does not appear to affect tag detection by the PIT reader. Trials are underway to characterize PIT retention in natural habitats, to determine tag longevity, and to use PITs to track adults reintroduced to aggregations.

Hansen, S. C. (2011). *Restoring endangered Northern Abalone (*Haliotis kamtschatkana*) populations in British Columbia, Canada, using hatchery-raised individuals.* (Master of Science), Thompson Rivers University, Kamloops, BC. Retrieved from https://my.tru.ca/__shared/assets/Hansen_Thesis_201133089.pdf

This study investigated the effectiveness of using hatchery-raised northern abalone (Haliotis kamtschatkana) to supplement wild populations in Barkley Sound, BC. Densities of abalone were assessed at sites outplanted by the Bamfield Huu-ay-aht Community Abalone Project, and all fell at or below the suspected Allee threshold. The potential for improving outplanting success was then examined by releasing both larval and juvenile hatchery-reared individuals at different treatment densities and tracking their survival over time using cohort analyses and mark-recapture methods, respectively. Predators represented the major source of mortality for outplanted abalone and congregated at outplant sites. Tagging, handling, and temperature stress did not result directly in mortality. Juvenile abalone were particularly vulnerable in the first 24 hours after outplanting, experiencing 64 % mortality during that period. The behaviours of hatchery-raised abalone differed from those of wild individuals. I recommend outplanting 50,000 larvae/m2 or groups of 100 juveniles in predator exclosure cages.

Jones, R., DeFreitas, B., Sloan, N., Lee, L., von Boetticher, K., & Martin, G. (2003). Abalone stewardship in Haida Gwaii: Forging a long-term commitment. In *Proceedings of the Workshop on Rebuilding Techniques for Abalone in British Columbia.* A. Campbell & L. D. Hiemstra (Eds.), (pp. 5-19). Nanaimo, BC: Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2482-eng.pdf

Local stewardship is a possible solution to the vexing problem of rebuilding over fished northern abalone (Haliotis kamtschatkana) stocks. Abalone fisheries in British Columbia were closed coastwide in 1990 but stocks have failed to rebuild and the species became federally listed as "threatened" in 1999. Three years of community-based stewardship effort in Haida Gwaii to rebuild abalone and prospects for

recovery over the long-term are discussed. Steps taken include forging a community partnership through regular meetings of a core group and development of a Community Action Plan. The Action Plan's goal is to rebuild abalone populations sufficiently to support both Haida traditional and recreational food fisheries. Specific initiatives include public education, curricula development, establishment of two large abalone stewardship areas and a research area, creation of an Abalone Watch (coastal surveillance) program and research diving to test rebuilding approaches and monitor recovery.

Jones, R., Rigg, C., & Lee, L. (2010). Haida marine planning: First nations as a partner in marine conservation. *Ecology and Society,* 15. https://doi.org/10.5751/ES-03225-150112

The Haida Nation is involved in an integrated marine planning initiative in northern British Columbia, Canada. The Haida continue to occupy traditional territory in and around Haida Gwaii, or the Queen Charlotte Islands, and are engaged in a larger planning process for the Pacific North Coast Integrated Management Area (PNCIMA). This initiative is in the early planning stage, focused on capacity building and creating enabling conditions for co-governance. Court decisions, government policies, and a modern treaty process are driving short- and long-term efforts to resolve issues of Aboriginal ownership and resource access, both on land and in the ocean. As a result, the PNCIMA process is being led by two levels of government, First Nations and federal, reflecting changing perceptions of Aboriginal title and rights in British Columbia. The Haida have been resource owners and managers on Haida Gwaii for millennia, and continue to apply traditional knowledge and experience to marine-use planning and fisheries management. The Haida approach is place based and guided by fundamental Haida ethics and values such as respect, balance, and reciprocity. We describe these values and discuss the emerging role of First Nations in integrated oceans management in the context of the six themes: lessons from land-use planning; the PNCIMA governance structure; the relationship of values to planning outcomes; developing an ecosystem-based management framework; applications of traditional knowledge, based on a study of Haida marine traditional knowledge currently in progress; and linking marine planning at various scales. On Haida Gwaii, collaborative marine planning is expected to result in improved protection of Haida Gwaii waters for future generations, greater Haida participation in management decisions, and increasing emphasis on sustainability of both local fisheries and communities.

Komick, N., & Ganton, A. (2020). *Proceedings of the Pacific regional peer review on the Pre-COSEWIC Assessment for Northern Abalone : September 26-27, 2019, Nanaimo, British Columbia*.Canadian Science Advisory Secretariat (CSAS) Proceedings Series (2020/023). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.893886/publication.html

These Proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting on September 26–27, 2019 at the Pacific Biological Station in Nanaimo, B.C. A working paper focusing on reviewing existing DFO information relevant to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status assessment for Northern Abalone in Canadian waters was presented for peer review.

Lee, L. C., Thorley, J., Watson, J., Reid, M., & Salomon, A. K. (2019). Diverse knowledge systems reveal social-ecological dynamics that inform species conservation status. *Conservation Letters,* 12(2). https://doi.org/10.1111/conl.12613

Understanding changes over historical timescales is essential to gauge conservation status of a species. Modern ecological data typically neglect past magnitudes of change, which fortunately can be evaluated by bridging disparate knowledge sources. We synthesized zooarchaeological, historical, traditional, and western science knowledge to document changes in relative abundance of key species in Canada's northern abalone social-ecological system (SES) from the Holocene to present. Integrated models fit to traditional and western science data revealed 3.7% annual population decline from 1940s to 2010s for large abalone, although traditional knowledge density estimates were 9.5x higher than those derived from western science. Abalone are presently scarce compared to the mid-1900s, but more abundant than before the early 1800s, calling their endangered status into question. Linking multiple knowledge sources can build SES understanding, facilitate power sharing, and support ecologically sustainable and socially just conservation outcomes.

Lessard, J., Campbell, A., Zhang, Z., MacDougall, L., & Hankewich, S. (2007). *Recovery potential assessment for the northern abalone (Haliotis kamtschatkana) in Canada*.Canadian Science Advisory Secretariat (2007/061). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/331907.pdf

This recovery potential assessment for the SARA-listed northern abalone includes a review of current status, population projections, and recommendations on permitting human-induced mortality and/or harm to abalone and their habitat. Recent surveys indicated northern abalone abundance was not recovering. Time series analyses of abalone survey data from areas free of sea otters in southeast Queen Charlotte Islands and Central Coast during 1978-2002 provided stock-recruitment relationships, recruitment trends and mortality estimates of 0.20. Simulations indicated that abalone populations could continue to decline if mortality rates remain 0.20. Mortality rates of 0.20 are required for abalone populations to recover. Several human activities were considered that could potentially harm and cause direct mortality to abalone populations. In order of importance, these activities were: 1) directed fishing; 2) habitat alterations, including finfish aquaculture, log booms and log dumps, and dredging; 3) abalone aquaculture; 4) fisheries on food supplies (i.e. kelp harvest); 5) scientific research; and 6) rebuilding activities, including larvae or juveniles outplanting and adult aggregations.

Levine, A. S., Richmond, L., & Lopez-Carr, D. (2015). Marine resource management: Culture, livelihoods, and governance. *Applied Geography,* 59, 56-59. https://doi.org/10.1016/j.apgeog.2015.01.016

The management of marine resources is a politically and culturally driven process, shaped by human livelihoods and perceptions, where notions of both space and place shape policies and decision-making in fundamental ways. An emerging sub-field within geography critically explores geographic aspects of marine resource management. However, there has been little work to fully articulate this field and to describe the contributions of geographic methodologies and lenses to understanding marine resource management processes. This special issue provides one of the first collections of geographic papers focused on the socio-cultural and socio-spatial dimensions of marine resource management,

emphasizing research that has or can be applied to management and policy discussions. The papers in this issue cover critical topics within this emerging field, examining the combined influences of social, ecological, cultural, political, economic, historical, and geographic factors on how marine spaces and resources are used, perceived, and managed. Important themes include: emerging spatial approaches to marine resource management, human dimensions of marine protected areas, the roles of mapping and GIS, the integration of quantitative and qualitative data, and the varying ways in which marine spaces and places are conceptualized by marine resource users and managers. Issues of marine resource governance, community engagement, and vulnerability also play key roles in the future of marine resource management. The papers in this issue shed light on space, place, and human-environment interactions in coastal marine systems, making it clear that questions about stakeholder inclusion and representation, particularly in spatial forms, will continue to dominate the field for some time to come. Future research in this field will be fruitfully informed by core geographical heuristics of space, place, and human-environment dynamics.

Liversage, K., & Chapman, M. G. (2018). Coastal ecological engineering and habitat restoration: incorporating biologically diverse boulder habitat. *Marine Ecology Progress Series,* 593, 173-185. https://doi.org/10.3354/meps12541

Ecological engineering is increasingly being studied and applied in order to reverse declines of biological diversity caused by coastal urbanisation and habitat degradation. As methods become more sophisticated and the theoretical framework more advanced, engineering of more complex and biologically diverse habitat types becomes possible. This review discusses the benefits of incorporating boulder habitat, which provides a unique combination of intermediate stability and high structural complexity, and can be occupied by many rare species. The inclusion of this habitat into engineered coastlines would therefore represent an important outcome for coastal ecological engineering by providing habitat for these species. Some methods are already in use to restore degraded boulder habitat; these methods should strive to closely mimic boulder habitat because semi-natural habitats (e.g. building rubble at bases of seawalls) have not been found to support rare species at this stage. Creation of new boulder habitat is also valuable for important fisheries (e.g. Haliotis spp.). Methods will be improved by focusing on small-scale microhabitats created by boulders and how these microhabitats provide shelter from locally relevant predators. Boulder habitat can reliably stabilise shorelines whereas alternative ecological engineering options based on littoral vegetation (e.g. mangroves, seagrass or saltmarsh) provide stabilisation involving strong spatiotemporal variability. Ecological engineering methods that include highly novel habitats, such as boulders, will achieve valuable biodiversity outcomes by allowing large-scale increases in along-shore distribution of specialist species. Overall, incorporation of boulder habitat in ecological engineering will help ensure coastal habitats include highly diverse assemblages and important ecological functionality as the pressure to modify coastlines increases.

MA. Rudd Enterprises Ltd. (1992). *Abalone enhancement options for British Columbia*.Vancouver, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/262972.pdf

A variety of potential tools exist for fisheries managers to aid in rehabilitating depressed British Columbia northern abalone (Haliotis kamstscatkana) stocks. Broodstock transplants, larval reseeding, and juvenile restocking programs have been used, on various scales and with varying degrees of success, in a number of other parts of the world. This report provides a brief background on abalone biology and market structure, a review of enhancement experiences in other regions, and recommendations for implementation of an abalone enhancement program in British Columbia.

Martin, T. G., Camaclang, A. E., Possingham, H. P., Maguire, L. A., & Chades, I. (2017). Timing of Protection of Critical Habitat Matters. *Conservation Letters,* 10(3), 308-316. https://doi.org/10.1111/conl.12266

With many conservation issues requiring urgent action, determining how much data are needed to inform good decisions is a common problem. We examine this problem in relation to the protection of critical habitat, the habitat required for species' recovery and persistence. The protection of critical habitat is an essential step in the threatened species recovery process. It is also one of the most contentious and protracted decisions faced by environmental agencies. Uncertainty about what constitutes critical habitat, and the challenges of balancing competing societal objectives and of protecting critical habitat once identified are stalling the recovery process. We offer insight into this challenge by investigating how long we can afford to spend identifying critical habitat before opportunities to recover a species are lost. We illustrate our decision model using Canada's threatened northern abalone (Haliotis kamtschatkana). Our method delivers the stopping time at which habitat protection must begin, despite uncertainty, in order to avoid an unacceptable risk of extinction.

Mathews, D. L., & Turner, N. J. (2017). Ocean cultures: Northwest coast ecosystems and indigenous management systems. In *Conservation for the Anthropocene Ocean: Interdisciplinary Science in Support of Nature and People.* P. S. Levin & M. R. Poe (Eds.), (pp. 169-199): Academic Press https://doi.org/10.1016/B978-0-12-805375-1.00009-X

Increasingly, ethnoecologists, anthropologists, and conservation biologists are recognizing that Indigenous People of the Northwest Coast and neighboring regions have been astute stewards and managers-not just harvesters and consumers-of the resources and ecosystems on which they have relied. Over thousands of years, these people have developed diverse practices and protocols that have not only sustained, but enhanced the resource species both in quantity and in quality. These practices are based on long-term observation and experience, and are embedded in belief systems, ceremonies, dances, art, and narratives. Here we provide an overview of marine and coastal resource management systems that have been documented to date, and then cite three examples in more detail: clam gardens, salmon production, and estuarine root gardens. These different production systems do not function alone but are components of an entire complex of land and resource management extending across the marine and terrestrial landscapes, "from ocean bottom to mountaintop." These traditional management systems have been seriously disrupted since the arrival of European newcomers and the resulting impacts on key habitats from colonial settlement, land encroachment, changes in land tenure, land-use conversion, and industrial scale exploitation. Today, collaborative efforts between Indigenous communities, ethnoecologists, and others are underway to recognize and restore some of these

critically important Indigenous production systems and associated practices as a means of ethnoecological restoration, habitat enhancement, and food system revitalization.

Menzies, C. (2010). Dm sibilhaa'nm da laxyuubm Gitxaała: Picking Abalone in Gitxaała Territory. *Human Organization,* 69, 213-220. https://doi.org/10.17730/humo.69.3.g68p1g7k40153010

In the face of aggressive overfishing of bilhaa (abalone) by non-Indigenous commercial fishermen, the Canadian Department of Fisheries and Oceans closed all forms of harvesting of bilhaa. This paper describes the longstanding ecologically appropriate harvesting practices of Gitxaala, an indigenous nation on the northwest coast of North America. The paper documents the antiquity of Gitxaala fisheries practices. The paper concludes by arguing for a return to a Gitxaala controlled bilhaa fishery.

Mills-Orcutt, K. A., Bouma, J. V., & Donovan, D. A. (2020). Outplanting Larval Pinto Abalone *Haliotis kamtschatkana* (Jonas) as a Recovery Tool in the Salish Sea. *Journal of Shellfish Research,* 39(2), 381-388. https://doi.org/10.2983/035.039.0220

Pinto abalone populations in Washington state have declined precipitously in the last few decades, despite closure of the fishery. Local restoration efforts have focused on outplanting juvenile abalone, which is costly because of the husbandry required to raise abalone to outplanting size. This study tested if hatchery-produced larval pinto abalone could be successfully outplanted and if postoutplant growth of larval abalone differed from hatchery-raised animals. Wild broodstock were spawned. and some larvae remained at the hatchery for rearing, whereas most were transported to the Shannon Point Marine Center (SPMC) for outplanting. At two sites in the Salish Sea, larvae were outplanted at a density of 13,000 larvae m(-2) into two types of larval abalone modules (LAM): tented LAM (125 mu m Nitex tenting) and open LAM (no tenting). There were also control LAM with no tenting and no abalone. Larvae were also seeded in LAM in aquaria at SPMC to compare field and aquaria survival and to estimate emigration. Shell lengths of field, laboratory. and hatchery-reared abalone were measured to better understand if hatchery life compromises early growth. Four months after outplanting, abundance of settled abalone was significantly greater in tented LAM than open and control LAM. Control LAM contained no abalone, suggesting reproduction by wild abalone did not occur at the field sites. Open LAM had a mean outplant success of 0.1% (0-12 settled abalone) and tented LAM a mean success of 0.4% (16-35 settled abalone). Outplant success was higher in SPMC aquaria. Open and tented LAM had 1.5% and 3.0% success, respectively. Abalone found on aquaria walls outside the LAM accounted for 0.2% of the seeded abalone for both open and tented LAM. Four months after outplanting, shell lengths of field abalone were not significantly different from lengths of hatchery-reared abalone, suggesting hatchery conditions did not compromise growth rates of newly settled abalone. These findings suggest that releasing larval pinto abalone into tented field modules has potential to supplement wild stocks in the Salish Sea as a lower cost alternative to outplanting juveniles.

National Resources Defense Council. (2014). *The pinto abalone deserves protection under the Endangered Species Act.* Retrieved from https://www.nrdc.org/sites/default/files/pinto-abalone-endangered-species-FS.pdf

Monitoring in Washington, Alaska, and British Columbia shows that pinto abalone populations have declined by 80 percent to 90 percent since the early 1990s. The southern subspecies of pinto abalone, found off Southern California's coast, is estimated to have declined 99 percent.

Parks Canada Agency. (2016). *Multi-species Action Plan for Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site*.Species at Risk Act Action Plan Series Ottawa, ON Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-GwaiiHaanas-v00-2016Jul4-Eng.pdf

The Multi-species Action Plan for Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site meets the requirements for an action plan set out in the Species at Risk Act (SARA (s.47)) for species requiring an action plan that occur inside the boundary of the site. This action plan will be updated to more comprehensively include measures to conserve and recover the marine species at risk once the first integrated Land, Sea, People management plan for Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve & Haida Heritage Site (hereafter called Gwaii Haanas) is complete. Measures described in this plan will also provide benefits for other species of conservation concern that regularly occur in Gwaii Haanas.

Parks Canada Agency. (2017). *Multi-species Action Plan for Pacific Rim National Park Reserve of Canada*.Species at Risk Act Action Plan Series Ottawa, ON Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-PacificRimNpr-v00-2017Aug21-Eng.pdf

Backed by the Insular Mountain Range of Vancouver Island and facing the open Pacific Ocean, Pacific Rim National Park Reserve of Canada (Pacific Rim NPR) protects and presents the rich natural and cultural heritage of Canada's west coast. Pacific Rim NPR consists of three distinct units, the Long Beach Unit, Broken Group Islands Unit, and West Coast Trail Unit, each offering a range of unique visitor experiences. With significant areas (51,216 ha in total) of old growth, temperate rainforest, coastal dune systems, wetlands and foreshore, and marine habitats, the park demonstrates the interconnectedness between land, sea, and people. These natural wonders are interwoven with the Nuu-chah-nulth First Nations culture (past and present), and that of European explorers and settlers.

Puget Sound Restoration Fund. (2014). *Recovery Plan for pinto abalone (*Haliotis kamtschatkana*) in Washington State (using a collaborative management approach).* Retrieved from https://restorationfund.org/wp-content/uploads/2020/06/2014_Kamtschatkana_Recovery_Plan_clean_Sept2015.pdf

The goals of abalone recovery efforts in Washington State are to reverse the decline of pinto abalone stocks and to attain self-sustaining populations throughout regions of historic abundance in the State.

Randall, R. G., Jones, R. P., Minns, C. K., & Rice, J. C. (2005). *Proceedings of a case study review of critical habitat identification for aquatic species-at-risk*.Canadian Scientific Advisory Secretariat (2004/047). Burlington, ON: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/324309.pdf

Background and objectives: To evaluate potential methods of identifying critical habitat for species-at-risk, seven case study species were reviewed at a national workshop at the Bedford Institute of Oceanography in December 2004. Under the Species at Risk Act (SARA), the identification to the extent possible of the habitat critical for the survival and recovery of a listed species is mandatory for recovery programs. The seven species were chosen to represent different aquatic taxa (fishes, marine mammals and molluscs), life histories and ecosystems (marine, estuarine, freshwater), and the level of information available for each species varied from low to high. The seven case studies, from east to west, were: Atlantic wolffishes (Anarhichas spp.; 3 species), inner Bay of Fundy Atlantic salmon (Salmo salar), the St. Lawrence Atlantic sturgeon (Acipenser oxyrinchus), St. Lawrence beluga (Delphinapterus leucas), black redhorse (Moxostoma duquesnei) in southern Ontario, Sakinaw Lake, BC, sockeye salmon (Oncorhynchus nerka), and Pacific coast northern abalone (Haliotis kamtschatkana). The specific objectives of the review were to compare and contrast methodologies for quantifying habitat requirements in these different ecosystems, to evaluate the minimum information requirements for designation, and to inform the development of guidelines for formally designating critical habitat. The COSEWIC (Committee on the Status of Endangered Wildlife in Canada) status of the case study species ranged from 'special concern' to 'endangered'.

Read, K. (2010). *Outplanting hatchery-reared northern abalone,* Haliotis kamtschatkana*: A restoration tool for an endangered shellfish species.* (Master of Science), University of Guelph, Guelph, ON. Retrieved from https://hdl.handle.net/10214/24546

This thesis investigates the effectiveness of releasing hatchery-reared ' Haliotis kamtschatkana' into the wild in an attempt to restore depleted populations. The first chapter assesses the effectiveness of a major larval and juvenile seeding effort in terms of its effect on local abalone population densities. Individuals sampled at the outplanting sites were genotyped and a pedigree was reconstructed that included known hatchery individuals. Based on this partitioning, hatchery-outplanted individuals were identified and it was determined that despite supplementation efforts, local abalone densities remained significantly below levels required for successful fertilization and recruitment. The second chapter examines the effect of excluding predators and adding complex substrate to outplanting sites on the survival of seeded juveniles. The results demonstrated that providing spatial refuge and manually removing predators could increase survival rates of outplanted juveniles. Considering factors such as local predation rates and life history stage released may increase the survival of outplanted individuals.

Rooper, C. N., MacNeill, S., Lee, L. C., McNeill, D., Yamanaka, K. L., Towler, R. H., & Williams, K. (2021). Underwater Stereo-Camera Survey Methodology for Estimating Density and Size of Northern Abalone (*Haliotis kamtschatkana*). *Journal of Shellfish Research,* 40(2). https://doi.org/10.2983/035.040.0209

Northern abalone are an important component of the intertidal and subtidal ecosystems of the Pacific Coast. This research was carried out to test the feasibility of utilizing underwater stereo-camera

technology to conduct surveys to estimate the abundance and size structure of northern abalone populations. Consistent with other studies, depth and substrate both impacted the density and length of northern abalone, and provided a basis for implementing stratification strategies for density estimation. The average deployment took about 18 min and resulted in 47 useable image quadrats. The estimated time to analyze each frame was about 3 min, translating into ~2.5 h of processing time per deployment. The precision of the resulting density estimates was high (relative error ~0.22–0.37 depending on the method used for stratification) and could be improved by increasing the number of study sites to 35 or greater. The pooled density of northern abalone was estimated as 1.07 individuals/ m−2 (SE = 0.21) and the mean length of northern abalone across the study sites was 67.7 mm (SE = 0.08). Future stereo-camera surveys could be used as a cost-effective supplement to self-contained underwater breathing apparatus diver surveys to increase the precision of abundance and size estimates of northern abalone populations.

Rudd, M. (1995). Abalone stock enhancement: A review of rationale and techniques. *Bulletin of the Aquaculture Association of Canada,* 95(4), 13-16. Retrieved from http://aquacultureassociation.ca/wp-content/uploads/bsk-pdf-manager/2018/01/Bulletin-95-4.pdf

Market demand for abalone (Haliotis kamtschatkana) has soared over the past decade in Asia and, as a result, wild abalone stocks worldwide have come under increasingly heavy fishing pressure. Landings in several regions have declined to as low as l0% of peak landing levels. In British Columbia, where there had been commercial, sport, and native food fisheries, a ban on all types of harvesting was imposed in l990 due to government concerns over declining stock levels. This ban, which remains in effect, has prompted increased interest in abalone enhancement. There are several potential enhancement methods available for use on abalone. Severe stock depletion in British Columbia makes active restocking programs the only real option for enhancement of local abalone stocks. Abalone restocking programs can utilize either larvae or juveniles. This paper reviews some of the advantages and disadvantages of each strategy given the unique biological aspects of abalone.

Searcy-Bernal, R., Montaño-Moctezuma, G., Anguiano-Beltrán, C., García-Esquivel, Z., Martínez-Sandoval, R. F., Macedo-Carranco, J. C., & Vásquez-Moreno, E. (2016). Preliminary Studies on the Use of Pit Tags to Evaluate Abalone Restocking. *Journal of Shellfish Research,* 35(3), 677-683. https://doi.org/10.2983/035.035.0314

The evaluation of abalone (Haliotis spp.) restocking programs might be improved by the use of microchips attached to seeds [ca. 20–30mmshell length (SL)]. Preliminary studies were conducted to standardize thismethodology and to assess tag retention and the potential impacts of tagging red abalone (Haliotis rufescens) seeds (initial averages: 26 mm SL, 2.5 g total weight) with passive integrated transponder (PIT) tags (9×2mm, Biomark, HPR Plus Reader). Tags were placed in previously made grooves in the shells and glued with a cyanoacrylate adhesive fast cured with sodium bicarbonate. Laboratory trials showed that metabolic rate increased in tagged seeds compared with untagged controls (t = 4.74, P = 0.009) immediately after the tagging procedure, but this effect was not significant after 3 h (t= 1.43, P = 0.23). Food (Macrocystis pyrifera) consumption after 24 h was similar by seeds marked with PIT tags, plastic tags, both tags, and untagged controls (F= 0.12, P = 0.94). Tag retention

and survival was 100% after 108 days in all treatments and no effects were detected on growth rates in length (range=0.92–1.11 mm/mo, F= 0.72,P= 0.57) or weight (range= 0.30–0.44 g/mo, F=2.44,P= 0.16). Results from a small-scale field experiment in tide pools, suggest that the detection of planted abalone seeds can be significantly improved when these are marked with PIT tags, compared with those marked with conventional plastic tags. Improvements should, however, bemade regarding antenna design and reading distance to optimize the use of this technology to evaluate restocking programs.

Shapcott, C. (1989). Environmental impact assessment and resource management, a Haida case study: Implications for native people of the north. *The Canadian Journal of Native Studies,* 9(1), 55-83. Retrieved from http://www3.brandonu.ca/cjns/9.1/shapcott.pdf

The relevance of conventional environmental impact assessment (EIA) to Native people is limited by the values of the dominant culture's world view, and the structures and policies created out of them. The traditional Native world view, as exemplified by the Haida, links people with their land base, and is community oriented and consultative.

Shepherd, S. A., & Brown, L. D. (1993). What is an abalone stock: Implications for the role of refugia in conservation. *Canadian Journal of Fisheries and Aquatic Sciences,* 50(9), 2001-2009. https://doi.org/10.1139/f93-224

This paper concerns the conservation of abalone stocks in a genetic and fisheries sense. We review genetic and ecological information relating to the differentiation of abalone stocks in South Australia and propose that metapopulation theory provides an apt framework in which to develop the concept of an abalone stock. We consider what is a minimum viable population for abalone and illustrate our discussion with a case study of an abalone population that declined through a combination of fishing, recruitment failure, and inadequate protection by a refugium. Refugia can play an important role in abalone conservation by maintaining egg production and genetic diversity and by preserving populations for scientific study.

Sloan, N. A. (2004). Northern abalone: Using an invertebrate to focus marine conservation ideas and values. *Coastal Management,* 32(2), 129-143. https://doi.org/10.1080/08920750490276128

Marine invertebrate species have usually been overlooked in favor of high-profile vertebrate species for facilitating dialogue towards area conservation. The northern abalone (Haliotis kamtschatkana) is proposed as a focal ("flagship") species whose protection and recovery could concentrate public concern for abalone and its associated kelp forest ecosystems in Haida Gwaii (Queen Charlotte Islands), British Columbia. I explain how issues of culture, commerce, and conservation unite to create a strong role for northern abalone in preparations for creating a large marine conservation area within Haida Gwaii. Culture is relevant, as local indigenous people ( the Haida) are currently denied access to constitutionally established subsistence fishing rights for northern abalone. Commerce is involved as ongoing kelp forest - associated fisheries co-occur with northern abalone. Finally, this is a challenging precedent in Canadian marine conservation, as restoring two "listed" species at risk ( northern abalone and their predator, the

sea otter ( Enhydra lutris)) is potentially mutually exclusive. As part of the forthcoming public consultations towards establishing a marine conservation area, the opportunity provided by northern abalone to focus ideas and values should be seized.

Sloan, N. A. (2005). Contemplating One-Sided Clams: The Northern Abalone Quincunx. *The George Wright Forum,* 22(3), 50-57. Retrieved from http://www.jstor.org/stable/43597956

In this paper I discuss a proposed national marine conservation area in British Columbia, Canada, using northern abalone (Haliotis kamtschatkana) as a lens through which regional communities can view issues of culture, commerce and conservation. Indigenous Haida people, whose traditional territory includes Haida Gwaii (Queen Charlotte Islands), sometimes refer to northern abalone as “one-sided clams.” British Columbia marine waters have one species of abalone, a herbivorous snail reaching 140 mm in shell length that uses its massive (and edible) foot to creep over lower intertidal and shallow subtidal rocky substrates under a canopy of kelp forest while grazing on algae.

Sowul, K., Carson, H. S., Bouma, J., & Fyfe, D. A. (2021). *DRAFT Washington State Recovery Plan for Pinto Abalone*. Retrieved from https://wdfw.wa.gov/publications/02284

This document is the Washington Department of Fish and Wildlife’s Pinto Abalone Recovery Plan. It identifies the recovery goal for WDFW and its partners, specifies population targets for reclassification, and outlines strategies and tasks necessary to meet the recovery goal. This plan also describes the essential partnerships and collaborations needed to restore this subtidal shellfish species back to a self-sustaining, healthy population. This document does not directly address the status of pinto abalone populations in Washington relative to recovery criteria. That will occur during the next status review, to take place every five years since the initial listing in 2019.

Stewart, E. A. (2004). *Communities Play an Important Role in the Recovery of Marine Species at Risk: Pinto Abalone and Sea Otter on the West Coast of Vancouver Island.* Paper presented at the Species at Risk 2004 Pathways to Recovery Conference, Victoria, BC. Retrieved from http://www.llbc.leg.bc.ca/Public/PubDocs/bcdocs/400484/stewart_edited_final_may_7.pdf

The British Columbia coast is in the center of a kelp forest ecosystem that extends along the Pacific coast of North America. Many marine species at risk depend either directly or indirectly on this system. This paper examines community recovery efforts for two marine species at risk, the pinto abalone (Haliotis kamstchatkana) and the sea otter (Enhydra lutris), on the west coast of Vancouver Island, British Columbia. The Nuu-chah-nulth First Nations and other coastal communities play critical roles in the recovery of these two species, and those efforts are examined here in light of improving collaboration and cooperation with the federal lead agencies responsible for marine species at risk recovery, namely Fisheries and Oceans.

Straus, K. M. (2010). *Shellfish aquaculture and conservation of two Puget Sound molluscs: The Pinto abalone (*Haliotis kamtschatkana kamtschatkana*) and the Pacific geoduck (*Panopea generosa*).* (Ph.D. Dissertation), University of Washington, Seattle, WA. Retrieved from http://wsg.washington.edu/wordpress/wp-content/uploads/publications/Strauss-Kristi-Dissertation.pdf

I examined aquaculture and conservation oftwo taxa native to Washington, USA (WA): Pinto abalone {Haliotis kamtschatkana kamtschatkana) and Pacific geoduck {Panopea generosa). Because pinto abalone populations continue to decline in WA despite fisheries closures, conservation aquaculture may be necessary. To determine appropriate culture methods, juveniles were reared in habitat-enriched or conventional tanks. No differences in survivorship or growth were observed but abalone behavior differed between rearing treatments. Abalone from habitat-enriched tanks changed habitats more often and spent different proportions oftime in available habitats. Results demonstrate that rearing conditions affect abalone behavior and should be considered for abalone restoration. Abalone are commonly misidentified, increasing the challenge of abalone management and conservation. I developed sequence-based genetic markers for species identification of Eastern Pacific abalone. I applied these tools and determined that flat abalone (H. walallensis) are a cryptic species in WA. Several individuals collected for the pinto abalone conservation aquaculture program were identified as flat abalone. Use ofthese individuals as broodstock may have led to interspecific hybridization and been detrimental to pinto abalone restoration. Results highlight the importance ofmolecular tools in abalone management, especially if conservation aquaculture is used.

To examine the potential genetic implications of geoduck aquaculture, I used five microsatellite loci to conduct two studies comparing genetic diversity in wild and cultured geoducks. In both studies, cultured geoduck showed reduced genetic diversity and effective number of breeders (Nb)- In one study, I examined geoduck seed produced in two hatcheries. Parentage assignment revealed that in one hatchery, many parents contributed to each seed cohort, with the largest full-sib family comprising 11-31% ofthe offspring. In contrast, 94% ofthe seed from the second hatchery were from a single fullsib family. In a complementary study, I examined five year classes of cultured geoducks. Sibship assignment revealed that year classes were comprised of nine to 25 full-sib families and many individuals unrelated to others at the full-sib level. Results from both studies demonstrate that hatchery practices affect genetic diversity; these results may aid in developing geoduck culture practices that minimize genetic risk to wild populations.

Timmins-Schiffman, E. B., Friedman, C. S., Metzger, D. C., White, S. J., & Roberts, S. B. (2013). Genomic resource development for shellfish of conservation concern. *Molecular Ecology Resources,* 13(2), 295-305. https://doi.org/10.1111/1755-0998.12052

Effective conservation of threatened species depends on the ability to assess organism physiology and population demography. To develop genomic resources to better understand the dynamics of two ecologically vulnerable species in the Pacific Northwest of the United States, larval transcriptomes were sequenced for the pinto abalone, Haliotis kamtschatkana kamtschatkana, and the Olympia oyster, Ostrea lurida. Based on comparative species analysis the Ostrea lurida transcriptome (41136 contigs) is relatively complete. These transcriptomes represent the first significant contribution to genomic resources for both species. Genes are described based on biological function with particular attention to those associated with temperature change, oxidative stress and immune function. In addition, transcriptome-derived genetic markers are provided. Together, these resources provide valuable tools

for future studies aimed at conservation of Haliotis kamtschatkana kamtschatkana, Ostrea lurida and related species.

Wallace, S. S. (1999). Evaluating the effects of three forms of marine reserve on northern abalone populations in British Columbia, Canada. *Conservation Biology,* 13(4), 882-887. https://doi.org/10.1046/j.1523-1739.1999.98117.x

Marine reserves have been suggested ns tools for assisting the management of fisheries by protecting vulnerable marine species from overexploitation. Although there is a theoretical basis for believing that marine reserves may serve as management tools, there are few marine reserves in the world in which to test their effectiveness. My research evaluated three forms of marine reserve on the south coast of Vancouver Island,, British Columbia, Canada, I used northern abalone (Haliotis kamtschatkana), a severely depleted shellfish in this region, ns an indicator of the effectiveness of the reserves Abalone populations in eight sites receiving different degrees of spatial protection were counted and measured ill situ during the spring of 1996 and 1997 In all sites with enforced harvest closures, populations of abalone were greater, and one site with nearly 40 years of protection had on average much larger (older) abalone. Reproductive output, as a function of abundance and size, was also greater in the enforced reserve areas. Larval dispersal from reserves, and hence the benefit to exploited areas, was not formally surveyed. Nevertheless, the results of my study, combined with knowledge of present abalone populations, life history, and regional hydrodynamics, suggest that establishment of reserves is justified in the absence of perfect knowledge of larval dispersal.

