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California Abalones, Family Haliotidae

By
KEITH W. COX
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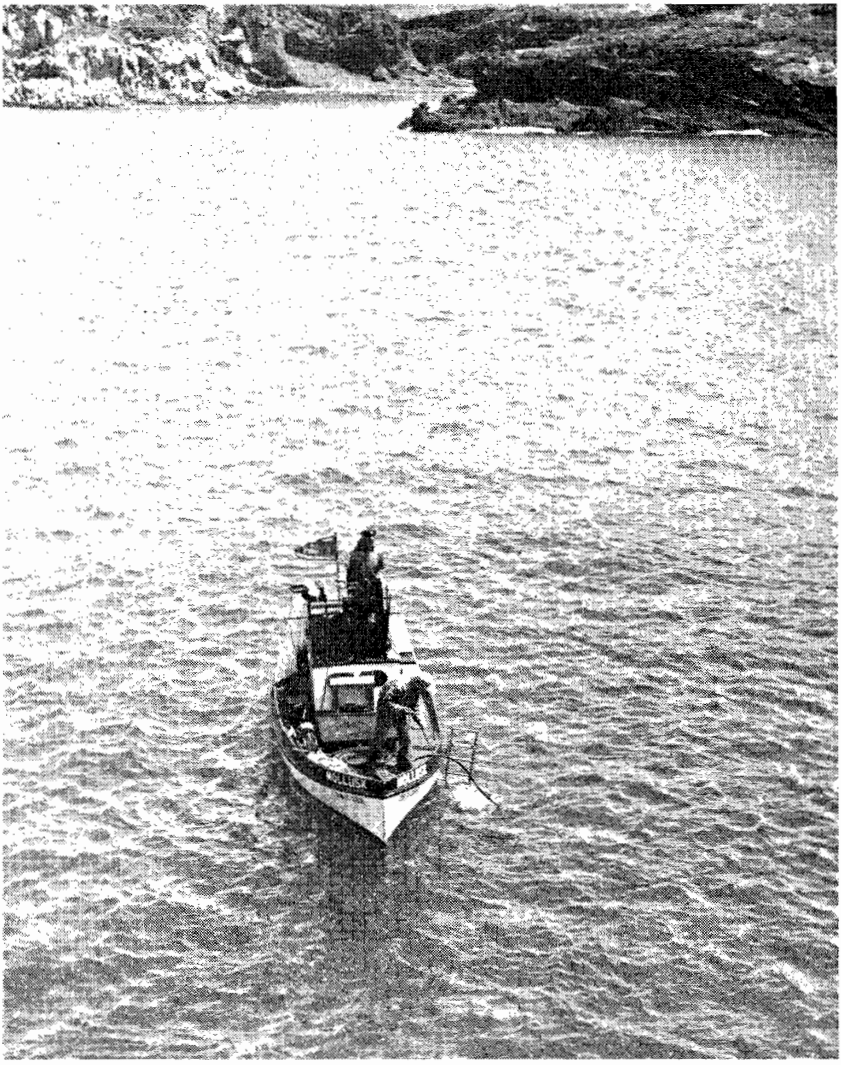

FRONTISPIECE: Department of Fish and Game abalone research boat *Mollusk* off Pt. Lobos, California. Air hose and life line lead to submerged diver whose exhaust bubbles can be seen on the water surface just in front of the ladder.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

It is with pleasure I acknowledge the support and assistance given me by numerous people during our field work and while compiling and writing this report.

Special thanks are due: to A. Myra Keen, Stanford University, for her assistance in locating some of the more obscure but important references; to Leo G. Hertlein, California Academy of Sciences, for providing certain references and the original specimen of H. lomaënsis; to Raymond Harriman, Professor Emeritus, Stanford University, for translating the Latin and Greek text of K. Gesner's Historia Animalium; to Bert A. Gerow and Miss T. Krepps, Department of Sociology and Anthropology, Stanford University, for the Castro shell-mound artifacts; to Phil C. Orr, Santa Barbara Museum of Natural History, for the photographs of archaeological sites and abalone shells from Santa Rosa Island; to Verne Peckham, who worked with the project for two summers, for his many photographs; to R. Talmadge for data on world abalone distribution; to R. Owens for information on California abalone hybrids and crab predation; to L. Burke Lucas for his brush drawing of the early Chinese spear and gaff fishermen; and to Takashi Ino, Chief of Biological Research, Ministry of Fisheries and Agriculture, Tokyo, for notes on the Japanese fishery and information concerning his spawning and development experiments, also for his kindness and many courtesies when I visited his laboratory in Tokyo.

Among Department of Fish and Game personnel, the services of two former employees, netman bos'n D. McFadden and assistant-engineer W. McFadden of the *Nautilus* are sincerely appreciated. I would like especially to thank Mrs. B. Odes, secretary, for deciphering my handwriting and typing the many drafts of the manuscript, J. B. Phillips for contributing photographs and for details of the Japanese fishery at Monterey, John E. Fitch for editing it into a final and readable form, and Mrs. P. Powell, librarian, for the many hours she spent checking my references for style and accuracy.

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Keith W. Cox,
May 1962.

1. INTRODUCTION

Abalones provide a unique fishery in California. It is the only fishery in which the fishermen use diving gear and the catch cannot be exported. Because they are taken both by sportsmen and commercial fishermen, abalones have almost always attracted considerable attention and interest. A lack of early life history and other quantitative information has caused almost continuous dispute between the sport and commercial fisheries. Several previous abalone studies were concerned primarily with the early fishery and fishing methods or discussed nomenclature and geographical distribution. Limited biological studies yielded inaccurate conclusions because of insufficient data.

In 1939, the commercial abalone industry was asked to offer suggestions for regulating the fishery, and a crew supervised by a Fish and Game biologist surveyed the coastline from Monterey to San Miguel Island. Thirty-four dives were made and 16½ hours were spent on the bottom; however, this survey (Bonnot, 1940) and others (Bonnot, 1948) failed to provide an answer to the question, "What is the effect of the commercial offshore fishery on the shoreside sportfishery?" In an attempt to obtain the answer, the State Legislature directed the Department of Fish and Game to set up an abalone program and solve the dispute once and for all. In 1951, the Department launched a full-scale investigation with two vessels and a diving crew. The untimely death in August 1951 of Paul Bonnot, who had been assigned to head the investigation, was a serious setback. It was necessary for a new biologist (me) to take over and start from the bottom. Since I had no previous diving experience, I had to undergo training so I could handle myself safely underwater.

With the exception of Bonnot's underwater experiences, almost all previous observations had been made from the littoral zone. It was decided that this investigation would concentrate on the underwater aspects of the problem and most effort was directed toward fulfilling this objective. Over 1,500 hours were logged underwater by the project's divers during the investigation. Considerable new information was gathered and this report contains many of our findings.

It was soon apparent that to understand abalones fully we would need to know details of their history and ecology available mainly in the published works of others.

Research into the literature revealed a great deal of abalone information, particularly on Japanese and European species. Unfortunately most of the older publications and many obscure recent ones are available only at specialized libraries or the larger universities.

This report has drawn freely on the works of other investigators particularly for details on abalone early life history, anatomy and development. Crofts (1929) and Ino (1952) are the two most up-to-date and comprehensive publications—Croft's is particularly good for anatomy and Ino for embryology and development.

It is my intent in this paper to provide not only the specific information requested by the State Legislature but, as far as is practical, to present as much additional information as seems appropriate and of interest.

2. THE GENUS HALIOTIS

2.1. Systematic Position

The phylum Mollusca is one of approximately 20 major divisions of the Animal Kingdom. Abalones, genus Haliotis, are mollusks (Mollusca). There is no standard molluscan shape or stereotyped pattern. The term "shellfish" is too narrow to include all members of this phylum; slugs and squids for example are mollusks that are seldom described or even recognized as "shellfish." Most mollusks usually have a shell, a soft body and a slippery skin. In addition, a mollusk possesses unique respiratory organs (the feather-like ctenidia), a primitive nervous system, and a reduced body cavity or coelum.

Few authorities agree on the details of molluscan classification and combinations of several systems may be followed by a single author. The system of classification I have used in this paper is adapted from L. R. Cox (1960).

The Mollusca are divided into seven classes, three subclasses, and several to many orders, suborders, superfamilies, and families plus a multitude of genera and species. Abalones belong to the class Gastropoda, subclass Prosobranchia, order Archaeogastropoda, suborder Zygobranchia, superfamily Pleurotomariacea, and family Haliotidae.

Gastropods or snails form the largest and most successful class of mollusks. More than half of the 80,000 known species are marine while the remainder live in fresh water or on land. All gastropods undergo torsion early in their development, a feature that distinguishes the group. In torsion, the visceral mass rotates 180 degrees counterclockwise so that the ctenidia (gills), mantle cavity and anus, which originally face to the rear, come to lie behind the head. In Haliotis, torsion is accomplished in two stages (Crofts, 1937): the first, a rapid rotation of 90 degrees occurs during their pelagic stage as a result of muscular action; the remaining 90 degrees is rotated much slower and results from differential growth of the columellar muscle.

All haliotids (abalones) belong to the family Haliotidae Rafinesque, 1815. Rafinesque gave the subfamily name Haliotidia in 1815 which was corrected to Haliotidae by Fleming in 1822. Haliotis is the only genus in the family and Haliotis midae Linnè, 1758, is the genotype. The principal characters of the family Haliotidae are: the auriform and more or less circular outline of the shell, a convex back which ranges from highly arched to extremely flattened, a row of rounded shell perforations overlying the respiratory cavity, and the enormous shell aperture. The epipodial sensory structures are usually well-developed and the markedly flattened body and visceral mass confine the animal to the last whorl.

L. R. Cox (1960) recognized one genus which he divided into seven more-or-less intergrading subgenera. In some areas, particularly Australia, a multitude of genera are listed but until these can be substantiated by more conclusive evidence than shell form, configuration, or

shell sculpture, it is best to retain all species within the genus Haliotis.

Conchologists believe there are about 130 species and subspecies of haliotids.

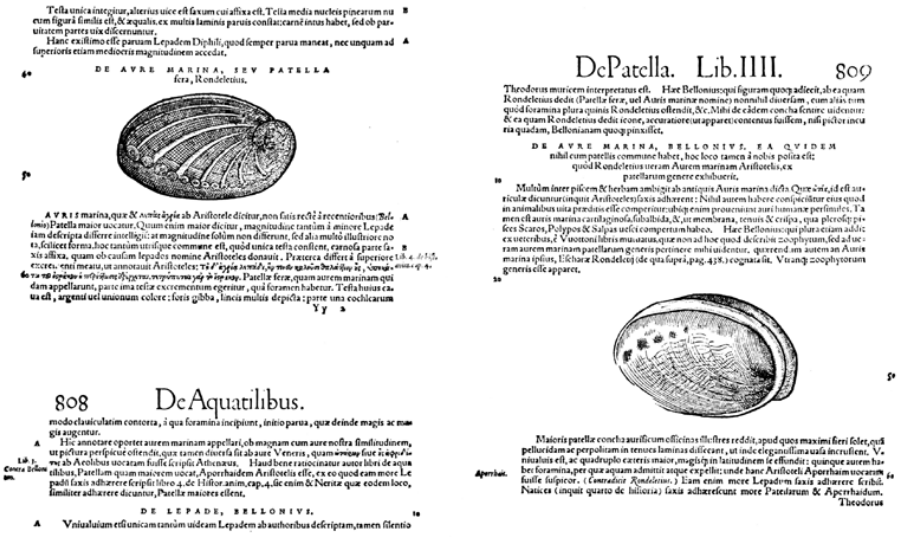
Some of the lack of agreement among conchologists on the genera of haliotids may be due to the occurrence of hybrids. Other than a note on an apparent hybrid (Stearns, 1867) there is little or no information on this phenomenon in the literature. However, recent observations by the author and by R. Owens (pers. corres.), have shown that among the abalones of California hybridization is common. Owens reported having collected nearly 600 hybrids as follows:

Parent stock	*Number collected*
H. rufescens x H. sorenseni	500
H. rufescens x H. corrugata	45
H. rufescens x H. assimilis	6
H. rufescens x H. fulgens	1
H. corrugata x H. fulgens	8
H. corrugata x H. walallensis	8
H. corrugata x H. sorenseni	3

Hybridization probably occurs in the other localities where haliotids are found and some forms described as separate species may be hybrids.

2.2. Historical Résumé

According to Crofts (1929), abalones were first mentioned in the fourth century B.C. by Aristotle who says, "but in the case of the wild limpet (called by some the 'sea ear') the residuum escapes beneath the shell for the shell is perforated to give an outlet." In D'Arcy Thompson's translation of Aristotle he notes that "wild limpet" is "commonly attributed to Fissurella graecea ... and conceals a forgotten name for Haliotis. "



808 De Aquatilibus.

DE AVRE MARINA, SEV PATELLA fera, Rondeletius.

DE LEPADE, BELLONIVS.

DePatella. Lib.IIII. 809

DE AVRE MARINA, BELLONIVS, EA QVIDEM

FIGURE 1. Pages from Gesner's (1558) *Historia Animalium* in which he reproduces two of the first known illustrations of abalone shells, one by Belon in 1553 (right) and the other by Rondelet in 1555 (left). Photo by Stanford University Photo Service, 1959.

FIGURE 1. Pages from Gesner's (1558) Historia Animalium in which he reproduces two of the first known illustrations of abalone shells, one by Belon in 1553 (right) and the other by Rondelet in 1555 (left). Photo by Stanford University Photo Service, 1959

The oldest abalone fishery was probably conducted by the Japanese, for it is recorded that: "a diver named Osahi, in north Shikoku, collected 'awabi' on September 12, 425 A.D. ... in order to offer an awabi pearl to the Inkyo Emperor at Awaji Island, south of Kobe. Osahi did not return to the surface after a particularly long, deep dive; his helpers became worried and pulled on the rope which was attached to his waist. He was brought to the surface dead (it was said that the length of rope was 60 feet) a great awabi still clutched in his hand. From this awabi was taken a pearl said to be the size of a peach" (Ino, pers. corres. 1961).

The first published figure of a haliotid is believed given by Belon (1553) who calls attention to Aristotle's reference to "the other *Patella major*" under the name "Aporrhias." Rondelet (1555) has what is believed the second published figure of an abalone, an external view inscribed, "*Di Oriella Marine*." Both of these illustrations were figured by Konrad Gesner (1558) (Figure 1) who discussed Auris marina and stated that the "sea ear" was familiar to the Greeks and was named *otia* (little ear) by Pliny. Gesner, as translated by Harriman, also noted that, "they are eaten fried [by the Greeks]. For otherwise they will not be pleasing nor do they show much nourishment ..."

A haliotid shell is visible in the 1604 painting by Brueghel entitled "The Gifts of Earth and Water." This painting, an allegory, is of particular interest for its accurate drawings of various mollusks, insects, fish, birds and mammals, as well as flowers, trees and vegetables. Approximately 20 species of mollusks can be identified in the painting (Figure 2).

According to Crofts (1929), the *Clacas* of Teneriffe (Canary Islands) to which Sprat (1667) refers, are in all probability Haliotis with the mantle tentacles extending through the top holes. Crofts further states that Grew (1681) said the sea-ear is, "found in abundance near Garnsey (Guernsey) Island" and, quoting Lister, he [Grew] says, "The Goldsmiths in France beautify cabinets with split plates."

Buonanni (1681), Lister (1685), Gualtieri (1725), and Rumpf (1741) illustrate haliotids some of which were referred to by Linné (1758) (Figure 3).

Kaempfer (1690) gives the following description of a Japanese haliotid: "There is another Shell which sometimes yields Pearls, found plentifully upon all the Japanese Coasts, and call'd by the Natives Awabi. It is a Univalve, in shape almost oval, pretty deep, open on one side, where it sticks to the Rocks and to the bottom of the Sea, with a row of holes, which grow bigger the nearer they come to the circumference of the Shell, rough and limey on its outward surface frequently with Corals, Sea Plants and other Shells sticking to it, on the inside of an exquisite Mother of Pearl's glimmering, sometimes rais'd into whitish pearly excrescencies, which are likewise observ'd in the common Persian Pearl-shell. A great lump of flesh fills the cavity of this Shell, for which sole reason they are look'd for by Fishermen, being a very good commodity for the market. They have an Instrument made on purpose to pull them off from the sides of the Rocks to which they stick close."

FIGURE 2. Detail from "The Gifts of Water and Earth," by P. Breughel, believed to be the first illustration of an abalone in art. (The shell, an inside view, is at the lower left.) The original, painted in 1604, measures 16½ by 28 inches and is part of the Vienna collection in the Kunsthistorisches Museum. Photograph by Willis Photo Lab., Palo Alto, 1962.

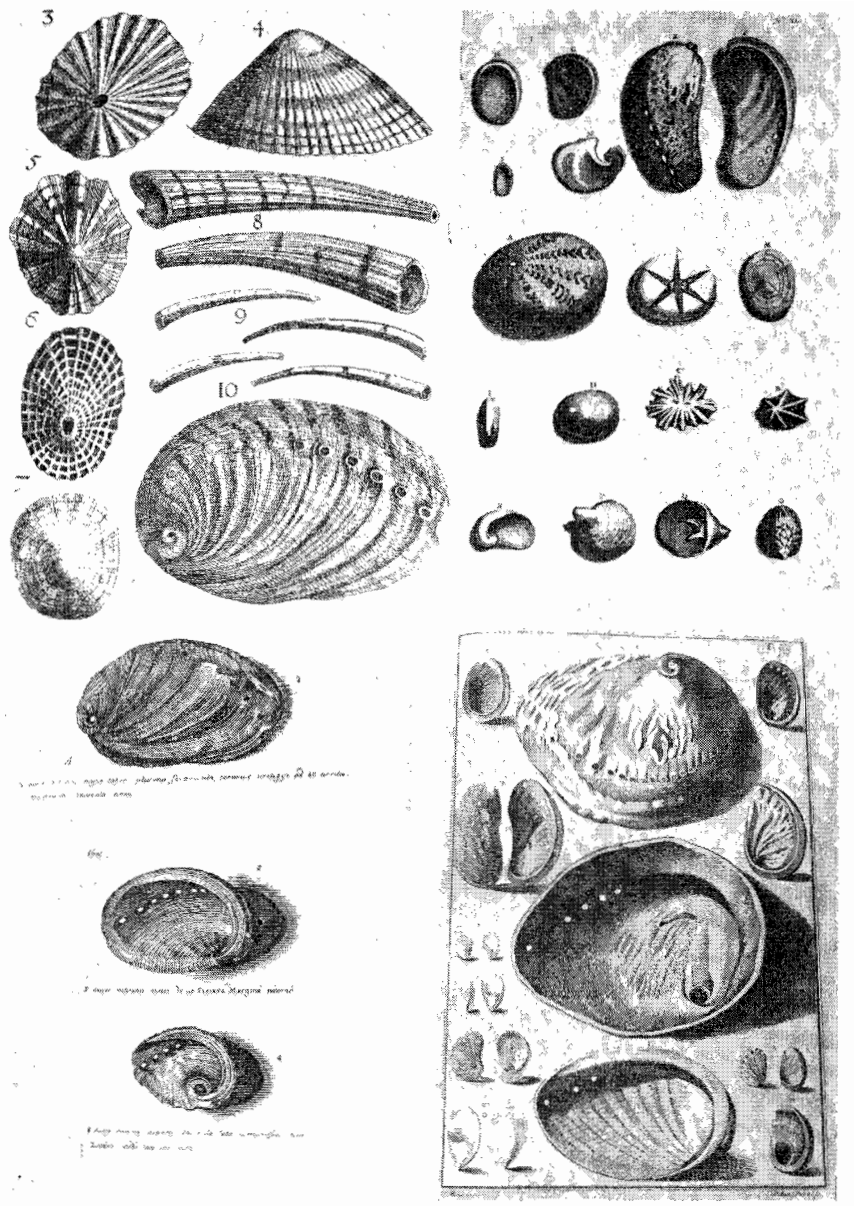


FIGURE 3. Pages from four early publications (1681-1741) illustrating abalones referred to by Linné in 1758. Photo by Glen Bickford, 1959.

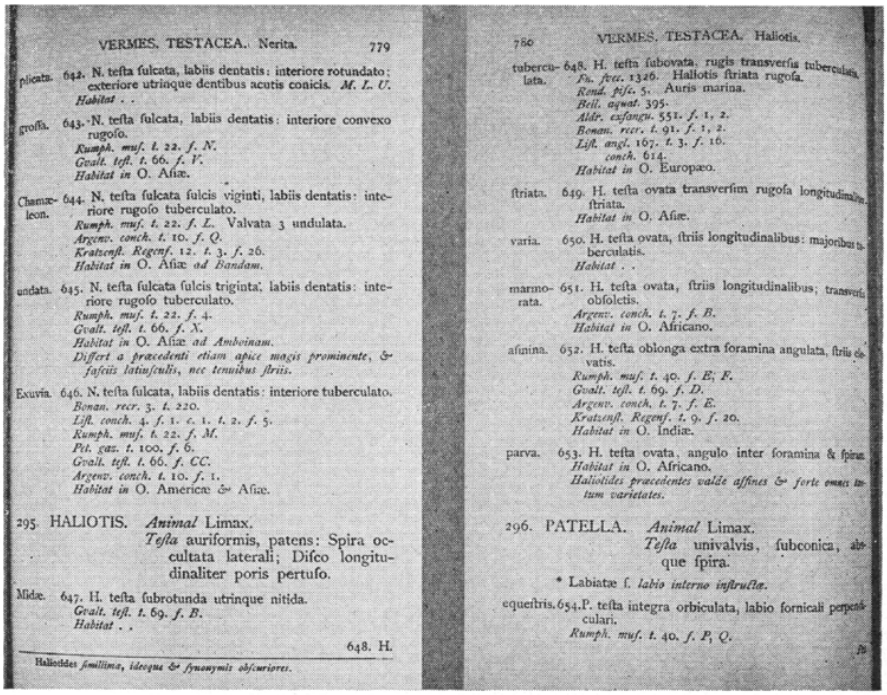
In this publication, Kaempfer describes how the Japanese divers, "the fishermen's wives," gathered abalones—a fishing method that is followed in parts of Japan today.

Linné (1740) appears to be the first authority to use the generic name Haliotis and in 1758 he described seven species in this genus (Figure 4).

The earliest illustrated anatomical account of Haliotis was by Cuvier (1817) but according to Crofts (1929) there are errors, particularly in the nervous system. The external features of Haliotis are mentioned by Lamarck (1843) and Lebert (1846) described their buccal organs. Milne-Edwards (1847) illustrated the circulatory system of Haliotis.

In 1859, Lacaze-Duthiers published a detailed account which became the foundation of our knowledge of the nervous system; in 1872 he described the "otocysts" of Haliotis. According to Crofts (1929): "His account of the double nature of each of the pedal nerve strands, with his lengthy application of this as evidence that the epipodium is of mantle derivation was based on faulty observation and is the one serious error in the work. Cuvier made the same error." This was corrected by Spengel (1881).

Matsubara (1882) gave an anatomical explanation of Haliotis spawning and described their eggs and sperm. In 1883, 1886, and 1894, according to Crofts (1929), Haller published a comparative anatomy with "good figures which do not agree with serious inaccurate statements he makes." Kishinouye (1894, 1895) in addition to carrying out experimental spawning studies discussed taxonomy, ecology and anatomy



VERMES. TESTACEA. Nerita. 779

plicata. 642. N. testa fulcata, labiis dentatis: interiore rotundato: exteriore utrinque dentibus acutis conicis. *M. L. U.* *Habitat* . .

grossa. 643. N. testa fulcata, labiis dentatis: interiore convexo rugoso. *Rumph. mus. t. 22. f. N.* *Gualt. test. t. 66. f. V.* *Habitat in* O. Asiæ.