Woodby, D., Larson, R., & Rumble, J. (2000). Decline of the Alaska abalone (*Haliotis spp.*) fishery and prospects for rebuilding the stock. In *Workshop on Rebuilding Abalone Stocks in British Columbia.* A. Campbell (Ed.), (Vol. 130, pp. 25-31). Ottawa, ON: Canadian Special Publication of Fisheries & Aquatic Sciences Retrieved from https://publications.gc.ca/site/eng/9.615332/publication.html

The commercial fishery for northern abalone (Haliotis kamtschatkana) in Alaska has a boom and bust his- tory and a clouded outlook for rebuilding. Unrestricted harvests in the 1970s peaked at 172 tonnes in the 1979–1980 season followed by stock collapse in the early 1980s despite restricted harvests. The fishery closed in 1995. Sea otter populations grew exponentially in the 25-year history of the fishery after otters were reintroduced to their former range in southeast Alaska. Abalone populations were decimated in areas where otters reestablished; however, these declines came after peak fishery harvests. If otters continue to expand their range, future fishing opportunities for abalone will be severely limited. Future openings also depend on improvements in understanding of abalone productivity and re- cruitment processes. Growth rates are estimated from historic tagging data and compared to rates estimated from shell ring counts. Those results indicated that size limits may have provided protection to individuals for at least 3 years after the average age of reproductive maturity. This protection was insufficient to prevent abalone stock collapse.

*Workshop on Rebuilding Abalone Stocks in British Columbia*. (2000). (A. Campbell Ed.). Ottawa, ON: Fisheries and Oceans Canada. Retrieved from https://publications.gc.ca/site/eng/9.615332/publication.html

An international Workshop on Rebuilding Abalone Stocks in British Columbia was held during February 23-26, 1999, in Nanaimo, British Columbia, Canada. The main goal of the workshop was to develop a realistic strategy to rehabilitate depleted northern (pinto) abalone, Haliotis kamtschatkana, stocks in British Columbia. The workshop was also meant to clarify the roles, expectations, and shared interests of many of the interest groups in British Columbia, emphasizing the key role in the rebuilding plan of local communities, including First Nations and non-native communities. The workshop was attended by approximately 120 participants representing First Nations, local communities, recreational and commercial interests including aquaculture, and international (Australia, Canada, Japan, South Africa, and U.S.A.) abalone research and management. Presentations at the workshop were centered around the following five topics: (i) introducing local perspectives; (ii) status of abalone fisheries in Alaska, California, British Columbia, and South Africa; (iii) experiences in rebuilding abalone stocks using abalone aquaculture, larval and juvenile seed, and brood stock aggregations; (iv) additional pieces of the rebuilding puzzle, including abalone genetics and disease, sea otters, and the use of marine protected areas and refuges; and (v) summarizing discussions on a strategy for rebuilding abalone stocks in British Columbia. There are 13 peer reviewed papers in the Proceedings.

## Section III – Ecology

Alter, K., Andrewartha, S. J., Morash, A. J., Clark, T., Hellicar, A. D., León, R., & Elliott, N. G. (2017). Hybrid abalone are more robust to multi-stressor environments than pure parental species. *Aquaculture,* 478, 25-34. https://doi.org/10.1016/j.aquaculture.2017.04.035

Many hybrids of marine molluscs show improved growth in comparison to their pure parental species. Yet, little is known about the physiological mechanisms underlying the better hybrid performance. In this study, movement, oxygen consumption rate (ṀO2), and heart rate were determined in 22 month old cultured abalone Haliotis rubra, H. laevigata and their interspecies hybrid, the latter of which exhibits improved growth rate. Abalone were exposed to an acute temperature increase following acclimation to 16 or 23 °C at high and low oxygen levels (100% or 70% air saturation, respectively). Movement of hybrids and H. laevigata was generally not affected by temperature and oxygen levels, yet H. rubra showed a strong thermal response. Heart rate and ṀO2/temperature slopes revealed that hybrids were least affected by oxygen levels. Arrhenius break-point temperatures of hybrids and H. laevigata, but not H. rubra, were generally higher when abalone were acclimated to 23 °C in comparison to 16 °C. The hybrid had more stable maximum heart rate and ṀO2 values across acclimation conditions in comparison to H. laevigata and H. rubra. Thus, it appears that hybrids are able to maintain physiological functions over a broader environmental range. This improved tolerance to environmental fluctuations may bolster energy metabolism and improve growth in variable environments such as aquaculture farms.

Austin, A. P., Ridley-Thomas, C. I., Lucey, W. P., & Austin, D. J. D. (1990). Effects of nutrient enrichment on marine periphyton: Implications of abalone culture. *Botanica Marina,* 33(3), 235-239. https://doi.org/10.1515/botm.1990.33.3.235

In an outdoor flow-through tank facility at a commercial abalone farm, marine periphyton were subjected to increased inorganic nitrate (N-NO sub(3): 4.45), phosphate (P-PO sub(4): 0.48), or N + P concentrations above ambient (1.15 and 0.16 mg/l, respectively). After 39 days increased periphyton biomass occurred in N (13.2) and N + P (11.9) treatments, whilst control (4.6) and P (3.9 g/m super(2)) were significantly lower. Periphyton ash free dry weight (AFDW) protein concentrations increased and AFDW lipid values decreased with enhanced N or N + P. Addition of P resulted in little change in either biomass or protein, however, lipid levels were lower. Mean growth rate of abalone (measured as shell length) in N enhanced treatments was 2 times that of control or P. It is suggested that enhancement of N leads to changes in periphyton which are beneficial for grazing by cultured juvenile abalone (Haliotis kamtschatkana)).

Bennett-Rogers, L., Allen, B. L., & Rothaus, D. P. (2011). Status and habitat associations of the threatened northern abalone: importance of kelp and coralline algae. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 21(6), 573-581. https://doi.org/10.1002/aqc.1218

Northern abalone (Haliotis kamtschatkana kamtschatkana) is a federally listed species of concern. The status of northern abalone and the characteristics of the habitats they associate with were determined showing that northern abalone have declined dramatically in Washington State with present day

abundances <10% of those found in 1979. Northern abalone inhabited kelp beds (Nereocystis luetkeana), more than red sea urchin beds (Strongylocentrotus franciscanus) (X2=16, d.f.=1, P<0.01) or habitats with both kelp and sea urchins (X2=13.2, d.f.=1, P<0.01). Sites with Nereocystis kelp canopy had twice the percentage cover of encrusting coralline algae compared with sea urchin sites. No juvenile abalone (<75mm) were found in any of the habitat types raising concerns about recruitment failure. Abalone co-occurred with other molluscs including limpets and scallops. Kelp holdfast microhabitats had significantly higher species richness (t=2.2, d.f.=6, P<0.05), twice the effective number of species and 5x more individuals than sea urchin spine microhabitats. In laboratory choice experiments, juvenile abalone (20mm) preferred coralline rocks to kelp holdfasts or sea urchin spine canopy. The small snail, Amphissa spp. (5-15mm) was more abundant inside kelp holdfasts than under sea urchins or in rock cobble, suggesting this may be an important microhabitat. It is recommended that kelp beds with abundant coralline substrate be used for restoration including stocking juveniles and adult aggregations as this biogenic habitat may enhance northern abalone restoration actions.

Bergman, C. M., Pattison, J., & Price, E. (2013). The Black Oystercatcher as a Sentinel Species in the Recovery of the Northern Abalone: Contemporary Diet of Black Oystercatchers on Haida Gwaii Includes an Endangered Prey Species. *The Condor,* 115(4), 800-807. https://doi.org/10.1525/cond.2013.120182

We documented the diet of the Black Oystercatcher (Haematopus bachmani) on Haida Gwaii, British Columbia, Canada, (2004–2010) with prey remains from 99 territories in Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site. The ranking of its four main prey types did not vary annually. Numerically, the prey comprised 50–75% limpets, 14–34% mussels, 8–18% chitons, 1–2% Northern Abalone (Haliotis kamtschatkana), and <1% other species. In 2009, we estimated prey availability and prey preference by Ivlev's electivity index. Northern Abalone, limpets, and chitons were highly preferred; mussels, turban snails, and barnacles were taken in proportion to their occurrence or avoided. Black Oystercatchers preferred abalone of 50 mm, smaller than the mean size available, in contrast to the selection of larger-than-average prey, typical for other prey species. In 2010, 52% of nesting territories sampled contained remains of Northern Abalone, despite that species' small contribution to the diet. The Northern Abalone has never been reported as prey of the Black Oystercatcher despite its high vulnerability to predation at low tides. We speculate that the recent inclusion of the Northern Abalone in the Black Oystercatcher diet on Haida Gwaii may indicate a greater abundance of Northern Abalone than in other regions of its distribution. The frequency of the oystercatcher's feeding on abalone was unexpected because under Canada's Species at Risk Act, the Northern Abalone was listed as “endangered” in 2010, after the population continued to decline after legal protection from harvest in 1990.

Berry, S. S. (1921). A distributional note on Haliotis. *California Fish and Game,* 7(1), 254-255. Retrieved from https://www.biodiversitylibrary.org/page/27307200

H. kamtschatkana has figured but scantily in the literature of our fauna, and although by no means the rarest, is one of the least known of all our species. By all odds the best available account of it is that of Thompson (:14), which concerns itself mainly with the economic aspects of this mollusk in British Columbia. Over much of the western coast of North America it is the only discovered species of abalone.

Bird, A. C. (2018). *Determining Population Structure, Reproductive Potential, and Habitat Associations of Pinto Abalone (*Haliotis kamtschatkana*) in Southern California.* (M.S.), California State University, Fullerton, Fullerton, CA. Retrieved from https://www.proquest.com/dissertations-theses/determining-population-structure-reproductive/docview/2102102531/se-2

This study provides the first assessment of demographic and habitat information for pinto abalone (Haliotis kamtschatkana) in San Diego, California, two decades after the closure of all abalone fisheries in southern California. SCUBA surveys conducted from June 2014 to December 2016 indicate that current low densities (0-0.03 individuals/m2) were far below critical thresholds identified for other abalone species (0.15-0.30 abalone/m2) for successful spawning and recruitment. A broad range of sizes were represented (13-146 mm), however, only 95 individuals were found. Some sites showed significant aggregation of adult (> 50 mm) pinto abalone, 30% of adults had a nearest-neighbor within a critical spawning distance of 2 m, and 65% had a neighbor within 5 m, indicating that at least a small proportion of individuals may be capable of reproducing successfully. Pinto abalone showed a significant preference for boulder habitat at a lower relief (< 10 cm) relative to available habitat– a preference that may influence aggregation around habitat features and enhance reproduction. The frequency, timing, and broad spatial distribution of these surveys was not sufficient to measure patterns in recruitment or changes in abundance, particularly over a strong El Niño event that occurred during the study period. There is a critical need for consistent long-term monitoring in southern California to better understand demographic and environmental processes affecting recovery and persistence of populations, particularly at the southern edge of the broad range of pinto abalone.

Carson, H. S., Ulrich, M., & Bouma, J. (2018, 2018/05/18). *Survival of hatchery-origin juvenile pinto abalone (*Haliotis kamtschatkana*) outplanted to restoration sites in the San Juan Islands.* Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/544/

The Washington Department of Fish and Wildlife, Puget Sound Restoration Fund, and other project partners have outplanted thousands of hatchery-reared pinto abalone in annual cohorts to ten sites in the San Juan Archipelago since 2009. We measured the “success” of each outplant site by the proportion of total juveniles placed that survived to a reproductive size. In winter 2017 surveys we observed a range of successes, from 0% at the worst site to 5.6% at the best. When nearby individuals are included, this success ranges as high as 7.5%. These percentages do not account for the probability of detection for a given abalone, which available information from tagged abalone suggests is between 20 – 40%. They also do not account for emigration from the sites, which has not been quantified. I’ll discuss these results, their implications for on-site reproduction, and their incorporation into an integrated population model describing the survival and growth of outplanted juveniles. I’ll also discuss the future of pinto abalone recovery, including our new strategy to “repeal and replace” low performing sites, optimize outplant efficiency, and scale-up restoration efforts to achieve population-wide recovery.

Chandler, P. C., King, S. A., & Boldt, J. (2017). *State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016*.Canadian Technical Report of Fisheries

and Aquatic Sciences (3225). Sidney, B.C.: Fisheries and Oceans Canada, Retrieved from https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2016/index-eng.html

Fisheries and Oceans Canada is responsible for the management and protection of marine resources on the Pacific coast of Canada. Oceanographically this area is a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions. There is strong seasonality and considerable freshwater influence, and an added variability from coupling with events and conditions in the tropical and North Pacific Ocean. The region supports ecologically and economically important resident and migratory populations of invertebrates, groundfish, pelagic fishes, marine mammals and seabirds.

Since 1999 an annual State of the Pacific Ocean meeting has been held by DFO scientists in the Pacific region to present the results of the most recent year's monitoring in the context of previous observations and expected future conditions. The workshop to review conditions in 2016 was held March 22 and 23, 2017 at the Mary Winspear Centre near the Institute of Ocean Sciences, Sidney, B.C. This technical report includes submissions based on the ten-minute presentations given at the meeting.

Ocean temperatures along the B.C. coast were above the 1981-2010 average, but this warm water anomaly did not set records as in 2015. As the year progressed the temperature anomaly decreased and the upwelling of cool nutrient rich waters along the west coast of Vancouver Island marked a return to conditions more favourable for productivity and fish growth. The returns of most B.C. Sockeye Salmon stocks in 2016 were higher than expected and higher than the long term averages. The returns of Fraser sockeye in 2016, expected to be low, set an historic low record.

A special session focused on ecosystem reporting processes. Several experts from a variety of government and non-government groups in both Canada and the U.S. provided overviews of the processes they use for ecosystem reporting.

Crim, R. N., Sunday, J. M., & Harley, C. D. G. (2011). Elevated seawater CO2 concentrations impair larval development and reduce larval survival in endangered northern abalone (*Haliotis kamtschatkana*). *Journal of Experimental Marine Biology and Ecology,* 400(1-2), 272-277. https://doi.org/10.1016/j.jembe.2011.02.002

Increasing levels of anthropogenic carbon dioxide in the world's oceans are resulting in a decrease in the availability of carbonate ions and a drop in seawater pH. This process, known as ocean acidification, is a potential threat to marine populations via alterations in survival and development. To date, however, little research has examined the effects of ocean acidification on rare or endangered species. To begin to assess the impacts of acidification on endangered northern abalone (Haliotis kamtschatkana) populations, we exposed H. kamtschatkana larvae to various levels of CO2 [400 ppm (ambient), 800 ppm, and 1800 ppm CO2] and measured survival, settlement, shell size, and shell development. larval survival decreased by ca. 40% in elevated CO2 treatments relative to the 400 ppm control. However, CO2 had no effect on the proportion of surviving larvae that metamorphosed at the end of the experiment. Larval shell abnormalities became apparent in approximately 40% of larvae reared at 800 ppm CO2, and almost all larvae reared at 1800 ppm CO2 either developed an abnormal shell or lacked a shell completely. Of the larvae that did not show shell abnormalities, shell size was reduced by 5% at 800 ppm compared to the control. Overall, larval development of H. kamtschatkana was found to be sensitive to ocean acidification. Near future levels of CO2 will likely pose a significant additional threat to

this species, which is already endangered with extinction due in part to limited reproductive output and larval recruitment.

Cummins, P., & Haigh, R. (2010). *Ecosystem status and trends report for North Coast and Hecate Strait ecozone*. Canadian Science Advisory Secretariat Research Document (2010/045). Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/341028.pdf

The status and trends of indicators of the condition of biodiversity of the northern coastal waters of British Columbia are reviewed. Among the notable results it is found that upper-ocean waters show warming and freshening trends, dissolved oxygen levels are decreasing, and dissolved CO sub(2) levels are increasing in intermediate waters of the NE Pacific basin. These changes are likely to impact marine ecosystems found along the continental shelf off British Columbia. Organisms may shift their location depending on sea surface temperature SST, moving with the water temperature that suits them best. Marine ecosystems in the North Coast and Hecate Strait ecozone may change, perhaps relatively more rapidly than in the past, due to climate change. Populations of a number of indigenous species to the North Coast are listed as endangered, threatened, or of special concern under the Species at Risk Act, including the northern abalone, (Haliotis kamtschatkana - Threatened), sea otters (Enhydra lutris - Special Concern) and northern resident killer whales (Orcinus orca - Threatened). Stocks of some commercially harvested fish remain depressed, notably the sockeye salmon (Oncorhynchus nerka) of Smith and Rivers Inlet, and certain stocks of Pacific herring (Clupea pallasii). Populations of most marine mammals that had been commercially harvested or purposefully eradicated in the twentieth century, and have since gained protected status, are recovering. Human activities still pose a threat to many of these animals primarily through over-fishing, contaminants, lost or damaged fishing gear, shipping and decline of prey food items.

Dahlhoff, E. P., & Somero, G. N. (1993). Kinetic and structural adaptations of cytoplasmic malate dehydrogenases of eastern Pacific abalone (genus haliotis) from different thermal habitats: biochemical correlates of biogeographical patterning. *Journal of Experimental Biology,* 185(1), 137-150. https://doi.org/10.1242/jeb.185.1.137

We measured the effects of temperature on cytosolic malate dehydrogenases (cMDHs) from the shell muscle of five species of eastern Pacific abalone, genus Haliotis, found at different latitudes and/or tidal heights. The apparent Michaelis-Menten constant (Km) of coenzyme (nicotinamide adenine dinucleotide, NADH) was conserved within a narrow range (11–21 micromolar) at physiological temperatures for all species. However, elevated temperatures perturbed the Km of NADH for cMDHs of the two species living at higher latitudes and/or lower tidal heights [Haliotis rufesens (red) and H. kamtschatkana kamtschatkana (pinto)] to a much greater extent than for cMDHs of congeners from lower latitudes and/or higher tidal heights [H. fulgens (green), H. corregata (pink) and H. cracherodii (black)]. The apparent Arrhenius activation energies for the cMDHs of these five species showed a similar interspecific divergence. Furthermore, green, pink and black abalone have cMDHs that are more resistant to thermal denaturation than are cMDHs of red and pinto abalone. Native gel electrophoresis showed that cMDHs of red and pinto abalone had identical mobilities, whereas cMDHs of green, pink and black abalone are distinct both from each other and from that of the two cold-adapted species. These data suggest that cMDHs from the abalone species living in warm habitats are adapted to function

optimally at higher temperatures than are the cMDHs of the two species living in cooler habitats. The relationships suggested by these criteria are in agreement with other studies that used morphological and molecular indices to predict abalone phylogeny. These results therefore provide further evidence that interspecific variation in protein structure and function may be driven by natural selection based on only small (i.e. several degrees Celsius) differences in average body temperature, and that such selection is an important element of the mechanisms of species formation and the maintenance of biogeographic patterning

DeFreitas, B. A. (2005). *Manipulations of adult density and juvenile habitat quality in Northern Abalone stock restoration.* (Master of Science Thesis), Simon Fraser University, Burnaby, BC. Retrieved from https://summit.sfu.ca/item/8465

Wild abalone populations throughout the world have declined dramatically over the past 40 years due primarily to market demands for the mollusc's edible foot. Northern abalone (Haliotis kamtschatkana), the only abalone species occurring in British Columbia (B.C.), is widely thought to be threatened by potential population collapse as a result of low adult densities that impair reproductive potential. This study examined the hypothesis that the abundance of wild northern abalone populations are below a critical density required for successful reproduction and assessed two techniques that may aid the 'recovery' of northern abalone in B.C. In the first study, I created dense aggregations of mature abalone during the reproductive period to test whether abalone preferred high density spawning aggregations that theoretically enhance reproductive potential. Twelve weeks following the manipulations, transplanted abalone had dispersed from enhanced densities at different rates and one year later, abalone densities had returned to pre-treatment levels. Slower rates of transplanted abalone dispersal at specific locations indicated that artificially aggregated abalone may have an enhanced theoretical reproductive potential. However, transplanted abalone dispersing to pre-treatment densities indicated that wild populations do not necessarily suffer from impaired reproductive potential. In the second study, I installed artificial habitats that provided standardized surrogate habitat for juvenile abalone and surveyed surrounding natural habitats to determine an index of juvenile abalone abundance. Juvenile abalone used artificial structures at greater mean densities than nearby natural habitat and juvenile abalone abundance was significantly different between sites but not within sites, suggesting artificial structures showed promise in their ability to detect area specific differences in recruitment and to easily measure juvenile abalone abundance. Benefits of these studies in relation to abalone stock restoration are discussed.

Geiger, D. L. (2000). Distribution and biogeography of the recent Haliotidae (Gastropoda: Vetigastropoda) world-wide. *Bollettino Malacologico,* 35, 57-120. Retrieved from https://www.researchgate.net/publication/284047373_Distribution_and_biogeography_of_the_Haliotidae_Gastropoda_Vetigastropoda_world-wide

The distribution of all 56 abalone species is documented based on specimen records. The three models for the origin of the family (Pacific Rim, Indo-Pacific, Tethys) are evaluated. The area cladogram, which treats the distribution of the individual species as characters and the areas as taxa, is in general agreement with an unrooted phylogenetic tree of the taxa for which the geographic occurrence is superimposed. The basal node of the area cladogram is a fairly large polytomy uniting rather distant

provinces such as the north Pacific, Australia, and Africa. A similar pattern emerges from the taxon cladogram. Accordingly, a very general Indo-Pacific origin emerges, best in agreement with the Indo-Pacific model for the origin of the family. The apparent discrepancy with the fossil record is discussed. Although the earliest fossils from the Upper Creatceous have been found in the Caribbean and in California, a major hiatus of on the order of 200 million years can easily account for the discrepancy between the earliest foss- sils and the biogeographical reconstruction, as well as for the large basal polytomy in the biogeographical analysis. All species are illustrated, including some distinct juvenile forms, and 30 photographs of live animals.

Griffiths, A. M., & Gosselin, L. A. (2008). Ontogenetic shift in susceptibility to predators in juvenile northern abalone, *Haliotis kamtschatkana*. *Journal of Experimental Marine Biology and Ecology,* 360(2), 85-93. https://doi.org/10.1016/j.jembe.2008.04.004

Predation has been suggested as a major cause of juvenile mortality in benthic marine invertebrates. However, the extent to which juveniles are susceptible to predators is unknown for most species, and it remains unclear to what extent ontogenetic shifts in susceptibility to predators are common among marine invertebrates. This study examined the northern abalone Haliotis kamtschatkana, a species listed as threatened in British Columbia, Canada. Our goals were to characterize the diversity and abundance of species that prey on juvenile abalone and determine if abalone experience an ontogenetic shift in susceptibility to predators. juvenile H. kamtschatkana were found to be susceptible to a broad variety of predators: 14 of the 37 potential predator species to which we offered juvenile abalone (<= 28 mm shell length (SL)) consumed at least one juvenile abalone. Four of those species (three crabs and one seastar) consumed >= 10% of the juvenile abalone that were offered in the laboratory. These species were present at field sites where abalone are found, indicating that they have the potential to be significant predators of juvenile H. kamtschatkana in the wild. The most abundant predators were small crabs, especially Lophopanopeus bellus (black-clawed crabs) and Scyra acutifrons (sharp-nosed crabs). juvenile H. kamtschatkana also experienced a pronounced ontogenetic shift in susceptibility to predators. The risk of predation for juvenile H. kamtschatkana decreased rapidly with increasing body size, especially over the 12-13 mm SL size range. Susceptibility remained low beyond 13 mm SL, indicating relatively low and unchanging levels of predation risk once the individual reaches this size. Although abalone are susceptible to several species during the first 1-2 years of life, predator effects on juvenile abalone abundance and microhabitat use may largely be attributable to the influence of only I or 2 predator species that can only kill abalone <13 mm SL.

Hansen, S. C., & Gosselin, L. A. (2013). Do predators, handling stress or field acclimation periods influence the survivorship of hatchery-reared abalone *Haliotis kamtschatkana* outplanted into natural habitats? *Aquatic Conservation-Marine and Freshwater Ecosystems,* 23(2), 246-253. https://doi.org/10.1002/aqc.2315

Northern abalone (Haliotis kamtschatkana) in British Columbia, Canada, are listed as endangered and are protected from fishing, yet their populations continue to decline. It is suspected that supplementation of wild populations with hatchery-reared abalone will be necessary for the recovery of this species. This study examines the magnitude, timing, and causes of post-outplanting mortality of hatchery-reared late-juvenile northern abalone. Abalone survivorship declined precipitously following

outplanting, with 83% of abalone surviving 24 h after release and only 34% surviving 2 weeks in the wild. Handling, tagging, and temperature variations experienced during the outplanting procedure did not cause mortality. The majority of the abalone mortality in this study was attributable to predators. Additional factors accounted for only 12% mortality over 7 d. A 1-week acclimatization period within predator exclosures did not improve subsequent survival of outplants. These results demonstrate that the ouplanting of hatchery-reared abalone as a method of restoring wild populations of this endangered species is primarily constrained by high mortality during the first few days after outplanting, and that almost all of this early mortality is caused by predation. Predation mortality will therefore have to be overcome if outplanting of hatchery-reared juvenile abalone is to be an effective restoration strategy.

Hansen, S. C., & Gosselin, L. A. (2016). Are hatchery-reared abalone naive of predators? Comparing the behaviours of wild and hatchery-reared northern abalone, *Haliotis kamtschatkana* (Jonas, 1845). *Aquaculture Research,* 47(6), 1727-1736. https://doi.org/10.1111/are.12627

Abalone populations have declined worldwide, generating interest in enhancement using hatchery-reared individuals. In many cases, such restoration efforts have met with limited success due to high predator-induced mortality rates. Furthermore, the mortality rates of outplanted hatchery abalone are often considerably higher than for wild individuals. This study uses northern abalone (Haliotis kamtschatkana) as a case study to determine whether hatchery-reared abalone behave differently than their wild counterparts. In the field, outplanted hatchery-reared abalone were significantly less responsive than wild abalone, in terms of number of abalone responding and intensity of response, to nearby movement and to physical contact with an inert probe. Also, when encountering a cue to which all abalone responded (a seastar predator), hatchery-reared individuals remained subdued. Anti-predator behavioural deficits in hatchery-reared abalone were more pronounced in 4-year-old individuals than in 1-year-old individuals, suggesting an influence of either age or amount of time spent in the hatchery environment. These behavioural differences are expected to increase the vulnerability of hatchery-reared abalone to predators, and are likely a major cause of their elevated predator-induced mortality when outplanted.

Hartwick, B., Tulloch, L., & MacDonald, S. (1981). Feeding and growth of *Octopus dofleini* (Wulker). *The Veliger,* 24(2), 129-138. Retrieved from https://www.biodiversitylibrary.org/page/42408324

Octopus dofleini (Wulker) is a large octopus inhabiting coastal waters on the west coast of North America. Mortett (1975) has reviewed some of the extensive literature on the fisheries biology of this octopus in Japanes waters. Although less is known about its habits on the west coast of North America, the potential of this octopus to support a limited fishery has been recognized (Pennington, 1979; Hartwick et al., 1978a; R. Clifton, Washington State, personal communication). Field studies of O. dofleini on the west coast have included aspects of natural history and behaviour (Hartwick et al., 1978b, 1978c; Kyte & Courtney, 1977; High, 1976a, b; Johnson, 1942) but relatively little is known of its feeding ecology and growth. Feeding and growth studies have been carried out for several other species of octopuses (see, for example, Nixon, 1966; Van Heukelem, 1973, 1976; Hanlon, 1977; Joll, 1977; Mather, 1980). Most of these studies have been restricted to the laboratory and the extent of such laboratory studies of one species, Octopus vulgaris Cuvier, is reflected in the recent book by Wells (1978). Considerably less work has been done on octopuses in their natural environment, although there

are exceptions (Kayes, 1974; Hochberg & Couch, 1970, Yarnell, 1969; Altman, 1967; Woods, 1965). An indirect study of predation by octopuses has been reported (Fotheringham, 1974) but, in general, detailed information on feeding and growth under natural conditions is lacking.

The present study was initiated to obtain data on the feeding and growth of Octopus dofleini in its natural habitat. Aspects of diet and its variation were considered along with predator-size relationships. Short term growth experiments were also carried out and are discussed in rlation to similar studies with other species.

Hollenbeck, J. P., Olsen, M. J., & Haig, S. M. (2014). Using terrestrial laser scanning to support ecological research in the rocky intertidal zone. *Journal of Coastal Conservation,* 18(6), 701-714. https://doi.org/10.1007/s11852-014-0346-8

Scale-appropriate, foundational datasets are necessary for ecological analyses of the rocky intertidal ecosystem. We used terrestrial laser scanning (TLS) to characterize and quantify the rocky intertidal zone topography at a western U.S. coastal site (Rabbit Rock, Oregon) to support ecological research relating to potential climate-induced changes in distribution and abundance of intertidal invertebrates and a large-bodied shorebird, the Black Oystercatcher (Haematopus bachmani). Alternate available data (e.g., aerial photography, airborne LIDAR) proved inadequate or infeasible for development of a topographic surface model inclusive of intertidal area from Mean Lower Low Water to Mean Higher High Water tidal elevation. Our TLS-derived topographic surface model competently supported development of an invertebrate distribution model relative to tidal elevation and topography. Using the developed model, we estimated current and future aerial extent of the intertidal zone and potential foraging habitat for Black Oystercatcher in our study area. Intertidal zone area decreased from 7,194 m^sup 2^ to 6,409 m^sup 2^ and 3,070 m^sup 2^ with 1 and 2 m sea-level rise, respectively. Surprisingly, due to the configuration of site substrate, potential foraging habitat for Black Oystercatcher increased from 5,658 to 5,903 m^sup 2^ with 1 m sea-level rise, but declined to 3,068 m^sup 2^ with 2 m sea-level rise. Our results demonstrate the utility of TLS for ecological research in the rocky intertidal zone. They further illustrate that climate change effects on ecological conditions may vary considerably depending on local configurations.

Jamieson, G. S., Gregr, E. J., & Robinson, C. (2004). *Northern abalone case study for the determination of SARA critical habitat*.Canadian Science Advisory Secretariat (2004/117). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2004/2004_117-eng.htm

This evaluation of critical habitat (SARA context) is one of a series of seven national case studies to investigate what critical habitat means for aquatic and marine species. It looks at this question for northern abalone (Haliotis kamtschatkana) in British Columbia, a cryptic, broadcast spawning, benthic gastropod of limited mobility that has been listed as "threatened" by COSEWIC. Little is know about this species' larval planktonic dispersal or coastal adult spatial distribution. However, populations are widespread and contagious in distribution, and recruitment has been declining for the past two decades. Over-harvesting during the fishery, which was terminated in 1990, and subsequent poaching are believed to have contributed to the recent low recruitment. To determine critical habitat for abalone, the following steps were adopted: 1) estimate total potential habitat suitable for northern abalone over

selected areas of the BC coast; 2) model potential abalone larval dispersal to determine dispersal characteristics and the likely scale of source and sink populations, and 3) identify subsequent studies to evaluate predictions made, and to refine the critical habitat assessment procedure for abalone developed and proposed here. Predictions of suitable abalone habitat for the west coast of Vancouver Island and Haida Gwaii (Queen Charlotte Islands) were produced, and larval dispersal modeling was conducted within the Broken Islands in Barkley Sound. This latter portion of the study suggested that specific spatial areas may have larger, more consistent abalone recruitment than others. Suggestions as to how to identify critical abalone habitat are made, given the data that are currently available.

Karpov, K. A., Tegner, M. J., Rogers-Bennett, L., Kalvass, P. E., & Taniguchi, I. K. (2001). Interactions among red abalones and sea urchins in fished and reserve sites of Northern California: Implications of competition to management. *Journal of Shellfish Research,* 20, 743-753. Retrieved from https://www.biodiversitylibrary.org/page/2148882

Red abalones (Haliotis rufescens), red sea urchins (Strongylocentrotus franciscanus), and purple sea urchins (S. purpuratus) share similar food and habitat requirements in northern California. Red abalones and red sea urchins also support important fisheries. Here we explore spatial interactions and apparent competitive effects among these species at an area where fishing has large impacts on both taxa, and at unfished reserve sites in which invertebrate density and food availability differ. There was an inverse correlation between adult red abalone and red sea urchin abundance at the scale of our transects when density of either or both species was high. In the poorest habitat for macroalgae, red abalones seldom occurred on the same transects with red urchins. The results suggest that differences in density, depth, and food availability play an important role in the observed spatial patterns of red abalones and red sea urchins. Purple sea urchins were not correlated to either of the other two species' distributions. An intense fishery for red sea urchins appears to have had a positive effect on kelp availability, and ablaone growth and abundance. Aerial photographs during the period of intense urchin fishing (from 1982 to 1989), showed a dramatic increase in the surface canopy. Similarly, during this period, size frequency distributions of fished red abalones show an increase in the number of individuals in larger size classes. Modal progression in abalone size frequency distributions suggests a faster growth rate during this period when compared with a growth sutdy, at the same location, conducted during the pre-urchin fishery years. Ultimately, red sea urchin removal apparently led to an increase in red abalone abundance even at a site that was heavily fished by recreational abalone fishers. Meanwhile, at a nearby reserve site where kelp populations are lower, red abalones have declined in abundance as red sea urchins increased. Our results suggest the need for multi-species ecosystem-based approaches to management of these valuable resources.

Kawana, S. K., Catton, C. A., Hofmeister, J. K. K., Juhasz, C. I., Taniguchi, I. K., Stein, D. M., & Rogers-Bennett, L. (2019). Warm Water Shifts Abalone Recruitment and Sea Urchin Diversity in Southern California: Implications for Climate-Ready Abalone Restoration Planning. *Journal of Shellfish Research,* 38(2), 475-484. https://doi.org/10.2983/035.038.0231

Nearshore kelp forest ecosystems are highly vulnerable to climate change and ocean warming, which can alter community dynamics and change the trajectory of species recovery in unpredictable ways. Abalone (Haliotis spp.) populations in the Southern California Bight (SCB) are still recovering from a

combination of overfishing and disease, despite the closure of the fisheries 20 years ago and active restoration programs for abalone species in the region. For this study, abalone recruitment and sea urchin populations were surveyed in artificial habitats (16-22 m) across a spatial and temporal climatic gradient in southern California from 2010 to 2017 to inform the development of climate-ready abalone restoration programs. The SCB encompasses warm and cool islands, and experienced two periods of ocean conditions-cool (2010-2013) and warm ocean conditions (2014-2016). Dive surveys of the artificial habitats revealed that juvenile abalone recruitment remained low during the study period, suggesting that recovery is slow. Warm-water years favored recruitment of juvenile pink (Haliotis corrugata) and green abalone (Haliotis fulgens), with the highest abalone recruitment observed at Catalina Island. Endangered white abalone (Haliotis sorenseni) were not observed despite placing the artificial habitats in suitable deep rocky reefs, which is further evidence supporting their endangered species status. The coolest site, San Diego, had little abalone recruitment, with a few juvenile red abalone (Haliotis rufescens) and threaded (Haliotis kamtschatkana) abalone present. Sea urchin abundance and diversity increased during the warm period, with the largest increase at Catalina Island. During the warm period, Coronado sea urchin (Centrostephanus coronatus) increased in abundance, coincident with a decrease in the commercially valuable temperate red sea urchin (Mesocentrotus franciscanus). Potential shifts in the sea urchin assemblage to warm-water sea urchins may negatively impact recovering abalone populations and the red sea urchin fishery. Climate-ready abalone restoration will require ecosystem-based monitoring, tracking on not only abalone recruitment but also sea urchins, algal abundances, ocean temperature, and kelp forest communities as climate change may lead to complex and unexpected ecosystem interactions.