Chamæleon. 644. N. testa fulcata sulcis viginti, labiis dentatis: interiore rugoso tuberculato. *Rumph. mus. t. 22. f. L.* Valvata 3 undulata. *Argenv. conch. t. 10. f. Q.* *Kratzenst. Regenf. 12. t. 3. f. 26.* *Habitat in* O. Asiæ *ad Bandam.*

undata. 645. N. testa fulcata sulcis triginta; labiis dentatis: interiore rugoso tuberculato. *Rumph. mus. t. 22. f. 4.* *Gualt. test. t. 66. f. X.* *Habitat in* O. Asiæ *ad Amboinam.* *Differt a præcedenti etiam apice magis prominente, & fasciis latiusculis, nec tenuibus striis.*

Exuvia. 646. N. testa fulcata, labiis dentatis: interiore tuberculato. *Bonan. recr. 3. t. 220.* *Lift. conch. 4. f. 1. c. 1. t. 2. f. 5.* *Rumph. mus. t. 22. f. M.* *Pet. gaz. t. 100. f. 6.* *Gualt. test. t. 66. f. CC.* *Argenv. conch. t. 10. f. 1.* *Habitat in* O. Americæ & Asiæ.

295. HALIOTIS. *Animal* Limax. *Testa* auriformis, patens: Spira occultata laterali; Discus longitudinaliter poris pertuso.

Midæ. 647. H. testa subrotunda utrinque nitida. *Gualt. test. t. 69. f. B.* *Habitat* . .

648. H.

Haliotides *similimæ, ideoque & synonymis obscuriores.*

780 VERMES. TESTACEA. Haliotis.

tuberculata. 648. H. testa subovata, rugis transversis tuberculatis. *Fn. suec. 1326.* Haliotis striata rugosa. *Rond. pisc. 5.* Auris marina. *Bell. aquat. 395.* *Aldr. exsangu. 551. f. 1, 2.* *Bonan. recr. t. 91. f. 1, 2.* *Lift. angl. 167. t. 3. f. 16.* *conch. 614.* *Habitat in* O. Europæo.

striata. 649. H. testa ovata transversim rugosa longitudinaliter striata. *Habitat in* O. Asiæ.

varia. 650. H. testa ovata, striis longitudinalibus: majoribus tuberculatis. *Habitat* . .

marmorata. 651. H. testa ovata, striis longitudinalibus; transversis obsoletis. *Argenv. conch. t. 7. f. B.* *Habitat in* O. Africano.

aſinina. 652. H. testa oblonga extra foramina angulata, striis elevatis. *Rumph. mus. t. 40. f. E, F.* *Gualt. test. t. 69. f. D.* *Argenv. conch. t. 7. f. E.* *Kratzenst. Regenf. t. 9. f. 20.* *Habitat in* O. Indiæ.

parva. 653. H. testa ovata, angulo inter foramina & spiram. *Habitat in* O. Africano. *Haliotides præcedentes valde affines & forte omnes tantum varietates.*

296. PATELLA. *Animal* Limax. *Testa* univalvis, subconica, absque spira.

* Labiatæ f. *labio interno instructæ.*

equestris. 654. P. testa integra orbiculata, labio fornicali perpendiculari. *Rumph. mus. t. 40. f. P, Q.*

FIGURE 4. Pages from a facsimile of Linné's 10th edition of *Systema Naturae* (1758) describing seven species of *Haliotis*. Photo by Glen Bickford, 1959.

FIGURE 4. Pages from a facsimile of Linné's 10th edition of Systema Naturae (1758) describing seven species of Haliotis. Photo by Glen Bickford, 1959

and included information on the structure of the reproductive organs. He also attempted artificial fertilization but was unsuccessful. Wegman (1884) published on the anatomy of Haliotis and, according to Crofts (1929), he repeats Lacaze-Duthiers' error of the nervous system but is particularly helpful in relation to the circulatory and digestive systems.

Numerous works have been published concerning various anatomical organs of Haliotis (Perrier, 1889; Kowalevsky, 1889, 1894; Cuénot, 1899; Pelseneer, 1891, 1896), and two workers, Fleure (1902) and Totzauer (1902), published comparative data on the renal organs with special reference to Haliotis. Boutan (1899) described the trochophore larva and shell development but his observations were terminated before the first respiratory pore appeared. Fleure's (1904) comprehensive description of Haliotis was the most authoritative until Crofts (1929). Palmer (1907) described the circulatory, renal and reproductive systems of two species of California haliotids, H. rufescens and H. cracherodii, and compared certain features with the European H. tuberculata. Delhaes (1909) presented a detailed study of the morphology and phylogeny of the family Haliotidae.

A number of other works during the early 1900's dealt with distribution and descriptions of various species. Okamura and Seno (1918, 1920) studied algal food of Japanese haliotids. Edwards (1913) and Tressler (1923) reported on the commercial abalone fishery in California. Curtner (1917) observed the growth and habits of two California species, H. rufescens and H. cracherodii, and Albrecht (1917) reported on the blood and chemical composition of H. rufescens. Stephenson (1924) reported on a short-term economic investigation of H. tuberculata in the Island of Guernsey. Kinoshita (1934a, 1934b, 1936, 1937, 1947, 1949, 1950) studied food habits, growth and reproduction of the Japanese species. In 1929, Crofts published a bionomic and anatomical examination and in 1937 and 1955, on the development of H. tuberculata; these three papers constitute most of our knowledge of the history and anatomy of Haliotis. Bonnot (1930, 1940, 1948) and Croker (1931) published accounts of the abalones of California. Bonnot's reports dealt primarily with the taxonomy of the California species and Croker's with the history of the fishery in California and Baja California, Mexico. Murayama (1935) successfully induced spawning, and reported the early stages of development for the Japanese H. gigantea. Kessell (1936) presented information concerning the structure of the shell and Phillips (1937) reported on the abalone fishery in California. Ueda and Okada (1939, 1941) conducted food studies with H. kamtschatkana (H. discus hannai) and H. gigantea, while Lissman (1945) described and analyzed the method of locomotion of H. tuberculata. Carlisle (1945) determined the time of spawning for the California abalone H. rufescens and developed a technique to induce spawning of this species.

Yonge (1947) investigated the respiratory process of zygobranch gastropods including Haliotis; his work is important in understanding phylogenetic relationships.

Medem (1948) presented a paper in German on the effective components in the eggs and sperm of mollusks including Haliotis and described the fertilization mechanism. Campbell (1949) reported on the

alimentary tract of H. cracherodii. Ino (1952) published a comprehensive work in Japanese on the biology and propagation of two species of Japanese abalones. He included the first description of their complete development through the larval stages to 13 months. His paper has been the basis for developmental studies on Haliotis. Bolognari (1953) reported on gonadal changes of H. lamellosa and attempted to determine ages by shell markings and by statistical methods. Leighton (1959) discussed the diet and its relation to growth for H. cracherodii. Sakai (1960) described a technique for determining age from annual rings on the shell of H. discus hannai. de Buen (1960) reported on the abalones of Baja California, describing fishing methods, areas and species. K. W. Cox (1960) described the abalones of California. Li (1960a, 1960b) and Prescott and Li (1960) found antimicrobial fractions in abalone blood effective against Staphylococcus aureus and certain polio and influenza viruses.

Numerous other notes and reports appear in the literature but most are concerned with new locality records, anatomy, morphology, physiology, and accounts of fisheries and fishery methods.

2.3. Fossils

Shelled forms, considered true gastropods, first appeared in the lower Cambrian (Table 1) . The first asymmetrical gastropod shells of the superfamily Pleurotomariacea are found in the upper Cambrian;

TABLE 1

Major Stratigraphic and Geological Time Divisions in Use by the U.S. Geological Survey

Era	System or Period		Series or Epoch	Approximate Time Boundaries in Millions of Years
Cenozoic	Quaternary	(Q)	Recent Pleistocene	1
	Tertiary	(T)	Pliocene Miocene Oligocene Eocene Paleocene	10 25 40 60
Mesozoic	Cretaceous	(K)	Upper, Lower	125
	Jurassic	(J)	Upper, Middle, Lower	150
	Triassic	(TR)	Upper, Middle, Lower	180
Paleozoic	Permian	(P)		205
	Pennsylvanian	(IP*)	Upper, Middle, Lower	
	Mississippian	(M*)	Upper, Lower	255
	Devonian	(D)	Upper, Middle, Lower	315
	Silurian	(S)	Upper, Middle, Lower	350
	Ordovician	(O)	Upper, Middle, Lower	430
	Cambrian	(Є)	Upper, Middle, Lower	510
Precambrian		(p Є)	Upper, Middle, Lower	3,000

* The letter-symbol designates Carboniferous systems in regions where Pennsylvanian and Mississippian systems are not differentiated.

TABLE 1

Major Stratigraphic and Geological Time Divisions in Use by the U.S. Geological Survey

however, representatives of the genus Haliotis did not appear until the Cretaceous. According to Hertlein (1937), the genus is known from the upper Cretaceous in California (Table 2) , from the upper Cretaceous of Maestricht, Belgium, from the upper Cretaceous of Sweden and Africa and from the Eocene-Oligocene of Australia. Fossil abalones have been described from the Miocene of California (Table 2), Australia, Europe, the Island of Cyprus, and Asia Minor. In the Pliocene,

TABLE 2

Fossil California *Haliotis*

Species	Location	Epoch
H. elsmerensis Vokes 1935	Elsmere Canyon, Los Angeles Co.	Miocene
H. lasia Woodering 1932	Temblor Range, San Luis Obispo Co.	Miocene
H. lomaënsis Anderson 1902	Pt. Loma, San Diego Co.	Cretaceous
H. kotiki Hertlein 1937	La Zaca Rancho, Santa Barbara Co.	Lower Miocene
H. palea Woodering 1931	Santa Monica Mts., Los Angeles Co.	Lower Miocene

TABLE 2
Fossil California Haliotis

they are known from California, Baja California, Japan, New Zealand and Barbados Island in the Caribbean.

Not all authorities agree that the specimens recovered from the Cretaceous (which in most cases are only fragments) are true haliotids. L. R. Cox (1960) states: "H. antiqua Binkhorst 1861, from the Maestricht was thought by Kaunhower (1898) to be a trochid. The type H. cretacea Lundgen, 1894, from Sweden needs reinvestigation. H. lomaënsis Anderson, 1902, Chico Group, California, was rejected as a haliotid by Woodering (1931) but accepted by Volkes (1935)."

H. lomaënsis (Figure 5) shows typical characteristics of the haliotids. Its bluntly oval shape, high arch, and five or six holes, bear a marked resemblance to Haliotis cracherodii, which ranges from Oregon to Cape San Lucas, Baja California.

Hertlein (1937) says that H. elsmerensis is thought to be closely related to H. rufescens, H. lasia resembles H. fulgens, H. palaea is said to belong to the H. corrugata group and H. kotiki is similar to H. assimilis.

2.4. Geographical Distribution

Abalones live in marine waters along the rocky shores of all the major continents and among many of the islands in the Pacific, Atlantic and Indian Oceans. The greatest concentrations, both in numbers of species and individuals, are off the coasts of Australia, Japan and western North America. The largest, H. rufescens, occurs on the California coast; it averages between 7 and 9 inches and some exceed 11 inches in diameter. The next largest, H. gigantea, comes from Japan, and attains a length of 10 inches. Other large haliotids live off South Australia, New Zealand and South Africa. The greatest numbers of species are found in the south and central Pacific and parts of the Indian Ocean but no large ones occur in these areas.

In the western hemisphere, haliotids range south along the mainland from Sitka, Alaska, to Cape San Lucas, Baja California. Although the

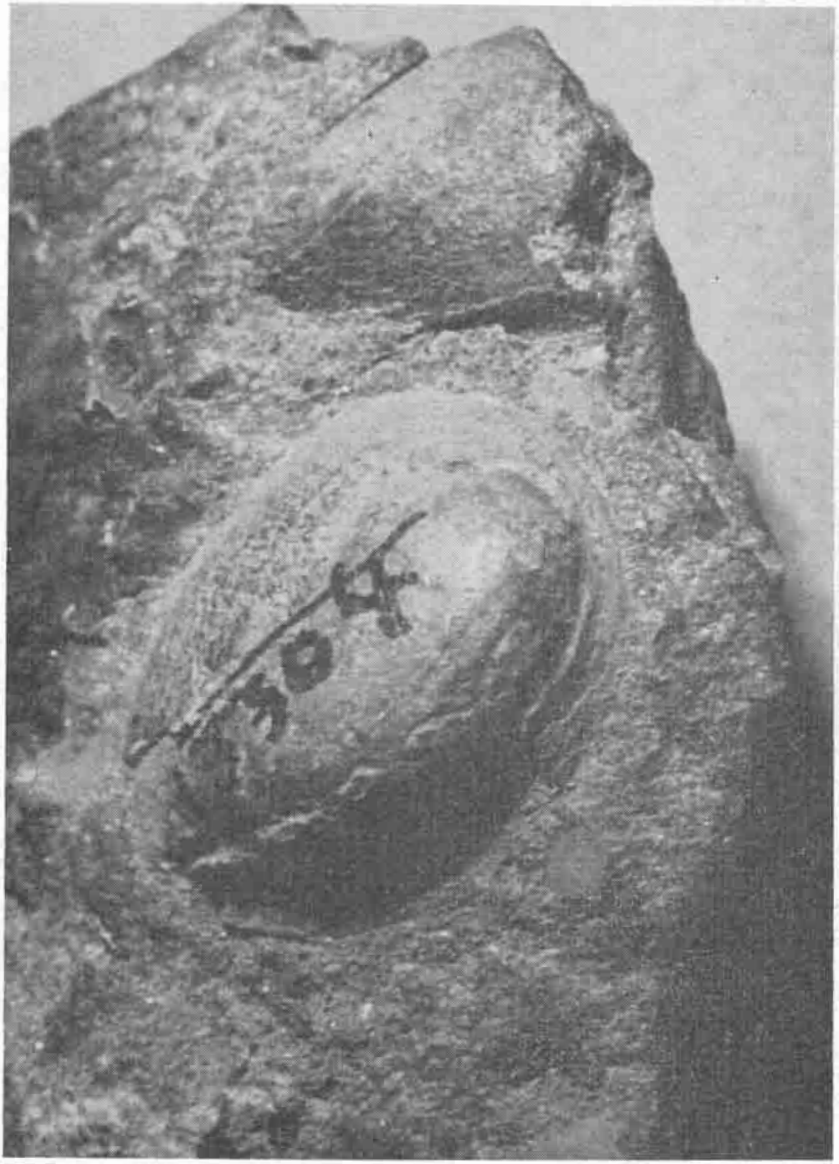


FIGURE 5. Fossil abalone, *H. lomaënsis*, from Pt. Loma, California, 12.8 mm long, 9.0 mm wide and 3.0 mm high, courtesy of California Academy of Sciences, San Francisco. Photograph by Glen Bickford, 1959.

holotype of H. kamtschatkana is reported to have been collected at Unalaska, Aleutians, Dall (1873), states, "Haliotis, which has long been tabulated as an inhabitant of the Aleutian chain, does not exist in that part of the archipelago east of Unalashka, and probably not in these islands at all." W. J. Eyerdam, in answer to a personal query from Ino (1952), says, "I have made extensive collections of shells in Alaska Islands but have never found Haliotis in the Aleutian Islands." Abalones are not found in the Gulf of California nor along the Mexican mainland. Records from these areas have been based on empty shells which probably were left there by tourists. No haliotids have been reported from the Gulf of Mexico, Central America or the west coast of South America except at the Galapagos Islands, approximately 700 miles off Ecuador. With two exceptions, none has been reported from the eastern seaboard of North America. The exceptions were two small individuals named H. pourtalesii dredged in deep water near Key West, Florida—one in 1869 and the other in 1913. A single specimen has been reported from the east coast of South America. It was an empty shell picked up on the beach of Copacabana, Rio de Janeiro, Brazil, and named H. barbouri; some workers believe it is only an eroded H. pulcherrima that was carried into this region by travelers.

In the eastern hemisphere, the northernmost abalones live on the outer coast of the Kamchatka Peninsula at Petropavlovsk, U.S.S.R. From there they range southward along the Asiatic mainland and are found in the coastal waters of Korea, China, Indo-China, Vietnam, Cambodia, Thailand and the Malay Peninsula. They extend through the islands of Japan, the Ryukyus, Formosa, the Philippines, the Indonesian Archipelago, Borneo, Ceram, the Moluccas, and southeastward through the Austral-Asian islands of New Guinea, the Bismarck Archipelago, the Solomons, New Hebrides, New Caledonia, Australia, New Zealand and Tasmania. Their southernmost limit is the sub-antarctic Macquarie Island, approximately 1000 miles southeast of New Zealand.

Although found throughout most of the Pacific Islands, their range is not completely known and they are quite rare in some areas. They are present among many of the islands of the Trust Territories (Marianas, Marshalls, Carolines) but are scarce in the western part. They have been reported from many of the islands of Melanesia (Solomons, Fiji, etc.) and undoubtedly further investigation would reveal new localities in this region. They are present among most of the Polynesian group including the Marquesas and the Tuamotus. They are not in the Hawaiian Islands and recent attempts to establish black abalones, H. cracherodii, on Oahu by transplanting young from California have not been successful. The eastern boundary of the Tuamotus apparently is the southeasternmost limit for Haliotis in the Pacific. None is found on Pitcairn, Henderson, Easter or Sala y Gomez Islands or on any of the other small, isolated islands in this region.

In southwest Asia, abalones are found on the islands in the Bay of Bengal (Andamans and Nicobars), along the coasts of India and Ceylon and off the islands of the Indian Ocean. They live on the shores of the Arabian Sea, the Persian Gulf and the Red Sea.

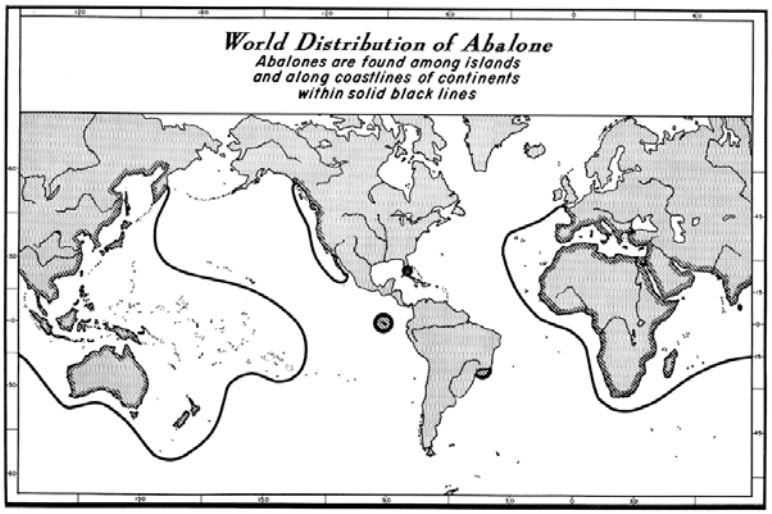


FIGURE 6. Abalones are distributed more or less continuously along continental shores and among islands. Three isolated localities where they occur are the Galapagos Islands in the eastern Pacific, the Florida Channel in the Gulf of Mexico and Rio de Janeiro on the east coast of South America.

FIGURE 6. Abalones are distributed more or less continuously along continental shores and among islands. Three isolated localities where they occur are the Galapagos Islands in the eastern Pacific, the Florida Channel in the Gulf of Mexico and Rio de Janeiro on the east coast of South America

Numerous species of Haliotis are found on the African east coast extending south along Tanganyika, Mozambique and Natal, offshore to Madagascar and its surrounding islands, Mauritius, Reunion, etc. Their range continues southward along the shores of South Africa, around the Cape of Good Hope and north along the coast of southwest Africa, the Gold Coast on the Gulf of Guinea, the coast of Senegal and offshore to the Cape Verde, Canary, Madeira and Azores Islands.

A single species, H. lamellosa, is native to the shores of France, Spain, Italy, Yugoslavia, Greece, Syria and Egypt, in the Mediterranean Sea. In the northeastern Atlantic, a single species, H. tuberculata, lives as far north as Cherbourg, France, and among the Channel Islands.

Although only general areas or localities where Haliotis occurs have been discussed, enough locations have been mentioned to establish its worldwide distribution (Figure 6). If haliotids exist in other areas, they have yet to be reported. With the increasing use of self-contained underwater breathing apparatus (SCUBA) by scientists, explorers and tourists, the possibilities of extending the known ranges of haliotids are greatly increased.

Frequently, abalone reports mention only the name common in the geographical area concerned. As many as two dozen common names (Table 3) in over 15 languages may be encountered in world publications dealing with abalones.

TABLE 3

Common Names of World Haliotids

Common Name	*Country/Language*
Orielle de Mer	France
Si-ieu	France
Ormer, Ormier, Omar	England
Venus Ear	England
Norman Shell	Old English
Lapa Burra	Portugal
Señorinas	Spain
Orecchiale	Italy
Patella Reale	Sicily
Ohrsnecke	Germany
Meerohren	Germany
Venus' Ear	Greece
Orechio de San Pietro	Adriatic, Dalmatia (Yugoslavia)
Mutton Fish	Australia
Paua	New Zealand, Tasmania (Maori)
Karariwha	New Zealand, Tasmania (Maori)
Perlemoen	South Africa
Cholburi	Siam
Hoiley	Amboina (Moluccas) Ceram
Telinga Maloli	Malaya
Bia Scatsjo	Malaya
Awabi	Japan
Aulon, Aulone	Spanish American
Aulone	Mexican

TABLE 3
Common Names of World Haliotids

3. CALIFORNIA ABALONES

3.1. Anatomy

The anatomy of Haliotis was first described by Cuvier (1817). Milne-Edwards (1847), Lacaze-Duthiers (1859), Haller (1883, 1886, 1894), Wegmann (1884) and Fleure (1904) made important contributions to the study of haliotid anatomy. The first comprehensive study published in English was a masterful work by Crofts (1929). It and Ino's ingenious report in 1952 are the two most important works on Haliotis.

Since both Crofts (1929) and Ino (1952) described anatomical features in detail, only a summary of the various systems will be given here. Although Crofts was concerned with the European H. tuberculata and Ino with the Japanese H. discus and H. sieboldii the anatomical structures of these three abalones differed only slightly from each other or from similar structures in California abalones.

3.1.1. Nervous System

The nervous system of Haliotis consists of numerous broad ganglia or nerve centers which are joined by nerve cords or commissures and communicate by means of threadlike nerves with the various organs, muscles and sensory structures (Figure 7). The ganglia are paired but not always symmetrically. The most important are: the cerebral, which receive nerves from the eyes and head tentacles, the anterior epipodium, the lips and mouth parts, the skin and connective tissue and from the statocysts; the pleural which receive the nerves from the internal organs; and, the pedal, which receive nerves from the foot and from the sensory structures in the epipodium. Where the pleural and pedal ganglia join, they form the pleuro-pedal ganglion mass. The pedal ganglia extend posteriorly from this mass as a rope-ladderlike structure which receives the nerves from the epipodium.

The nervous system of Haliotis is representative of the primitive or streptoneurous-type gastropod. The twisted nerves of streptoneuran gastropods result from internal torsion which winds them into the form of a "figure 8." Torsion takes place early in the development of Haliotis.

3.1.2. Sensory Receptors

Abalones have a profusion of sensory receptors over their entire integument. These may be scattered or they may be collected in buds in special tactile or chemical perception regions.

Tentacles, expecially the cephalic, are sensitive to touch and are thought to be light perceptive.