Kroeker, K. J., Powell, C., & Donham, E. M. (2021). Windows of vulnerability: Seasonal mismatches in exposure and resource identity determine ocean acidification's effect on a primary consumer at high latitude. *Global Change Biology,* 27(5), 1042-1051. https://doi.org/10.1111/gcb.15449

It is well understood that differences in the cues used by consumers and their resources in fluctuating environments can give rise to trophic mismatches governing the emergent effects of global change. Trophic mismatches caused by changes in consumer energetics during periods of low resource availability have received far less attention, although this may be common for consumers during winter when primary producers are limited by light. Even less is understood about these dynamics in marine ecosystems, where consumers must cope with energetically costly changes in CO2-driven carbonate chemistry that will be most pronounced in cold temperatures. This may be especially important for calcified marine herbivores, such as the pinto abalone (Haliotis kamschatkana). H. kamschatkana are of high management concern in the North Pacific due to the active recreational fishery and their importance among traditional cultures, and research suggests they may require more energy to maintain their calcified shells and acid/base balance with ocean acidification. Here we use field surveys to demonstrate seasonal mismatches in the exposure of marine consumers to low pH and algal resource identity during winter in a subpolar, marine ecosystem. We then use these data to test how the effects of exposure to seasonally relevant pH conditions on H. kamschatkana are mediated by seasonal resource identity. We find that exposure to projected future winter pH conditions decreases metabolism and growth, and this effect on growth is pronounced when their diet is limited to the algal species available during winter. Our results suggest that increases in the energetic demands of pinto abalone caused by ocean acidification during winter will be exacerbated by seasonal shifts in their resources. These findings have profound implications for other marine consumers and highlight the importance of

considering fluctuations in exposure and resources when inferring the emergent effects of global change.

Lee, L. C., Watson, J. C., Trebilco, R., & Salomon, A. K. (2016). Indirect effects and prey behavior mediate interactions between an endangered prey and recovering predator. *Ecosphere,* 7(12). https://doi.org/10.1002/ecs2.1604

Managing for simultaneous recovery of interacting species, particularly top predators and their prey, is a longstanding challenge in applied ecology and conservation. The effects of sea otters (Enhydra lutris kenyoni) on abalone (Haliotis spp.) is a salient example along North America's west coast where sea otters are recovering from 18th- and 19th-century fur trade while efforts are being made to recover abalone from more recent overfishing. To understand the direct and indirect effects of sea otters on northern abalone (H. kamtschatkana) and the relative influence of biotic and abiotic conditions, we surveyed subtidal rocky reef sites varying in otter occupation time in three regions of British Columbia, Canada. Sites occupied by sea otters for over 30 years had 16 times lower densities of exposed abalone than sites where otters have yet to recover (0.46 +/- 0.08/20 m(2) vs. 7.56 +/- 0.98/20 m(2)), but they also had higher densities of cryptic abalone (2.17 +/- 1.31/20 m(2) vs. 1.31 +/- 0.20/20 m(2)). Abalone densities were greater in deeper vs. shallower habitats at sites with sea otters compared to sites without otters. Sea otter effects on exposed abalone density were three times greater in magnitude than those of any other factor, whereas substrate and wave exposure effects on cryptic abalone were six times greater than those of sea otters. While higher substrate complexity may benefit abalone by providing refugia from sea otter predation, laboratory experiments revealed that it may also lead to higher capture efficiency by sunflower stars (Pycnopodia helianthoides), a ubiquitous mesopredator, compared to habitat with lower complexity. Sea otter recovery indirectly benefitted abalone by decreasing biomass of predatory sunflower stars and competitive grazing sea urchins, while increasing stipe density and depth of kelp that provides food and protective habitat. Importantly, abalone persisted in the face of sea otter recovery, albeit at lower densities of smaller and more cryptic individuals. We provide empirical evidence of how complex ecological interactions influence the effects of recovering predators on their recovering prey. This ecosystem-based understanding can inform conservation trade-offs when balancing multifaceted ecological, cultural, and socio-economic objectives for species at risk.

Lessard, J., & Campbell, A. (2007). Describing northern abalone, *Haliotis kamtschatkana,* habitat: Focusing rebuilding efforts in British Columbia, Canada. *Journal of Shellfish Research,* 26(3), 677-686. https://doi.org/10.2983/0730-8000(2007)26[677:Dnahkh]2.0.Co;2

The northern abalone is listed as threatened under the Canadian Species at Risk Act. Northern abalone occur in a wide range of habitats from fairly sheltered bays to exposed coastlines. However, not all habitats are likely to support high abalone densities with large northern abalone that have high fecundity. Therefore, habitats that can support dense concentrations of large abalone would be better suited for aggregation rebuilding projects. Several experimental rebuilding projects are currently underway; the experimental sites were, in general, selected based on abalone presence and relative abundance. This study attempts to describe abalone habitat suitable for rebuilding efforts by using data from surveys completed at the start of the large decline of abalone densities observed in British

Columbia (BC). Several areas were surveyed to determine abalone density on the southeast coast of the Queen Charlotte Islands and the north central mainland coast of BC between 1978 and 1980. Habitat data were recorded after each dive, including substrate types and dominant algae cover and species. Four categories of algal types were analyzed based on height and growth patterns: (1) canopy; (2) understorey (large bottom cover); (3) turf (short bottom cover); and (4) encrusting. In addition, an index of wave exposure was also calculated for each site surveyed. Northern abalone density was inversely correlated to mean abalone shell lengths. The exposure index was correlated positively to abalone density but negatively to mean shell length. Regression tree classifications successfully separated habitats of high and low abalone densities, but these differed from habitats classified using mean shell length as the response variable. To optimize rebuilding efforts, a compromise between the two classification models, one with density as the response variable and the other with mean shell length, may have to be developed.

Liversage, K., & Chapman, M. G. (2018). Coastal ecological engineering and habitat restoration: incorporating biologically diverse boulder habitat. *Marine Ecology Progress Series,* 593, 173-185. https://doi.org/10.3354/meps12541

Ecological engineering is increasingly being studied and applied in order to reverse declines of biological diversity caused by coastal urbanisation and habitat degradation. As methods become more sophisticated and the theoretical framework more advanced, engineering of more complex and biologically diverse habitat types becomes possible. This review discusses the benefits of incorporating boulder habitat, which provides a unique combination of intermediate stability and high structural complexity, and can be occupied by many rare species. The inclusion of this habitat into engineered coastlines would therefore represent an important outcome for coastal ecological engineering by providing habitat for these species. Some methods are already in use to restore degraded boulder habitat; these methods should strive to closely mimic boulder habitat because semi-natural habitats (e.g. building rubble at bases of seawalls) have not been found to support rare species at this stage. Creation of new boulder habitat is also valuable for important fisheries (e.g. Haliotis spp.). Methods will be improved by focusing on small-scale microhabitats created by boulders and how these microhabitats provide shelter from locally relevant predators. Boulder habitat can reliably stabilise shorelines whereas alternative ecological engineering options based on littoral vegetation (e.g. mangroves, seagrass or saltmarsh) provide stabilisation involving strong spatiotemporal variability. Ecological engineering methods that include highly novel habitats, such as boulders, will achieve valuable biodiversity outcomes by allowing large-scale increases in along-shore distribution of specialist species. Overall, incorporation of boulder habitat in ecological engineering will help ensure coastal habitats include highly diverse assemblages and important ecological functionality as the pressure to modify coastlines increases.

Lloyd, M. J., & Bates, A. E. (2008). Influence of density-dependent food consumption, foraging and stacking behaviour on the growth rate of the Northern abalone, *Haliotis kamtschatkana*. *Aquaculture,* 277(1-2), 24-29. https://doi.org/10.1016/j.aquaculture.2008.01.039

Growth of abalone in the wild and hatchery is density-dependent in response to intraspecific competition for food and/or space. To determine if a candidate aquaculture species, Haliotis

kamtschatkana, exhibits density-dependent growth we raised animals at three density levels and two food treatments: unlimited (ad libitum) and rationed (individual portions were the same among density treatments). We also tested for differences in food consumption, foraging patterns and stacking behaviour among the density levels. We observed density-dependent growth in the rationed treatments, indicating that relatively high growth rates at lower densities are driven, in part, by factors other than differences in food consumption. However, overall the quantity of food consumed related directly to growth; treatments fed ad libitum had higher growth rates. Furthermore, even when food was provided in excess, foraging was restricted to similar to 2 h after sunset in all treatments and the amount consumed per abalone was significantly lower at high densities. This is probably because high density animals could not access the food provided: fewer were observed foraging and they had to move from prominent stacks. Our results indicate that both temporal and spatial access to food are critical and that managers can observe foraging and stacking by abalone in tanks to determine if a specific design will limit food consumption, and ultimately growth.

Marliave, J. B., Gibbs, C. J., Gibbs, A. O. L. D. M., & Young, S. J. F. (2011). Biodiversity Stability of Shallow Marine Benthos in Strait of Georgia, British Columbia, Canada Through Climate Regimes, Overfishing and Ocean Acidification. In *Biodiversity Loss in a Changing Planet.* O. Grillo & G. Venora (Eds.): InTech https://doi.org/10.5772/24606

The highest human population density in British Columbia, Canada is situated around the shores of the Strait of Georgia, where current government policy is focusing early efforts toward achieving ecosystem-based management of marine resources. Climate regime shifts are acknowledged to have affected commercial fishery production in southern British Columbia (McFarlane et al., 2000), and overfishing is well documented in the Strait of Georgia region for a variety of important species, to the extent that Rockfish Conservation Areas have been created (Marliave & Challenger, 2009). As CO2 levels rise in the atmosphere, the oceans become progressively more acidic. While ocean acidification is predicted to be a great threat to marine ecosystems, little is known about its ecosystem impacts. Few taxpayer-funded studies have committed to long-term monitoring of full ecosystem biodiversity. This document presents results of over forty years of private taxonomic monitoring of shallow seafloors in the region centering on the Strait of Georgia. Also presented are records of ambient ocean acidity levels (pH), documented continuously by the Vancouver Aquarium through the same time period. Biodiversity data are summarized in ways that enable visualization of possible relationships to climate regimes and ocean acidification. This work does not attempt statistical analyses, in the hope that the data trends can be incorporated into future models. Biodiversity survey data can reveal fundamental differences in community function, as with the disparate trophic complexity and rockfish nursery capacity of glass sponge gardens versus reefs (Marliave et al., 2009). Trophic cascades can be elucidated when coupling biodiversity surveys with transect abundance surveys (Frid & Marliave, 2010). It has been suggested that biodiversity provides more accurate definition of climate regime shifts than does physical oceanographic data (Hare & Mantua, 2000) and the abundance, survival and spawning distribution of commercial fish species have been linked to decadal-scale changes in ocean and climate conditions (McFarlane et al., 2000). Ocean acidification can detrimentally impact anti-predator behaviors of fish (Dix et al., 2010). Ocean acidification is most intensive in the geographic area of the NE Pacific Ocean.

O'Connell, V. (2017). *Coastal Resilience in Sitka Sound: Monitoring Pinto Abalone and Kelp Forests in a Changing Climate*. Sea Grant Alaska. Retrieved from https://seagrant.uaf.edu/research/projects/summary.php?id=1024

Kelp forests have long been known as ecological powerhouses that support high levels of biodiversity and fish production, which helps to support local economies. They also serve as critical habitat to species of conservation concern, such as pinto (or northern) abalone (Haliotis kamtschatkana), an important subsistence species recently under consideration for listing as endangered in Alaska. However, kelp beds themselves are also susceptible to the very weather events they protect coastal communities against, and recent research indicates they may also be negatively impacted by ocean acidification. The pinto abalone is currently being considered for listing under the US Endangered Species Act. There is a renewed interest in assessing the current status of pinto abalone populations in Alaska. Fortunately, several long-term data sets are available that can be used as a baseline to quantify temporal trends as well. Resampling abalone density and size frequency at these historical survey locations will provide much needed data to assist with the upcoming evaluation by the National Marine Fisheries Service. Through a collaborative project with the Sitka Sound Science Center, the Alaska Department of Fish and Game, University of Alaska Southeast, and the US Coast Guard Academy, cadet interns will map, assess, and monitor Sitka Sound kelp beds and evaluate changing environmental conditions (pH, temperature, currents). Concurrently, scientists will collect density and demographic data on pinto abalone in Sitka Sound. Kelp beds and pinto abalone are important species in the coastal ecosystem of Sitka Sound. Monitoring these populations and correlating trends with factors related to climate change will help inform management decisions and help the community respond to a changing environment. Further, this study will be a conduit for training and mentoring a new generation of scientists and managers through internship programs at the Sitka Sound Science Center.

Read, K. D., Lessard, J., & Boulding, E. G. (2013). Improving Outplanting Designs for Northern Abalone (*Haliotis kamtschatkana*): The Addition of Complex Substrate Increases Survival. *Journal of Shellfish Research,* 32(1), 171-180. https://doi.org/10.2983/035.032.0123

Hatchery-reared abalone outplanted into the wild at higher than ambient densities often experience very high levels of mortality as a result of density-dependent predation by natural predators. We conducted 2 experiments to assess the effectiveness of different methods of reducing predation on outplanted northern abalone (Haliotis kamtschatkana). During the first experiment, we removed small predators from brick-filled habitat cages that excluded large predators. The survival rates of juvenile abalone (mean shell length (SL), 22 mm) were greater in cages from which sea stars and other predators were removed periodically than in control cages. During the second experiment, we constructed 30 fenced 1-m(2) outplanting plots and assigned 10 randomly to be controls and 20 to be filled with 1 of 4 complex substrates (0.3-m layer of cobbles, 0.3-m layer of boulders, 0.9-m layer of cobbles, and 0.9-m layer of boulders). We then released 30 large juvenile abalone (mean SL, 51.5 mm) into each plot. The number of live outplanted abalone remaining in the complex substrate plots was significantly greater than in the control plots during the first 6 days. Surveys of a 4-m radius around each plot showed that emigration was lower from complex substrate plots than from control plots, and fewer shell fragments were found. The addition of complex substrate to plots provided crypsis from large predators but also resulted in significantly higher densities of small predators. Outplanting lower densities of abalone into larger plots of natural high-substrate complexity might attract fewer predatory sea stars and crabs, and thus result in higher survival rates.

Rogers-Bennett, L. (2007). Is climate change contributing to range reductions and localized extinctions in northern (*Haliotis kamtschatkana*) and flat (*Haliotis walallensis*) abalones? *Bulletin of Marine Science,* 81(2), 283-296. Retrieved from https://www.ingentaconnect.com/content/umrsmas/bullmar/2007/00000081/00000002/art00013

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

Seamone, C. B., & Boulding, E. G. (2011). Aggregation of the Northern Abalone *Haliotis kamtschatkana* with Respect to Sex and Spawning Condition. *Journal of Shellfish Research,* 30(3), 881-888. https://doi.org/10.2983/035.030.0329

Current low densities of the northern abalone Haliotis kamtschatkana may be affecting the fertilization success of this endangered broadcast spawner, thus preventing its populations from recovering to historical levels. This study attempted to determine whether the northern abalone were significantly aggregated during the period just before spawning because this may compensate in part for their low densities. We used scuba to map the spatial distribution, sex, and spawning condition of tagged abalone within grids at three different sites close to Bamfield Marine Sciences Center on the west coast of Canada. Underwater tagging methods were then used to monitor individuals over a 3-wk period during the 2009 spawning season. We found that the populations at all sites had nearest neighbor R ratios significantly less than 1.0, which indicates an aggregated distribution. Within the range of densities observed for our 3 sites (0.12-0.64 adults/m(2)), the mean distances to the nearest neighbor (1) of either sex, (2) of the opposite sex, and (3) of the opposite sex with ripe gonads were always less than 1.00 m except in one case. Individual abalone aggregated independently of sex; therefore, the probability of finding both a ripe male and a ripe female within an aggregation increased linearly with density. We estimated that the northern abalone populations observed were sufficiently aggregated to make successful fertilization more likely at low densities. This is the first study to map abalone sex and degree of gonad development that allow the analysis of nearest neighbor measurements with respect to gender and spawning condition.

Shaffer, J. A. (2000). Seasonal variation in understory kelp bed habitats of the Strait of Juan de Fuca. *Journal of Coastal Research,* 16(3), 768-775. Retrieved from https://journals.flvc.org/jcr/article/view/80880

Kelp habitats in Washington state, including the Strait of Juan de Fuca, are classified as a critical habitat for a number of federally listed, proposed listed, and declining stocks, including Chinook, coho and chum salmon, and quilback, copper, and brown rockfish, surfsmelt, sandlance, and northern abalone. The Strait of Juan de Fuca supports the majority of kelp resources in the state of Washington. Despite this importance, virtually no information exists on kelp habitat community structure for the Strait of Juan de Fuca. This study defined understory composition of two dominant kelp habitats of the Strait. The understory composition of two Macrocystis integrifolia and Nereocystis luetkeana beds were sampled seasonally for one year. Variables assessed included macroalgal composition and abundance of three commercially and recreationally important species of urchin and one species of abalone. Similarities and differences were found with bed type, season, and geographic location. Similarities included strong seasonal variation in understory cover, and the dominance of the perennial, understory kelp Pterygophora californica. Both bed types were also similar in their difference from understory communities described for Puget Sound kelp beds. Differences between the two kelp bed types included variation in total algal cover. Macrocystis beds showed less seasonal variation in total cover and algal composition, and had greater overall percent cover, which M. integrifolia contributed to seasonally. Nereocystis beds showed seasonal changes in percent algal cover. However, N. luetkeana did not contribute to the understory algal cover of these beds. Nereocystis beds had higher total number of urchins and abalone than Macrocystis beds. Recent increases in kelp habitat management activities, combined with differences in kelp community with season, bed type, and location observed in this study underscore the need for well defined goals and detailed site studies for successful kelp habitat management, including restoration and preservation.

Standley, C. S. (1987). *Temperature and salinity effects on gamete viability and early development of pinto abalone, red sea urchins and green sea urchins.* (Master of Science Thesis), Univeristy of Alaska, Juneau, AK. Retrieved from https://www.worldcat.org/title/temperature-and-salinity-effects-on-gamete-viability-and-early-development-of-pinto-abalone-red-sea-urchins-and-green-sea-urchins/oclc/39248472&referer=brief_results

Tomascik, T., & Holmes, H. (2003). Distribution and abundance of *haliotis kamtschatkana* in relation to habitat, competitors and predators in the Broken Group Islands, Pacific RIM National Park reserve of Canada. *Journal of Shellfish Research,* 22(3), 831-838. Retrieved from https://www.biodiversitylibrary.org/page/3105204

Baseline information on the distribution and abundance of Haliotis kamtschatkana was obtained throughout the Broken Group Islands (BGI) in shallow- (2-5 m) and deep-water (6-9 m) habitats. The study demonstrates that abundance of northern (pinto) abalone varied spatially throughout the area and with depth. The shallow habitats in the study area supported significantly higher densities (0.18 abalone/m(2) +/- 0.02 SE) of northern abalone when compared with deep habitats (0.10 abalone/m(2)

+/- 0.02 SE). Maximum and minimum sizes of northern abalone measured in BGI were 132 and 4 mm shell length (SL), respectively. There were significant differences in abalone SL among the 5 island groups and the 2 depth zones. Juvenile abalones were more abundant in the deep habitat than in the shallow habitat. A significant correlation was detected between abalone densities and the relative index of exposure. There was a positive correlation between abalone size and the abundance of benthic macroalgae and an inverse relationship between abalone size and the abundance of red sea urchins (Strongylocentrotus franciscanus). A positive correlation between abalone and red sea urchin densities was observed. Seven percent of juvenile abalone (less than or equal to45 mm SL) was found under the red sea urchins' spine canopy. Distribution and abundance of selected invertebrate species associated with northern abalone including its known predators (ie, sea stars, crabs, octopuses) were assessed. The abundance of northern abalone was inversely correlated with predator abundance and density of benthic macroalgae. Detailed surveys of associated organisms and substrate types suggest that the distribution and abundance of northern abalone is a complex function of community interactions and substrate habitat characteristics.

Won, N.-i., Kawamura, T., Takami, H., & Watanabe, Y. (2013). Trophic structure in natural habitats of the abalone *Haliotis discus hannai* with distinct algal vegetation of kelp and crustose coralline algae: implication of ontogenetic niche shifts. *Fisheries Science,* 79(1), 87-97. https://doi.org/10.1007/s12562-012-0578-1

The abundance, species composition, and stable isotope ratios of benthic organisms were investigated to determine the trophic structures in abalone (Haliotis discus hannai) habitats, which are characterized by contrasting vegetation of crustose coralline algae (CCA) and kelp beds. A size-frequency analysis revealed that juvenile abalones with shell lengths (SLs) smaller than ~30 mm primarily inhabited CCA beds, whereas adults were abundant in kelp beds. Stable isotope analyses indicated that CCA beds were composed of a single food chain, whereas kelp beds supported multiple food chains. The abalone were divided into three size groups to estimate potential species interactions during their ontogeny. A small gastropod, Homalopoma sangarense, was the most abundant species, but is suspected to be less competitive with abalone, especially in CCA beds. An abundant starfish Asterina pectinifera appeared to function as a potential predator of juvenile abalones in both CCA and kelp beds. We concluded that CCA beds are essential for immediate post-settlement processes of abalones, whereas kelp beds are more important for providing refuge and food sources for adult abalones. The present study highlights that ontogenetic niche shifting can be a successful life-history strategy to sustain the abalone population in a subtidal rocky shore ecosystem.

## Section IV – Population

Adkins, B., & Stefanson, A. P. (1977). *An examination of harvested and unharvested abalone populations in the Moresby Island area*. Fisheries and Marine Service manuscript report (1435). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/18130.pdf

In October, 1976, we dived at 11 sites on the east coast of Moresby Island to examine density and size structure of abalone populations in both harvested and unharvested areas. The population size structure varied with exposure. We found smaller abalone in more exposed areas. Wave exposure and competition for food with the red sea urchin are discussed as possible factors leading to their size differences.

Adkins, B. E. (1978). *An examination of some commercially harvested abalone populations in the Moresby Island area*. Fisheries and Marine Service manuscript report (1455). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/10861.pdf

In July 1977, five sites were visited on the est coast of Moresby Island where abalone (Haliotis kamtschatkana) had recently been commercially harvested. Population density and size structure were determined for each site and these results compared with a similar study done in 1976. Only three of the five sites had abalone densities and size structures indicative of a commercially harvested population. In the remaining two sites, one had a density of an unharvested population and abalone were too small for commercial harvesting in the other site. Abalone density in the commercially harvested areas was determined to be about one abalone/m SUP-2 .

Adkins, B. E., & Stefanson, A. P. (1979). *North coast abalone survey in harvested areas, November 1978*. Fisheries and Marine Service manuscript report (1500). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/60034.pdf

A survey was made of abalone (Haliotis kamtschatkana ) populations in 13 sites in the Banks Island area, where harvesting had occurred in 1977 and 1978. The standard methods described in Breen and Adkins (1979) were used. Size frequencies, density measurements and site descriptions are presented.

Atkins, M., & Lessard, J. (2004). *Survey of northern abalone,* Haliotis kamtschatkana*, populations along north-west Vancouver Island, British Columbia, May 2003*. Canadian manuscript report of fisheries and aquatic sciences (2690). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/468470/publication.html

Northern, or pinto, abalone, Haliotis kamtschatkana, have been protected by harvest closures since 1990 due to low population levels. Index site surveys have been performed by Fisheries Oceans Canada since 1978 to monitor the recovery of the abalone populations in British Columbia. This survey was the first on the north-west coast of Vancouver Island, and will be used as reference for future surveys in this

area. Northern abalone were found at eight (25%) of the 32 sites surveyed. The density in Quatsino Sound was 0.21 plus or minus 0.04 abalone/m super(2), which is close to the densities surveyed in 2002 in the Queen Charlotte Islands (0.34 plus or minus 0.06 abalone/m super(2)), and in 2001 on the central coast (0.27 plus or minus 0.04 abalone/m super(2)). In total, nearly 60% of the individuals sampled were immature (<70 m shell length); the large proportion of immature individuals shows a potential for a future recruitment pulse, however, population increases will be small until such time.

Atkins, M., Lessard, J., & Campbell, A. (2004). *Resurvey of northern abalone,* Haliotis kamtschatkana*, populations in Southeast Queen Charlotte Islands, British Columbia, April, 2002*.Canadian manuscript report of fisheries and aquatic sciences (2704). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/fra/9.579999/publication.html?wbdisable=true

Northern abalone, Haliotis kamtschatkana, have been protected by harvest closures since 1990 due to low population levels. Index site surveys have been performed since 1978 to monitor abalone populations in British Columbia (BC). In April 2002, a total of 362 abalone were found from 45 of the 68 index sites surveyed along the southeast coast of the Queen Charlotte Islands. Mean shell length (SL) was 67.0 mm; 12.4% of abalone surveyed were of historic legal size ( greater than or equal to 100 mm). Abalone density for all sizes was 0.34/m super(2), significantly lower than all previous survey years (except 1994). Densities of legal and of mature ( greater than or equal to 70 mm SL) abalone were significantly lower in 2002 than all other years. Since the fishery closure in 1990, there has been no evidence of a recovery of northern abalone populations in southeast Queen Charlotte Islands.

Bell, L. E., White, T., Donnellan, M., Hebert, K., & Raimondi, P. (2018). Monitoring Pinto Abalone Populations and Recruitment in Sitka Sound, Alaska. In *Impacts of a Changing Environment on the Dynamics of High-latitude Fish and Fisheries.* F. J. Mueter, M. R. Baker, S. C. Dressel, & A. B. Hollowed (Eds.). Fairbanks, AK: Alaska Sea Grant, University of Alaska Fairbanks https://doi.org/10.4027/icedhlff.2018.04

The absence of basic population data for pinto abalone in Alaska poses an ongoing challenge to monitoring of environmental impacts on this important subsistence species at the northernmost end of its range. In 2014, the National Marine Fisheries Service determined that listing pinto abalone as “Endangered” or “Threatened” under the Endangered Species Act was not warranted. However, the review prompted interest in filling data gaps in Alaska, where harvest of pinto abalone remains legal in personal use and subsistence fisheries and regional populations of sea otters, a known predator of abalone, have rebounded in recent decades. To understand current demographics of pinto abalone in this region, researchers at the Sitka Sound Science Center, the Alaska Department of Fish and Game, and University of California Santa Cruz collaboratively initiated a long-term monitoring program of abalone populations in Sitka Sound, Alaska. Findings from the first two years of aggregation-targeted surveys at eight subtidal index sites provide an initial view of potential population vulnerabilities as well as indicators of resiliency. Although abalone abundances varied by site, depth, and survey, divers observed absolute densities of adult size classes above the threshold considered necessary for fertilization success within each site. Furthermore, there was evidence of recent successful recruitment of young-of-the-year abalone at all sites. Methodology and results from this project have already informed survey extensions

across other areas of Southeast Alaska, with an ongoing goal of utilizing these data to evaluate impacts of environmental change on pinto abalone populations in Alaska waters.

Bird, A. C. (2018). *Determining Population Structure, Reproductive Potential, and Habitat Associations of Pinto Abalone (*Haliotis kamtschatkana*) in Southern California.* (M.S.), California State University, Fullerton, Fullerton, CA. Retrieved from https://www.proquest.com/dissertations-theses/determining-population-structure-reproductive/docview/2102102531/se-2

This study provides the first assessment of demographic and habitat information for pinto abalone (Haliotis kamtschatkana) in San Diego, California, two decades after the closure of all abalone fisheries in southern California. SCUBA surveys conducted from June 2014 to December 2016 indicate that current low densities (0-0.03 individuals/m2) were far below critical thresholds identified for other abalone species (0.15-0.30 abalone/m2) for successful spawning and recruitment. A broad range of sizes were represented (13-146 mm), however, only 95 individuals were found. Some sites showed significant aggregation of adult (> 50 mm) pinto abalone, 30% of adults had a nearest-neighbor within a critical spawning distance of 2 m, and 65% had a neighbor within 5 m, indicating that at least a small proportion of individuals may be capable of reproducing successfully. Pinto abalone showed a significant preference for boulder habitat at a lower relief (< 10 cm) relative to available habitat– a preference that may influence aggregation around habitat features and enhance reproduction. The frequency, timing, and broad spatial distribution of these surveys was not sufficient to measure patterns in recruitment or changes in abundance, particularly over a strong El Niño event that occurred during the study period. There is a critical need for consistent long-term monitoring in southern California to better understand demographic and environmental processes affecting recovery and persistence of populations, particularly at the southern edge of the broad range of pinto abalone.

Bouma, J., & Dinnel, P. A. (2018). *Pinto Abalone Recovery Project: 2018 Final Report to the Skagit MRC.* Skagit Marine Resources Committee, Retrieved from http://www.skagitmrc.org/media/40550/Task%205.6%20and%205.7%20Pinto%20Abalone%20Final%20Report.pdf

The pinto (northern) abalone, Haliotis kamtschatkana, is the primary abalone species indigenous to Washington waters. Populations are severely depleted and considered functionally extinct because the current number and distribution of reproductive wild abalone is too low and too widely distributed to maintain a sustainable population. The current threatened state of the Washington pinto abalone population is largely due to anthropogenic factors, including overharvesting during the legal recreational fishery and poaching during the 1980-90s (Bouma 2007). Populations in Washington state never supported a commercial fishery for abalone. Between 1992 and 2017, the density of pinto abalone declined by 98% at 10 index sites in the San Juan Archipelago (SJA) even after the closure of the recreational fishery in 1994 (Rothaus et al. 2008, WDFW unpublished data). Insignificant numbers of juvenile recruits have been observed and the average size of abalone continues to increase (Rothaus et al. 2008, Bouma et al. 2012, WDFW unpublished data). Both of these measures indicate likely recruitment failure of pinto abalone in areas of historical presence. They are now listed as a U.S. Federal Species of Concern, a Washington State Candidate Species and Species of Greatest Conservation Need and as a Canadian Endangered Species (PSRF 2014).

Bouma, J. V., Rothaus, D. P., Straus, K. M., Vadopalas, B., & Friedman, C. S. (2012). Low Juvenile Pinto Abalone *Haliotis kamtschatkana kamtschatkana* Abundance in the San Juan Archipelago, Washington State. *Transactions of the American Fisheries Society,* 141(1), 76-83. https://doi.org/10.1080/00028487.2011.651551

To investigate contemporary pinto abalone Haliotis kamtschatkana kamtschatkana recruitment events and juvenile abundance, 66 abalone recruitment modules (ARMs) were deployed at two depths and three sites in the San Juan Archipelago (Washington State) that were historically inhabited by substantial abalone populations. Based on published studies from California and British Columbia, ARMs are proven tools for surveying juvenile pinto abalone abundance. Abalone recruitment modules provide complex habitat and protection from predation. The ARMs were surveyed in situ for juvenile abalone abundance six times over the course of 26 months. Only eight abalones were observed, including three juveniles that were less than 50 mm (shell length). The mean density of juvenile abalones inhabiting the ARMs across all three sites during the 2006 surveys was 0.012/m(2). The absence of juvenile abalones within the ARMs, combined with sharp regional declines in adult pinto abalone abundance, suggests limited local recruitment of this species, which is currently designated as threatened in Canada and as a species of concern in the USA.

Boutillier, J. A., Carolsfeld, W., Breen, P. A., & Bates, K. (1984). *Abalone survey in the Estevan Group and Aristazabal Island, May 1983*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (1747). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/68739.pdf

This survey was conducted to determine whether northern abalone (Haliotis kamtshatkana ) abundance had declined on a part of the British Columbia, Canada, coast. A team of two biologists and a commercial abalone diver measured abalone abundance at 42 sites in the Estevan Group and along the west coast of Aristazabal Island, on the north coast of British Columbia, in May 1983. Overall abalone density had declined, abundance of legal sized abalone had decreased, and pre-recruits were less numerous than during previous surveys in 1979 and 1980.

Boutillier, J. A., Carolsfeld, W., Breen, P. A., Farlinger, S., & Bates, K. (1985). *Abalone resurvey in the southeast Queen Charlotte Islands, July 1984*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (1818). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/38077.pdf

A survey of northern abalone (Haliotis kamtschatkana ) abundance was conducted on the south-east coast of the Queen Charlotte Islands, British Columbia, Canada, to assess suspected declines of stocks. A comparison of 61 sites with results from previous surveys in 1978 and 1979, showed significant declines of 75% for legal-sized abalone and 81% for total abalone stocks. The observed continuing decline of abalone in this area, together with similar results from a survey of the central coast of B.C. in 1983, indicates that the stock is not at equilibrium.

Breen, P. A., & Adkins, B. E. (1979). *A survey of abalone populations on the east coast of the Queen Charlotte Islands, August 1978*. Fisheries and Marine Service Manuscript Report (1490). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/20054.pdf

During a 20-day survey at most of 131 sites, the authors measured the abalone (Haliotis kamtschatkana) density from 16 quadrats and recorded the bottom type, slope, dominant plants, sea urchin abundance, and major grazing fauna. They took abalone samples for size frequency analysis at 46 sites. The methods used and descriptions of each site are given; detailed analysis will follow in a later report.

Breen, P. A., & Adkins, B. E. (1980). *Observations of abalone populations in Emily Carr Inlet and Lotbiniere Bay, April 1980*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (1576). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/754.pdf

Commercial abalone (Haliotis kamtschatkana ) populations were absent from Emily Carr Inlet, although the habitat appeared to be suitable. The area has been closed since the commercial abalone fishery began in this area, and the density and size structure of abalone suggest that harvesting is not responsible for the scarcity of abalone. In Lotbiniere Bay, a heavily harvested commercial bed still supported a good commercial density of abalone. The density of sub-legal abalone within one year's growth of attaining legal size suggested that the rate of recruitment to the fishery is excellent on this bed, but the remainder of the size structure and the appearance of the shells cast some doubt on this conclusion.

Breen, P. A., & Adkins, B. E. (1981). *Abalone Surveys and Tagging Conducted During 1979*. Canadian Manuscript Reports of Fisheries and Aquatic Sciences (1623). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/164.pdf

This report describes the results of three cruises undertaken to sample populations of abalone (Haliotis kamtschatkana ) on the northern coast of British Columbia, Canada. Descriptions are provided of all stations occupied and we present and discuss the abundance and population structure of abalone that were observed.

Breen, P. A., & Adkins, B. E. (1982). *Observations of abalone populations on the north coast of British Columbia, July 1980*. Canadian manuscript report of fisheries and aquatic sciences (1633). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/20396.pdf

Populations of northern abalone (Haliotis kamtschatkana ) were studied at 20 sites during a research cruise aboard the charter vessel Elfin . Sites were located in the Spider Island, Goose Island, and Estevan

Groups; on Aristazabal Island and in Juan Perez Sound, British Columbia, Canada. This report presents observations of habitats encountered; population density and size structure of abalone and red sea urchins (Strongylocentrotus franciscanus ), abalone length-weight, length-height and length-width relations; and growth observed in tagged abalone released in 1979.

Breen, P. A., Adkins, B. E., & Heritage, G. D. (1978). *Observations of abalone and subtidal communities made during a survey of the Queen Charlotte Strait and upper Johnstone Strait areas, July 13-20, 1977*. Fisheries & Marine Service Technical Report (789). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/10987.pdf

The research vessel Caligus was used from July 13 through 20, 1977; and examinations were made for abalone (Haliotis kamtschatkana) at 34 sites. Abalone were abundant in good commercial quantities at only two sites, but were marginally commercial at several others. The effect of harvesting was seen in the Port Hardy area, where densities are generally low; in addition, low juvenile numbers indicate slow recovery from fishing. Abalone were not found south of Malcolm Island in the areas surveyed, except for an isolated and self-sustaining population in Port Neville. Observations were made on the kelp communities present at each site, and are presented here.

Breen, P. A., Adkins, B. E., & Sprout, P. E. (1982). *Abalone populations on the west coast of Banks Island, June 1980*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (1640). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/22890.pdf

The northern part of Banks Island was closed to the commercial abalone (Haliotis kamtschatkana ) fishery for the 1980 season in response to local native groups, who reported a decline in the native Indian food fishery. The authors surveyed 43 sites in the Banks Island area, and they evaluated each site's potential to support food and commercial fishing. Without a previous survey it was not possible to measure the impact of the commercial fishery and estimate competition between the two fisheries; but they observed potential for conflict.

Breen, P. A., Stefanson, A. P., & Adkins, B. E. (1978). *North coast abalone surveys in harvested areas, spring 1978*. Fisheries & Marine Service Manuscript Report (1480). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40683060.pdf

Brief surveys were made of the abalone populations in 21 locations where harvesting had taken place in 1977. Ten sites were in the Queen Charlotte Islands and eleven sites were in the Banks Island area. Size freq

Campbell, A., Brouwer, D., Rogers, J., & Miller, D. C. (2000). *Abalone resurvey in south east Queen Charlotte Islands, 1998*.Canadian manuscript report of fisheries and aquatic sciences (2528).

Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/465878/publication.html?wbdisable=true

Northern or "Pinto" abalone, Haliotis kamtschatkana, fisheries in British Columbia (B.C.) have been closed since 1990 due to conservation concerns. The 1998 survey results indicated that northern abalone population densities were similar to those surveyed during 1984-94, but significantly lower than those found during 1978-79, in south east coast of the Queen Charlotte Islands, B.C.. The similarity in abalone density between the new random sites and historic index sites suggested that the mean densities from all index sites were reasonably representative of adult abalone sampled in areas of the south east Queen Charlotte Islands. The common historic index sites with no "legal" exposed abalone generally increased from 25% to over 60% between the late 1970s and the late 1990s. In contrast, the index sites with no exposed abalone (of any size) increased from 0% to 16% during 1978-1984, and then fluctuated between 5 and 16% during 1984-98. Although 8 years had elapsed since closure of the abalone fishery in B.C. there was no statistical evidence of recovery of northern abalone stocks in the south east coast of the Queen Charlotte Islands by 1998.

Campbell, A., Brouwer, D., Servant, S., Webb, N., Canada, O., & Region, P. (2004). *Survey of northern abalone,* Haliotis kamtschatkana*, populations in Southeast Barkley Sound, British Columbia, October 2002*.Canadian manuscript report of fisheries and aquatic sciences (2685). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://lens.org/110-032-581-493-514

A survey was conducted to provide an estimate of the population size of emergent northern abalone (Haliotis kamtschatkana) on the east side of Edward King Island, Deer Group, Barkley Sound, British Columbia, during October 16-18, 2002. The estimated mean density for emergent abalone of all sizes was 0.295/m2 , while the estimated mean density for abalone 81-120 rom in shell length (SL) was 0.123/m2 . The estimated total population number (and lower 90% confidence interval) of emergent abalone for all sizes was 21,075 individuals (15,744). The total population number (and 90% confidence interval) of emergent abalone of the 81-120 rom SL size range was estimated to be 8,791 individuals (6,220). This survey is compared to an earlier one conducted in July 2000 at the same location.

Campbell, A., & Cripps, K. (1998). *Survey of abalone populations at Stryker Island, Tribal Group and Simonds Group, central coast of British Columbia, May, 1997*.Canadian manuscript report of fisheries and aquatic sciences (2451-1). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.579664/publication.html

Transect surveys were conducted to determine the density of the northern abalone, Haliotis kamtschatkana from intertidal to approximate 8m depths, in the Tribal and Simonds, Stryker group of islands of the central coast of British Columbiaa during May, 1997. Most (>96%) adult abalone ( greater than or equal to 70 mm shell length SL) were exposed or emergent (visible on rocks). Mean abalone sizes were generally largest in the -1-3 m depth range and smallest in > 7 m depths. Adult abalone were more abundant 4 m.

Campbell, A., Winther, I., Adkins, B., Brouwer, D., & Miller, D. (1998). *Survey of the Northern abalone, (*Haliotis kamschatkana*), in the central coast of British Columbia, May 1997*.Canadian Stock Assessment Secretariat research document (98/89). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/1998/1998_089-eng.htm

Northern or "Pinto" Abalone, Haliotis kamtschatkana, fisheries in British Columbia (B.C.) have been closed since 1990 due to conservation concerns. Surveys by DFO (Fisheries and Oceans Canada) at indicator sites, during 1979-97, indicated a continued decline of abalone densities on the central coast of B.C. Total abalone density declined 43.75 % between the 1993 and 1997 survey. The percentage of index sites in which no "legal" abalone were found almost doubled to 62.5 % in 1997 from 33.3 % in 1993. Comparison between areas, surveyed during 1997, indicated higher total exposed abalone densities in the south, such as the Simonds Group and near Stryker Island, than for other north areas. The density estimates from this study were similar to those from an independent transect survey conducted by the Heiltsuk First Nations in the Simonds Group and near Stryker Island during May, 1997, after the data were standardized to similar depth ranges. However, abalone densities in these southern areas of the central coast of B.C. were still well below those reported by Breen and Adkins (1982) in a few samples during 1980, and were at density levels similar to those at index sites when the fishery was closed. The mean size of a sample of over 6000 illegally harvested abalone, found in Calamity Bay during 1997, was larger than that found in any of the abalone populations surveyed in this study. This indicated that poachers had selectively harvested mostly large mature abalone, but with no regard for the legal size limit since 16.6 % of the illegally harvest abalone were < 100 mm SL. Illegal harvesting not only further depletes already depressed abalone stocks, but also reduces their reproductive potential, by removal of large mature abalone, and hinders attempts to rehabilitate abalone populations in B.C. through fishery closure.

Canadian Science Advisory Secretariat. (2012). *Science response to information requests submitted to the Enbridge pipeline project environmental impact assessment hearings respecting Northern Abalone*. Science Response (2012/023). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/440423/publication.html

Fisheries and Oceans Canada's (DFO) Environmental Assessment and Major Projects Division (EAMP), Pacific Region, requested that DFO Science, Pacific Region, on May 15, 2012, provide information regarding specific Information Requests (IRs) submitted to the Enbridge Review Panel that DFO Science has the expertise to evaluate. As the IRs for which Science advice was requested cover a range of issues and scientific disciplines, separate Science Responses have been developed for each category of IRs, and in some cases specific IRs. In addition to science related questions, some IRs included elements that were questions pertaining to DFO policy, management or legal information. This Science Response addresses the scientific elements of the following questions: What information does DFO have on the presence of Northern Abalone in the Project area?

Canadian Science Advisory Secretariat. (2016). *Review of Dive Survey Methods for Northern Abalone in British Columbia*. Science Response (2016/044). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40622204.pdf

DFO Species at Risk (SARA) program has requested guidance on the selection and use of appropriate survey methods for Northern Abalone. This information will support First Nations and other stakeholders to ensure surveys are executed consistently and in a manner such that data can be used to reliably assess population densities and monitor species recovery.

Carolsfeld, W., Farlinger, S., Kingzett, B. C., Sloan, N. A., & Thomas, G. (1988). *Abalone resurvey in the Southeast Queen Charlotte Islands, June 1987*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (1966). Prince Rupert, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/17463.pdf

A resurvey of northern abalone (Haliotis kamtschatkana ) abundance was conducted along the east coast of the southern Queen Charlotte Islands from Cumshewa Inlet south to Luxana Bay on Kunghit Island. A team of five biologists and a commercial diver sampled a total of 77 sites, of which 69 were useable for analysis. A comparison with 63 sites sampled in this same area in 1984 revealed no significant changes in relative abundance or population structure since 1984; however, more high density sites and fewer zero sites were observed in 1987 than in 1984. No differences in abalone populations were found between open and closed areas. Abalone populations in Cumshewa Inlet appear to be top-heavy and unsupported by small abalone.

Carson, H. S., & Ulrich, M. (2019). *Status Report for the Pinto Abalone in Washington*.Olympia, WA Retrieved from https://wdfw.wa.gov/publications/02031

The pinto abalone (Haliotis kamtschatkana) is a shallow-water marine mollusk native to the marine waters of Washington State, particularly the San Juan Islands and Strait of Juan de Fuca. It is a grazer, feeding on diatoms and kelp, living on bedrock or boulder reefs. Juveniles are cryptic but emerge as adults around the reproductive size of 40 – 70 mm shell length. Males and females spawn gametes directly into the water in spring and summer; fertilization occurs outside the body. After a relatively short drifting larval phase of 7 – 10 days, abalone settle into appropriate habitat, often bull kelp beds and on rock covered in crustose coralline algae.

Likely harvested for subsistence by early inhabitants of the Pacific Northwest for centuries, the Department authorized the state recreational harvest of abalone in 1959. In 1992, managers grew concerned about observed abundance trends and established ten fixed monitoring sites in the San Juan Islands. Upon a resurvey of those stations in 1994 that showed a decline in abundance, and evidence of significant illegal harvest, managers closed the fishery. The population on these sites continued to decline despite the fishery closure. The most recent survey in 2017 found 12 total abalone remaining from an original tally of 359 in 1992 – a 97% decline. Furthermore, the average size of abalone has increased over time, and juveniles have not been sighted during Department surveys since 2008.

Available evidence suggests that the Washington population is aging and has experienced widespread reproductive failure. Since the animals spawn directly into the water, males and females must be in close proximity for fertilization to occur. Adults maintain a small home range and may not migrate long distances to spawn with other individuals. Therefore, when legal or illegal fishing reduces the density of adults below some fertilization threshold, successful reproduction is reduced and remnant populations are unlikely to recover naturally. In addition to a low density of adults, pinto abalone populations in

Washington face threats from changing ocean conditions, illegal harvest, reduced genetic diversity, disease, contaminants, and native or introduced predators.

A captive breeding and reintroduction partnership was formed between the Department, Puget Sound Restoration Fund, the National Oceanic and Atmospheric Administration, treaty tribes, universities and others. Since 2009 the partnership has outplanted groups of hatchery-origin juveniles onto sites in the San Juan Islands. The growth and survival of these individuals suggests that this restoration strategy is a viable one. However, pinto abalone would have to be produced and outplanted in significantly greater numbers to achieve population-scale recovery.

Due to the dwindling numbers of wild individuals, their apparent lack of natural reproduction, and a number of identified threats, it is recommended that the pinto abalone be listed as endangered in the state of Washington.

Cripps, K., & Campbell, A. (1998). *Survey of abalone populations at Dallain Point and Higgins Pass, central coast of British Columbia, 1995-96*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (2445). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/collections/collection_2007/dfo-mpo/Fs97-4-2445E.pdf

Random transect surveys were conducted to determine the density of the northern abalone, Haliotis kamtschatkana, from intertidal to 8 m depth, near Dallain Point during May, 1995, and Higgins Pass during May, 1996. Most (>97%) abalone greater than 70 mm shell length were exposed or emergent (visible on rocks). Mean densities for all sizes of abalone were similar (0.425 and 0.519 per m super(2)) between sites. Mean abalone sizes and densities were generally largest in the 1-3 m depth range, with fewer abalone found in the intertidal areas and to depths of about 8 m.

Cummins, P., & Haigh, R. (2010). *Ecosystem status and trends report for North Coast and Hecate Strait ecozone*. Canadian Science Advisory Secretariat Research Document (2010/045). Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/341028.pdf

The status and trends of indicators of the condition of biodiversity of the northern coastal waters of British Columbia are reviewed. Among the notable results it is found that upper-ocean waters show warming and freshening trends, dissolved oxygen levels are decreasing, and dissolved CO sub(2) levels are increasing in intermediate waters of the NE Pacific basin. These changes are likely to impact marine ecosystems found along the continental shelf off British Columbia. Organisms may shift their location depending on sea surface temperature SST, moving with the water temperature that suits them best. Marine ecosystems in the North Coast and Hecate Strait ecozone may change, perhaps relatively more rapidly than in the past, due to climate change. Populations of a number of indigenous species to the North Coast are listed as endangered, threatened, or of special concern under the Species at Risk Act, including the northern abalone, (Haliotis kamtschatkana - Threatened), sea otters (Enhydra lutris - Special Concern) and northern resident killer whales (Orcinus orca - Threatened). Stocks of some commercially harvested fish remain depressed, notably the sockeye salmon (Oncorhynchus nerka) of Smith and Rivers Inlet, and certain stocks of Pacific herring (Clupea pallasii). Populations of most marine mammals that had been commercially harvested or purposefully eradicated in the twentieth century, and have since gained protected status, are recovering. Human activities still pose a threat to many of

these animals primarily through over-fishing, contaminants, lost or damaged fishing gear, shipping and decline of prey food items.

Curtis, D. L., & Zhang, Z. (2018). *Northern Abalone,* Haliotis kamtschatkana*, stock status and re-analysis of index site surveys in British Columbia, 2000-2016*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (3162). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40732812.pdf

The legal harvest of Northern Abalone, Haliotis kamtschatkana, was closed in 1990 due to population declines and subsequent conservation concerns. Despite the closure, declines continued, leading to a legal listing of 'Threatened' in 2004 and a relisting as 'Endangered' in 2011 under Schedule 1 of the Species at Risk Act (SARA). Northern Abalone has been monitored at index sites along the East Coast of Haida Gwaii (ECHG) and the Central Coast (CC) Regions of British Columbia by Fisheries and Oceans Canada (DFO) since 1978. In response to conservation concerns, surveys were expanded to include the West Coast of Vancouver Island (WCVI) Region in 2003, the Queen Charlotte Strait (QCS) Region in 2004, and the West Coast of Haida Gwaii (WCHG) Region in 2008. This report presents survey data collected for each of these Regions since either 2000 or the initiation of the survey and includes the results of analysis using a hurdle gamma Bayesian model to examine long-term trends in the population and distribution within each Region. Some of these data have not been previously published: CC (2011, 2016), ECHG (2012), WCHG (2008, 2013), QCS (2014), and WCVI (2008, 2013). The results are presented in the context of the Population and Distribution Objectives from the Northern Abalone Action Plan.

Davies, K., Atkins, M., Lessard, J., & Canada, O. (2006). *Survey of Northern Abalone,* Haliotis kamtschatkana*, Populations in Queen Charlotte and Johnstone Straits, British Columbia, May 2004*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (2743). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/325737.pdf

A survey was conducted during May 17-20, 2004, in Queen Charlotte and Johnstone Straits to estimate the distribution and density of emergent northern abalone (Haliotis kamtschatkana). The estimated mean density for emergent abalone of all sizes was 0.064 ± 0.022 abalone/m in Queen Charlotte Strait and 0.017 ± 0.014 abalone/m in Johnstone Strait. The mean shell length for both areas combined was 85.7 mm. This study was compared to two earlier surveys conducted in 1977 and 1986 in the same area, as well as recent surveys on other parts of the coast.

Defreitas, B. (2003). Estimating juvenile northern abalone (*Haliotis kamtschatkana*) abundance using artificial habitats. *Journal of Shellfish Research,* 22(3), 819-823. Retrieved from https://www.biodiversitylibrary.org/page/3105033

This study assesses the use of artificial concrete block habitats that provide standardized sample areas for measuring the abundance of northern abalone (Haliotis kamtschatkana Jonas) in comparison to 10 randomly selected 1-m(2) quadrant samples where all movable rocks were examined for cryptic

abalone. A total of 278 abalone were measured within artificial structures and juvenile abalone (less than or equal to50 mm shell length, SL) were the most abundant size class. Juvenile abalone used artificial structures at greater mean densities (abalone/m(2)) than nearby natural habitat (1.27 +/- 0.25 SE versus 0.07 +/- 0.09 SE) and emergent abalone (>50 mm SL) used artificial habitats at similar densities as they did in nearby natural habitats (0.38 +/- 0.09 SE versus 0.44 +/- 0.10 SE). Juvenile abalone abundance was significantly different between sites but not within sites, suggesting artificial structures showed promise in their ability to detect area specific differences in recruitment and to easily measure juvenile abalone abundance.

Donnellan, M., & Hebert, K. (2017). *Pinto Abalone (*Haliotis kamtschatkana *Jonas 1845) Surveys in Southern Southeast Alaska, 2016*. Fishery Data Series (No. 17-40). Anchorage, AK Retrieved from https://media.fisheries.noaa.gov/dam-migration/adfg-finalrpt-fds17-40-pinto-abalone-surveys-se-alaska2016.pdf

Pinto abalone (Haliotis kamtschatkana) is listed as a species of concern under the U.S. Endangered Species Act (ESA), and is listed as endangered by Canada and the International Union for Conservation of Nature. The status of pinto abalone in Southeast Alaska, the northernmost portion of its range, is largely unknown. Based on recommendations from a recent ESA status review, we conducted this study to fill basic knowledge gaps on population status in two areas of former abalone abundance in Southeast Alaska, one with and one without sea otters, and to establish long-term monitoring index sites for tracking population status over time. During four days in July 2016, we collected data at 15 sites (1 historical, 14 new) along Gravina Island and 10 sites (all historical) in Meares Pass. Timed swims and transects were used to obtain relative and absolute density data, as well as length measurements. Length frequency distributions were statistically different between methods (Gravina only) and between areas, indicating sampling bias and possible effects of sea otter predation, respectively. Average abalone absolute densities (± SE) at Gravina Island and Meares Pass were 0.29/m2 (0.08) and 0.17/m2 (0.03), respectively. Area- and site-specific densities were near or below the threshold for population collapse and recruitment failure reported in the literature (0.2/m2 ). Timed swim data from Meares Pass were compared to historical surveys from 1980–1981, and corresponded to a steep decline shown by commercial fishery catch data. There was no relationship between site-specific relative and absolute density, so the interpretation of relative density was unclear. The length frequency distribution was much smaller in 2016 than in the 1980s, but sampling bias could not be ruled out. Overall, there was cause for concern, but length frequency data showing recent and regular recruitment to the populations in both study areas was encouraging.

Donnellan, M., Hebert, K., O'Connell, V., White, T., & Bell, L. E. (2015). *Pinto Abalone (*Haliotis kamtschatkan*a Jonas 1845) Research and Monitoring Plan for Sitka Sound, Southeast Alaska, 2015–17.* Alaska Sea Grant, Retrieved from http://www.sitkascience.org/alpha/wp-content/uploads/2017/04/SitkaSoundAbaloneMonitoringPlan_2015_Final.pdf

The question of whether abalone populations could sustain ongoing subsistence and personal use fisheries was the primary impetus for this study. Additionally, the potential listing of pinto abalone as “Threatened” or “Endangered” under the Endangered Species Act has rekindled interest in assessing the status of the species in Alaska. Limited staffing and financial resources require that this study is small in

spatial and temporal scope, so the emphasis will be on quantifying key population characteristics of abalone within a small geographic area where aggregations are known to persist, and then monitoring several aggregations over time at fixed sites to assess temporal variability. Specifically, our study goals are to: 1) collect basic information about typical aggregation sizes and density within patches/localized sites, 2) determine the extent to which adult abalone aggregations exist at densities and between-neighbor distances sufficient to successfully spawn, 3) quantify how these densities and between-neighbor distances vary over a range of times scales from bi-weekly to annually, 4) examine population size structure and determine if there is evidence for successful recent reproduction, and 5) determine how key characteristics of the abalone population in Sitka Sound compare to those in British Columbia and Washington, where they are better-studied and have long histories of monitoring. We considered several other additional questions (Appendix A), but determined that the questions listed above warranted the highest priority, given limited resources. Notably, this study will be the first to formally collect data for absolute density and aggregation characteristics of abalone in Alaska. Our intent is that the results of this study will inform management about whether further action may be warranted (e.g., changing bag limits and/or size limits, initiating restoration planning, creating a management plan), as well as serve as a pilot project for scaling up to the larger geographic region.

Egli, T. P., Lessard, J., & Canada, O. (2011). *Survey of Northern Abalone,* Haliotis kamtschatkana*, Population in the Strait of Georgia, British Columbia, October 2009*. Canadian manuscript report of fisheries and aquatic sciences (2955). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.573569/publication.html

Index site surveys have been conducted by the Department of Fisheries and Oceans Canada to monitor northern abalone, Haliotis kamtschatkana, populations in British Columbia since 1978. Due to low population levels and steadily decreasing densities, the coast of British Columbia has been completely closed to abalone harvesting since 1990. First listed as 'threatened' in 1999 by the Committee on the Status of Endangered Wildlife in Canada, the status of northern abalone was up-listed to 'endangered' in 2009, furthering the need for conservation planning. The northern Strait of Georgia has never been extensively surveyed for abalone and this study will be used as reference for future surveys in the area. A total of six northern abalone were found at four (13.3%) of the 30 sites surveyed. Overall density for the area was estimated to be 0.013 ± 0.007 abalone/m, which is below what is generally regarded as densities required for successful fertilization. The low numbers found in this survey may indicate poor abalone habitat and low levels of recruitment, along with poaching in accessible areas.

Farlinger, S., & Bates, K. T. (1986). *Abalone survey in the Estevan Group and Aristazabal Island, June 1985*. Canadian manuscript report of fisheries and aquatic sciences (1896). Prince Rupert, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/103967.pdf

Reductions in the commercial abalone Haliotis kamtschatkana fishery quota in recent years have been supported by surveys indicating substantial declines in the index of abalone abundance. In 1985, the Central Coast commercial fishing areas were resurveyed in response to to reports of increasing availability of abalone. In 12 out of 25 comparative sites, an increase in density of legal size abalone was observed relative to the 1983 survey. Mean total density increased from 1.43 abalone per square meter

in 1983 to 1.57 abalone per square meter in 1985. A non-significant increase in abalone density was observed in a comparison of new recruits and pre-recruits. The abalone population in the surveyed area does not appear to have decreased since 1983.

Farlinger, S., Thomas, G. A., Winther, I., & Carolsfeld, W. (1991). *Abalone resurvey in the Estevan Group and Aristazabal Island, June 1989*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (2104). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-4-2104-eng.pdf

Abalone (Haliotis kamtschatkana) populations were resurveyed in 25 sites in area 6 of the Central Coast. The 16 quadrat method of previous surveys was sued. Results were compared to those obtained in 1979/80, 1983 and 1985. Number of abalone, legal abalone, recruit abalone and pre-recruit abalone per square meter were less than in previous surveys. There had been no apparent decline between 1983 and 1985, although 1983 results were 50% less than earlier surveys. The survey may not be adequate to measure the change in abundance; the design and methodology should be reviewed. The apparent decline may be local; port sampling and the 1990 survey in the Queen Charlotte Islands will provide more information. (DBO).

Hankewich, S., & Lessard, J. (2008). *Resurvey of northern abalone,* Haliotis kamtschatkana*, populations along the central coast of British Columbia, May 2006*.Canadian manuscript report of fisheries and aquatic sciences (2838). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.565407/publication.html

To monitor the status of abalone populations the Department of Fisheries and Oceans Canada has conducted periodic surveys of index sites along the coast of British Columbia (BC) since 1978. The index sites along the central coast of BC were resurveyed in 2006. Four hundred and thirty three abalone were measured at 52 (76.5%) of the 68 index sites surveyed in 2006. The mean shell length (SL) of abalone on the central coast in 2006 was 69.4 rnm, significantly smaller than the previous mean SL in the 2001 survey (77.6 mm). The overall density was 0.40 c 0.06 (SE) abalone/m super(2), a slight increase over the 2001 estimate of 0.27 c 0.04 abalone/m super(2). Immature (<70 mm SL) and mature ( greater than or equal to 70 mm SL) abalone densities also slightly increased when compared to those estimated in 2001. Conversely, the density of large adult abalone (. 100 mm SL) decreased by 50% between 2001 and 2006, to the current estimate of 0.02 c 0.01 abalone/m super(2). Large abalone were found at only 17.6% of the sites surveyed. Despite slightly higher density estimates in 2006, there is no statistical evidence of abalone populations rebuilding in the central coast of BC since the fishery closure.

Hankewich, S., Lessard, J., & Grebeldinger, E. (2008). *Resurvey of northern abalone,* Haliotis kamtschatkana*, populations in Southeast Queen Charlotte Islands, British Columbia, May 2007*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (2839). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/334663.pdf

In order to monitor northern abalone populations and evaluate recovery efforts, surveys of index sites have continued. This report presents the results of the survey in the southeast Queen Charlotte Islands in May 2007 and compares abalone size frequency and density estimates with those measured in previous surveys.

Hansen, S. C., Obradovich, S. G., Rooper, C. N., Waddell, B. J., Nichol, L., MacNeill, S., & Barton, L. L. (2020). *Identifying variables for standardization of the Northern Abalone* (Haliotis kamtschatkana*) Index Site Surveys time series (1978-2018) based on survey methodology and environmental variability*.Canadian Technical Report of Fisheries and Aquatic Sciences (3330). Naniamo, BC: Fisheries and Oceans Canada, Retrieved from https://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2020/20-05/publications.gc.ca/collections/collection_2020/mpo-dfo/Fs97-6-3330-eng.pdf

The Northern Abalone (Haliotis kamtschatkana) is a culturally and ecologically significant endangered marine snail. This report examines forty years of data from the Northern Abalone Index Site Surveys in British Columbia. Northern Abalone densities were generally insensitive to changes in the number of surveyed index sites and quadrats. There was high imprecision around the mean estimates in both the full and restricted datasets. Inclusion of environmental variables identified with generalized additive modelling in a standardized index yielded small improvements in precision of the annual indices. Trend detection using the existing survey data is limited by the large confidence intervals around the mean densities. Recommendations are to include the full dataset in further analyses, to use a subset of environmental variables to standardize the time series, and to increase the number of index sites surveyed in future Northern Abalone surveys.

Hester, J. B., Walker, J. M., Dinnel, P. A., & Schwarck, N. T. (2011). *Survey of Previously Outplanted Pinto (Northern) Abalone (Haliotis kamtschatkana) in the San Juan Island Archipelago, Washington State.* Paper presented at the American Academy of Underwater Sciences 30th Scientific Symposium Portland, ME. Retrieved from https://d1wqtxts1xzle7.cloudfront.net/53089293/Discoveries_of_new_marine_species_of_the20170511-3632-1a4dj1q-with-cover-page-v2.pdf?Expires=1637099458&Signature=IpZc23gxdeyh7yZdqknWUJ0i3ORm33Wgj8Nsp8ejI6Mx2bcMoOQ5RbbuQOVhYh93CFTpBoAbJg4BLMh-EGiM2cvVUSd45cpUAwWn2j~-5uY-JJtPmx-W9HI3gk-0RsQjC3JQfHzIbEuKMsT76nPLu14jjHLg0B1Djp5j7r-8xpjMvTb8VuC1kXJ88EiAuAdCzwB2kU~Xqp9Dt7y3nBJ~6bnTdF~clFNnYF0OhPcSZ7xD3Hgzz2VtXnqOFcT7XxHb5HPAfk5iiO8XXWwLbPRWc7Hd73BYUejyhEWv1f6hpyaYYvgatB~iyUCOuc9PTUg5NaX8Me6FFjNQ57ol3tfsbQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA#page=27

In 1992, the Washington Department of Fish and Wildlife (WDFW) began monitoring the pinto abalone (Haliotis kamtschatkana) populations at 10 index sites in the San Juan Island Archipelago in Northern Washington State. As of 2009, there has been an 83% decrease in the population since the beginning of the WDFW index site monitoring. It has recently been determined that this species will not likely recover without human intervention; so, in 2009, restoration efforts began by outplanting juvenile abalone to four different test sites. In March 2011, two new outplant sites were added. In July and August 2011, surveys of the six outplant sites were completed based on techniques used by WDFW to collect annual

data on survival and growth rates. One site was repeatedly surveyed a total of four times at weekly intervals to compare data obtained from the repeated surveys. The Schnabel method was used to obtain a population estimate of 121 abalone out of the 350 tagged abalone known to have been outplanted in March 2011 at this site. Perimeter surveys were performed at two of the sites to determine if any abalone emigration was evident. The perimeter surveys found a total of three abalone, supporting the hypothesis that there has been little emigration from the test plots.

Jamieson, G. (1999). *Review of Status of Northern, or Pinto, Abalone,* Haliotis kamtschatkana*, in Canada*.Canadian Stock Assessment Secretariat Research Document (99/190). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/243092.pdf

Jamieson (1989) reviewed the status of northern, or pinto, abalone (Haliotis kamtschatkana) in British Columbia, Canada, but while the paper was accepted and reviewed by COSEWIC in April, 1988, no status could be assigned, as at that time COSEWIC had no mandate for invertebrates. COSEWIC's mandate changed in 1994, however, and COSEWIC is now able to assign status to molluscs. Here, I update the review of the status of this species in relation to recognised threats which might lead to this species' extirpation in Canada. Threats are identifiable, but the risks of population extinction associated with them are impossible to quantify. For example, natural northern abalone population size and size frequency structure equilibria are unknown (recent prefishery levels may have been high because of earlier abalone predator (sea otter) extirpation); unquantifiable but possibly substantial continued illegal northern abalone harvest in British Columbia, even though all northern abalone fisheries have been closed since 1990; and an unknown overall spatial abundance distribution, with time-series abundance data only available from a limited number (53) of index sites. Nevertheless, available data indicate continued declining abundance following fishery closure, and as sea otters slowly expand their range, natural mortality rate of northern abalone in areas where sea otters do not now occur will increase. Biological data suggests that the absolute abundance of adult abalone in close proximity to each other affects spawning success (external gamete fertilisation), and that larval dispersal range from concentrations of abalone may be quite limited. Individual concentrations of abalone may thus be largely self-sustaining, and potentially vulnerable to local extirpation over time if they experience a sustained high adult mortality. Monitoring of index sites, where abalone previously occurred, shows an increased frequency of sites which have no abalone now.

Jamieson, G. S. (1989). Status of the northern abalone, *Haliotis kamtschatkana*, in Canada. *The Canadian Field-Naturalist,* 103(2), 153-158. Retrieved from https://www.biodiversitylibrary.org/page/34347981

The Northern Abalone (Haliotis kamtschatkana) is the only abalone species in Canada and is widely distributed along the outer coast of British Columbia. It forms the basis for a small commercial fishery (47.2 t in 1986) and is harvested in the recreational fishery. Its distribution in commercial concentrations is patchy, and because of its cryptic behaviour on rocky bottoms, no total biomass estimates are available. Instead, stock status is  monitered through regularly sampling sites, which have in the past supported abalone concentrations, in order to establish population recruitment trends. There is currently insufficient data to indicate the pattern of fluctuations in abundance over the long term, but it

appears that the relatively high abundance of larger, older abalone, which was present prior to commercial fishery expansion in 1976, is unlikely to be re-established. Exploitation by the fishery, coupled with an anticipated increase in the distribution of Sea Otters (Enhydra lutris), a natural abalone predator in British Columbia, is expected to maintain future abalone population size at a moderate level.

Jamieson, G. S. (2001). Review of the status of the Northern Abalone, *Haliotis kamtschatkana*, in Canada. *The Canadian Field-Naturalist,* 115(4), 555-563. Retrieved from https://www.biodiversitylibrary.org/page/35014722

The Northern Abalone (Haliotis kamtschatkana) is the only abalone species in Canada and is widely distributed along the entire outer coast of British Columbia. In the late 1970s and 1980, there was a commercial fishery, but following a peak in landings in 1978-1979, landings rapidly declined. Its distribution in commercially exploitable concentrations is patchy, making stock assessments difficult to conduct. However, in the late 1980s, consistently low estimated abundance levels and increasing evidence for a substantial illegal harvest of abalone raised conservation concerns, resulting in aboriginal, recreational and commercial fisheries closures in 1990. Studies in other abalone species suggest that abalone larvae disperse over relatively short distances. If true for Northern Abalone as well, then this species may be particularly vulnerable to localised extirpations. Through the 1990s, there was no evidence of significant Northern Abalone recruitment along Canada's Pacific coast, and because of a high price, abalone poaching is still occurring. Expansion in the range of Sea Otters (Enhydra lutris), a major abalone predator, is also increasing natural mortality. Given these circumstances, a COSEWIC status of "threatened" was recommended.

Larson, R., & Blankenbeckler, D. (1980). *Abalone Research*. Alaska Department of Fish and Game, Ketchikan, AK. Retrieved from https://www.worldcat.org/title/abalone-research/oclc/886943449&referer=brief_results

A study of the size and growth of abalones in Southeast Alaska.