The epipodium is more elaborate in Haliotis than in any other mollusk; it is a development of the foot and is elaborately supplied with nerves from the cerebral and pleuro-pedal ganglia. Delicate nerve

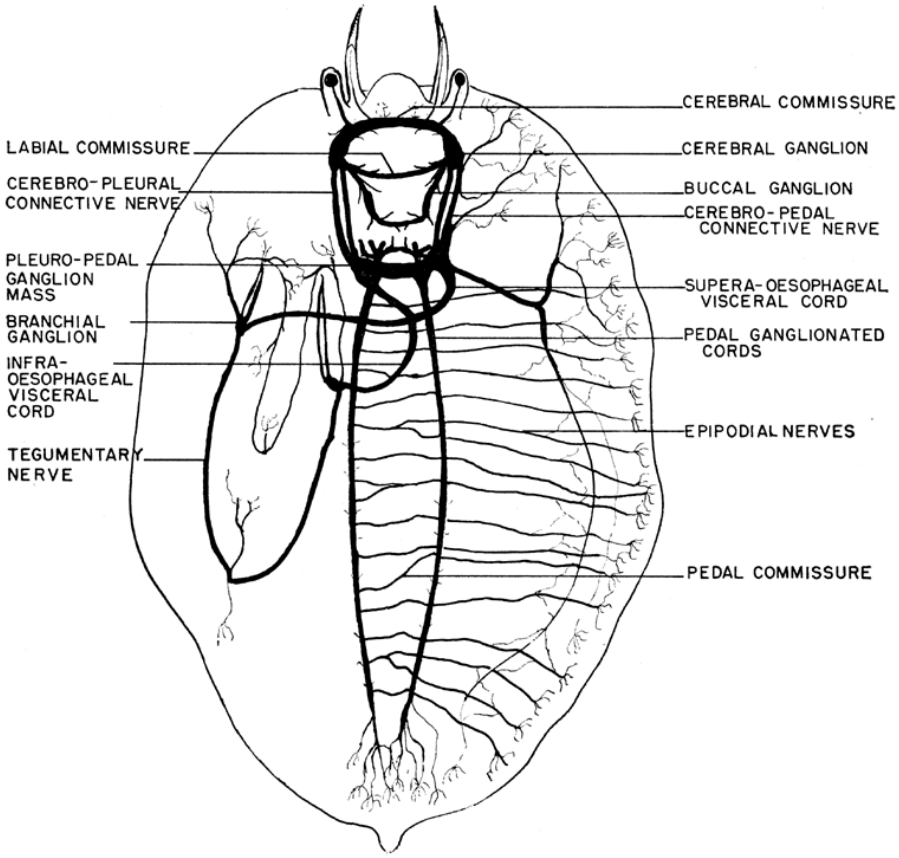
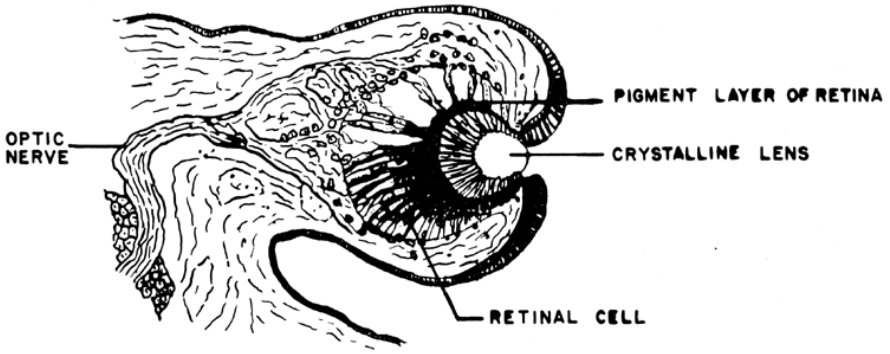


FIGURE 7. Nervous system of *Haliotis*. Note crossing of visceral nerves leading from pleuro-pedal mass.

FIGURE 7. Nervous system of Haliotis. Note crossing of visceral nerves leading from pleuro-pedal mass



MEDIAN LONGITUDINAL SECTION
EYESTALK AND EYE OF
H. TUBERCULATA 4 M.M. LONG, X 200.
AFTER CROFTS (1929).

FIGURE 8. Median section of *Haliotis* eye. There is no cornea; the lens is exposed to sea water.

FIGURE 8. Median section of Haliotis eye. There is no cornea; the lens is exposed to sea water

branches extend through the centers of the epipodial tentacles as well as through other epipodial sensory structures.

The epipodium is believed different for each species of Haliotis. Among the eight California abalones it is distinctive and is one of the most reliable characters for determining specific identification.

Osphradia, organs of smell on each side of the entrance to the respiratory cavity, presumably test the water before it passes over the ctenidia. The paired osphradia are greenish-yellow and extend along the entire length of the free edge of each gill support.

There are eyes at the tips of each pair of eye stalks (Figure 10). Each eye is cup-shaped and has a spherical crystalline lens which is bathed in sea water because the ocular cup has no corneal lens (Figure 8). When the eye stalk is extended, the crystalline lens appears to reach slightly beyond the outside aperture of the cup. Its surface becomes hardened by sea water.

Statocysts, organs of balance or orientation, are attached to the pleuro-pedal ganglia just above the pedal muscle. They are hollow and contain statoliths which vary in size and may be spherical or oval. As reported by Crofts (1929), "they appear to have a centrum surrounded by concentric growth marks. In a specimen of H. tuberculata 8 mm long the largest statolith had three growth rings but the smallest had none." This suggests statoliths might be useful for determining abalone ages.

3.1.3. Circulatory System

In Haliotis, the heart is on the left side of the visceral mass a little behind the mantle cavity (Figure 9). The auricles are posterior to the ctenidia and are symmetrically placed on each side of the ventricle, which surrounds the intestine. Deoxygenated blood passes through the portal system of the right kidney before going to the ctenidia, thus the excretory products are removed. Aortae extend posteriorly to the various body organs and anteriorly to the head. Arteries branch into lacunae which take the place of capillaries in the connective tissue of

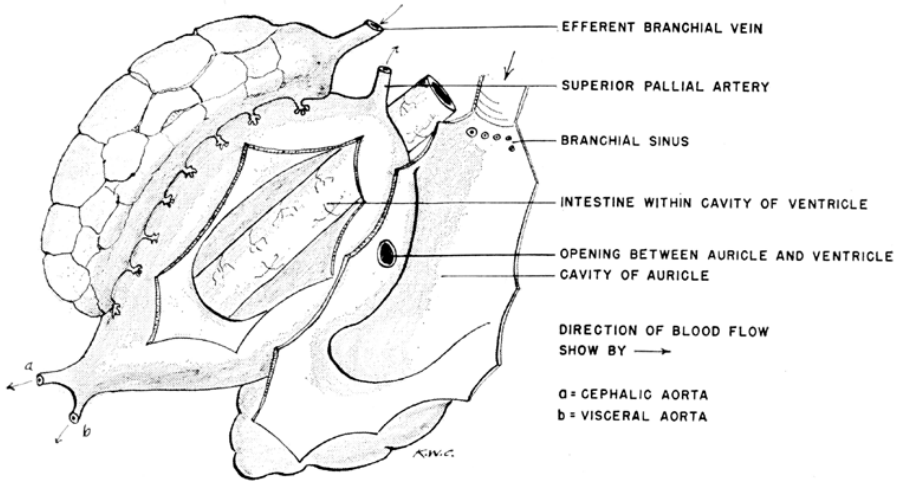


FIGURE 9. The *Haliotis* heart. The intestine passes through the ventricular chamber.

FIGURE 9. The Haliotis heart. The intestine passes through the ventricular chamber

all parts of the body. The blood from the lacunae collects in venous sinuses before returning by way of veins or a series of sinuses through the kidneys, the ctenidia and into the auricles again. The blood is moved through the sinuses and veins by the connective tissue and neighboring muscles; there are no muscles in either the arteries or veins.

The blood has a slight bluish tinge due to haemocyanin which carries the oxygen. Haemoglobin is present but only in the odontophore musculature. There is no mechanism to coagulate the blood and if the abalone is deeply cut, or if a large piece is bitten out by a predator, it may bleed to death. An abalone weighing two pounds exclusive of the shell, contains approximately 30 cc of blood (Albrecht, 1917). Abalone blood contains antimicrobial properties (Li, 1960 a and 1960 b) that are effective against a wide variety of micro-organisms including penicillin-resistant Staphlococcus aureus, Bacillus subtilis, Salmonella paratyphi *A* and *B,* Salmonella typhi and Streptococcus pyogenes.

3.1.4. Musculature

Most of the body of an abalone is a large muscle mass consisting of the foot, including its epipodium and the large right shell columellar muscle (Figure 10). The left shell muscle is very small and attaches

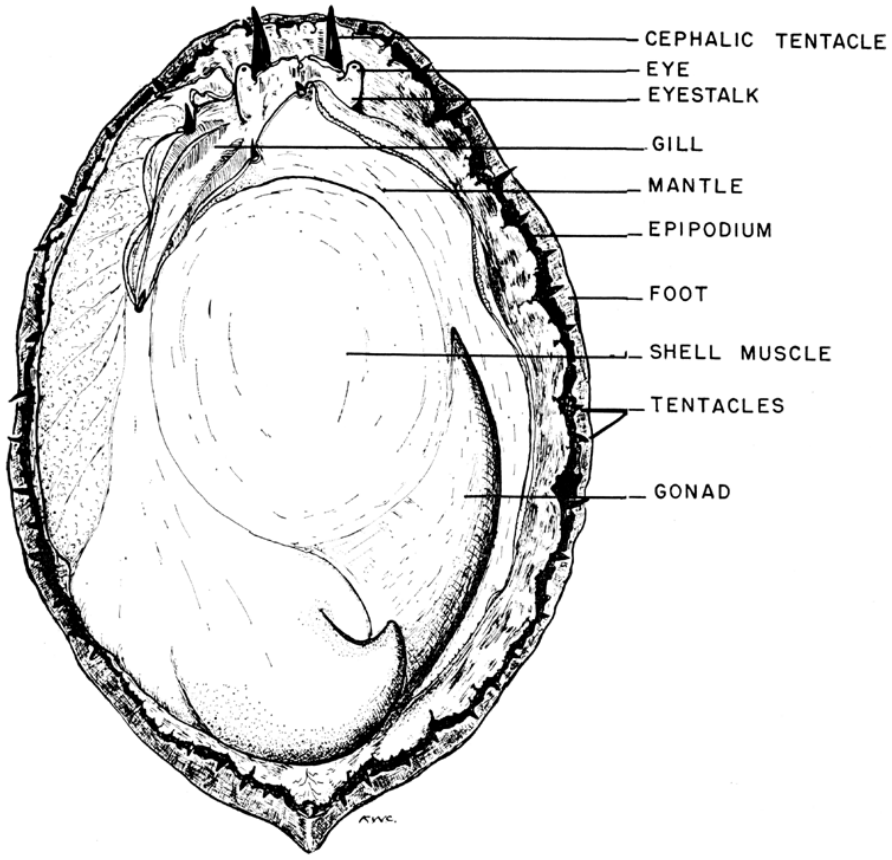


FIGURE 10. Dorsal view of abalone with shell removed.

FIGURE 10. Dorsal view of abalone with shell removed

at the edge of the shell. The right shell muscle, which stands as a vertical pillar of closely packed fibers, continues into the muscles of the foot. These fibers are covered on the surface that attaches to the shell by flattened epithelial cells. How muscles attach to the shell was described by Hubendick (1958) for a freshwater limpet-like gastropod, Acroloxus lacustries; probably the shell of Haliotis is attached by a similar mechanism.

A number of muscle fibers extend and retract the collar-like epipodium when it is used to capture food.

The visceral organs are supported by muscles attached to the columellar shell muscle. The mouth parts, including the radula are held in position by muscle strands which radiate to the dorsal surface of the foot and to the head wall. There are numerous muscular supports in the right renal organ but none in the left.

Chemical studies conducted by Albrecht (1917) indicated the muscle tissue of H. rufescens contains approximately 70 percent water and 30 percent solids. Further analysis revealed that abalones contain 23 percent proteins, which is quite high, and 3.42 percent ash. Mammalian muscle averages about 1.0 percent ash and fish about 1.5 percent. Two important products of vertebrate metabolism, creatinine and creatin, are present in abalones but in no other mollusks. These substances are believed to play important parts in muscle contraction; their presence in abalones may explain the great strength of this mollusk. Large amounts of reducing sugars are present but glycogen and urea are not.

3.1.5. Alimentary and Digestive Systems

Both of these systems have been described in detail by Crofts (1929) and Ino (1952), and the structure and function of the alimentary canal of the California black abalone was reported on by Campbell (1949). The brief description below, taken mainly from Crofts and Ino, probably is typical for all species.