Lessard, J., Atkins, M., & Campbell, A. (2007). *Resurvey of Northern Abalone,* Haliotis kamtschatkana*, populations Along the Coast of British Columbia, April 2001*.Canadian manuscript report of fisheries and aquatic sciences (2791). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/328441.pdf

As a result of over-exploitation, the legal harvest of northern abalone, Haliotis kamtschatkana, was closed in 1990. Since 1978, the Department of Fisheries and Oceans Canada has conducted periodic surveys of index sites along the coast of British Columbia (BC) to monitor the status of abalone populations. In 2001, the index sites along the central coast of BC were resurveyed. Two hundred and thirty abalone were measured at 40 (72.7%) of the 55 historic index sites surveyed. The overall density was 0.27 abalone/m super(2); the lowest density observed in the nine surveys of this area since1978. Densities of mature ( similar to .70mm shell length) abalone were also at their lowest levels. Abalone similar to .100 mm shell length were observed at only 25% of sites surveyed. Statistical comparisons

were made for size and density across years. There was no evidence of abalone population recovery along the central coast. Poaching continues to be the main concern preventing the recovery of abalone populations in British Columbia.

Lessard, J., & Egli, T. P. (2011). *Survey of northern abalone,* Haliotis kamtschatkana*, population in Queen Charlotte Strait, British Columbia, May 2009*.Canadian manuscript report of fisheries and aquatic sciences (2959). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/404323/publication.html

In May 2009, selected sites in Queen Charlotte Strait were surveyed to examine changes in wild northern abalone, Haliotis kamtschatkana, population. Approximately half the sites had been previously surveyed in May 2004. A total of 54 abalone were found at 14 of the 34 (41%) sites surveyed. Mean shell length (SL) was 78.7[+ or -]2.6 mm and 18.5% of the individuals were large adult size (&gt=100 mm SL). The mean size did not change significantly since the last survey. The overall density of abalone was 0.109 + or - 0.033 abalone/m super(2). Densities of immature (&lt70 mm SL), mature (&gt=70mm SL), and large adult (&gt=100 mm SL) size classes were estimated as 0.038 + or - 0.014 abalone/m super(2), 0.072 + or - 0.025 abalone/m super(2), and 0.021 + or - 0.009 abalone/m super(2), respectively. While all estimated densities were higher than those found at the same sites in 2004, only the difference in large adults was statistically significant. The density estimates were still low compared to pre-fishery closure levels and suggest continued pressure on the abalone populations. Poaching, increased predation pressure from sea otters, along with low recruitment success are likely causes for the slow recovery of this species which is now listed as endangered by the Committee on the Status of Endangered Wildlife in Canada.

Livingstone, R., Carlson, C. J., & Dassow, J. A. (1952). Preliminary investigation of the southeastern Alaska abalone (*Haliotis kamtschatkana*). *Commerical Fisheries Review,* 14(9), 8-18. Retrieved from https://www.biodiversitylibrary.org/page/31936494

For many years residents of southeastern Alaska have gathered sufficient abalone from the rocky shores of Prince of Wales and Baranof Islands for home consumption. In 1947, Dr. G. Dallas Hanna of the California Academy of Sciences, while making a species study, reported incidentally that abalone occur in considerable numbers along the shores of the outer islands. Fairly extensive beds of abalone are also found in northern British Columbia along the rocky shores bordering the open ocean on the west coast of the Queen Charlotte Islands (Quayle 1940). All evidence at hand suggested that abalone were available along the west coast of Prince of Wales and Baranof Islands and that this region held promise for exploration. These reports, however, did not furnish sufficient information to establish definitely whether a commercial fishery is actually possible. In view of the need for off-season fisheries in southeastern Alaska, a survey was made by the U.S. Fish and Wildlife Service to determine if abalone existed in commercial quantities.

For the explorations, a professional Alaska salmon-trap diver was employed, together with his 38-foot boat. The diving was carried on from September 15 to October 10, 1951. The work was confined to the waters of the west coast of Prince of Wales Island and the vicinity of Craig, Alaska.

Lucas, B. G., Brouwer, D., & Campbell, A. (2000). *Survey of Northern Abalone,* Haliotis kamtschatkana, *populations at Malcolm Island and Cormorant Island, British Columbia, October 1999 [Revised]*.Canadian manuscript report of fisheries and aquatic sciences (2620). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/315288/publication.html?wbdisable=true

A population census was conducted to provide an estimate of population numbers of mature emergent abalone (Haliotis kamtschatkana) in areas near Malcolm Island, British Columbia during October 5-7, 1999. The abalone encountered in these areas were generally large and most were dispersed, even though the habitat was extensive and appeared ideal for abalone. The estimated mean density for abalone of all sizes was 0.05/m super(2) at Cormorant Island, 0.04/m super(2) at Bere Bay, and 0.03/m super(2) at Trinity Bay. The estimated mean total population number (and 90% confidence interval) for all sizes at Cormorant Island was 3636 (2608-4620), at Bere Bay was 5034 (3522-6640), and at Trinity Bay was 4089 (3027-5048) emergent abalone. The mean total population number (and 90% confidence interval) in the 120-140 mm SL size range was estimated for Cormorant Island to be 909 (674-1212), for Bere Bay to be 4075 (2654-5412), and for Trinity Bay to be 2516 (2121-2979) emergent abalone. The low densities indicate that the removal of any abalone from these areas must be considered with caution.

Lucas, B. G., Brouwer, D., & Campbell, A. (2001). *Survey of northern abalone,* Haliotis kamtschatkana*, populations near Kitkatla, British Columbia, March 2000*.Canadian manuscript report of fisheries and aquatic sciences (2572). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/466427/publication.html

A survey was conducted, during March 14 to 21, 2000, to provide an estimate of population numbers of mature emergent northern abalone (Haliotis kamtschatkana) in areas near Kitkatla, British Columbia. Abalone shell lengths (SL) ranged from 27 to 146 mm. The estimated mean density for abalone of all sizes was 0.16/m super(2) at McCauley Island and 0.05m super(2) at Goschen Island. The estimated mean density for abalone 90 - 110 mm SL was 0.05m super(2) at McCauley Island and 0.01/m super(2) at Goschen Island. The estimated mean total population number (and 90% confidence interval) of emergent abalone for all sizes at McCauley Island was 34, 406 (31,595 -37,216) and at Goschen Island was 20,750 (18,114 -23,386). The mean total population number (and 90% confidence interval) of emergent abalone in the 90 - 110 mm SL size range was estimated for McCauley Island to be 11,326 (10,363 - 12,289) and for Goschen Island to be 4,000 (3,490 - 4,510).

Lucas, B. G., Brouwer, D., & Campbell, A. (2002). *Survey of northern abalone,* Haliotis kamtschatkana*, populations at Malcolm Island and Cormorant Island, British Columbia, October 1999 [Revised]*.Canadian manuscript report of fisheries and aquatic sciences (2620). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/315288/publication.html?wbdisable=true

A population census was conducted to provide an estimate of population numbers of mature emergent abalone (Haliotis kamtschatkana) in areas near Malcolm Island, British Columbia during October 5-7, 1999. The abalone encountered in these surveys were generally large and most were dispersed, even though the habitat was extensive and appeared ideal for abalone. The estimated mean density for

abalone of all sizes was 0.05/m super(2) at Cormorant Island, 0.04/m super(2) at Bere Bay, and 0.03/m super(2) at Trinity Bay. The estimated mean total population number for all sizes at Cormorant Island was 3614, at Bere Bay was 5081, and at Trinity Bay was 4038 emergent abalone. The mean total population number in the 120 - 140 mm SL size range was estimated for Cormorant Island to be 943, for Bere Bay to be 4033, and for Trinity Bay to be 2550 emergent abalone. The low densities indicate that the removal of any abalone from these areas must be considered with caution.

Lucas, B. G., Brouwer, D., & Campbell, A. (2002). *Survey of northern abalone,* Haliotis kamtschatkana*, populations near Kitkatla, British Columbia, March 2000 [Revised]*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (2622). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/269786.pdf

A survey was conducted, during March 14 to 21, 2000, to provide an estimate of population numbers of mature emergent northern abalone (Haliotis kamtschatkana) in areas near Kitkatla, British Columbia. Abalone shell lengths (SL) ranged from 27 to 146 mm. The estimated mean density for abalone of all sizes was 0.16/m super(2) at McCauley Island and 0.05/m super(2) at Goschen. The estimated mean density for abalone 90 - 110 mm SL was 0.05/m super(2) at McCauley Island and 0.01/m super(2) at Goschen Island. The estimated mean total population number of emergent abalone for all sizes at McCauley Island was 34,405 and at Goschen Island was 20,750. The mean total population number of emergent abalone in the 90 - 110 m SL size range was estimated for McCauley Island to be 11,326 and for Goschen Island to be 4,000.

Lucas, B. G., Campbell, A., & Brouwer, D. (2000). *Survey of northern abalone,* Haliotis kamtschatkana*, populations in Lotbiniere Bay, British Columbia, March 2000*.Canadian manuscript report of fisheries and aquatic sciences (2545). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/466131/publication.html

A survey was conducted, during March 23-27, 2000, to provide an estimate of population numbers of mature emergent northern abalone (Haliotis kamtschatkana) in Lotbiniere Bay, British Columbia, an area where abalone were historically abundant. Abalone shell lengths (SL) ranged from 19 to 130 mm. The estimated mean density for abalone of all sizes was 0.29/m super(2). The estimated mean density for abalone 90 - 110 mm SL was 0.08/m super(2). The estimated mean total population number of emergent abalone for all sizes was 1,786,000. The mean total population number of emergent abalone in the 90 - 110 mm SL size range was estimated for Lotbiniere Bay to be 477,000.

Lucas, B. G., Campbell, A., & Brouwer, D. (2002). *Survey of northern abalone,* Haliotis kamtschatkana*, populations at Chrome Island and southern Denman Island, May - June 2000 and May 2001*.Canadian manuscript report of fisheries and aquatic sciences (2624). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.562447/publication.html

A survey was conducted to provide an estimate of population numbers of emergent northern abalone (Haliotis kamtschatkana) in areas known to have abalone present at Chrome Island and southern Denman Island, British Columbia, during May 30 to June 2, 2000 and on May 29, 2001. Abalone shell lengths (SL) ranged from 26 to 137 mm SL. The estimated mean density for abalone of all sizes was 0.06 /m super(2), and for abalone 90 - 110 mm SL was 0.02/m super(2). The estimated mean total population number of emergent abalone for all sizes was 14,734, and for 90 - 110 mm SL abalone was 4,820. The highest density for all sizes of abalone in a transect was 0.23 /m super(2), and for abalone 90 - 110 mm SL was 0.10/m super(2).

Lucas, B. G., Campbell, A., Brouwer, D., Servant, S., & Webb, N. (2001). *Survey of northern abalone,* Haliotis kamtschatkana*, populations in southeast Barkley Sound, British Columbia, July 2000*.Canadian manuscript report of fisheries and aquatic sciences (2571). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/466423/publication.html

A survey was conducted to provide an estimate of population numbers of emergent northern abalone (Haliotis kamtschatkana) in areas known to have abalone present in southeast Barkley Sound, British Columbia, during July 5 to 7, 2000. Abalone shell lengths (SL) ranged from 38 to 119 mm. The estimated mean density for abalone of all sizes in all areas combined was 0.10/m super(2), while the estimated mean density for abalone 90-110 mm SL in all areas was 0.04/m super(2). The estimated mean total population number (and 90% confidence interval) of emergent abalone for all sizes in all areas combined was 28,485 (25,997 - 30,973). The mean total population number (and 90% confidence interval) of emergent abalone for all areas combined in the 90-110 mm SL size range was estimated to be 12,558 (11,275 -13,842). The highest concentration of abalone was found on the east side of Edward King Island, where the mean density for all sizes was 0.23/m super(2) and for abalone 90-110 mm SL was 0.11/m super(2). The estimated mean total population number (and 90% confidence interval) of emergent abalone for all sizes on the east side of Edward King Island was 20,624 (18,170 -23,078), and for the 90-110 mm SL size range was 10,179 (8,206 - 12,153).

Lucas, B. G., Campbell, A., Brouwer, D., Servant, S., & Webb, N. (2002). *Survey of northern abalone,* Haliotis kamtschatkana*, populations in southeast Barkley Sound, British Columbia, July 2000 [Revised]*.Canadian manuscript report of fisheries and aquatic sciences (2623). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/269788.pdf

A survey was conducted to provide an estimate of population numbers of emergent northern abalone (Haliotis kamtschatkana) in areas known to have abalone present in southeast Barkley Sound, British Columbia, during July 5 to 7, 2000. Abalone shell lengths (SL) ranged from 38 to 119 mm. The estimated mean density for abalone of all sizes in all areas combined was 0.10/m super(2), while the estimated mean density for abalone 90 - 110 mm SL in all areas was 0.04/m super(2). The estimated mean total population number of emergent abalone for all sizes in all areas combined was 28,485. The mean total population number of emergent abalone for all areas combined in the 90 - 110 mm SL size range was estimated to be 12,558. The highest concentration of abalone was found on the east side of Edward King Island, where the mean density for all sizes was 0.23 /m super(2) and for abalone 90 - 110 mm SL was

0.11/m super(2). The estimated mean total population number of emergent abalone for all sizes on the east side of Edward King Island was 20,624, and for the 90 - 110 mm SL size range was 10,179.

Lucas, B. G., Campbell, A., & Cripps, K. (1999). *Resurvey of abalone populations at Tribal Group, Simonds Group and Stryker Island, central coast of British Columbia, 1998*.Canadian manuscript report of fisheries and aquatic sciences (2487). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.579740/publication.html?wbdisable=true

Transect surveys were conducted to determine population size structure and density for northern abalone, Haliotis kamtschatkana, in the Tribal, Simonds and Stryker Island Groups on the central coast of British Columbia during May and June, 1998. Size frequencies and mean shell length (SL) of abalone decreased with depth in all areas. Adult abalone( greater than or equal to 70 mm SL) were more abundant in <5 m depths, whereas small juveniles (<50 mm SL) were found at all depths, but less frequently at intertidal depths. Exposed abalone densities ranged from 0 - 3.58 per m super(2), with a mean for all areas of 0.42 per m super(2). Mean densities were greater for all size groups in the Tribal Group than at Stryker Island, and were greater than all size groups except legal ( greater than or equal to 100 mm SL) in the Simonds Group. Comparisons between 1997 and 1998 surveys for all three areas combined indicated that, although mean densities were generally lower in 1998, the differences between the two years were not statistically significant. Persistent low densities of exposed abalone warrant continued concern for the conservation of H. kamtschatkana in this area of the central coast of British Columbia.

Miller, D. C. (1974). *Abalone and sea urchin survey 1974: federal-provincial cost-shared project*. Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40589900.pdf

The abalone, Haliotis kamtschatkana, is found on both the lower east and lower west coasts of Vancouver Island and lives exclusively on a rock bottom. The red urchin, Strongylocentrotus franciscanus, is the largest and most abundant species of sea urchin on the British Columbia coast. This present survey, a federal-provincial cost-sharing project, was initiated to evaluate the commercial potential of abalones and sea urchins on the lower east and west coast of Vancouver Island. The survey hoped to obtain indications whether fisheries on a sustained yield basis are possible and whether depletion of either abalone or sea urchins will have a lasting and irreversible effect on the sublittoral ecosystem. Abalone and red urchin stocks seem to inhabit similar sites but not to reciprocal expense. Harvesting one species does not seem to markedly enhance the other.

National Marine Fisheries Service. (2014). *Status Review Report for Pinto Abalone (*Haliotis kamtschatkana*)*. Retrieved from https://repository.library.noaa.gov/view/noaa/17309

The pinto abalone (Haliotis kamtschatkana Jonas 1845) is a relatively large prosobranch gastropod mollusk ranging from approximately Salisbury Sound (north of Sitka), Alaska, to Bahia Tortugas, Baja California, Mexico and occurring in intertidal and subtidal habitats from 0- 40m depth. The quality and quantity of abundance information derived from both fisherydependent and independent sources vary

by geographic area. The best available data indicate that pinto abalone abundance has declined in many areas throughout the species' range due to fisheries harvest. Subsistence and personal use fisheries in Alaska and a commercial fishery in Mexico persist. Preliminary data from surveys in 2011 and 2012 indicate signs of recovery in pinto abalone populations along the British Columbia coast, most likely due to a reduction in illegal harvest.

Neuman, M. J., Wang, S., Busch, S., Friedman, C., Gruenthal, K., Gustafson, R., . . . Wright, S. (2018). A status review of pinto abalone (*Haliotis kamtschatkana*) along the west coast of North America: interpreting trends, addressing uncertainty, and assessing risk for a wide-ranging marine invertebrate. *Journal of Shellfish Research,* 37, 869-910. https://doi.org/10.2983/035.037.0415

Pinto abalone (Haliotis kamtschatkana), the widest ranging abalone species in North America, occurs from Alaska, United States to Central Baja California,Mexico. The species has been observed in intertidal and subtidal habitats from 0 to 40mdepth. The best available data indicate that pinto abalone abundance has declined in many areas throughout the species range due to fisheries harvest. Subsistence and personal use fisheries in Alaska and a commercial fishery in Mexico persist. Preliminary data from 2008 to 2016 indicate signs of recovery for some pinto abalone populations along the British Columbia coast due to multiple contributing factors including a reduction in illegal harvest, natural recovery following fishery closure, and low predation pressure. By contrast, pinto abalone populations at the San Juan Islands in Washington are experiencing recruitment failure and continuing to decline, despite closure of the fisheries and no evidence of poaching. Throughout the remainder of the species range, trends are less clear, due to the lack of regular, long-term monitoring surveys for pinto abalone. The limited data from surveys and/or opportunistic sightings indicate that pinto abalone populations are small, patchily distributed, and/or fluctuate episodically in Alaska, California, and Mexico, with evidence of recent recruitment in a number of locations within these three areas. Baseline abundance and trend data for the species before the advent of commercial fisheries and, in some areas, the local extirpation of sea otters is lacking. Without a clear baseline with which to compare the current abundance levels and trend information, it is difficult to interpret what these levels mean for the status and viability of the species. Threats to pinto abalone were evaluated and characterized using a qualitative rating (i.e., low, moderate, high, very high) based on the threats scope, severity, and persistence and the sufficiency of the data to support the rating. Several threats that posed a moderate level of risk to pinto abalone were identified including the following: low densities as a result of historical overfishing; the potential threat posed by ocean acidification; and illegal take because of poaching and inadequate law enforcement. The overall risk that pinto abalone face throughout their range was evaluated, and it was determined that they have a low to moderate level of extinction risk now and in the foreseeable future (over both the 30-y and 100-y time horizons). There is a high level of uncertainty regarding demographic factors, in particular regarding whether abundance and productivity levels are sufficient to support the persistence and recovery of the species in the face of continuing and potential future threats. Although recruitment failure may be occurring in some areas (e.g., San Juan Islands Archipelago), in other areas throughout the range recurring and/or recent recruitment events have been observed, despite low densities, and have even resulted in increased densities (across all size classes) at several index sites in British Columbia. Limitations in using demographic data to guide conservation actions and help ensure species persistence could be overcome by conducting consistent monitoring of pinto abalone populations throughout their range.

Rogers-Bennett, L., Haaker, P. L., Huff, T. O., & Dayton, P. K. (2002). Estimating baseline abundances of abalone in California for restoration. *California Cooperative Oceanic Fisheries Investigations Reports,* 43, 97-111. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=123709

Abalone populations in California have declined dramatically; however, reliable estimates of baseline abundances are lacking. The lack of sufficient time scales seriously limits the value of most baselines. We use historical data to define baselines for abalone in California and to evaluate current abundances and suggest restoration targets. Using the fishery as a "sampling tool," we estimate that baseline abundances for pink abalone (Haliotis corrugata) were 9.3 million, black abalone were 3.5 million (H. crachcrodii), green abalone (H.fulgens) were 1.5 million, white abalone (H. soreriseni) were 360,000, and threaded abalone (H. kamtschatkana assimilis) were 21,000. All of these species now number less than 1% of their estimated baselines. For species poorly represented in the fishery, we use survey data to estimate that baseline abundances for pinto abalone (H. k. kamtschatkana) were 153,000, and for flat abalone (H. walallensis) were 71,000. Our modern surveys suggest that pinto abalone populations have undergone a ten-fold decline and that flat abalone populations remain similar to their baseline. These baselines underline the dramatic declines in abalone populations and thus define the magnitude of the challenges we face in restoring formerly abundant species. The identification of rare species brings into question the wisdom of fishing species in the absence of baseline information. This approach may serve to help set restoration targets for other depleted species for which we have limited data.

Rothaus, D. P., Vadopalas, B., & Friedman, C. S. (2008). Precipitous declines in pinto abalone (*Haliotis kamtschatkana kamtschatkana*) abundance in the San Juan Archipelago, Washington, USA, despite statewide fishery closure. *Canadian Journal of Fisheries and Aquatic Sciences,* 65(12), 2703-2711. https://doi.org/10.1139/f08-168

Pinto abalone (Haliotis kamtschatkana kamtschatkana) index stations in the San Juan Archipelago were systematically monitored by the Washington Department of Fish and Wildlife from 1992 through 2006. During this period, abalone abundance declined by 77% and the mean shell length (SL) increased 10.4 mm. Abalone densities at all index stations are currently well below the threshold of 0.15 abalone.m(-2) required for successful fertilization. From 1992 to 1996, 16% of individuals encountered measured < 90 mm SL, while only 6% of the individuals from 2003 to 2006 were in this small size class. Similarly, the number of those > 114 mm SL was greater in the 2000s than in the 1990s. The mean SL of all live abalone observed in the 1990s (107.62 +/- 0.87 mm) was significantly different from the mean SL of empty shells (114.21 +/- 2.1 mm), but no difference was detected between the mean SLs of empty shells and live abalone in the 2000s (114.97 +/- 1.42 mm). Taken together, these data suggest recruitment failure from an Allee response to low population densities.

Thomas, G. (1990). *Shellfish stock assessments for the west coast of Canada in 1990.* Canadian manuscript report of fisheries and aquatic sciences (2099). Prince Rupert, B.C.: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/143751.pdf

This manuscript contains shellfish management advice for the Pacific Region in 1990, provided in the form of position papers and fishery updates by the shellfish Subcommittee of the Pacific Stock

Assessment Review Committee. Position papers contain recommendations to management and were subject to scientific review, while fishery updates summarize recent progress in species fisheries. Management advice is provided for intertidal clams, geoduck (Panopea abrupta ), abalone (Haliotis kamtschatkana ), shrimp (Pandalus jordani ), euphausiids, and purple urchin (Strongylocentrotus purpurataus ). Dungeness crab (Cancer magister ), and horseclam (Tresus sp.) papers were published elsewhere. Reviews are provided for ten major and six minor shellfish fisheries.

Thomas, G. (1992). *Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC).* Canadian manuscript report of fisheries and aquatic sciences (2169). Prince Rupert, B.C.: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/143752.pdf

This manuscript contains shellfish management advance for the Pacific Region of Canada in 1991, provided by the Shellfish Subcommittee of the Pacific Stock Assessment Review Committee. There are two categories of documents included: Working Papers contains recommendations to management and were subject to scientific review; and Fishery Updates review progress in shellfish fisheries. In 1991, Working Papers were provided for geoduck (Panopea abrupta ), intertidal clams, mussel (Mytilus edulis ), abalone (Haliotus kamtschatkana ), shrimp (Panadalus sp.), prawn (Pandalus platycerus ), and sea cucumber (Parastichopus californicus ). Fishery Updates were provided for ten major and seven minor shellfish fisheries.

Thomas, G., Farlinger, S., & Carolsfeld, W. (1992). *Abalone resurvey in the southeast Queen Charlotte Islands in 1990*. Canadian Manuscript Report of Fisheries and Aquatic Sciences (2166). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/165549.pdf

Abalone Haliotis kamtschatkana stocks at 69 standard sites on the east coast of the Queen Charlotte Islands (Area 2E) were resurveyed in 1990 and the results compared to previous surveys. Present abalone abundance in Area 2E is similar to that observed in 1984, remaining at 20% of levels in 1978-79. The failure of abalone abundance in Area 2E to return to initial levels may be attributed to a variety of causes. It is possible that large removals by the commercial fishery in the late 1970's (and by other undocumented sources) may be a contributing factor.

White, T., & Raimondi, P. (2020). *Pinto Abalone Dive Transect Monitoring in Select Locations in Southeast Alaska*.(NMFS AKR-18-0820). Retrieved from https://media.fisheries.noaa.gov/2020-09/pinto-abalone-ucsc-rpt-0820.pdf?VersionId=cfQjIf2s8zTtFhV.ZLnk3WEbkEgMH8yz

Pinto abalone (Haliotis kamtschatkana Jonas 1845), a marine gastropod, range from Salisbury Sound, Alaska to Point Conception, California (Busch et al. 2014). In Alaska, pinto abalone have long been harvested for cultural and commercial purposes (Mills 1982). Commercial harvest in Southeast Alaska began in 1965 and closed in 1996, following an 89% decline in catch during peak harvest years 1978 - 1981 (Woodby et al. 2000, McDougall et al. 2006). Following the closure of the commercial fishery in

Alaska, pinto abalone personal use limits were reduced from 50 per day (20 surrounding Sitka) to 5 per day after 2012 (Hebert 2014). No reporting is required for personal use and the size limit of 89 mm is loosely enforced (Scott Walker personal communication). Similar population declines followed pinto abalone fisheries in British Columbia, where all forms of harvest have been closed since 1990 and in Washington State, where there was no prior commercial harvest, but a recreational fishery, which was closed in 1994 following critical population declines. Despite closures, abalone have not fully recovered to populations pre-harvest (Donnellan and Hebert 2017, Rothaus et al. 2008) and pinto abalone in Washington continue to experience recruitment failure (Bouma 2012).

Winther, I., Campbell, A., Thomas, G. A., Adkins, B. E., & Clapp, B. G. (1995). *Abalone resurvey in the southeast Queen Charlotte Islands, 1994*. Canadian manuscript report of Fisheries and aquatic sciences (2273). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/181547.pdf

Abalone (Haliotis kamtschatka) stocks on the southeast coast of the Queen Charlotte Islands were assessed from surveys of 70 standard sites. Mean total abalone density estimated in 1994 was 11% of the original mean density measured in 1978 and 1979. Significant declines were observed in estimates of total abalone density and new recruit (100-106 mm) abalone density between 1994 and 1990, while no significant difference was observed in legal (>100 mm), mature (>70 mm) and pre-recruit (92-99 mm) abalone. Total estimated abalone abundance has declined 30% since surveys in 1990.

Zhang, Z., Campbell, A., & Lessard, J. (2007). Modeling northern abalone, *Haliotis kamtschatkana,* population stock and recruitment in British Columbia. *Journal of Shellfish Research,* 26(4), 1099-1107. https://doi.org/10.2983/0730-8000(2007)26[1099:Mnahkp]2.0.Co;2

The northern abalone, Haliotis kamtschatkana, fisheries in British Columbia (BC) were closed in 1990 because of substantial declines in the stock biomass. Abalone biomass has remained low since the fishery closure. We used abalone survey data and established growth models to study the stock-recruitment (SR) relationships, estimate mortality rates, and simulate population growth trajectories at various mortality levels for abalone populations in the Queen Charlotte Islands and the Central Coast of BC. The fitted SR curves were flat and near linear, indicating a lack of productivity in the abalone populations. At low spawning stock biomass (<0.05 kg/m(2)) the SR relationships appeared to be density independent. Annual mortality rates (Z) were estimated to be 0.29-0.36, which included natural mortality and poaching rates. Simulation studies showed that abalone population growth was sensitive to mortality rates. The abalone populations would be sustainable with Z around 0.25, and would increase or decrease with lower or higher Z, respectively. To rebuild the northern abalone populations, measures need to be taken to minimize or eliminate poaching to reduce mortality rates.

## Section V – Threats

Bower, S. M. (1987). Artificial culture of *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a pathogenic parasite of abalone. *Canadian Journal of Zoology,* 65(8), 2013-2020. https://doi.org/10.1139/z87-306

Labyrinthuloides haliotidis was isolated from infected abalone (Haliotis kamtschatkana) and successfully cultured in minimum essential medium with 10% fetal calf serum at 10 °C for at least 1 year. On transfer to sea water, some subcultures produced numerous motile biflagellate zoospores while zoospore production of other subcultures was poor. On return to minimum essential medium, zoospores transformed into rapidly dividing vegetative forms. Labyrinthuloides haliotidis was not fastidious in its nutrient requirements and vegetative forms grew well in several different liquid media, on agar containing 10% bovine serum, and on pine pollen (Pinus contorta) in sea water. The mean diameter of the round vegetative forms often varied significantly (Student's t-test, $P < 0.05$) but the overall range in diameter (3.1 to 16.2 µm) observed in the various media was similar. Best growth occurred at 10 °C and in media made up with 30‰ sea water. No growth occurred at 28 °C or above, or in thioglycollate culture medium at 10 °C. Although L. haliotidis grew on pine pollen in sea water, zoosporoblasts and zoospores were not produced. The disappearance of precipitated proteins in agar medium around colonies of L. haliotidis and the destruction of host tissue around the parasite in infected abalone suggest that extracellular digestion occurs with this organism.

Bower, S. M. (1987). *Labyrinthuloides haliotidis* n.sp. (Protozoa: Labyrinthomorpha), a pathogenic parasite of small juvenile abalone in a British Columbia mariculture facility. *Canadian Journal of Zoology,* 65(8), 1996-2007. https://doi.org/10.1139/z87-304

Labyrinthuloides haliotidis n.sp. is an achlorophyllous eucaryotic protist that is pathogenic to juvenile abalone (Haliotis kamtschatkana and Haliotis rufescens) less than 190 days of age (postsetting). Within the muscle and nervous tissue of the head and foot of susceptible abalone and in axenic nutrient culture media at 10 °C, vegetative stages of L. haliotidis proliferated by binary fission and produced ectoplasmic nets from sagenogenetosomes located on the cell periphery. When the abalone died and the parasites were released from the decaying tissue or when culture forms were washed free of nutrient medium and placed in sea water, internal multiple fission (sporulation) occurred within some cells, producing zoosporoblasts. After 24 to 72 h of incubation at 10 °C, the zoosporoblasts ruptured to release from 3 to about 10 infective biflagellated zoospores. After about 24 h of active swimming, or on contact with a glass surface, the zoospores shed their flagella. Ultrastructure of vegetative stages and zoospores related this species more closely to the thraustochytrids than to the labyrinthulids. Confusion still prevails concerning the higher taxonomic affinities of this group of organisms. In keeping with recent publications on the taxonomy of the kingdom Protozoa, L. haliotidis was considered to be a protozoan of the phylum Labyrinthomorpha and not allied with the fungi.

Bower, S. M. (1987). The life cycle and ultrastructure of a new species of thraustochytrid (Protozoa: Labyrinthomorpha) pathogenic to small abalone. *Aquaculture,* 67(1-2), 269-270. https://doi.org/10.1016/0044-8486(87)90054-8

Infections of a new species of thraustochytrid belonging to the genus Labyrinthuloides were lethal to almost all juvenile abalone (Haliotis kamtschatkana and Haliotis rufescens ) less than 190 days of age (post setting) in an abalone mariculture facility in British Columbia, Canada. By 230 days of age, the juvenile abalone seemed refractive to the lethal effects of the infection. The parasite rapidly multiplied by binary fission within the muscle and nerve tissue of the head and foot of infected abalone and could overwhelm an abalone by day 5 of incubation at 12 degree C.

Bower, S. M. (1987). Pathogenicity and host specificity of *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a parasite of juvenile abalone. *Canadian Journal of Zoology,* 65(8), 2008-2012. https://doi.org/10.1139/z87-305

Infections with Labyrinthuloides haliotidis, an achlorophyllous, eucaryotic protist, were lethal to almost all juvenile abalone (Haliotis kamtschatkana and Haliotis rufescens) less than 6 months of age in an abalone mariculture facility in British Columbia, Canada. In laboratory experiments, L. haliotidis isolated from infected abalone or grown in axenic nutrient medium was infective for abalone (H. kamtschatkana) less than 4.0 mm in shell length and 140 days of age. Ten days after exposure to at least 104 parasites in 20 mL of sea water, about 90% of these abalone died with numerous parasites throughout the tissues of the head and foot. By about 190 days of age, regardless of shell size, abalone mortalities were reduced to less than 50% after exposure to about 105 parasites. Finally, by about 340 days of age, most juvenile abalone (4.0 to 10.5 mm in shell length) did not succumb after three consecutive exposures, 13 days apart, to between 2 × 105 and 5 × 106L. haliotidis. Larger abalone (15 to 25 mm in shell length) did not become infected following intramuscular injections of about 1.5 × 104L. haliotidis. Small juvenile scallops (Patinopecten yessoensis) and juvenile oysters (Crassostrea gigas), both less than 8 months of age, were also resistant to infection. However, two of the oysters with badly cracked shells became infected. This suggests that if L. haliotidis can gain access, it is capable of using living oyster tissue as a source of nutrients for growth and multiplication.

Bower, S. M. (1988). *Abalone disease research*. Aquaculture Update (28). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/337853.pdf

Scientists at the Pacific Biological Station have recently investigated a previously unknown organism which has caused high mortalities of juvenile abalone cultured at a mariculture facility in British Colurrbia. The cause of the hicjl mortality rates is a microscopic parasite that is new to science. The parasite belongs to a group of single-celled organisms historically studied by mycologists and therefore known as fungi. About 5 years ago, this group of organisms was transferred to the protozoan kingdom and placed in their own phylum called Labyrinthomorpha.

Bower, S. M. (1989). Disinfectants and therapeutic agents for controlling *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), an abalone pathogen. *Aquaculture,* 78(3), 207-215. https://doi.org/10.1016/0044-8486(89)90098-7

Labyrinthuloides haliotidis, a pathogenic parasite of juvenile abalone (Haliotis kamtschatkana and Haliotis rufescens), was destroyed by a 20-min exposure to 25 mg chlorine per l of sea water. This parasite showed high resistance to six other potential disinfectants: formalin, iodophor, isopropanol, methylene blue, malachite green, and copper sulfate. The antibiotic fungicide cycloheximide at 1–2 mg per l for 23 h per day on 5 consecutive days proved efficacious. However, this treatment had three disadvantages: (1) it was detrimental to some diatoms upon which the abalone fed, (2) it was ineffective against non-growing but infective zoospores of L. haliotidis and thus reinfection usually occurred within 2–3 weeks following treatment, and (3) it resulted in cycloheximide resistant forms of L. haliotidis. Two different combinations of three sulfonamides (sodium sulfamethazine and sodium sulfathiazole with either sodium sulfapyridine or sodium sulfacetamide), especially in conjunction with neomycin sulfate, partially retarded the progression of the disease. Nine other therapeutic agents (betanaphthol, acriflavin hydrochloride, rivanol, furanace, oxytetracycline, chloramine-B, oxolinic acid, metronidazole, and neomycin sulfate) showed little or no activity against L. haliotidis at concentrations higher than would be feasible for use in an abalone culture facility.