The entire alimentary tract is on the left side of the body between the columellar shell muscle and the edge of the epipodium (Figure 11). Except for the portion of the esophagus which passes through the muscles of the foot in the head region, the entire tract and viscera are outside of the large muscle mass and are held in place by the ventral and dorsal muscles.

The tract consists successively of the mouth, the esophagus, a three-or four-part stomach and the intestine. The intestine enters and passes through the heart before terminating at the anus.

The mouth contains a rasp-like radula which scrapes up food and passes it into the esophagus. Two valves at the opening of the esophagus prevent the food flow from reversing. Several ducts in the rear portion of the esophagus connect to the coelum and liver. Abalone livers are rich in such enzymes as catalase, glycoginase, lactase, lipase, maltase, protease, invertase, urease, emulsion and amylase. No cellular digestive enzymes are present in either the intestine or the stomach (Albrecht, 1921). Iron (ferric oxide) makes up 31.9 percent of the ash of the liver (Albrecht, 1917). Hashimoto and Tsutsumi (1961) isolated a photodynamic agent from the liver of Haliotis discus hannai which was

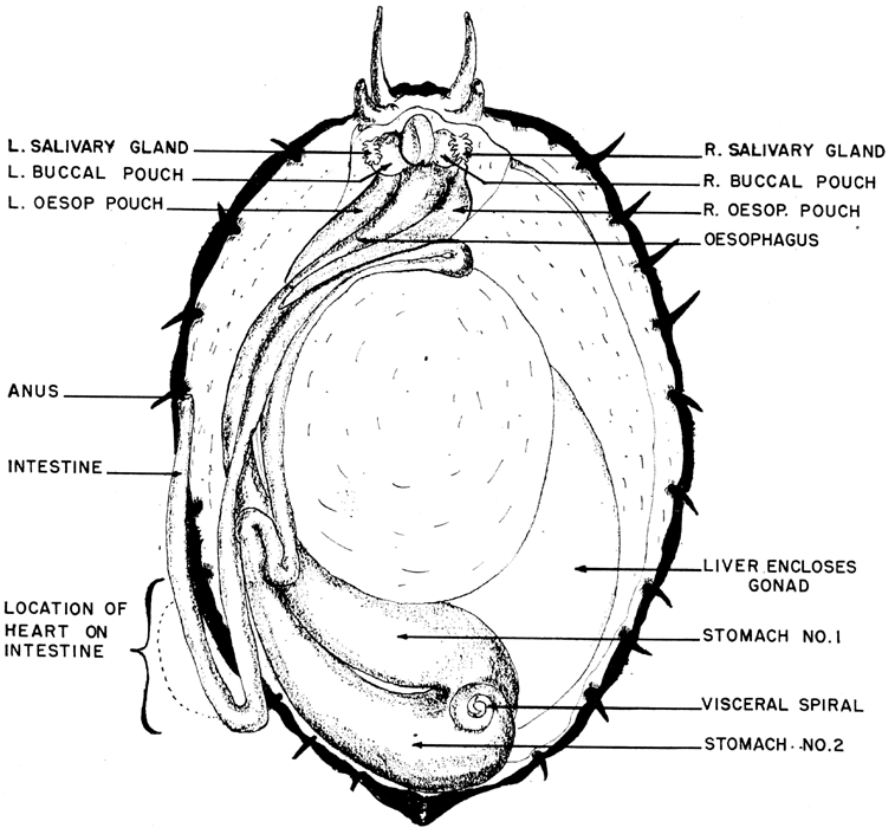


FIGURE 11. The *Haliotis* alimentary tract, ctenidia and viscera removed. Dotted lines show the position of the heart.

FIGURE 11. The Haliotis alimentary tract, ctenidia and viscera removed. Dotted lines show the position of the heart

responsible for a type of dermatitis reported on abalone fishermen as early as 1899. Hashimoto, *et al.* (1960), working with cats, rats and mice, determined that the symptoms were due to ingesting abalone liver and subsequent exposure to sunlight. All other known photodynamic agents appear to be of vegetable or synthetic origin.

The walls of the posterior part of the second stomach contain highly complex ciliated columnar cells.

3.1.6. Reproductive System

The sexes are separate in Haliotis. There is no evidence of a sex change and there is only one report of a monoecious form (Murayama, 1935). The single gonad occupies the same position in both sexes; it is extensively developed over the digestive gland and extends posteriorly as a conical, horn-shaped structure along the left side of the columellar shell muscle. Prior to and during spawning it covers much of the liver, stomach, renal organs and heart. The sex products are discharged into the right renal cavity where they are released through the external renal opening into the respiratory chamber and from there to the outside.

An abalone's sex can be distinguished by the color of its gonad; the male's gonad is creamy biege, while the female's is green. The gonads are readily observed after pulling back the foot and epipodium on the right side and looking under the conical appendage.

Among H. tuberculata of Europe, the gonads become visible when specimens are 2.5 cm long and spawning occurs at 5 cm. The male gonad can be recognized in abalones 4 cm long. Palmer (1907) found that gonads of California black abalones were not visible until the shells were slightly longer than 5 cm but were well-established by 8 cm. Ova and sperm, while immature in specimens 7 to 8 cm long, were advanced in their development. He stated that breeding activity did not begin until the shells were more than 9 cm long and that sexual activity of the males preceded that of the females. Gonad development in California red abalones closely parallels that of the blacks and spawning probably does not occur until they reach 9 to 10 cm.

The maturation cycles of sex products established for black abalones by Leighton (1959) and observed by me for red abalones, appear to coincide. In general the gonads are smallest during the late fall and winter. They start developing in late winter and early spring and from then until the middle of summer, gonadal tissue is at its peak of development, depending upon locality and species. From summer through fall the tissue mass rapidly decreases. Occasionally, abalones will be found with mature gonads throughout the year but these are exceptional and represent unusual conditions. As mentioned in the spawning discussion, warm water is necessary to induce spawning and this occurs along the California coast only during the summer and early fall, rarely in the spring.

3.1.7. Excretory System

Paired kidneys are present in Haliotis but the bi-lobed right one is the principal excretory organ. It is well-developed and lies to the right of the pericardium, usually overlapped slightly by the digestive gland. Its anterior lobe extends as far forward as the anterior end of the shell muscle and the posterior lobe extends around and under the pericardium. Almost all of the venous blood passes through the right kidney and is carried away by the efferent renal vessels. The left kidney is to the left of the pericardium, much reduced, and consists of a papillated sac, "with modified renal and perhaps newly acquired functions" (Crofts 1929). There is considerable literature on the structure, function and morphology of the haliotid kidney but few of these accounts agree with each other.

3.2. Description of Species

In the course of the Department's abalone investigation, much new information has been gathered and this section, which redescribes California species, is based on some of these findings. Many conservationists, biologists, wardens and others who are charged with management and law enforcement are unable to identify all eight California abalones. Fewer than 10 percent of the sportsmen who fish for abalones know all of the species they take and many persons engaged in the

commercial fishery are unfamiliar with all the abalones they encounter. Since the laws and regulations governing the fishery are different for most species, proper identification is of greatest importance.

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 variations in shell form, sculpture and color, numerous abnormal and atypical individuals have been described as new. With few exceptions, abalone descriptions have been confined to shell characteristics; only rarely has 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 and habitat, a field key (Table 4) is included for identifying the eight California species.

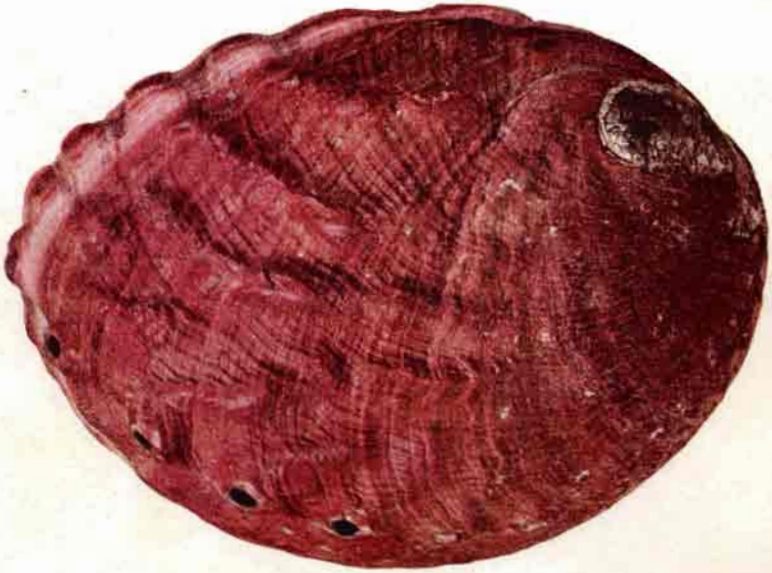
3.3. RED ABALONE
Haliotis refescens Swainson 1822

Distinguishing Characters: This is the largest of all abalones, reaching over 11 inches in diameter. Outside color of shell dull brick red. Surface sculpture lumpy, usually covered with vegetation, barnacles, or other marine growth making color and sculpture difficult to determine. Inside iridescent and highly polished with large, distinctive, prominent, muscle scar having dark green markings. Muscle scar has a central "flow" area with smooth borders crossed by numerous paralleling fine lines. These lines are continuous across the anterior end of the muscle scar. Outer lip of shell extends over inner nacreous surface typically forming a narrow red rim (giving species its name); rim may be green, brown, blue, orange or mottled. Holes slightly raised, tubular, oval, usually three to four open, although specimens with no holes and others with more than four have been found. Body and epipodium are smooth, usually black, although some have alternate "dark" and "light" vertical stripes. Edges of epipodium scalloped, with black tentacles extending beyond edge of shell. In some individuals upper edge of epipodium is white and projects just beyond edge of shell.

Distribution: Sunset Bay, Oregon, to Turtle Bay, Baja California, and reported from the Farallons and all the Channel Islands. Over 800 were transplanted by the Department of Fish and Game in 1956 to Santa Catalina Island. In 1958, approximately 300 were transplanted to Washington where they were placed in the vicinity of the Strait of Juan de Fuca.

Habitat: Inhabits rock shores in certain areas along the coast from near high tide mark out to at least 540 feet, with maximum concentrations between 20 and 50 feet. In Northern California where it is not too plentiful, it is found near shore in shallower waters. It increases in abundance in central California and in the area from Cape San Martin to Morro Bay the greatest numbers are found. South of Point Conception it is only occasionally found along the shoreline and then in deeper water. These abalones apparently require an active surf. Usually they are not found in sheltered bays but prefer locations where there is considerable wave action and water exchange such as along rocky headlands and promontories.

Red abalone, *Haliotis rufescens,* 8½ inches long from 6 fathoms off Pt. Estero, California, March 31, 1951. *Photographs by Glen Bickford.*



3.4. PINK ABALONE
Haliotis corrugata Gray 1828

Distinguishing Characters: Shell thick, circular and highly arched. Surface roughened with wavy corrugations (hence the name "corrugata"). Two to four large open holes bordered by sharply elevated rims, which may be worn flush with shell in some individuals. Edge of shell is usually sharply scalloped. Exterior of shell dull green to reddish brown, surface usually covered by heavy vegetation and other marine growth. Interior brilliantly iridescent, nacreous portion predominantly pink with traces of green. Large muscle scar with prominent dark green markings. Grows to 10 inches in diameter, but most are six to seven. Young specimens are quite flat until they reach three to four inches when shell begins to arch. This species offers a variety of shell forms making identification by shell characteristics alone sometimes difficult. The epipodium extending below the edge of the shell is roughened, its upper edge delicately lacelike in structure, is mottled black and white. The long, slender, black tentacles extend beyond the edge of the shell and the body is blackish.

Distribution: Pt. Conception south to Turtle Bay, Baja California. They are abundant on Santa Barbara and San Clemente Islands and have been found on all of the Channel Islands. Individuals of this species have been recovered from Cortez Bank and are also found at Guadalupe Island, Baja California.