Bower, S. M., McLean, N., & Whitaker, D. J. (1989). Mechanism of infection by *Labyrinthuloides haliotidis* (Protozoa: Labyrinthomorpha), a parasite of abalone (Haliotis kamtschatkana) (Mollusca: Gastropoda). *Journal of Invertebrate Pathology,* 53(3), 401-409. https://doi.org/10.1016/0022-2011(89)90106-7

Biflagellated zoospores of the thraustochytrid Labyrinthuloides haliotidis (Protozoa: Labyrinthomorpha), a pathogenic parasite of juvenile abalone (Haliotis kamtschatkana), lost their flagella on contact with the abalone host. Within 4 hr, and prior to the complete development of the ectoplasmic net, sagenogenetosomes were produced and extracellular lytic activity disrupted the plasmalemma layer of host epithelial cells adjacent to the parasite. The damaged epithelial cells were lysed and the parasites entered into the resulting lesion. The ectoplasmic nets extending from the sagenogenetosomes were well developed within 24 hr and may have released lytic agents since net elements were observed deep within the cytoplasm of host cells. Nevertheless, the ectoplasmic net enabled the parasite to move into and within the head and foot tissues of the abalone. As demonstrated by their ultrastructural morphology, the motile zoospores were transformed to vegetative cells within 4 hr and binary fission was observed in the resulting vegetative cells within 24 hr.

Bower, S. M., Whitaker, D. J., & Elston, R. A. (1989). Detection of the abalone parasite *Labyrinthuloides haliotidis* by a direct fluorescent antibody technique. *Journal of Invertebrate Pathology,* 53(2), 281-283. https://doi.org/10.1016/0022-2011(89)90021-9

Labyrinthuloides haliotidis (Thraustochytriaceae) is an achlorophyllous eukaryotic protist that is pathogenic to juvenile abalone (Haliotis kamtschatkana and Haliotis rufescens) (S. M. Bower, Canad. J. Zool. 65, 2008-2012, 1987). Unfortunately, without determining its pathogenicity for small abalone or observing its morphological and growth characteristics in axenic cultures, this parasite has no distinctive taxonomic features (S. M. Bower, Canad. J. 2001. 65, 1996-2007, 1987). In order to facilitate identification of this pathogen, a fluorescein conjugated antiserum was produced so that a direct fluorescent antibody technique could be developed and its specificity was tested.

Camaclang, A. E., Curtis, J. M. R., Naujokaitis-Lewis, I., Poesch, M. S., & Koops, M. A. (2017). Modelling the impact of poaching on metapopulation viability for data-limited species. *Canadian Journal of Fisheries and Aquatic Sciences,* 74(6), 894-906. https://doi.org/10.1139/cjfas-2015-0508

We developed a spatially explicit simulation model of poaching behaviour to quantify the relative influence of the intensity, frequency, and spatial distribution of poaching on metapopulation viability. We integrated our model of poaching with a stochastic, habitat-based, spatially explicit population model, applied it to examine the impact of poaching on northern abalone (Haliotis kamtschatkana) metapopulation dynamics in Barkley Sound, British Columbia, Canada, and quantified model sensitivity to input parameters. While demographic parameters remained important in predicting extinction probabilities for northern abalone, our simulations indicate that the odds of extinction are twice as high when populations are subjected to poaching. Viability was influenced by poaching variables that affect the total number of individuals removed. Of these, poaching mortality was the most influential in predicting metapopulation viability, with each 0.1 increase in mortality rate resulting in 22.6% increase in the odds of extinction. By contrast, the location and spatial correlation of events were less important predictors of viability. When data are limited, simulation models of poaching combined with sensitivity analyses can be useful in informing management strategies and future research directions.

COSEWIC. (2009). *COSEWIC Assessment and Update Status Report on the Northern Abalone* Haliotis kamtschatkana *in Canada.* Ottawa, ON. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_northern_abalone_0809_e.pdf

Highly valued for its meat, this marine mollusc is patchily distributed along the west coast of Canada. Despite a total moratorium on harvest in 1990, the species was designated as Threatened in 2000. Poaching is the most serious threat and continues to reduce population abundance, particularly the larger, more fecund component; however, all size classes have declined significantly over the past three generations (i.e. since 1978) with mature individuals declining an estimated 88-89%. Low densities may further exacerbate the problem by reducing fertilization success in this broadcast spawner (the Allee effect). Although predators such as the recovering Sea Otter population are not responsible for recently observed declines, they may ultimately influence future abundance of abalone populations.

Crim, R. N. (2010). *Effects of ocean acidification on different life history stages of northern abalone (Haliotis kamtschatkana).* (Master of Science Thesis), University of British Columbia, Vancouver, BC. Retrieved from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071410

Anthropogenic atmospheric $CO_2$ levels are rapidly increasing; however, much of this $CO_2$ (ca. 30%) dissolves into the surface ocean (upper 200 m) where it reacts with seawater and disrupts both ocean pH and carbonate chemistry, a process termed ocean acidification. Average pH of the surface ocean has already decreased by 0.1 units since the beginning of the Industrial Revolution and is expected to drop another 0.2 to 0.4 units by the end of this century. Of primary concern is the potential for ocean acidification to dramatically disrupt biological processes, especially biogenic calcification. Different life history stages may also be affected in different ways. Furthermore, interactions between ocean

acidification and other environmental perturbations are often non-additive and thus result in non-predictive outcomes. Here, I investigate the effects of ocean acidification on different life history stages of an endangered abalone, Haliotis kamtschatkana. I reared larvae and adults under elevated $CO_2$ conditions (800 and 1800 ppm), representing levels expected by the end of this century and beyond. Adults were also reared under two temperatures (9 and 12°C) to investigate interactions between $CO_2$ and temperature. Larval survival, shell size and shell morphology were negatively affected by elevated $CO_2$. At 1800 ppm, almost all larvae completely lacked a shell. Adults seem more tolerant of elevated $CO_2$. Survival, growth and feeding rates were unaffected by elevated $CO_2$, at either temperature. Early life history stages may be more sensitive due to differences in calcification processes. Near future levels of ocean acidification may dramatically impair early development of H. kamtschatkana but later life history stages may be more tolerant. Since H. kamtschatkana population growth is thought to be currently limited by successful fertilization, decreases in larval survival may have severe consequences for the recovery of this endangered species. Efforts to mitigate the dramatic population decline of H. kamtschatkana will need to consider the potential repercussions of ocean acidification.

Crim, R. N., Sunday, J. M., & Harley, C. D. G. (2011). Elevated seawater CO2 concentrations impair larval development and reduce larval survival in endangered northern abalone (*Haliotis kamtschatkana*). *Journal of Experimental Marine Biology and Ecology,* 400(1-2), 272-277. https://doi.org/10.1016/j.jembe.2011.02.002

Increasing levels of anthropogenic carbon dioxide in the world's oceans are resulting in a decrease in the availability of carbonate ions and a drop in seawater pH. This process, known as ocean acidification, is a potential threat to marine populations via alterations in survival and development. To date, however, little research has examined the effects of ocean acidification on rare or endangered species. To begin to assess the impacts of acidification on endangered northern abalone (Haliotis kamtschatkana) populations, we exposed H. kamtschatkana larvae to various levels of CO2 [400 ppm (ambient), 800 ppm, and 1800 ppm CO2] and measured survival, settlement, shell size, and shell development. larval survival decreased by ca. 40% in elevated CO2 treatments relative to the 400 ppm control. However, CO2 had no effect on the proportion of surviving larvae that metamorphosed at the end of the experiment. Larval shell abnormalities became apparent in approximately 40% of larvae reared at 800 ppm CO2, and almost all larvae reared at 1800 ppm CO2 either developed an abnormal shell or lacked a shell completely. Of the larvae that did not show shell abnormalities, shell size was reduced by 5% at 800 ppm compared to the control. Overall, larval development of H. kamtschatkana was found to be sensitive to ocean acidification. Near future levels of CO2 will likely pose a significant additional threat to this species, which is already endangered with extinction due in part to limited reproductive output and larval recruitment.

Crosson, L. M. (2020). *Withering Syndrome Disease Dynamics in Wild and Cultured Northeastern Pacific Abalones.* (Ph.D. Thesis), University of Washington, Seattle, WA. Retrieved from http://hdl.handle.net/1773/46008

Withering syndrome (WS) is a chronic bacterial disease of abalones, Haliotis spp., caused by a Rickettsia-like organism (WS-RLO). The etiological agent, Candidatus Xenohaliotis californiensis, occurs along the eastern Pacific margin of North America in California, US and Baja California, Mexico. However, as

infected abalones have been transported to Chile, China, Taiwan, Iceland, Ireland, Israel, Spain, Thailand, and Japan, the geographic range of the bacterium is likely broad especially where California red abalone (Haliotis rufescens) are cultured or in areas where native species have been exposed to red abalone. Disease susceptibility varies among abalones with up to 99% losses of black abalone (H. cracherodii) in lab and field studies in the US, to no losses among the small abalone (H. diversicolor supertexta) in Thailand. Some abalone populations that have suffered severe WS mortality events have developed resistance to the disease. In addition, a newly identified phage hyperparasite of the WS-RLO may reduce pathogenicity and dampen associated losses. Proper diagnosis of WS requires the identification of infection with the pathogen (WS-RLO detected via in situ hybridization or histology coupled with PCR and sequence analysis) accompanied by morphological changes that characterize this disease (e.g. digestive gland metaplasia and pedal atrophy). A quantitative PCR (qPCR) assay was recently developed and validated for the detection of WS-RLO DNA in abalone tissues, feces, and seawater. While confirmation of infection cannot be done by PCR-based assays alone, they can be used as proxies for infection in areas where the WS-RLO is established and are recommended for inclusion in all abalone health examinations. Avoidance of WS is best accomplished by the establishment of a health history, good husbandry practices, and multiple health examinations prior to the movement of animals. Population declines in wild and cultured abalones due to WS have been well documented along the northeastern Pacific Ocean. However, observed differences in species susceptibility to the disease are not well understood. The first objective of my dissertation was to examine the susceptibility of three temperate abalone species, the cool water (4-14Â°C) pinto or northern abalone (H. kamtschatkana), the intermediate water (8-18Â°C) red abalone, and the warm water (12-23Â°C) pink abalone (H. corrugata), to experimental WS infection at temperatures facilitating disease proliferation. Mortality data paired with histological and molecular detection of the WS pathogen confirmed that these abalone species exhibit different levels of susceptibility to infection and resistance to WS development ranging from high susceptibility and low resistance in pinto abalone to moderate/low susceptibility and resistance in red and pink abalones. The temperature associated with WS induced mortalities also varied among species: pinto abalone died at the lowest experimental temperature (17.32 Â± 0.09Â°C), while red abalone died at an intermediate temperature (17.96 Â± 0.16Â°C), and pink abalone required the highest temperature (18.84 Â± 0.16Â°C). When data from the current and previous studies were examined, susceptibility to WS was inversely related to phylogenetic distance from white abalone (H. sorenseni), which had the highest susceptibility and lowest resistance of all abalone species tested prior to the current study. These results provide further evidence that an abalone's thermal optima and phylogenetic relationship can determine its susceptibility to WS; species with cool water evolutionary histories are most susceptible to WS and the most susceptible species appear to be closely related. Differences among the thermal ranges of abalone species have broad implications for WS disease dynamics and highlight the importance of understanding the mechanisms governing the abalone-WS relationship in order to properly manage declining abalone populations. My second dissertation objective was to elucidate important epidemiological information on the WS-RLO. The bacterium remains unculturable thereby limiting our understanding of WS disease dynamics. My goals were to: (1) determine the temporal stability of WS-RLO DNA outside of its abalone host in 14Â°C and 18Â°C seawater, (2) develop a standardized protocol for exposing abalones to known concentrations of WS-RLO DNA and (3) calculate the dose of WS-RLO DNA required to generate 50% infection prevalence (ID50) in the highly cultured red abalone. WS-RLO stability trials were conducted in October 2016, February 2017, and June 2017 during which qPCR analysis was used to quantify bacterial DNA for 7 days in seawater collected at an abalone farm in southern California where the pathogen is endemic. For all trials and temperature treatments, WS-RLO DNA was not stable in seawater longer than 2 days. To determine an ID50, groups of uninfected juvenile red abalone were subjected to 3-hour bath exposures of WS-RLO at four concentrations: 0, 103, 104, and 105 DNA copies/mL. Abalone feces were monitored bi-weekly for the presence of WS-RLO DNA

and abalone tissues were sampled 9 weeks after dosing for histology and qPCR examination. Results from the ID50 indicated that our protocol was successful in generating WS-RLO infections and a pathogen dose of 2.3 x 103 DNA copies/mL was required to generate 50% infection prevalence in the tissue of red abalone as assessed by qPCR. The WS-RLO is considered an established bacterial pathogen in coastal CA seawaters and is of great concern to coastal managers and local abalone aquaculture facilities (AFs) conducting open or flow-through seawater culture methods. California AFs are at high risk for spillback (wild to farm) and spillover (farm to wild) disease transmission due to high abalone host densities and the use and release of coastal seawater that may contain the WS-RLO and its associated novel phage. To address these concerns, my third and final dissertation objective was to sample nearshore surface seawater from nine established wild black abalone sites and four red abalone AFs from Bodega Bay, Sonoma County, CA, US to Ventura County, CA, US including the Channel Islands over two consecutive summers to determine the presence and amount of WS-RLO and phage DNA via qPCR. In July 2010, WS-RLO DNA was detected as far north as Andrew Molera State Park, Big Sur, CA and as far south as San Nicolas Island (SNI). Phage DNA was detected from Monterey Bay, CA to SNI. In July 2011, WS-RLO DNA was detected as far north as Davenport, CA and as far south as SNI. The phage DNA detection range remained the same as the 2010 survey. Phage DNA loads did not vary by year at AF or wild sites. However, WS-RLO DNA loads were greater in 2011 than 2010 at wild sites, while those at AFs did not vary by year. In October 2013, surface seawater surveys were conducted at the two southern-most AFs in Cayucos and Goleta, CA to assess fine-scale WS-RLO DNA dilution potential from a point-source discharge. In the 2013 samples, WS-RLO DNA loads in seawater directly adjacent to the AFs were less than the mean levels detected at all wild black abalone sites previously surveyed within 50 to 500 m of the AFs effluent outfalls. While these findings present management concerns for both wild and cultured California abalones, it is important to acknowledge that PCR-based assays do not indicate the presence of viable pathogen or active infection and serve as a proxy for WS exposure. In order to fully assess the potential for wild and cultured abalone disease interactions, additional experiments should be conducted to determine the longevity and infectivity of the WS-RLO and novel phage in seawater. Collectively, these findings are critical components of disease dynamics that will help assess WS transmission risk within and among abalone populations and facilitate appropriate management and restoration strategies for both wild and cultured abalone species in WS-endemic areas.

Crosson, L. M., & Friedman, C. S. (2018). Withering syndrome susceptibility of northeastern Pacific abalones: A complex relationship with phylogeny and thermal experience. *Journal of Invertebrate Pathology,* 151, 91-101. https://doi.org/10.1016/j.jip.2017.11.005

Population declines in wild and cultured abalones (Haliotis spp.) due to a bacterial disease called withering syndrome (WS) have been documented along the northeastern Pacific Ocean. However, observed differences in species susceptibility to the disease are not well understood. Here, we examined the susceptibility of three temperate abalone species, the cool water (4-14 degrees C) pinto or northern abalone (Haliotis kamtschatkana), the intermediate water (8-18 degrees C) red abalone (H. rufescens), and the warm water (12-23 degrees C) pink abalone (H. corrugata), to experimental WS infection at temperatures facilitating disease proliferation. Mortality data paired with histological and molecular detection of the WS pathogen confirmed that these abalone species exhibit different levels of susceptibility to infection and resistance to WS development ranging from high susceptibility and low resistance in pinto abalone to moderate/low susceptibility and resistance in red and pink abalones. The temperature associated with WS induced mortalities also varied among species: pinto abalone died at the lowest experimental temperature (17.32 +/- 0.09 degrees C), while red abalone died at an

intermediate temperature (17.96 +/- 0.16 degrees C), and pink abalone required the highest temperature (18.84 +/- 0.16 degrees C). When data from the current and previous studies were examined, susceptibility to WS was inversely related to phylogenetic distance from white abalone (H. sorenseni), which had the highest susceptibility and lowest resistance of all abalone species tested prior to the current study. These results provide further evidence that an abalone's thermal optima and phylogenetic relationship can determine its susceptibility to WS; species with cool water evolutionary histories are most susceptible to WS and the most susceptible species appear to be closely related. Differences among the thermal ranges of abalone species have broad implications for WS disease dynamics and highlight the importance of understanding the mechanisms governing the abalone-WS relationship in order to properly manage declining abalone populations.

Crosson, L. M., Wight, N., VanBlaricom, G. R., Kiryu, I., Moore, J. D., & Friedman, C. S. (2013). *Abalone Withering Syndrome: Distribution, Impacts, Current Diagnostic Methods, and New Findings.* Paper presented at the 40th U.S.-Japan Aquaculture Panel Symposium, Honolulu, Hawaii. Retrieved from https://repository.library.noaa.gov/view/noaa/4598

Withering syndrome (WS) is a fatal disease of abalone caused by a Rickettsiales-like organism (WS-RLO). The causative agent, “Candidatus Xenohaliotis californiensis,”occurs along the eastern Pacific margin of North America in California, USA and Baja California, Mexico. However, as infected abalones have been transported to Chile, China (People’s Rep. of), Taiwan, Iceland, Ireland, Israel, Spain, Thailand, and most recently Japan, and possibly other countries, the geographical range of the etiological agent is suspected to be broad, especially where California red abalones, Haliotis rufescens, are cultured or in areas where native species have been exposed to this species. Susceptibility varies among species with up to 99% losses of black abalone, H. cracherodii, in lab and field studies in the USA, to no losses among the small abalone, H. diversicolor supertexta, in Thailand. Some populations that have suffered catastrophic losses due to WS have developed resistance to the disease. In addition, a newly identified phage hyperparasite of the WS-RLO may reduce pathogenicity and dampen losses from the WS-RLO. Diagnosis of WS requires the identification of infection with the pathogen (WS-RLO detected via in situ hybridization or histology coupled with PCR and sequence analysis) accompanied by morphological changes that characterize this disease (e.g. pedal and digestive gland atrophy, and digestive gland metaplasia). A quantitative PCR (qPCR) assay was developed and may be useful in quantifying amounts of pathogen DNA. Confirmation of infection by the WS-RLO cannot be done by PCR analysis alone as this method only detects pathogen DNA, but can be used as a proxy for infection in areas where the agent is established. Control measures include avoidance, culling infected animals, cooler temperature and, as per federal regulations, oral or bath treatment with oxytetracycline. Avoidance is best accomplished by the establishment of a health history and multiple health examinations prior to movement of animals. Although histology or in situ hybridization are required to confirm infection, PCR is able to detect small amounts of pathogen DNA and is recommended for inclusion in health examinations.

Davis, R. W., Bodkin, J. L., Coletti, H. A., Monson, D. H., Larson, S. E., Carswell, L. P., & Nichol, L. M. (2019). Future Directions in Sea Otter Research and Management. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2018.00510

The conservation and management of sea otters has benefited from a dedicated research effort over the past 60 years enabling this species to recover from a few thousand in the early 20th century to about 150,000 today. Continued research to allow full, pre-exploitation recovery and restoration of nearshore ecosystems should focus on at least seven key challenges: 1) Defining sea otter populations at smaller spatial scales that reflect this species' life history and dispersal patterns; 2) Understanding factors that regulate sea otter population density with a focus on index sites that are representative of the variety of littoral habitats occupied by sea otters around the North Pacific Rim; 3) Quantifying the effects of sea otters on the littoral community with a focus on how food availability limits population and ecosystem recovery and on predicting the effect of sea otter reoccupation on commercially valuable invertebrates; 4) Making sea otter monitoring programs comparable across geo-political boundaries through international collaboration to optimize survey efforts both spatially and temporally and to determine the cause of changes in sea otter demographics; 5) Evaluating the conservation benefits of sea otter reintroductions into historical habitat; 6) Assessing the socioeconomic costs and benefits of sea otter range expansion to anticipate and mitigate conflicts; 7) Recognizing in conservation and management plans that sea otters can be significantly affected by higher level predators in some circumstances. Many of these challenges will require new tools including the next generation geolocation tag technology that will allow assessments of long-range movements, dispersal and gene flow in various populations.

Frederick, A. R., Freidman, C. S., & German, D. P. (2018). Withering-syndrome induced gene expression changes in pinto abalone, *Haliotis kamtschatkana*. *Integrative and Comparative Biology,* 58, E69-E69. https://doi.org/10.1016/j.cbd.2021.100930

In the abalone and Candidatus Xenohaliotis californiensis (Ca. Xc) system, the Ca. Xc bacterium infects abalone digestive tissues and leads to extreme starvation and a characteristic "withering" of the gastropod foot. First identified in black abalone in California after an El Niño event, withering syndrome (WS) has caused large declines in wild black and captive white abalones on the northeastern Pacific coast, but disease resistance levels are species-, and possibly population-specific. This study compared gene expression patterns in the digestive gland of Ca. Xc-exposed and unexposed (control) Pinto abalone (Haliotis kamtschatkana), a particularly susceptible species. Lab-induced Ca. Xc infections were followed over 7 months and RNAseq to identify differential gene expression (DEG). Exposed Pinto abalone showed distinct changes in expression of 68 genes at 3 and 7 months post-infection relative to those in control animals. Upregulation of an orexin-like receptor (which is involved in feeding signaling) and a zinc peptidase-like region (many amino peptidases are zinc peptidases) in animals infected for 7 months indicates that animals with Ca. Xc infection may be starving and upregulating processes associated with feeding and digestion. Other groups of differentially expressed genes were upregulated or downregulated across control and exposed individuals over the 7-month experiment, including DEG groups that likely correspond to early disease state and to general stress response of being held in captivity. No patterns emerged in genes known to involved in molluscan immune response, despite this being an expectation during a 7-month infection; immune genes and unannotated DEGs were identified as targets for future research on immune response to WS in abalone.

Frederick, A. R., Heras, J., Friedman, C. S., & German, D. P. (2021). Withering syndrome induced gene expression changes and a de-novo transcriptome for the Pinto abalone, *Haliotis kamtschatkana*.

*Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, 100930. https://doi.org/10.1016/j.cbd.2021.100930

In the abalone and Candidatus Xenohaliotis californiensis (Ca. Xc) system, the Ca. Xc bacterium infects abalone digestive tissues and leads to extreme starvation and a characteristic "withering" of the gastropod foot. First identified in black abalone in California after an El Niño event, withering syndrome (WS) has caused large declines in wild black and captive white abalones on the northeastern Pacific coast, but disease resistance levels are species-, and possibly population-specific. This study compared gene expression patterns in the digestive gland of Ca. Xc-exposed and unexposed (control) Pinto abalone (Haliotis kamtschatkana), a particularly susceptible species. Lab-induced Ca. Xc infections were followed over 7 months and RNAseq to identify differential gene expression (DEG). Exposed Pinto abalone showed distinct changes in expression of 68 genes at 3 and 7 months post-infection relative to those in control animals. Upregulation of an orexin-like receptor (which is involved in feeding signaling) and a zinc peptidase-like region (many amino peptidases are zinc peptidases) in animals infected for 7 months indicates that animals with Ca. Xc infection may be starving and upregulating processes associated with feeding and digestion. Other groups of differentially expressed genes were upregulated or downregulated across control and exposed individuals over the 7-month experiment, including DEG groups that likely correspond to early disease state and to general stress response of being held in captivity. No patterns emerged in genes known to involved in molluscan immune response, despite this being an expectation during a 7-month infection; immune genes and unannotated DEGs were identified as targets for future research on immune response to WS in abalone.

Friedman, C. S., Roberts, W., Kismohandaka, G., & Hedrick, R. P. (1993). Transmissibility of a coccidian parasite of abalone, *Haliotis spp*. *Journal of Shellfish Research,* 12(2), 201-205. Retrieved from https://www.biodiversitylibrary.org/page/3446917

Renal coccidian infections developed in seed red abalone, Haliotis rufescens, after 5-7 mo of exposure to infective waters at the Fish and Game Marine Culture Laboratory in Monterey County, California. Similar infections developed in cohort seed abalone after 3 mo of exposure to infective waters in a barrel culture system located in an embayment near Pt. Hueneme, California. In the experimental trials the coccidian was directly transmitted from red abalone to pinto abalone after 10.5 mo of cohabitation. One hundred percent of the pinto abalone that shared aquaria with infected red abalone had coccidian infections after 17 mo of cohabitation, while no control abalone developed infections with coccidia. No change in the condition of the abalone or mortality resulted from natural or experimental infections with coccidia.

Fuller, A. M. (2017). *Transmission Dynamics of the Withering Syndrome Rickettsia-like Organism to Abalone in California.* (Master of Science Thesis), University of Washington, Seattle, WA. Retrieved from http://hdl.handle.net/1773/40574

A sentinel study was conducted to investigate the distribution of the withering syndrome (WS) pathogen by deploying modules containing live red abalone at two different field sites, one near an onshore commercial abalone farm and one in proximity to wild aggregations of abalone, both in Southern California. A newly validated quantitative polymerase chain reaction (qPCR) assay was used to quantify the withering syndrome rickettsia like organism (WS-RLO) DNA in water, tissue and fecal samples. In

addition, histological screenings were conducted on tissues from all surviving abalone to understand clinical infections of the pathogen. WS-RLO DNA copies were detected in modules at the wild site but not at the site off of the abalone farm (even though WS-RLO DNA was detected in the farm's effluent; $p > 0.05$). Overall, proportions of clinical infections and WS-RLO DNA at both sites were very low and similar between sites ($p > 0.05$). Abalone infection prevalence and intensity of the WS-RLO was independent of WS-RLO DNA copy density in seawater. This study demonstrated the use of caged sentinel abalone to monitor RLO transmission in the field. The results of this study will help managers better understand the risk of infection of abalone exposed to the WS-RLO in situ.

Gazeau, F., Parker, L. M., Comeau, S., Gattuso, J.-p., O'Connor, W. A., Martin, S., . . . Ross, P. M. (2013). Impacts of ocean acidification on marine shelled molluscs. *Marine Biology,* 160(8), 2207-2245. https://doi.org/10.1007/s00227-013-2219-3

Issue Title: Special Issue: Acidification Over the next century, elevated quantities of atmospheric CO2 are expected to penetrate into the oceans, causing a reduction in pH (-0.3/-0.4 pH unit in the surface ocean) and in the concentration of carbonate ions (so-called ocean acidification). Of growing concern are the impacts that this will have on marine and estuarine organisms and ecosystems. Marine shelled molluscs, which colonized a large latitudinal gradient and can be found from intertidal to deep-sea habitats, are economically and ecologically important species providing essential ecosystem services including habitat structure for benthic organisms, water purification and a food source for other organisms. The effects of ocean acidification on the growth and shell production by juvenile and adult shelled molluscs are variable among species and even within the same species, precluding the drawing of a general picture. This is, however, not the case for pteropods, with all species tested so far, being negatively impacted by ocean acidification. The blood of shelled molluscs may exhibit lower pH with consequences for several physiological processes (e.g. respiration, excretion, etc.) and, in some cases, increased mortality in the long term. While fertilization may remain unaffected by elevated pCO2, embryonic and larval development will be highly sensitive with important reductions in size and decreased survival of larvae, increases in the number of abnormal larvae and an increase in the developmental time. There are big gaps in the current understanding of the biological consequences of an acidifying ocean on shelled molluscs. For instance, the natural variability of pH and the interactions of changes in the carbonate chemistry with changes in other environmental stressors such as increased temperature and changing salinity, the effects of species interactions, as well as the capacity of the organisms to acclimate and/or adapt to changing environmental conditions are poorly described.

Griffiths, A. M., & Gosselin, L. A. (2008). Ontogenetic shift in susceptibility to predators in juvenile northern abalone, *Haliotis kamtschatkana*. *Journal of Experimental Marine Biology and Ecology,* 360(2), 85-93. https://doi.org/10.1016/j.jembe.2008.04.004

Predation has been suggested as a major cause of juvenile mortality in benthic marine invertebrates. However, the extent to which juveniles are susceptible to predators is unknown for most species, and it remains unclear to what extent ontogenetic shifts in susceptibility to predators are common among marine invertebrates. This study examined the northern abalone Haliotis kamtschatkana, a species listed as threatened in British Columbia, Canada. Our goals were to characterize the diversity and abundance of species that prey on juvenile abalone and determine if abalone experience an ontogenetic shift in

susceptibility to predators. juvenile H. kamtschatkana were found to be susceptible to a broad variety of predators: 14 of the 37 potential predator species to which we offered juvenile abalone (<= 28 mm shell length (SL)) consumed at least one juvenile abalone. Four of those species (three crabs and one seastar) consumed >= 10% of the juvenile abalone that were offered in the laboratory. These species were present at field sites where abalone are found, indicating that they have the potential to be significant predators of juvenile H. kamtschatkana in the wild. The most abundant predators were small crabs, especially Lophopanopeus bellus (black-clawed crabs) and Scyra acutifrons (sharp-nosed crabs). juvenile H. kamtschatkana also experienced a pronounced ontogenetic shift in susceptibility to predators. The risk of predation for juvenile H. kamtschatkana decreased rapidly with increasing body size, especially over the 12-13 mm SL size range. Susceptibility remained low beyond 13 mm SL, indicating relatively low and unchanging levels of predation risk once the individual reaches this size. Although abalone are susceptible to several species during the first 1-2 years of life, predator effects on juvenile abalone abundance and microhabitat use may largely be attributable to the influence of only I or 2 predator species that can only kill abalone <13 mm SL.

Kawana, S. K., Catton, C. A., Hofmeister, J. K. K., Juhasz, C. I., Taniguchi, I. K., Stein, D. M., & Rogers-Bennett, L. (2019). Warm Water Shifts Abalone Recruitment and Sea Urchin Diversity in Southern California: Implications for Climate-Ready Abalone Restoration Planning. *Journal of Shellfish Research,* 38(2), 475-484. https://doi.org/10.2983/035.038.0231

Nearshore kelp forest ecosystems are highly vulnerable to climate change and ocean warming, which can alter community dynamics and change the trajectory of species recovery in unpredictable ways. Abalone (Haliotis spp.) populations in the Southern California Bight (SCB) are still recovering from a combination of overfishing and disease, despite the closure of the fisheries 20 years ago and active restoration programs for abalone species in the region. For this study, abalone recruitment and sea urchin populations were surveyed in artificial habitats (16-22 m) across a spatial and temporal climatic gradient in southern California from 2010 to 2017 to inform the development of climate-ready abalone restoration programs. The SCB encompasses warm and cool islands, and experienced two periods of ocean conditions-cool (2010-2013) and warm ocean conditions (2014-2016). Dive surveys of the artificial habitats revealed that juvenile abalone recruitment remained low during the study period, suggesting that recovery is slow. Warm-water years favored recruitment of juvenile pink (Haliotis corrugata) and green abalone (Haliotis fulgens), with the highest abalone recruitment observed at Catalina Island. Endangered white abalone (Haliotis sorenseni) were not observed despite placing the artificial habitats in suitable deep rocky reefs, which is further evidence supporting their endangered species status. The coolest site, San Diego, had little abalone recruitment, with a few juvenile red abalone (Haliotis rufescens) and threaded (Haliotis kamtschatkana) abalone present. Sea urchin abundance and diversity increased during the warm period, with the largest increase at Catalina Island. During the warm period, Coronado sea urchin (Centrostephanus coronatus) increased in abundance, coincident with a decrease in the commercially valuable temperate red sea urchin (Mesocentrotus franciscanus). Potential shifts in the sea urchin assemblage to warm-water sea urchins may negatively impact recovering abalone populations and the red sea urchin fishery. Climate-ready abalone restoration will require ecosystem-based monitoring, tracking on not only abalone recruitment but also sea urchins, algal abundances, ocean temperature, and kelp forest communities as climate change may lead to complex and unexpected ecosystem interactions.

Kroeker, K. J., Powell, C., & Donham, E. M. (2021). Windows of vulnerability: Seasonal mismatches in exposure and resource identity determine ocean acidification's effect on a primary consumer at high latitude. *Global Change Biology,* 27(5), 1042-1051. https://doi.org/10.1111/gcb.15449

It is well understood that differences in the cues used by consumers and their resources in fluctuating environments can give rise to trophic mismatches governing the emergent effects of global change. Trophic mismatches caused by changes in consumer energetics during periods of low resource availability have received far less attention, although this may be common for consumers during winter when primary producers are limited by light. Even less is understood about these dynamics in marine ecosystems, where consumers must cope with energetically costly changes in CO2-driven carbonate chemistry that will be most pronounced in cold temperatures. This may be especially important for calcified marine herbivores, such as the pinto abalone (Haliotis kamschatkana). H. kamschatkana are of high management concern in the North Pacific due to the active recreational fishery and their importance among traditional cultures, and research suggests they may require more energy to maintain their calcified shells and acid/base balance with ocean acidification. Here we use field surveys to demonstrate seasonal mismatches in the exposure of marine consumers to low pH and algal resource identity during winter in a subpolar, marine ecosystem. We then use these data to test how the effects of exposure to seasonally relevant pH conditions on H. kamschatkana are mediated by seasonal resource identity. We find that exposure to projected future winter pH conditions decreases metabolism and growth, and this effect on growth is pronounced when their diet is limited to the algal species available during winter. Our results suggest that increases in the energetic demands of pinto abalone caused by ocean acidification during winter will be exacerbated by seasonal shifts in their resources. These findings have profound implications for other marine consumers and highlight the importance of considering fluctuations in exposure and resources when inferring the emergent effects of global change.

MacCallum, G. S., Blackbourn, J., McGladdery, S. E., Bower, S. M., & Davidson, J. T. (2001). Disease issues relevant to the culture of shellfish in Atlantic and Pacific Canada. *Bulletin of the Aquaculture Association of Canada,* 101(3), 5-12. Retrieved from http://aquacultureassociation.ca/wp-content/uploads/bsk-pdf-manager/2017/10/Bulletin-101-3.pdf

A project initiated in October, 2000 at the Atlantic Veterinary College and Pacific Biological Station (PBS) assessed the health /disease issues relevant to the culture of indigenous shellfish species. This project included a thorough geographic survey of infections affecting the Stimpson's bar clam (Mactromeris polynyma), European oyster (Ostrea edulis), green sea urchin (Strongylocentrotus droebachiensis), orange-footed sea cucumber (Cucumaria frondosa), and northern shrimp (Pandalus borealis) on the east coast, and the green and red sea urchin (S. droebachiensis, S. franciscanus), California sea cucumber (Parastichopus californicus), cockle (Clinocardium nuttali), varnish clam (Nutallia obscurata) and pinto abalone (Haliotis kamtschatkana) on the west coast. All species are currently under culture development, or of culture interest, on their respective coasts. Gross observations found the presence of the boring sponge (Cliona vastifica) in the shells of O. edulis and Clinoa sp., and Polydora sp. in such as Trichodina sp., unidentified intestinal ciliates, Rickettsia - like organisms, unidentified copepods, Nematopsis - like gregarine spores, and digenean metacercarian cysts in or near tissues in the bivalves, echinoderms and crustaceans. It is essential to establish baseline information on what is "normal" for species going into culture production to: 1) accurately assess disease risks, and 2) differentiate true

pathogens from opportunists taking advantage of sub-optimal culture conditions. This proactive research approach sets a precedent for the development of shellfish culture species, since health research rarely occurs before a disease crisis occurs.