Habitat: Along the rocky shores from the intertidal area out to 180 feet of water with major quantities located in the 20- to 80-foot depths. They are found in the more protected coves and bays as well as along the exposed coast in the active surf. They feed on giant kelp (Macro-cystis) but will also eat other species of seaweed. The young remain under rocks and in cracks and crevices until attaining a size of three and one-half to four inches. They then move out and take up residence on the exposed surfaces of the rocks and cliffsides of the ocean bottom. Tagging experiments indicate that there is little movement. Tagged abalones have been recovered in the same general area in which they were released as much as three years later.

Pink abalone, *Haliotis corrugata*, 6⅝ inches long from 10 fathoms off La Jolla, California, February 26, 1952. *Photographs by Glen Bickford.*

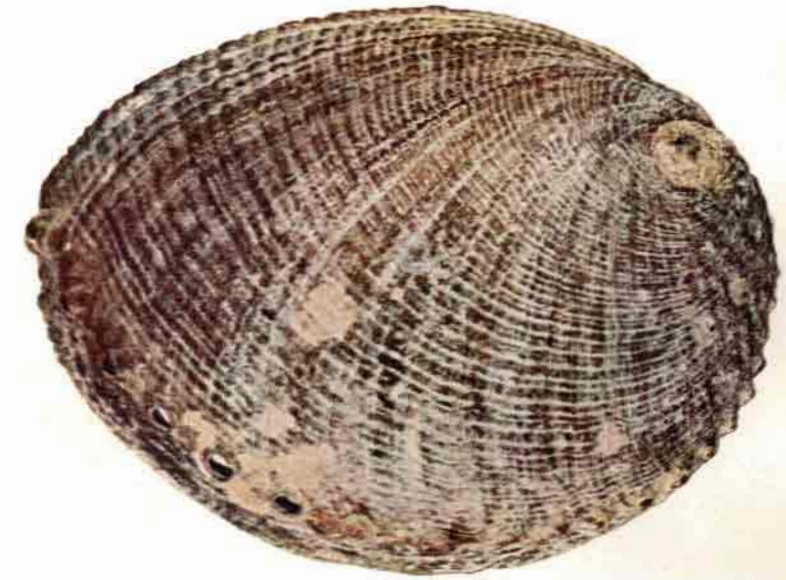
3.5. GREEN ABALONE
Haliotis fulgens Philippi 1845

Distinguishing Characters: Shell is oval, fairly thick, reaching 10 inches in greatest diameter but most individuals between five and eight. Outer surface an olive green to reddish brown color, regular in form and sculpture, with numerous, broad, flat-topped ribs separated by narrow, straightsided grooves. The holes are small, circular, only slightly elevated (may be worn flush with shell in larger individuals) and five to seven are open. The shell may be covered by marine growths. The interior is brilliantly iridescent with predominant shades of dark green and blue. The muscle scar is vivid and striking in appearance. The interior is considered by many to be among the most beautiful of all abalones. The epipodium is an olive green with patches of brown. It is scalloped along the edge and small protuberances give it a rough, frilled surface. The tentacles are greyish green and somewhat short and thick and project from under the shell a short distance. This species shows considerable variation and H. splendens Reeve, H. revea Bartsch, and H. turveri are synonyms.

Distribution: Although reported from the Farallon Islands and from Monterey it is doubtful that the species is found so far north. Its northern range appears to be Pt. Conception and it extends south to Magdalena Bay, Baja California. This or a subspecies also is found at Guadalupe Island, Baja California. Records from the Gulf of California are based upon dead shells, probably carried there by travelers.

Habitat: This is a shallow water abalone inhabiting the rocky areas from about low tide out to 25 feet; occasional individuals are taken at from 50 to 60 feet but the great majority are located in 10- to 20-foot depths.

Green abalone, *Haliotis fulgens*, 7 inches long from 1 fathom off Long Point, Santa Catalina Island, February 22, 1952. *Photographs by Glen Bickford.*



3.6. BLACK ABALONE
Haliotis cracherodii Leach 1817

Distinguishing Characters: Color of outside shell typically dark blue or greenish black, sometimes orange. The exterior is usually quite smooth, with little or no marine growth on it. The inside is silvery with green and pink reflections, typically with no muscle scar. Shell deep, bluntly oval, although variations in shape and form are common. Reaches a diameter of eight inches but most are three to five. The outer edge of the shell projects over the inner nacreous surface forming a narrow dark blue, sometimes black or orange rim. Holes are flush with surface of shell and small in diameter; usually five to nine are open. Some shells may lack holes altogether (unnecessarily named H. cracherodii holzeneri Hemphill, H. c. imperforata Dall, and H. c. lusus Finlay). (A subspecies found on Guadalupe Island, Baja California, H. c. californiensis Swanson, is characterized by 12 to 16 small open holes. H. c. bonita Orcutt is the same as the Guadalupe Island subspecies.) The body is smooth and black in color with small scallops along the upper edge of the epipodium; scattered short, slender, black tentacles protrude slightly beyond the edge of the shell.

Distribution: Coos Bay, Oregon, to Cape San Lucas, Baja California.

Habitat: From near high tide out to about 20 feet with most intertidal. Usually found in great numbers crowded close together and at times stacked two or three on top of each other. This serves to keep shells free of marine growth since the intertidal area is sometimes lacking in sea weeds and they obtain food by grazing on each other's shells. They also capture broken bits of sea weeds which wash by.

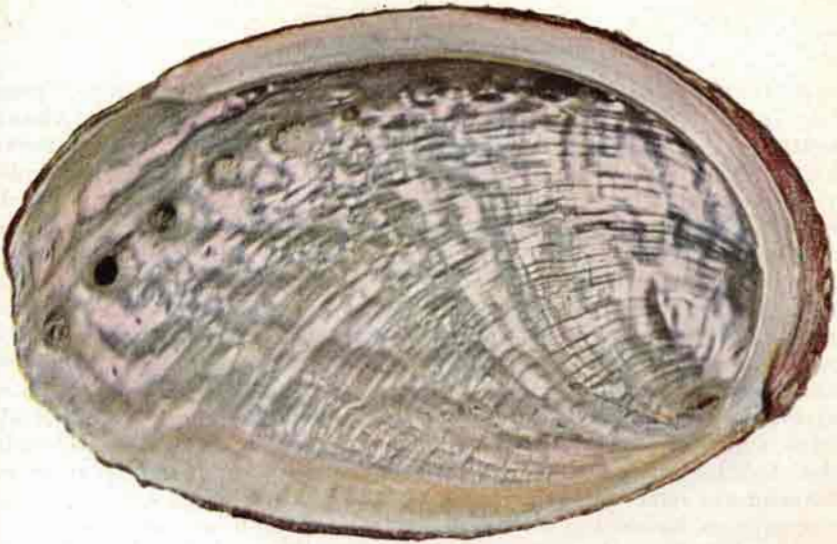
Black abalone, *Haliotis cracherodii*. Top: 3½ inches long from intertidal zone, Catalina Harbor, Santa Catalina Island, California. Bottom: 3⅞ inches long from intertidal zone, Catalina Harbor, Santa Catalina Island, California. *Photographs by Glen Bickford.*

3.7. FLAT ABALONE
Haliotis walallensis Stearns 1899

Distinguishing Characters: Ranges in size up to seven inches, but most individuals are three to five. Shell oval, long and narrow, considerably flattened. Exhibits less variation in shell form than other species. Color dark brick red with occasional mottlings of greenish blue and white. Holes four to eight, usually five or six open. Surface sculpture regular with numerous low, evenly rounded ribs crossed by closely spaced, lamellae-like striae. Inside of shell pale pink, with green reflections. No muscle scar although some may have small clumps of scattered green and brownish nacre in the muscle attachment area. The body is a mottled yellow and brown with tinges of green. The epipodium is lacklike along the upper edge, colored a yellowish-green with large brown and yellow splotches. The surface of the epipodium is rough and the tentacles are dark green and slender.

Distribution: British Columbia to La Jolla, California, but rare south of Carmel, California. Generally not plentiful, but occasionally abundant in small areas.

Habitat: Found subtidally and to depths greater than 70 feet. Lives on and under rocks with other species of abalones. Feeds by grazing on small attached algae.



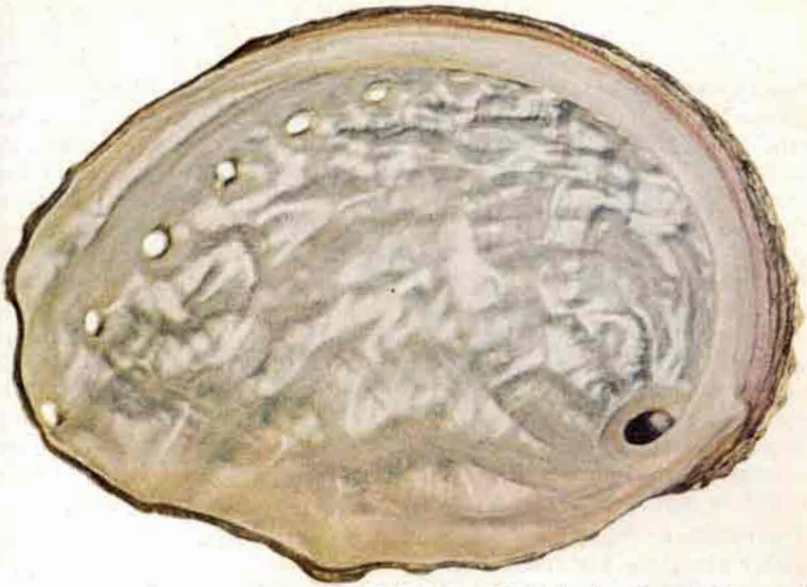
Flat abalone, *Haliotis walallensis*. Top: 3¼ inches long from 5 fathoms off Pt. Estero, California, April 30, 1956. Bottom: 3¾ inches long from 9 fathoms off Pt. Estero, California, May 1, 1956. *Photographs by Glen Bickford.*

3.8. PINTO ABALONE
Haliotis kamtschatkana Jonas 1845

Distinguishing Characters: This species exhibits considerable variation in shell form. In its northern range, which extends from Alaska south to Pt. Sur, California, it is characterized by a long, narrow, highly arched shell, having a rough, irregular surface. Larger individuals usually have a prominent spire. In its southern form, which extends from Pt. Sur to Pt. Conception, the shell is more oval in shape and not as highly arched; the surface is more regular and smooth and the spire is not as high. In both forms the shell is thin, colored a mottled greenish-brown with occasional white and blue scattered over the surface. Holes number from three to six, usually five, with raised edges and in some specimens a shallow, grooved channel under the line of holes parallel to the edge. The interior is an iridescent pearly white, typically with no marked muscle scar although larger individuals may have small clumps of greenish nacreous substance scattered inside the shell in the region of muscle attachment. Raised, lumpy areas of exterior are reflected by hollows and pit-like areas in the interior. Sizes range to six inches, but seldom exceed four. The epipodium is scalloped and lacelike along the upper edge and colored a mottled greenish-brown. The body is mottled tan and greenish brown; some with tinges of orange. The tenacles are green and slender, and the tips extend from under the edge of the shell when the animal is moving or feeding.

Distribution: Sitka, Alaska, to Pt. Conception, California. Formerly thought to extend to northern Japan via the Aleutian Island chain, but the Japanese form has been established as a subspecies.

Habitat: In its northern range in Alaska it is found in shallow water among the rocks at low tide. Further south it is found in deeper water, and in central California the greatest numbers are found in the 35 to 50 foot depths. Although not a common species it is not rare and in some areas in deep water offshore may be found in large numbers. In deeper water this abalone is found more or less in the open on top of the substrate, rather than in cracks and crevices and on the undersides of rocks. The shells are covered with the same marine growths that are found on the substrate, making them difficult to distinguish from the surroundings. Food consists principally of small algae growing on the subsurface rather than the larger seaweeds which are favored by most of the other species. It is this diet which apparently gives the varied colors to the shell. H. aulae Bartsch 1940 and H. smithsoni Bartsch 1940 are synonyms.