Maguire, A. K., & Rogers-Bennett, L. (2013). An ectoparasitic snail (*Evalea tenuisculpta*) infects red abalone (*Haliotis rufescens*) in northern California. *California Fish and Game,* 99(2), 80-89. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=69452

We document the presence of the ectoparasitic fine-sculptured odostome snail (Evalea tenuisculpta) on red abalone (Haliotis rufescens) in northern California. Red abalone form the basis for an important recreational fishery north of San Francisco. We found that 82% of the red abalone examined from three sites (n=73) in Sonoma County had these small snail parasites. We document that the parasitic snails also infects northern abalone (H. kamtschatkana). Infected red abalone had an average of 12 parasitic snails, averaging 4.8mm in length (range 1.0 to 8.8 mm) on their shell. In the laboratory, starved parasitic snails presented with live abalone elongated their proboscis to feed. Over three days, parasitic snails (85%) laid at least one egg mass, with larger snails laying more egg masses (containing more eggs) than smaller snails. Egg masses averaged 360 eggs per mass. More work is needed on the biology of this parasitic snail to determine its impacts on abalone, abalone populations, and the abalone fishery.

Marliave, J. B., Gibbs, C. J., Gibbs, A. O. L. D. M., & Young, S. J. F. (2011). Biodiversity Stability of Shallow Marine Benthos in Strait of Georgia, British Columbia, Canada Through Climate Regimes, Overfishing and Ocean Acidification. In *Biodiversity Loss in a Changing Planet.* O. Grillo & G. Venora (Eds.): InTech https://doi.org/10.5772/24606

The highest human population density in British Columbia, Canada is situated around the shores of the Strait of Georgia, where current government policy is focusing early efforts toward achieving ecosystem-based management of marine resources. Climate regime shifts are acknowledged to have affected commercial fishery production in southern British Columbia (McFarlane et al., 2000), and overfishing is well documented in the Strait of Georgia region for a variety of important species, to the extent that Rockfish Conservation Areas have been created (Marliave & Challenger, 2009). As CO2 levels rise in the atmosphere, the oceans become progressively more acidic. While ocean acidification is predicted to be a great threat to marine ecosystems, little is known about its ecosystem impacts. Few taxpayer-funded studies have committed to long-term monitoring of full ecosystem biodiversity. This document presents results of over forty years of private taxonomic monitoring of shallow seafloors in the region centering on the Strait of Georgia. Also presented are records of ambient ocean acidity levels (pH), documented continuously by the Vancouver Aquarium through the same time period. Biodiversity data are summarized in ways that enable visualization of possible relationships to climate regimes and ocean acidification. This work does not attempt statistical analyses, in the hope that the data trends can be incorporated into future models. Biodiversity survey data can reveal fundamental differences in community function, as with the disparate trophic complexity and rockfish nursery capacity of glass sponge gardens versus reefs (Marliave et al., 2009). Trophic cascades can be elucidated when coupling biodiversity surveys with transect abundance surveys (Frid & Marliave, 2010). It has been suggested that biodiversity provides more accurate definition of climate regime shifts than does physical oceanographic data (Hare & Mantua, 2000) and the abundance, survival and spawning distribution of commercial fish

species have been linked to decadal-scale changes in ocean and climate conditions (McFarlane et al., 2000). Ocean acidification can detrimentally impact anti-predator behaviors of fish (Dix et al., 2010). Ocean acidification is most intensive in the geographic area of the NE Pacific Ocean

Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J. A., Hurst, T. P., . . . Feely, R. A. (2015). Ocean acidification risk assessment for Alaska's fishery sector. *Progress in Oceanography,* 136, 71-91. https://doi.org/10.1016/j.pocean.2014.07.001

The highly productive fisheries of Alaska are located in seas projected to experience strong global change, including rapid transitions in temperature and ocean acidification-driven changes in pH and other chemical parameters. Many of the marine organisms that are most intensely affected by ocean acidification (OA) contribute substantially to the state's commercial fisheries and traditional subsistence way of life. Prior studies of OA's potential impacts on human communities have focused only on possible direct economic losses from specific scenarios of human dependence on commercial harvests and damages to marine species. However, other economic and social impacts, such as changes in food security or livelihoods, are also likely to result from climate change. This study evaluates patterns of dependence on marine resources within Alaska that could be negatively impacted by OA and current community characteristics to assess the potential risk to the fishery sector from OA. Here, we used a risk assessment framework based on one developed by the Intergovernmental Panel on Climate Change to analyze earth-system global ocean model hindcasts and projections of ocean chemistry, fisheries harvest data, and demographic information. The fisheries examined were: shellfish, salmon and other finfish. The final index incorporates all of these data to compare overall risk among Alaska's federally designated census areas. The analysis showed that regions in southeast and southwest Alaska that are highly reliant on fishery harvests and have relatively lower incomes and employment alternatives likely face the highest risk from OA. Although this study is an intermediate step toward our full understanding, the results presented here show that OA merits consideration in policy planning, as it may represent another challenge to Alaskan communities, some of which are already under acute socio-economic strains.

Okey, T. A., Alidina, H. M., Lo, V., & Jessen, S. (2014). Effects of climate change on Canada's Pacific marine ecosystems: a summary of scientific knowledge. *Reviews in Fish Biology and Fisheries,* 24(2), 519-559. https://doi.org/10.1007/s11160-014-9342-1

Issue Title: Special Issue: Impacts, Adaptation and Lessons from Ocean Warming Hotspots The marine life of Canada's Pacific marine ecosystems, adjacent to the province of British Columbia, may be relatively responsive to rapid oceanographic and environmental change associated with global climate change due to uniquely evolved plasticities and resiliencies as well as particular sensitivities and vulnerabilities, given this dynamic and highly textured natural setting. These marine ecosystems feature complex interfaces of coastal geomorphology, climate, and oceanography, including a dynamic oceanographic and ecological transition zone formed by the divergence of the North Pacific Current into the Alaskan coastal current and the California Current, and by currents transporting warm tropical waters from the south. Despite long-term warming in the region, sea surface temperatures in Canada's Pacific have been anomalously cool since 2007 with La Niña-type conditions prevailing as we enter a cool phase of the Pacific Decadal Oscillation, possibly masking future warming. When warmer El Niño

conditions prevail, many southern species invade, strongly impacting local species and reorganizing biological communities. Acidification and deoxygenation are anomalously high in the region due to the weakening ventilation of subsurface waters resulting from increased stratification. A broad spectrum of biological responses to these changes are expected. Non-climate anthropogenic stressors affect the capacity of biota to adapt to climate changes. It will be challenging to forecast the responses of particular species, and to map climate vulnerabilities accurately enough to help prioritize and guide adaptation planning. It will be more challenging to develop forecasts that account for indirect effects within biological communities and the intricate and apparently non-deterministic behaviours of highly complex and variable marine ecosystems, such as those of Canada's Pacific. We recommend and outline national and regional climate assessments in Canada and adaptation planning and implementation including integrated coastal management and marine spatial planning and management.

Raum-Suryan, K. L., Pitcher, K. W., & Lamy, R. (2004). Sea Otter, *Enhydra lutris*, Sightings off Haida Gwaii / Queen Charlotte Islands, British Columbia, 1972-2002. *The Canadian Field-Naturalist,* 118(2), 270-272. https://doi.org/10.22621/cfn.v118i2.928

On 27 June 2001 we observed and photographed a Sea Otter ( Enhydra lutris ) adjacent to a Steller Sea Lion ( Eumetopias jubatus ) haulout near Sgang Gwaay (Anthony Island), Haida Gwaii / Queen Charlotte Islands. This is one of only eight documented sightings of Sea Otters in these waters during the past 30 years. These sightings may represent the beginning of the expansion of Sea Otters to their former range off Haida Gwaii.

Rogers-Bennett, L. (2007). Is climate change contributing to range reductions and localized extinctions in northern (*Haliotis kamtschatkana)* and flat (*Haliotis walallensis*) abalones? *Bulletin of Marine Science,* 81(2), 283-296. Retrieved from https://www.ingentaconnect.com/content/umrsmas/bullmar/2007/00000081/00000002/art00013

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

Ross, P. M., Parker, L., O'Connor, W. A., & Bailey, E. A. (2011). The Impact of Ocean Acidification on Reproduction, Early Development and Settlement of Marine Organisms. *Water,* 3(4), 1005-1030. https://doi.org/10.3390/w3041005

Predicting the impact of warming and acidifying on oceans on the early development life history stages of invertebrates although difficult, is essential in order to anticipate the severity and consequences of future climate change. This review summarises the current literature and meta-analyses on the early life-history stages of invertebrates including fertilisation, larval development and the implications for dispersal and settlement of populations. Although fertilisation appears robust to near future predictions of ocean acidification, larval development is much more vulnerable and across invertebrate groups, evidence indicates that the impacts may be severe. This is especially for those many marine organisms which start to calcify in their larval and/or juvenile stages. Species-specificity and variability in responses and current gaps in the literature are highlighted, including the need for studies to investigate the total effects of climate change including the synergistic impact of temperature, and the need for long-term multigenerational experiments to determine whether vulnerable invertebrate species have the capacity to adapt to elevations in atmospheric CO2 over the next century.

## Section VI – Fisheries and Aquaculture

Bates, K. T. (1984). *Review of the 1982 commercial abalone fishery in British Columbia*. Canadian manuscript report of fisheries and aquatic sciences (1749). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.578011/publication.html

The 1982 commercial abalone (Haliotis kamtschatkana ) fishery in British Columbia harvested 82,175 kg (181,166 lb). Most of the catch was taken in Area 6 (33% of total B.C. catch), with lesser amounts in Area 1 (16%), Area 2E (16.5%) and Area 20 (10.5%). Abalone fishing effort by Statistical Area varied widely and averaged 137 kg/diver day. This is similar to the levels reported in 1980 and 1981, but is down from levels recorded during the period 1977 to 1979. The 1982 was the first year that the total allowable catch for the B.C. coast was not harvested.

Bates, K. T. (1985). *Review of the 1983 commercial abalone fishery in British Columbia*. Canadian manuscript report of fisheries and aquatic sciences (1826). Prince Rupert, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/15132.pdf

The 1983 commercial abalone (Haliotis kamtschatkana ) fishery in British Columbia harvested 58,813 kg (129,660 lb). Most of the catch was taken in Area 2E (35%), with lesser amounts in Area 1 (21%), Area 20 (13%) and Area 6 (13%). Abalone fishing effort by Statistical Area varied widely and averaged 130 kg/diver day. This is slightly below the levels reported in 1980, 1981, and 1982, and below the levels recorded during the period 1977 to 1979. The year 1983 was the second year that the reported total catch did not reach the allowable coast-wide catch.

Biagi, M. (2004). Hatchery techniques for Northern Abalone. 2. Larval development and juvenile culture. *Hatchery International,* 5(3), 10-11. Retrieved from https://europepmc.org/article/AGR/IND43658108

The successive stages of larval development are trochophore, veliger, and juvenile, however, before inducing the abalone to spawn, it is important to have everything ready to receive the larvae, since the planktonic phase is quite short. Most important are the settlement plates. These must be constructed well ahead of time, and conditioned with benthic diatoms prior to larval settlement. Although there are other techniques, we used corrugated PVC plates assembled into settlement 'condos' (condominiums). Each has 15 plates, 45.7 cm. (18 inches) square, mounted 2.5 cm apart for a total surface area of about 7 m' per condo. The plates must be of PVC or other non-reactive plastic. Fibreglass is not acceptable because the juvenile abalone will eat the glass along with the bacterial and diatom film that covers the plates once they are properly conditioned. Plates were mounted in 47 .5 cm (18") lengths of 10 cm. (4") PVC pipe that had been cut in two, lengthwise and notched at 2.5 cm intervals. The corners of the corrugated plates were inserted into the notches, and a plastic rod threaded through holes drilled in the corner of each plate to secure them in place. This allows the condos to be dismantled easily for cleaning and storage, and reassembled when needed again. The condos should be arranged in the settlement tank so that the plates are horizontal, and with a minimum of 10 cm clearance from the sides and bottom of the tank and surface of the water. Conditioning is accomplished simply by filling the tank with running seawater. Given direct sunlight, diatoms begin to settle on every surface of the condo.

Bourne, N. (1972). Molluscan aquaculture in British Columbia. *Bulletin of the American Malacological Union for 1971*, 25-27. Retrieved from https://www.biodiversitylibrary.org/page/52551098

The 15,000 miles of British Columbia coastline extends from latitudes 48 20' to 54 40' N and has many fiords and inlets which provide much protected water. Approximately 800 species of mollusks have been recorded from these waters but only six enter the commercial fishery and but one, the Pacific oyster (Crassostrea gigas Thunberg), is cultured.

One species of gastropod (of approximately 450), the British Columbia abalone (Haliotis kamtschatkana Jonas), is harvested commercially. The fishery is small (annual landings less than 20,000 lbs) and sporadic, and it is unlikely this species can be cultured economically in the immediate future.

Bourne, N. F. (1997). Molluscan Fisheries of British Columbia. In *The history, present condition, and future of the molluscan fisheries of North and Central America and Europe. Volume 2 : Pacific coast and supplemental topics.* C. L. MacKenzie, V. G. Burrell, A. Rosenfeld, & W. L. Hobart (Eds.), (pp. 115-130): National Marine Fisheries Service Retrieved from https://repository.library.noaa.gov/view/noaa/3028

Mollusks have long been important to Native Americans, being used for food, decoration, and money. They also were important to early settlers. Commerical fisheries for mollusks are relatively small, but they form an important part of the heritage and economic viability of many coastal communities. In addition to the commercial fisheries that began in the late 1800's, mollusks proved important recreational fisheries. The only gastropod harvested commercially is the northern abalone, *Haliotis kamtschatkana*. In 1990, 97.5% of mollusks landed were comprised of bivalves. Three species of oysters have been harvested: Olympia, *Ostrea conchaphila*; eastern, *Crassostrea virginica*; and Pacific, *G. gigas*. Four species of clams comprise nearly all the intertidal clam landings: Razor, *Siliqua patula;* butter, *Saxidomus giganteus*; littleneck, *Protothaca stamina;* and Manila, *Tapes philippinarum*. A recent development is a fishery of subtidal clam stocks, primarily geoducks, *Panope abrupta*, but also for two species of horse clams, *Tresus capax* and *T. nuttallii.* There is considerable interest in clam culture. Four species of scallops have been or are harvested commercially: Weathervane, *Patinopecten caurinus*; rock, *Crassoderma gigantea*; and pink, *Chlamys rubia* and *C. hastata*. Landings of mussels, *Mytilus edulis* and *C. californianus*, have been minor. In recent years, mollusk landings have been increasing as markets have expanded. In 1990, the total landed weight of mollusks in commercial fisheries was 11,258 metric tons. The future of these fisheries appears promising.

Breen, P. A. (1979). *Observations of the commercial abalone fishery made from the patrol vessel Cutter Rock, April 13-21, 1979*.Confidential report series (43). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/365672.pdf

The purpose of this trip was to observe the abalone fishery in action. There were several reasons I wanted to do this: a.) I had no previous firsthand knowledge of the techniques used in finding and collecting abalone by commercial interests; b.) In our surveys , we could only guess at what constitutes a

population of commercial abundance; so I wanted to see the abundance of abalone that fishermen operate on; c.) I wanted to spot some fished areas (areas that I saw being fished, rather than reading about them on logsheets) for study sites; d.) I wanted to see whether there were damaging practices, particularly in the handling of sub-legal abalone, being carried out by the fleet; e.) I wanted to measure abalone abundance ahead of and behind a commercial operation, in order to see what the intensity of fishing is.

Breen, P. A. (1980). *Measuring fishing intensity and annual production in the abalone fishery of British Columbia*. Canadian Technical Report of Fisheries and Aquatic Sciences (947). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/17423.pdf

This report presents an analysis of abalone (Haliotis kamtschatkana ) survey data collected up to the end of 1978 on the north half of the B.C. coast. It was concluded that legal abalone have decreased in abundance by about 60% since 1976, but that much greater decreases can be observed in places with locally intense fishing. Natural mortality rate was estimated by two methods to be around 0.24. The von Bertalanffy growth parameters were estimated. The present minimum legal length of 101.6 mm is above the critical size; so theoretical maximum sustainable yield is simply the biomass of recruiting individuals. This was estimated and used to calculate the theoretical maximum sustainable yield for the north coast of B.C. Differences were found between abalone populations in different ecological communities, defined on the basis of the dominant kelp species present. From the pattern of these observations, it could be concluded that final size, and probably growth rate, are determined by food availability; but also that abalone abundance is not determined by food supply.

Calderwood, G. (1985). *Technological advances in the field of abalone mariculture: final report, 1982-1985.* P. T. M. Ltd., Victoria, BC. Retrieved from https://www.worldcat.org/title/technological-advances-in-the-field-of-abalone-mariculture-final-report-1982-1985/oclc/38160074&referer=brief_results

No abstract available.

Campbell, A. (1997). *Possible criteria for re-opening the northern abalone fishery in British Columbia*. Canadian Stock Assessment Secretariat Research Document (97/64). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/243183.pdf

This paper reviews the literature for relevant biological and fishery characteristics of different abalone species, makes yield and egg per recruit calculations and suggests biological reference points, criteria for reopening a potential fishery, and possible rehabilitation and management actions for the northern abalone, Haliotis kamtschatkana, in British Columbia. The biology of the H. kamtschatkana makes this species vulnerable to over exploitation. The northern abalone is slow growing, relatively long lived and sedentary, and has low or sporadic recruitment with accumulations of older individuals distributed in shallow water locations easily accessible to harvesters. The high market value, reduced availability, and

the difficulty of enforcing the fishery closure since 1990 in a large mostly uninhabited coastal area, has encouraged illegal harvesting of northern abalone populations, hampering attempts to rebuild stocks to a level that would allow a sustainable legal harvest. Evidence to date, from surveys in the central coast of British Columbia and Queen Charlotte Islands, indicate that there has been insufficient recruitment during the last two decades to maintain estimated fishing rates (F) during 1976-90 when the legal fishery was open (mean F about 0.5) and during the closure 1990-94 (F ranged from 0.1 to 0.7 in some locations). Samples from abalone illegally harvested during 1995 suggested that poachers removed all sizes of available abalone with no regard to the minimum size limit of 100 mm shell length that was in force during the legal fishery. Without size and fishing rate controls, egg per recruit (EPR) analyses suggested that egg production, during the closed fishery, could probably be at or less ( 50%EPR have been sustained; other fisheries that conserved lower egg production have suffered poor recruitment, stocks have declined and many fisheries closed. However, because of the difficulties of showing a stock-recruitment relation, predicting how environmental / ecosystem changes influence abalone stock dynamics, and ongoing poaching problems, there are no guarantees that various rebuilding / rehabilitation strategies will work.

Chandler, P. C., King, S. A., & Boldt, J. (2017). *State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2016*. Canadian Technical Report of Fisheries and Aquatic Sciences (3225). Sidney, B.C.: Fisheries and Oceans Canada, Retrieved from https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2016/index-eng.html

Fisheries and Oceans Canada is responsible for the management and protection of marine resources on the Pacific coast of Canada. Oceanographically this area is a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions. There is strong seasonality and considerable freshwater influence, and an added variability from coupling with events and conditions in the tropical and North Pacific Ocean. The region supports ecologically and economically important resident and migratory populations of invertebrates, groundfish, pelagic fishes, marine mammals and seabirds.

Since 1999 an annual State of the Pacific Ocean meeting has been held by DFO scientists in the Pacific region to present the results of the most recent year's monitoring in the context of previous observations and expected future conditions. The workshop to review conditions in 2016 was held March 22 and 23, 2017 at the Mary Winspear Centre near the Institute of Ocean Sciences, Sidney, B.C. This technical report includes submissions based on the ten-minute presentations given at the meeting.

Ocean temperatures along the B.C. coast were above the 1981-2010 average, but this warm water anomaly did not set records as in 2015. As the year progressed the temperature anomaly decreased and the upwelling of cool nutrient rich waters along the west coast of Vancouver Island marked a return to conditions more favourable for productivity and fish growth. The returns of most B.C. Sockeye Salmon stocks in 2016 were higher than expected and higher than the long term averages. The returns of Fraser sockeye in 2016, expected to be low, set an historic low record.

A special session focused on ecosystem reporting processes. Several experts from a variety of government and non-government groups in both Canada and the U.S. provided overviews of the processes they use for ecosystem reporting.

D'Armengol, L., Castillo, M. P., Ruiz-Mallén, I., & Corbera, E. (2018). A systematic review of co-managed small-scale fisheries: Social diversity and adaptive management improve outcomes. *Global Environmental Change,* 52, 212-225. https://doi.org/10.1016/j.gloenvcha.2018.07.009

Small-scale fisheries are an important source of livelihoods, particularly among poor coastal populations. To improve fisheries' condition and maximize their contribution to human welfare, co-management approaches have proliferated worldwide. In this article, we conduct a systematic review of academic literature to examine the context and attributes of co-management initiatives in small-scale fisheries, and their expected outcomes. The review suggests that a supporting legal and institutional framework facilitates the emergence of co-management, because it contributes to clarify and legitimize property rights over fish resources. It is also found that co-management delivers both ecological and social benefits: it increases the abundance and habitat of species, fish catches, actors' participation, and the fishery's adaptive capacity, as well as it induces processes of social learning. Furthermore, co-management is more effective if artisanal fishers and diverse stakeholders become involved through an adaptive institutional framework. However, the review also suggests that more research is needed to discern when co-management initiatives can transform pre-existing conflicts, challenge power asymmetries and distribute benefits more equitably.

Farlinger, S., & Campbell, A. (1992). Fisheries management and biology of northern abalone, *Haliotis kamtschatkana*, in the northeast Pacific. In *Abalone of the world: biology, fisheries, and culture.* S. A. Shepherd, M. J. Tegner, & S. A. Guzman del Proo (Eds.). Oxford: Fishing News Books Retrieved from https://www.worldcat.org/title/abalone-of-the-world-biology-fisheries-and-culture/oclc/24694338

Northern abalone are harvested in commercial dive, native food and sports fisheries in the northeast Pacific. Commercial abalone landings in Alaska and British Columbia (BC) increased rapidly in the late 1970s, but have since declined to low levels. Catch per unit effort has generally declined in BC during 1977-86 and stabilized at low levels. For Washington State there are only recreational and native food fisheries for which few landing data are available. Fishery management in BC is conservative and includes vessel quotas, whereas in Alaska area quotas are used. The total annual quota has been reduced to the present 47t for BC and 15-26t for Alaska. The reductions in landings and quota in BC have decreased the number of vessels and increased the unit price ($/kg) at a greater rate than the consumer price index, making the fishery lucrative for both legal and illegal participants. Abalone stock assessment in BC invovles bi- or triennial dive surveys to provide indices of abundance from which quotas can be adjusted. A 1989 resurvey of a major fishing area in BC suggested a further decline in both legal and pre-recruit abundance indices. Future research should focus on factors affecting recruitment and an evaluation of the survey methodology and size limit.

Fedorenko, A. Y., & Sprout, P. E. (1982). *Abalone biology, fishery regulations, commercial catch (1952-1980), and current state of resource in British Columbia*.Canadian manuscript report of fisheries and aquatic sciences (1658). Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/454836/publication.html

Landings of northern abalone (Haliotis kamtschatkana ) in British Columbia have expanded greatly since 1976, with 1,474 m.t. harvested during 1976 to 1980. By late 1970's, the abundance of legal-sized abalone has declined by 60 - 85%. This report reviews the biology of northern abalone, world-wide production and trading of abalone, and its aquaculture; examines the development of commercial abalone fishery in B.C.; reviews management strategies in B.C., especially from 1976 to 1980; summarizes the annual landings by Statistical Area during 1952-1980, emphasizing catch trends and fishing effort in the last five years; examines biological studies in fishery management of abalone; and makes recommendations for a more viable abalone fishery in B.C.

Foster, N. R. (1997). The Molluscan Fisheries of Alaska. In *The history, present condition, and future of the molluscan fisheries of North and Central America and Europe. Volume 2 : Pacific coast and supplemental topics.* C. L. MacKenzie, V. G. Burrell, A. Rosenfeld, & W. L. Hobart (Eds.), (pp. 131-144): National Marine Fisheries Service Retrieved from https://repository.library.noaa.gov/view/noaa/3028

Alaska's long coastline and broad continental shelf support large populations of mollusks. Commercially harvested mollusks are abundant on the south coast of the Alaska peninsula and further south, but they are scarce on western coasts facing the Bering Sea. Weathervane scallops, *Patinopecten caurinus*, and razor clams, *Siliqua patula* and *S. alta*, have dominated the landings, but others such as butter clams, *Saxidomus giganteus*; cockles, *Clinocardium nuttalli*; ovsters, *Crassostrea gigas*; abalone, *Haliotis kamtschatkana;* geoducks, *Panope abrupta*; and mussels, *Mytilus edulis* or *M. trossulus,* have also been important. Between the 1970's and 1987, the Japanese potted large quantites of whelks (*Neptunea pribilofensis, Buccinum angulosum, B. scalariforme*, and other species) in the Berin Sea. The fisheries for butter clams, cockles, and Bering Sea whelks have since nearly disappeared. Alaska's earliest inhabitants harvested the abundant bivalves, snails, and chitons along with other sea life, and Native residents today continue to harvest mollusks in intertidal zones as subsistence foods. Weathervane scallops are harvested by large sea-going vessels using dredges and modified beam and otter trawls. Fishermen once dug large quantities of razor clams on beaches using shovels and took them to canneries for sale, but that fishery has become much smaller because of contamination by parlaytic shellfish poison (PSP). In 1991 the value of scallops, oysters, mussels, clams, abalone, and whelks was just over $3 million, most from the scallop fishery. The culture of oysters, mussels, and scallops has some promise as Alaska's waters are productive and relatively free of pollutants.

Gaumer, T. F. (1976). *Methods of supplementing clam and abalone production. Completion report July 1, 1973 to June 30, 1976*. Technical report. Retrieved from https://ir.library.oregonstate.edu/concern/technical_reports/6395w758c

Clam surveys have been conducted in Oregon's estuaries since 1973. During this project period primary objectives were (1) to locate suitable intertidal and subtidal clam planting sites and to determine the feasibility of planting laboratory spawned clams; (2) to determine the potential for a subtidal clam fishery in Oregon; (3) to develop techniques for spawning and rearing clams, (4) to refine techniques for aging clams, (5) to develop appropriate subtidal clam management schemes applicable on a coastwide basis, and (6) to determine the feasibility of purchasing and planting juvenile red abalone along the Oregon coast.

Jamieson, G. S. (1983). Commercial catch sampling: A review of its usage in the management of contagiously distributed subtidal mollusc species. In *Sampling Commercial Catches of Marine Fish and Invertebrates: Proceedings of a Workshop held at Ottawa, February 23-25, 1982.* W. G. Doubleday & D. Rivard (Eds.), (pp. 240-248): Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs41-31-66.pdf

The quality and usage in management of commercial cath sampling data are discussed for three major Canadian subtidal mollusk fisheries: sea scallop, Placopecten magellanicus , abalone, Haliotis kamtschatkana , and geoduc clams, Panope generosa . Atlantic sea scallop catch data have been collected since 1970, but the frequent inability to identify the precise fishing location of a subsample and the lack of a statistically rigorous sampling design impedes data usage. In British Columbia, both abalone and geoduc fisheries are relatively recent, and little catch sampling has occurred. The potential, value, and usage of commercial catch data in all three fisheries are discussed, and it is suggested that with present programs, commercial catch sampling of these species should be of low priority.

Jamieson, G. S. (1984). *1982 Shellfish management advice, Pacific region*.Canadian manuscript report of fisheries and aquatic sciences Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/455486/publication.html

Biological advice given to resource managers by staff of the Shellfish Section in December, 1982 is presented as a series of documents. Topics discussed include the status of abalone (Haliotis kamtschatkana ) and pink shrimp (Pandalus jordani ) stocks; minimum size limits recommendations for prawns (P. platyceros ), sea urchins (Stronglyocentrotus franciscanus ), and scallops (Patinopecten caurinus , Chlamys rubida and C. hastata ); and obsrvations on British Columbia sea otter (Enhydra lutris ) abundance.

Jones, L., & Bixby, M. (2003). Abalone. In *Managing fish: ten case studies from Canada's Pacific coast.* (pp. 11-20). Vancouver, BC: Fraser Institute Retrieved from https://www.fraserinstitute.org/sites/default/files/ManagingFish.pdf

Abalone is a type of marine snail, related to other molluscs including scallops, squid, and clams (DFO 2000b). Northern or “pinto” abalone (Haliotis kamtschatkana), the only abalone species found on the Pacific coast of Canada, is one of over 90 varieties found around the world (Fedorenko 1982: 4). Abalone is found close to shore and is harvested by divers for its meaty “foot,” which is considered a delicacy in many Asian countries. Most of the abalone harvested on Canada’s Pacific coast prior to the 1990 fishery closure was sold to Japan. Northern abalone is found off the west coast of North America from Baja California to Alaska.

Koss, P. A. (1987). *A case study of the British Columbia abalone fishery.* (Master of Arts Thesis), Simon Fraser University, Burnaby, BC. Retrieved from http://summit.sfu.ca/item/4560

The price of British Columbia abalone increased dramatically in 1976 as a result of a surge in Japanese demand. Since then, the British Columbia abalone fishery has undergone a number of regulatory changes in an attempt to improve the efficiency of harvesting the resource. Although current rationalization techniques have met with some success, a potential for improvement remains. This analysis estimates the optimal level of exploitation by first deriving the yield-effort curve for the fishery, and then evaluating the long-run revenues associated with that curve. The results indicate that the application of effort exceeds that which is required to obtain the optimal level of sustainable rent from the fishery. A critique of past and current management regimes is provided.

A review of the property rights and contracting literature suggests that a system of private property rights is liable to effect a more efficient allocation of resources than one in which individual private property is non-existent or ill-defined. A number of property-right structures are considered. After reviewing the potential costs and benefits associated with each contractual arrangement, the analysis concludes that a leasing arrangement in which rights are transferable represents a potentially superior alternative to the present system of individual quota management.

Lee, L. C., Reid, M., Jones, R., Winbourne, J., Rutherford, M., & Salomon, A. K. (2019). Drawing on indigenous governance and stewardship to build resilient coastal fisheries: People and abalone along Canada's northwest coast. *Marine Policy,* 109. https://doi.org/10.1016/j.marpol.2019.103701

Small-scale indigenous abalone fisheries on the northwest coast of Canada persisted for at least two millennia prior to modern commercial and recreational fisheries that lasted for four decades before collapsing, causing a coast wide closure that remains today. What traditional governance and stewardship practices fostered resilient fisheries along Canada's northwest coast and how might they inform collaborative institutions that foster ecologically sustainable and socially just coastal fisheries in future? In collaboration with two coastal First Nations, a policy analysis of northern abalone (GaalGuuhlkyan -Skidegate Haida, galgniq -Heiltsuk, Haliotis kamtschatkana) stewardship was conducted to assess where traditional and modern fisheries governance and management aligned or failed to align with seven theoretical principles of social-ecological resilience. The analysis revealed that traditional principles of reciprocity and contingent proprietorship of clan-based fishing areas aligned with resilience principles whereas contemporary centralized decision-making and region-wide management policies did not. Moreover, current issues of power asymmetry and lack of trust need to be addressed to build a future indigenous-state governance approach to coastal fisheries. This research demonstrates how indigenous resource governance and stewardship practices generated over millennia of social learning and experimentation offer insights that could be broadly applied to foster resilient coastal fisheries today.

Lessard, J., Campbell, A., & Hajas, W. C. (2002). *Survey protocol for the removal of allowable numbers of northern abalone,* Haliotis kamtschatkana*, for use as broodstock in aquaculture in British Columbia*.Canadian Science Advisory Secretariat (2002/126). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/273275.pdf

A survey protocol and methodology to determine abalone abundance have been in use for the last three years. The present paper reviews the data collected during 6 surveys for broodstock purposes and uses

these data to determine the appropriate level of removal. The proposed survey protocol and broodstock removal considerations are discussed. These surveys provide little evidence of recovery of abalone populations. During abalone broodstock collections, more abalone were harvested than the allowable 1% of the calculated population under the initial protocol at several sites. As part of a precautionary approach, the recommended maximum number of abalone to be removed for broodstock is 1% of the lower 90% confidence limit on the estimated population in the size range of 81-120 mm shell length. Abalone is a threatened species and all removal of abalone from the wild should be carefully considered.

Mills, D. D. (1982). *The procurement and use of abalone in Southeast Alaska*. Alaska Department of Fish and Game, Division of Subsistence Retrieved from https://www.arlis.org/docs/vol1/10988587.pdf

This report describes the non-commercial procurement and uses of abalone in Southeast Alaska. Patterns of harvest and use in the communities of Hydaburg, Klawock, and Craig are described and discussed in Part I of this study. Descriptions of use in Ketchikan and Sitka, which will supplement this report as Part II, will be distributed at the Board of Fisheries meeting.

Obradovich, S. G., Hansen, S. C., Zhang, Z., MacNeill, S., Nichol, L. M., Rooper, C. N., . . . Barton, L. L. (2021). *Pre-COSEWIC review of DFO information on Northern Abalone (*Haliotis kamtschatkana*) along the Pacific Coast of Canada*. Canadian Science Advisory Secretariat (CSAS) Research Document (2020/001). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.899136/publication.html

This review presents updated DFO data on Northern Abalone (Haliotis kamtschatkana) for use in a Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report. Northern Abalone were frst designated as “Threatened” in 1999 by COSEWIC and re-designated as “Endangered” in 2009, and have been legally listed as “Endangered” under the Species At Risk Act since 2009. Northern Abalone occur from Salisbury Sound, Alaska to Bahía Tortugas, Baja California. Genetic studies show no evidence for more than one population of Northern Abalone in BC. Adults generally occupy exposed and semi-exposed coastal waters of less than 10 m depth, but have been observed from the low intertidal zone to 40 m depth. The extent of occurrence in BC waters was estimated at 6,985 km2 based on a recently developed habitat suitability index model. The largest recorded shell length for a Northern Abalone in BC is 165 mm. Northern Abalone reach 50 mm in 2-5 years and 100 mm in 6-9 years. Fifty percent of individuals are sexually mature around 50 mm and 100% are mature at 70 mm. Estimated total mortality (0.20 – 0.50 y-1), varied by region and with the presence/absence of Sea Otters (Enhydra lutris). All fsheries for Northern Abalone have been closed since 1990, including commercial, recreational, and First Nations’, but illegal harvest continues to be a major concern for this species. Density time series based on the DFO Northern Abalone Index Site Surveys show that estimated Northern Abalone densities have declined since the start of the time series (1978 in Northern BC), but have shown recent large increases in juvenile (shell length ≥ 20 mm to < 70 mm) densities and small increases in adult (≥ 70 mm) densities in Northern BC. However, the survey is marked by high variability in observed and estimated densities. Densities from a repeated transect survey near Kitkatla, BC, in 2000 and 2016, show similar trends to the densities estimated from the DFO Northern Abalone Index

Site Surveys in Northern BC. Patterns are less clear in Southern BC where densities are much lower and have not shown large increases in any size category.

Olsen, S. J. (1984). *Completion report on invertebrate aquaculture: Shellfish Enhancement Project, 1978-1983*. Washington State Department of Fisheries, Olympia, WA. Retrieved from https://www.worldcat.org/title/completion-report-on-invertebrate-aquaculture-shellfish-enhancement-project-1978-1983/oclc/20832009&referer=brief_results

Pearce, C. M., Agerup, P., Alabi, A., Renfrew, D., Rosser, J., Whyte, G., & Yuan, F. (2003). Recent progress in hatchery production of pinto abalone, Haliotis kamtschatkana, in British Columbia, Canada. In *Proceedings of the Workshop on Rebuilding Techniques for Abalone in British Columbia.* A. Campbell & L. D. Hiemstra (Eds.), (pp. 29-44). Nanaimo, BC: Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2482-eng.pdf

In July 1999, Fisheries and Oceans Canada issued a Request for Proposals for 18-month pilot projects that would develop land-based hatchery rearing techniques for the pinto abalone, Haliotis kamtschatkana. A percentage of the cultured juveniles produced were to be utilised for wild stock rebuilding. Six projects were initially approved and five proceeded with the collection of wild broodstock for the purpose of developing hatchery techniques. Of these projects, three were successful at rearing substantial numbers of juveniles. Their techniques for broodstock conditioning, spawning, larval rearing, larval settlement, and early juvenile grow out are summarised in this review paper. Adult broodstock were conditioned with wild kelp (Laminaria saccharina, Macrocystis integrifolia, Nereocystis luetkeana) and spawned using hydrogen peroxide, temperature shock, and/or UV-treated seawater. Larvae were reared in flow-through or static systems at 11-15'C at a density of 1-9 larvae ml super(-1) and settled on wavy or flat plastic sheets covered with natural biofilms of various ages. Early juveniles fed on benthic diatoms and were later converted to kelp and or prepared diets. Grow out time to commercial size is predicted to be four to six years. To date, these three projects have produced approximately 170,000 juvenile abalone of various sizes.

Rumble, J., & Hebert, K. (2011). *Report to the Board of Fisheries, miscellaneous dive fisheries.* Fishery management report ( 11-59). Anchorage, AK Retrieved from http://www.adfg.alaska.gov/static/regulations/regprocess/fisheriesboard/pdfs/2011-2012/se_shellfish/fmr11-59.pdf

The commercial dive fisheries in the Southeast Region (Registration Area A/Southeast Alaska and Registration Area D/Yakutat) are a group of fisheries targeting geoduck clams, red sea urchins, sea cucumbers, and abalone. The common feature of these fisheries is that all are limited to hand picking by diving. With the exception of abalone, all of the dive fisheries have well developed management plans, with abundance-based stock assessment programs at their core. Most development of these fisheries has occurred since the 1990's, making the dive fisheries relatively new to Alaska. The Alaska Department of Fish and Game works closely with the Southeast Alaska Regional Dive Fisheries Association (SARDFA),

to develop management plans for these fisheries. SARDFA is a non-profit organization that represents limited entry permit holders of the dive fisheries, and that generates funds for management, research, and the promotion of dive fisheries. Sea otters pose a major threat to the dive fisheries in Southeast Alaska. The department has documented substantial declines in population levels of sea cucmber, sea urchins, and geoducks in areas occupied by sea otters. Consequently, guideline harvest levels have been reduced, and some areas have been closed to commercial harvest.

Sill, L. A., & Koster, D. (2017). *The harvest and use of wild resources in Haines, Hoonah, Angoon, Whale Pass, and Hydaburg, Alaska, 2012*. Technical Paper (No. 399). Alaska Department of Fish and Game Division of Subsistence Retrieved from https://www.arlis.org/docs/vol1/M/993708884.pdf

This report provides updated information about the harvests and uses of fish, wildlife, and wild plant resources by the community of Sitka. During February and March 2014, eligible households in Sitka answered questions about their harvest and use of fish, wildlife, and wild plants in 2013. Through these household surveys, researchers: 1) estimated annual harvests and uses of wild fish, wildlife, and wild plant resources in a 12-month study period by residents of the study community; 2) mapped areas used for hunting, fishing, and gathering; 3) collected demographic and income information; and 4) evaluated trends in wild resource harvests. During the 2013 study year, most Sitka households used and harvested wild resources both for nutrition and to support their way of life. Sitka residents used a large variety of resources, harvested throughout much of Baranof Island, including salmon and other fish, marine invertebrates, large land mammals, marine mammals, and wild plants and berries, as well small land mammals, migratory waterfowl, and upland game birds. The total estimated harvest of wild foods for Sitka in 2013 was 1,377,571 usable pounds (175 lb per capita), slightly less than the previous harvest estimate but likely not a significant difference. Results indicate that the use, harvest, and sharing of wild resources remain important to the community. Funding for the study was provided through the Alaska State Legislature as one component of an overall index community program, the purpose of which is to develop and implement a program to monitor subsistence harvests of fish and wildlife in all areas of the state through a system of index communities. The project was conducted collaboratively by research staff of the Division of Subsistence, Alaska Department of Fish and Game, and the Sitka Tribe of Alaska.

Sloan, N. A., & Breen, P. A. (1988). *Northern abalone,* Haliotis kamtschatkana*, in British Columbia: fisheries and synopsis of life history information*. Canadian Special Publication of Fisheries and Aquatic Sciences (103). Nanaimo, BC: Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.816448/publication.html

A comprehensive review of the life history and fisheries for the northern abalone, Haliotis kamtschatkana Jonas 1845, is presented with special emphasis on British Columbia populations. The literature on northern abalone throughout its range is discussed and compared with the literature on life histories of other Haliotis species worldwide. The exploitation (commercial/recreational/native) and management of northern abalone resources are described. The commercial northern abalone fishery is a minor one in British Columbia with populations fully exploited. There is some evidence that the a recent history of declining population abundance may be abating. Local commercial exploitation by divers expanded rapidly in the late 1970s (peaking at 433 t in 1978), but is now conducted at a much

reduced level (quota of 47.2 t in 1987). Reasons for population decline are discussed and key gaps in life history data are identified. We conclude that the highest research priority for northern abalone should be to determine factors affecting recruitment.

Sprout, P. E. (1983). *Review of 1981 Commercial Abalone Fishery in British Columbia*.Canadian Manuscript Report of Fisheries and Aquatic Sciences (1692). Prince Rupert, BC: Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/34275.pdf

The 1981 commercial abalone fishery harvested 93,651 kg (206,470 lbs). Most of the catch was taken in Area 6 (40% of total B.C. catch), with lesser amounts in Area 2E (23%) and Area 12 (10%). Abalone fishing effort by Statistical Area varied widely and averaged 133 kg/diver day. This is similar to the level reported in 1980, but is down from the levels recorded during the period 1977 to 1979.

Straus, K. M. (2010). *Shellfish aquaculture and conservation of two Puget Sound molluscs: The Pinto abalone (*Haliotis kamtschatkana kamtschatkana*) and the Pacific geoduck (*Panopea generosa*).* (Ph.D. Dissertation), University of Washington, Seattle, WA. Retrieved from http://wsg.washington.edu/wordpress/wp-content/uploads/publications/Strauss-Kristi-Dissertation.pdf

I examined aquaculture and conservation oftwo taxa native to Washington, USA (WA): Pinto abalone {Haliotis kamtschatkana kamtschatkana) and Pacific geoduck {Panopea generosa). Because pinto abalone populations continue to decline in WA despite fisheries closures, conservation aquaculture may be necessary. To determine appropriate culture methods, juveniles were reared in habitat-enriched or conventional tanks. No differences in survivorship or growth were observed but abalone behavior differed between rearing treatments. Abalone from habitat-enriched tanks changed habitats more often and spent different proportions oftime in available habitats. Results demonstrate that rearing conditions affect abalone behavior and should be considered for abalone restoration. Abalone are commonly misidentified, increasing the challenge of abalone management and conservation. I developed sequence-based genetic markers for species identification of Eastern Pacific abalone. I applied these tools and determined that flat abalone (H. walallensis) are a cryptic species in WA. Several individuals collected for the pinto abalone conservation aquaculture program were identified as flat abalone. Use ofthese individuals as broodstock may have led to interspecific hybridization and been detrimental to pinto abalone restoration. Results highlight the importance ofmolecular tools in abalone management, especially if conservation aquaculture is used.

To examine the potential genetic implications of geoduck aquaculture, I used five microsatellite loci to conduct two studies comparing genetic diversity in wild and cultured geoducks. In both studies, cultured geoduck showed reduced genetic diversity and effective number of breeders (Nb)- In one study, I examined geoduck seed produced in two hatcheries. Parentage assignment revealed that in one hatchery, many parents contributed to each seed cohort, with the largest full-sib family comprising 11-31% ofthe offspring. In contrast, 94% ofthe seed from the second hatchery were from a single fullsib family. In a complementary study, I examined five year classes of cultured geoducks. Sibship assignment revealed that year classes were comprised of nine to 25 full-sib families and many individuals unrelated to others at the full-sib level. Results from both studies demonstrate that hatchery practices affect

genetic diversity; these results may aid in developing geoduck culture practices that minimize genetic risk to wild populations.

Straus, K. M., & Friedman, C. S. (2009). Restoration aquaculture of the pinto abalone (*Haliotis kamtschatkana kamtschatkana* Jonas): impacts of rearing method on behaviour, growth and survivorship in the hatchery. *Marine and Freshwater Research,* 60(10), 1021-1028. https://doi.org/10.1071/mf08262

Pinto abalone (Haliotis kamtschatkana kamtschatkana) populations in Washington State (USA) and British Columbia (Canada) continue to decline despite fisheries closures. For successful recovery, supplementation may be necessary. To determine appropriate culture methods, juveniles were reared in habitat-enriched tanks (supplemented with rocks, macroalgae and sea urchins) or conventional aquaculture tanks and assessed for growth and survivorship in the laboratory over 15 months. No differences in survivorship or growth were observed. Subsequent experiments examined whether abalone behaviour (habitat selection and movement patterns) differed between rearing treatments. Abalone were exposed to one of three predator treatments (sea star arm, small crab, or no predator (control)) and filmed for 8 h. Abalone from habitat-enriched tanks changed habitats significantly more often than abalone from conventional tanks regardless of predator treatment. Significant differences in the percentage of time that abalone occupied the various habitats were also observed. Abalone in the sea star and control treatments primarily occupied the rocks, whereas abalone in the crab treatment behaved differently depending on the rearing method; conventionally reared abalone spent more time in corners, whereas abalone from habitat-enriched tanks spent more time exposed. These results demonstrate that rearing conditions can affect abalone behaviour and should be considered for abalone restoration efforts worldwide.

Whyte, G. (1988). *Abalone aquaculture on the Pacific Coast and its applicability to Alaska.* Paper presented at the Fourth Alaska Aquaculture Conference, Sitka, AK. Retrieved from https://www.proquest.com/conference-papers-proceedings/abalone-aquaculture-on-pacific-coast/docview/15976926/se-2?accountid=28258

Haliotis kamtschatkana is the local British Columbia species of abalone; it is the same one that occurs in the kelp beds in Alaska. In 1977 British Columbia produced close to a million pounds of abalone. Since 1983, an equal quota system of 104,000 pounds has been in effect. The 26 licensed harvesters get 4,000 pounds apiece. If they could harvest at the 1977-78 levels, it would be an $8 million industry. But now it's an $800,000 industry. Harvesting size for native abalone in British Columbia is 4 inches. 43 to 45% edible meat is obtained from the abalone, which is the most expensive shellfish in British Columbia.

Yamada, S., Zhao, B., & Hirayama, N. (1989). On the catchability coefficient of abalone fisheries. [Awabi Saiho Gyogyo no Gyokaku Noritsu ni tsuite ]. *Journal of the Tokyo University of Fisheries* 76(1-2), 7-17. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/119064.pdf

In this paper we tried to estimate how seriously fishermen's experiences and skill explains the catchability coefficient of abalone fishing by diving. First we found the principal components of the weather and price data, and then adopted them as explanation variables of the fluctuation of a model of the catchability coefficient. Our results suggest that the fishermen's experience and skill would explain from 1/3 to 2/3 of the fluctuations. [Translated into English from the original Japanese and re-published as no. 5526 of the Canadian Translation of Fisheries and Aquatic Sciences series in 1991.]

## Section VII – Abalone and Sea Otters

Chadès, I. (2013). Conservation of Biodiversity. In *Markov Decision Processes in Artificial Intelligence.* O. Sigaud & O. Buffet (Eds.), (pp. 375-394) https://doi.org/10.1002/9781118557426.ch12

This chapter examines two biodiversity conservation applications of Markov decision problems. First, it examines the problem of managing an endangered species, the Sumatran Tiger (Panthera tigris sumatrae), which is difficult to observe. Second, the chapter investigates the problem of how to recover two endangered species which interact as predator and prey. Northern abalone (Haliotis kamtschatkana) are the preferred prey of sea otters (Enhydra lutris), both co-habiting along the pacific northwestern coast of Canada and United States. It provides for the first time an optimal recovery strategy for these two species which takes into account their functional relationship using two types of reinforcement learning algorithms over a finite-time horizon. Finally, the chapter discusses the need for further research development in the MDP community to solve challenging optimization problems in conservation biology.

Chades, I., Curtis, J. M. R., & Martin, T. G. (2012). Setting Realistic Recovery Targets for Two Interacting Endangered Species, Sea Otter and Northern Abalone. *Conservation Biology,* 26(6), 1016-1025. https://doi.org/10.1111/j.1523-1739.2012.01951.x

Failure to account for interactions between endangered species may lead to unexpected population dynamics, inefficient management strategies, waste of scarce resources, and, at worst, increased extinction risk. The importance of species interactions is undisputed, yet recovery targets generally do not account for such interactions. This shortcoming is a consequence of species-centered legislation, but also of uncertainty surrounding the dynamics of species interactions and the complexity of modeling such interactions. The northern sea otter (Enhydra lutris kenyoni) and one of its preferred prey, northern abalone (Haliotis kamtschatkana), are endangered species for which recovery strategies have been developed without consideration of their strong predator-prey interactions. Using simulation-based optimization procedures from artificial intelligence, namely reinforcement learning and stochastic dynamic programming, we combined sea otter and northern abalone population models with functional-response models and examined how different management actions affect population dynamics and the likelihood of achieving recovery targets for each species through time. Recovery targets for these interacting species were difficult to achieve simultaneously in the absence of management. Although sea otters were predicted to recover, achieving abalone recovery targets failed even when threats to abalone such as predation and poaching were reduced. A management strategy entailing a 50% reduction in the poaching of northern abalone was a minimum requirement to reach short-term recovery goals for northern abalone when sea otters were present. Removing sea otters had a marginally positive effect on the abalone population but only when we assumed a functional response with strong predation pressure. Our optimization method could be applied more generally to any interacting threatened or invasive species for which there are multiple conservation objectives.

Davis, R. W., Bodkin, J. L., Coletti, H. A., Monson, D. H., Larson, S. E., Carswell, L. P., & Nichol, L. M. (2019). Future Directions in Sea Otter Research and Management. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2018.00510

The conservation and management of sea otters has benefited from a dedicated research effort over the past 60 years enabling this species to recover from a few thousand in the early 20th century to about 150,000 today. Continued research to allow full, pre-exploitation recovery and restoration of nearshore ecosystems should focus on at least seven key challenges: 1) Defining sea otter populations at smaller spatial scales that reflect this species' life history and dispersal patterns; 2) Understanding factors that regulate sea otter population density with a focus on index sites that are representative of the variety of littoral habitats occupied by sea otters around the North Pacific Rim; 3) Quantifying the effects of sea otters on the littoral community with a focus on how food availability limits population and ecosystem recovery and on predicting the effect of sea otter reoccupation on commercially valuable invertebrates; 4) Making sea otter monitoring programs comparable across geo-political boundaries through international collaboration to optimize survey efforts both spatially and temporally and to determine the cause of changes in sea otter demographics; 5) Evaluating the conservation benefits of sea otter reintroductions into historical habitat; 6) Assessing the socioeconomic costs and benefits of sea otter range expansion to anticipate and mitigate conflicts; 7) Recognizing in conservation and management plans that sea otters can be significantly affected by higher level predators in some circumstances. Many of these challenges will require new tools including the next generation geolocation tag technology that will allow assessments of long-range movements, dispersal and gene flow in various populations.

Raum-Suryan, K. L., Pitcher, K. W., & Lamy, R. (2004). Sea Otter, *Enhydra lutris*, Sightings off Haida Gwaii / Queen Charlotte Islands, British Columbia, 1972-2002. *The Canadian Field-Naturalist,* 118(2), 270-272. https://doi.org/10.22621/cfn.v118i2.928

On 27 June 2001 we observed and photographed a Sea Otter ( Enhydra lutris ) adjacent to a Steller Sea Lion ( Eumetopias jubatus ) haulout near Sgang Gwaay (Anthony Island), Haida Gwaii / Queen Charlotte Islands. This is one of only eight documented sightings of Sea Otters in these waters during the past 30 years. These sightings may represent the beginning of the expansion of Sea Otters to their former range off Haida Gwaii.

## Section VIII – Abalone and Indigenous Cultures

Berkes, F., Berkes, M. K., & Fast, H. (2007). Collaborative integrated management in Canada's North: The role of local and traditional knowledge and community-based monitoring. *Coastal Management,* 35, 143-162. https://doi.org/10.1080/08920750600970487

The objective of this article is to take stock of integrated management in the Canadian North, assessing its contribution to the advancement of knowledge and practice regarding the role of indigenous knowledge and community-based monitoring. This is done in three steps. ( 1) The Beaufort Sea, designated a Large Ocean Management Area under Canada's Oceans Action Plan, is used as an example of a consultative planning process, with special attention to indigenous peoples. ( 2) How specifically can indigenous knowledge contribute to integrated management? The problem of Arctic marine food web contamination is used to illustrate the strengths and limitations of traditional ecological knowledge and its relationship to science. ( 3) The discussion of community-based monitoring relies on Voices From The Bay study involving the Inuit and Cree of Hudson and James Bay, and Inuit observations of climate change study in the Canadian western Arctic. The examples together address integrated coastal management and the health of ocean ecosystems, showing how stakeholder participation and knowledge to understand and help monitor environmental change

Huntington, H. P., Gearheard, S., Mahoney, A. R., & Salomon, A. K. (2011). Integrating traditional and scientific knowledge through collaborative natural science field research: Identifying elements for success. *Arctic,* 64, 437-445. https://doi.org/10.14430/arctic4143

We discuss two recent projects to examine the role of collaborative environmental fieldwork both in research and in the interactions between academically trained researchers and experienced local residents. The Bidarki Project studied black leather chitons (Katharina tunicata) in the lower Kenai Peninsula, Alaska. Its conclusion that chiton declines are part of a serial decline of intertidal invertebrates drew on collaborative fieldwork, archaeological data, historical records, and interviews with local residents. The Siku-Inuit-Hila Project studied sea ice in Barrow, Alaska; Clyde River, Nunavut; and Qaanaaq, Greenland. Quantitative data from locally maintained observation sites were supplemented by knowledge exchanges among hunters from the communities and by discussion in local working groups to develop an understanding of the physical dynamics and human uses of sea ice at each locale. We conclude that careful planning and preparation, along with the effort to build strong personal relationships, can increase the likelihood that collaborative fieldwork will be productive, enjoyable, and rewarding. © The Arctic Institute of North America.

Jones, R., DeFreitas, B., Sloan, N., Lee, L., von Boetticher, K., & Martin, G. (2003). Abalone stewardship in Haida Gwaii: Forging a long-term commitment. In *Proceedings of the Workshop on Rebuilding Techniques for Abalone in British Columbia.* A. Campbell & L. D. Hiemstra (Eds.), (pp. 5-19). Nanaimo, BC: Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2482-eng.pdf

Local stewardship is a possible solution to the vexing problem of rebuilding over fished northern abalone (Haliotis kamtschatkana) stocks. Abalone fisheries in British Columbia were closed coastwide in

1990 but stocks have failed to rebuild and the species became federally listed as "threatened" in 1999. Three years of community-based stewardship effort in Haida Gwaii to rebuild abalone and prospects for recovery over the long-term are discussed. Steps taken include forging a community partnership through regular meetings of a core group and development of a Community Action Plan. The Action Plan's goal is to rebuild abalone populations sufficiently to support both Haida traditional and recreational food fisheries. Specific initiatives include public education, curricula development, establishment of two large abalone stewardship areas and a research area, creation of an Abalone Watch (coastal surveillance) program and research diving to test rebuilding approaches and monitor recovery.

Jones, R., Rigg, C., & Lee, L. (2010). Haida marine planning: First nations as a partner in marine conservation. *Ecology and Society,* 15. https://doi.org/10.5751/ES-03225-150112

The Haida Nation is involved in an integrated marine planning initiative in northern British Columbia, Canada. The Haida continue to occupy traditional territory in and around Haida Gwaii, or the Queen Charlotte Islands, and are engaged in a larger planning process for the Pacific North Coast Integrated Management Area (PNCIMA). This initiative is in the early planning stage, focused on capacity building and creating enabling conditions for co-governance. Court decisions, government policies, and a modern treaty process are driving short- and long-term efforts to resolve issues of Aboriginal ownership and resource access, both on land and in the ocean. As a result, the PNCIMA process is being led by two levels of government, First Nations and federal, reflecting changing perceptions of Aboriginal title and rights in British Columbia. The Haida have been resource owners and managers on Haida Gwaii for millennia, and continue to apply traditional knowledge and experience to marine-use planning and fisheries management. The Haida approach is place based and guided by fundamental Haida ethics and values such as respect, balance, and reciprocity. We describe these values and discuss the emerging role of First Nations in integrated oceans management in the context of the six themes: lessons from land-use planning; the PNCIMA governance structure; the relationship of values to planning outcomes; developing an ecosystem-based management framework; applications of traditional knowledge, based on a study of Haida marine traditional knowledge currently in progress; and linking marine planning at various scales. On Haida Gwaii, collaborative marine planning is expected to result in improved protection of Haida Gwaii waters for future generations, greater Haida participation in management decisions, and increasing emphasis on sustainability of both local fisheries and communities.

Lee, L. C., Reid, M., Jones, R., Winbourne, J., Rutherford, M., & Salomon, A. K. (2019). Drawing on indigenous governance and stewardship to build resilient coastal fisheries: People and abalone along Canada's northwest coast. *Marine Policy,* 109. https://doi.org/10.1016/j.marpol.2019.103701

Small-scale indigenous abalone fisheries on the northwest coast of Canada persisted for at least two millennia prior to modern commercial and recreational fisheries that lasted for four decades before collapsing, causing a coast wide closure that remains today. What traditional governance and stewardship practices fostered resilient fisheries along Canada's northwest coast and how might they inform collaborative institutions that foster ecologically sustainable and socially just coastal fisheries in future? In collaboration with two coastal First Nations, a policy analysis of northern abalone

(GaalGuuhlkyan -Skidegate Haida, galgniq -Heiltsuk, Haliotis kamtschatkana) stewardship was conducted to assess where traditional and modern fisheries governance and management aligned or failed to align with seven theoretical principles of social-ecological resilience. The analysis revealed that traditional principles of reciprocity and contingent proprietorship of clan-based fishing areas aligned with resilience principles whereas contemporary centralized decision-making and region-wide management policies did not. Moreover, current issues of power asymmetry and lack of trust need to be addressed to build a future indigenous-state governance approach to coastal fisheries. This research demonstrates how indigenous resource governance and stewardship practices generated over millennia of social learning and experimentation offer insights that could be broadly applied to foster resilient coastal fisheries today.

Lee, L. C., Thorley, J., Watson, J., Reid, M., & Salomon, A. K. (2019). Diverse knowledge systems reveal social-ecological dynamics that inform species conservation status. *Conservation Letters,* 12(2). https://doi.org/10.1111/conl.12613

Understanding changes over historical timescales is essential to gauge conservation status of a species. Modern ecological data typically neglect past magnitudes of change, which fortunately can be evaluated by bridging disparate knowledge sources. We synthesized zooarchaeological, historical, traditional, and western science knowledge to document changes in relative abundance of key species in Canada's northern abalone social-ecological system (SES) from the Holocene to present. Integrated models fit to traditional and western science data revealed 3.7% annual population decline from 1940s to 2010s for large abalone, although traditional knowledge density estimates were 9.5x higher than those derived from western science. Abalone are presently scarce compared to the mid-1900s, but more abundant than before the early 1800s, calling their endangered status into question. Linking multiple knowledge sources can build SES understanding, facilitate power sharing, and support ecologically sustainable and socially just conservation outcomes.

Levine, A. S., Richmond, L., & Lopez-Carr, D. (2015). Marine resource management: Culture, livelihoods, and governance. *Applied Geography,* 59, 56-59. https://doi.org/10.1016/j.apgeog.2015.01.016

The management of marine resources is a politically and culturally driven process, shaped by human livelihoods and perceptions, where notions of both space and place shape policies and decision-making in fundamental ways. An emerging sub-field within geography critically explores geographic aspects of marine resource management. However, there has been little work to fully articulate this field and to describe the contributions of geographic methodologies and lenses to understanding marine resource management processes. This special issue provides one of the first collections of geographic papers focused on the socio-cultural and socio-spatial dimensions of marine resource management, emphasizing research that has or can be applied to management and policy discussions. The papers in this issue cover critical topics within this emerging field, examining the combined influences of social, ecological, cultural, political, economic, historical, and geographic factors on how marine spaces and resources are used, perceived, and managed. Important themes include: emerging spatial approaches to marine resource management, human dimensions of marine protected areas, the roles of mapping and GIS, the integration of quantitative and qualitative data, and the varying ways in which marine spaces and places are conceptualized by marine resource users and managers. Issues of marine resource

governance, community engagement, and vulnerability also play key roles in the future of marine resource management. The papers in this issue shed light on space, place, and human-environment interactions in coastal marine systems, making it clear that questions about stakeholder inclusion and representation, particularly in spatial forms, will continue to dominate the field for some time to come. Future research in this field will be fruitfully informed by core geographical heuristics of space, place, and human-environment dynamics.

Mahajan, S. L., Jagadish, A., Glew, L., Ahmadia, G., Becker, H., Fidler, R. Y., . . . Mascia, M. B. (2020). A theory-based framework for understanding the establishment, persistence, and diffusion of community-based conservation. *Conservation Science and Practice*, 1-18. https://doi.org/10.1111/csp2.299

Over decades, biodiversity conservation researchers and practitioners have developed theories and conceptual frameworks to inform the planning, implementation , and evaluation of community-based conservation (CBC). While a diversity of mechanisms for understanding and supporting CBC has helped tailor approaches to local needs and conditions, the absence of a unified lens to understand CBC has limited the capacity for integrating foundational theory into practice more systemically, and for learning across different projects, stakeholders, and institutions. We introduce a theory-based framework called "the CBC framework" that draws upon three foundational theories from sociology , economics, and political science to understand the establishment, persistence , and diffusion of CBC. Experience applying aspects of the framework within different conservation organizations demonstrates how this integrative approach can provide a gateway for practitioners to engage with social science theory to understand the status and context of CBC interventions and efforts.

Mathews, D. L., & Turner, N. J. (2017). Ocean cultures: Northwest coast ecosystems and indigenous management systems. In *Conservation for the Anthropocene Ocean: Interdisciplinary Science in Support of Nature and People.* P. S. Levin & M. R. Poe (Eds.), (pp. 169-199): Academic Press https://doi.org/10.1016/B978-0-12-805375-1.00009-X

Increasingly, ethnoecologists, anthropologists, and conservation biologists are recognizing that Indigenous People of the Northwest Coast and neighboring regions have been astute stewards and managers-not just harvesters and consumers-of the resources and ecosystems on which they have relied. Over thousands of years, these people have developed diverse practices and protocols that have not only sustained, but enhanced the resource species both in quantity and in quality. These practices are based on long-term observation and experience, and are embedded in belief systems, ceremonies, dances, art, and narratives. Here we provide an overview of marine and coastal resource management systems that have been documented to date, and then cite three examples in more detail: clam gardens, salmon production, and estuarine root gardens. These different production systems do not function alone but are components of an entire complex of land and resource management extending across the marine and terrestrial landscapes, "from ocean bottom to mountaintop." These traditional management systems have been seriously disrupted since the arrival of European newcomers and the resulting impacts on key habitats from colonial settlement, land encroachment, changes in land tenure, land-use conversion, and industrial scale exploitation. Today, collaborative efforts between Indigenous communities, ethnoecologists, and others are underway to recognize and restore some of these

critically important Indigenous production systems and associated practices as a means of ethnoecological restoration, habitat enhancement, and food system revitalization.

Menzies, C. (2010). Dm sibilhaa'nm da laxyuubm Gitxaała: Picking Abalone in Gitxaała Territory. *Human Organization,* 69, 213-220. https://doi.org/10.17730/humo.69.3.g68p1g7k40153010

In the face of aggressive overfishing of bilhaa (abalone) by non-Indigenous commercial fishermen, the Canadian Department of Fisheries and Oceans closed all forms of harvesting of bilhaa. This paper describes the longstanding ecologically appropriate harvesting practices of Gitxaala, an indigenous nation on the northwest coast of North America. The paper documents the antiquity of Gitxaala fisheries practices. The paper concludes by arguing for a return to a Gitxaala controlled bilhaa fishery.

Shapcott, C. (1989). Environmental impact assessment and resource management, a Haida case study: Implications for native people of the north. *The Canadian Journal of Native Studies,* 9(1), 55-83. Retrieved from http://www3.brandonu.ca/cjns/9.1/shapcott.pdf

The relevance of conventional environmental impact assessment (EIA) to Native people is limited by the values of the dominant culture's world view, and the structures and policies created out of them. The traditional Native world view, as exemplified by the Haida, links people with their land base, and is community oriented and consultative.

Sloan, N. A. (2003). Evidence of California-Area Abalone Shell in Haida Trade and Culture. *Canadian journal of archaeology,* 27(2), 273-286. Retrieved from https://www.jstor.org/stable/41103451

Abalone (Haliotis spp.) shell was a trade commodity in northwestern North American and part of a marine shell trade that also included tusk shell (Dentalium spp.) and olive snail ( Olivella spp.) . The occurrence of abalone trade shell in Haida art, language, and family crest usage demonstrates, at a minimum, an appreciable influence of the abalone shell trade in the post-contact era. However, despite archaeological evidence that trade in other shells regionally extends back at least 7,000 years, radiocarbon dating of California-area abalone trade shells excavated from the Haida village of Kiusta in northern Haida Gwaii (Queen Charlotte Islands) reveals them to be post-contact only. Compared to California-area abalone, the poor quality of local northern abalone (H. kamtschatkana kamtschatkana) shell may have accounted for their infrequent use. This paper reviews the post-contact abalone shell trade in southern British Columbia and Washington, and offers speculation on its pre- contact manifestation.

Sloan, N. A. (2005). Contemplating One-Sided Clams: The Northern Abalone Quincunx. *The George Wright Forum,* 22(3), 50-57. Retrieved from http://www.jstor.org/stable/43597956

In this paper I discuss a proposed national marine conservation area in British Columbia, Canada, using northern abalone (Haliotis kamtschatkana) as a lens through which regional communities can view

issues of culture, commerce and conservation. Indigenous Haida people, whose traditional territory includes Haida Gwaii (Queen Charlotte Islands), sometimes refer to northern abalone as “one-sided clams.” British Columbia marine waters have one species of abalone, a herbivorous snail reaching 140 mm in shell length that uses its massive (and edible) foot to creep over lower intertidal and shallow subtidal rocky substrates under a canopy of kelp forest while grazing on algae.

Stewart, E. A. (2004). *Communities Play an Important Role in the Recovery of Marine Species at Risk: Pinto Abalone and Sea Otter on the West Coast of Vancouver Island.* Paper presented at the Species at Risk 2004 Pathways to Recovery Conference, Victoria, BC. Retrieved from http://www.llbc.leg.bc.ca/Public/PubDocs/bcdocs/400484/stewart_edited_final_may_7.pdf

The British Columbia coast is in the center of a kelp forest ecosystem that extends along the Pacific coast of North America. Many marine species at risk depend either directly or indirectly on this system. This paper examines community recovery efforts for two marine species at risk, the pinto abalone (Haliotis kamstchatkana) and the sea otter (Enhydra lutris), on the west coast of Vancouver Island, British Columbia. The Nuu-chah-nulth First Nations and other coastal communities play critical roles in the recovery of these two species, and those efforts are examined here in light of improving collaboration and cooperation with the federal lead agencies responsible for marine species at risk recovery, namely Fisheries and Oceans

Thornton, T. F. (2001). Subsistence in Northern Communities: Lessons from Alaska. *The Northern Review,* 23, 82-102. Retrieved from https://thenorthernreview.ca/index.php/nr/article/view/167

This paper examines the roots of the Alaskan subsistence crisis and sug-gests that there are lessons to be learned from the state and federal govern-ments’ myopic focus on fish and wildlife harvest allocation issues and theirfailure to consider subsistence economies in the broader context invoked byPresident Lynge and Senator Inouye.

Vaughan, J. D. (1985). *Toward a new and better life: Two hundred years of Alaskan Haida culture change.* (Ph.D. Dissertation), University of Washington, Seattle, WA. Retrieved from https://www.worldcat.org/title/toward-a-new-and-better-life-two-hundred-years-of-alaskan-haida-culture-change/oclc/463853761&referer=brief_results

Traces the history of the Kaigani Haida using archival materials in coordination with oral accounts given by people in and of Hydaburg, Alaska.