Pinto abalone, *Haliotis kamtschatkana*. Top: 3⅜ inches long from 8 fathoms off Pt. Estero, California, April 7, 1955. Bottom: 3½ inches long from 5 fathoms off Pt. Estero, California, April 24, 1956. *Photographs by Glen Bickford.*

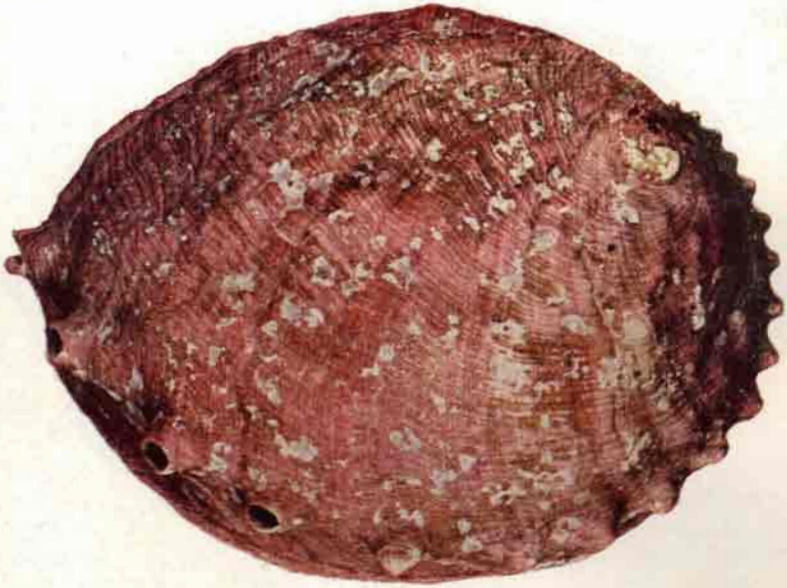
3.9. WHITE ABALONE
Haliotis sorenseni Bartsch 1940

Distinguishing Characters: Shell thin and light, oval, highly arched, reddish brown color exteriorly. Surface sculpture regular, with low spiral ribs, usually covered by lush marine growth, especially tube dwelling mollusks. The holes are highly elevated and between three and five are open. The interior is a striking pearly white with iridescent tints mainly pink; the outer edge of the lip is quite thin with a narrow red border. The muscle scar is typically absent, but if present is poorly differentiated; in some larger individuals small blue-colored nacreous clumps are scattered over the interior. The epipodium is roughened and is mottled yellowish green and biege color. Its edges are scalloped and lacelike with occasional edgings of orange. The long, thin, light green and yellowish tentacles extend beyond edge of the shell. The portion of the mantle extending over the head region of the animal is edged in purple. The body is typically yellow or orange colored and the meat is quite tender. Shell attains a length of 10 inches, but most are five to eight. Individuals smaller than four inches are rare.

Distribution: Not found north of Pt. Conception, taken only occasionally along the mainland at Pt. Dume, Palos Verdes and San Diego. Most abundant among the Channel Islands of Santa Catalina, Santa Cruz, Santa Barbara, San Clemente and Los Coronados; also reported from Turtle Bay and Cedros Island, Baja California.

Habitat: A deep-water form found from 15 feet (rarely) to 150 (may extend to greater depths), with greatest concentration between 80 and 100 feet.

White abalone, *Haliotis sorenseni*, 7⅜ inches long from 16½ fathoms on Harbor Reef, Santa Catalina Island, California, November 12, 1958. *Photographs by Glen Bickford.*



3.10. THREADED ABALONE
Haliotis assimilis Dall 1878

Distinguishing Characters: Shell oval, moderately thin, arched. Attains a length of six inches but most are smaller than four. Surface fairly regular with prominent, broad spiral ribs interspaced by several low, narrow ribs or ridges. Four to six holes open, small, tubular, raised. Shallow groove between holes and edge of shell. Spire moderately high. Surface of shell primarily greenish with patches and spots of dull brown, white, red or yellow. Outer lip of shell extends over inner nacreous surface, producing typical narrow reddish-brown and greenish colored border. Interior surface iridescent, light pearly white. No muscle scar in most individuals, occasional scar-like impression in larger specimens, some with small clumps of greenish nacre in vicinity of muscle attachment.

Body yellowish cream with brown blotching, epipodium light brown and cream, banded. Numerous small rounded protuberances on surface of epipodium, upper edge fringelike and flecked with white. Orange tinted on edge of foot and mantle, eye stalks and in throat region. Tentacles short and light brownish-yellow in color.

Distribution: From Pt. Conception south to Turtle Bay, Baja California, primarily along the mainland.

Habitat: Rocky bottoms offshore in depths ranging from 10 feet (rare) to over 120 feet; greatest numbers are found in 70- to 100-foot depths.

Threaded abalone, *Haliotis assimilis*, 5 inches long from 12 fathoms off Pt. Loma, California, June 1955. *Photographs by Glen Bickford.*

3.11. Key to the Abalones of California

No single character will positively distinguish one abalone from another. Rather, identification is dependent upon a combination of characters including any or all of a number of items such as the color of the shell, the number of open holes, shell sculpture, body color, muscle scars, etc. These items and others are briefly described for each species in the key (Table 4). It should be kept in mind that while the descriptions are typical for the species, it is not uncommon for individuals of a given species to vary from one or more items listed in the key. These variations are discussed in the following terms used in key characters.

3.11.1. Terms Used in Key to Abalones of California

Number of Open Holes: For typical specimens, the number of open holes will fall within the ranges given in the key. However, individuals having more or fewer than the typical number listed for a given species are not uncommon.

Shape and Structure of Holes: The shape of the openings varies from circular to elipsoid and the holes range in diameter from approximately 1/16-inch to over ½-inch depending on the size of individual and the species.

The structures on which the holes are located vary in height from almost flush with the surface of the shell to chimney-like extensions projecting, in some species, over ½-inch from the surrounding surface.

Color of Exterior of Shell: Because most abalones support a considerable growth of marine organisms on the exteriors of their shells it may be necessary to remove some of this encrustation before the color can be determined. It should be kept in mind that color variations are not uncommon and in some species the intensity of the colors will be found to cover a relatively large range.

Shell Sculpture: The surface of the shell while characteristic for each species is subject to modification due to marine growths, wear, etc., and the sculpturing may be considerably masked. Two separate features, the general surface configuration and the spiral ribs or striations are indicated in the key for typical species. The surface configuration of some species is almost smooth while others are lumpy and irregular or with deep corrugations.

The spiral ribs or striations which run parallel to the holes are also characteristic for species; in some they are evenly rounded and smooth, in others they are coarse and roughened, and in still others they are in a pattern of various (irregular) widths.

Shell Margin: Inside of the shell will be found a colored rim running around the anterior or growing edge of the shell, usually more prominent near the holes. The color of this rim is the same as that on the surface of the shell. It will vary in width depending upon the species and upon the condition of the individual abalone. Older abalones usually have a narrow, rounded edge, while the young and growing specimens will have a wider, sharp-edged rim, usually scalloped.

Color of Body: This feature in combination with the color of the tentacles and the area between the tentacles is perhaps the most reliable and constant character for separating the species. Body color

TABLE 4

Key to the Abalones of California

Abalone species	Number of open holes	Shape and structure of holes	Color of exterior of shell	Shell sculpture	Shell margin	Color of body	Color of tentacles	Area between tentacles	Muscle scar	Characteristics of muscle scar	Interior of shell major iridescence
Red	3-4	oval, slightly tubular	dull brick-red	lumpy undulating	red rim	black	black	lobed, smooth	prominent	straight green lines at sides and front edge	dull green
Pink	2-4	round, highly elevated	dull green to reddish brown	irregular corrugated	mottled, sharp, scalloped	black	black	white lace-like edge	prominent	wavy bands and clusters of closely spaced "flow" lines with pinkish iridescence	pink
Black	5-9	round, small flush with shell	dark blue to balck	smooth	blue or black smooth	black	black	lobed, smooth	absent	--	pearly white
Green	5-7	round, small slightly raised	olive green to reddish brown	regular with coarse spiral ribbing	brownish, sharp	olive green to light brown	olive green	green lace-like edge	prominent	same as for pink with green and blue iridescence	green and blue
White	3-5	oval highly elevated	reddish brown	regular with low spiral ribbing	red, sharp	yellowish tan traces of orange	yellowish green	beige lace-like edge	absent	--	pearly white and pink
Pinto	3-6	oval raised	mottled greenish brown with scattered white & blue	lumpy exterior reflected on interior by hollows, pits, etc.	narrow, mottled, scalloped	mottled greenish tan or brown	greenish brown	lace-like edge, greenish brown, rough	absent	--	pearly white
Flat	4-8	oval raised	brick red with white blue & green mottlings	numerous evenly rounded spiral ribs crossed by thin raised striations	thin, red	yellowish green mottled	yellowish green	lace-like edge, yellow-green roughened	absent	--	purplish pink
Threaded	3-6	oval slightly raised	mottled greenish with red, white or brownish spotting	widely separated prominent spiral ribs interspaced with numerous fine ribs	thin, mottled greenish, red-blue	yellowish cream and brown	brownish-yellow	lace-like edge, yellowish-brown roughened	absent	--	pearly white

tends to remain consistent for most. Only minor deviations from those given in the key are encountered. The primary exception is in red abalones (H. rufescens) where occasional variations in color patterns and color shades are not unusual.

Color of Tentacles: The colors in the key are for the longest tentacles, and are usually similar to the major body color.

Area Between Tentacles: This area is part of the epipodium, which is the band- or collar-like structure arising from the dorsal part of the foot and stretching laterally from the head region around the posterior end of the body. The epipodial structures, other than the tentacles, are numerous and are pigmented black, brown, green, yellow, etc., depending on species. The top and the bottom edge of the epipodium has a scalloped or lacelike fringe cut by larger and smaller notches. The large tentacles in most species extend from the larger notches and appear more numerous on the upper edge. The area between the top and bottom edges of the epipodium ranges from smooth to roughened and is characteristically colored for each species.

Color of Muscle Scar: Only three species have a true muscle scar with a characteristic color and pattern. Among those species which do not have a true scar, small nacreous deposits are sometimes found in the muscle attachment region.

Interior of Shell, Major Iridescence: The interior of the shell of all abalones is iridescent but some species have a predominant color which gives a characteristic sheen or cast as indicated in the key.

3.12. Life History

3.12.1. Spawning

Although the spawning season for the different species of Haliotis may vary according to their location, liberation of sex products is believed to depend upon the water's temperature. Ino (1952) reported that Japanese haliotids do not spawn until the water reaches 20°C.

Crofts (1929, 1937) says that the spawning period for H. tuberculata among the English Channel Islands, "extends from June to September and may continue into autumn." Stephenson (1924), who also worked with this species in the same area, believed they were "late summer breeders." He reported that, "gonads ripen gradually during June and July with both males and females spawning during the first week of August." Medem (1948) observed H. tuberculata spawning in aquaria from June through the middle of September. The waters are warmest during the summer in this area; they range from 16° to 17°C. during August (Sverdrup, *et al.* 1944). Graham (1941), reporting on the breeding habits of 22 mollusks in New Zealand states that, "an aquarium specimen (Dec. 14, 1931), of H. iris commenced to exude clouds of eggs at 7 a.m. and within 15 hours had produced approximately one million eggs." December is mid-summer in New Zealand and water temperatures are warmest then.

Carlisle (1945), the first to induce California red abalones to spawn under laboratory conditions, demonstrated that the season extends from July through September, the period of warmest water along this coast. Although Heath (1925) reported red abalones were spawning between February 15 and April 1, Carlisle showed that while apparent

spawning can be observed, fertilization will not occur until later in the year. Other workers have found motile sperm and mature eggs in the gonads of red abalones at Monterey throughout the year. Although male reds can be induced to eject sperm during practically any month of the year, females will liberate eggs only during certain months. Their ovaries may appear to be mature throughout the year but egg fertilization and larval development will proceed only after their gonads have undergone complete physiological development.

During 1957, 1958 and 1959, the main food supply of the abalones off California practically disappeared when an unseasonal influx of warm water destroyed most of the kelp beds. During this starvation period, the gonads of the abalones did not increase in size during their regular spawning seasons and many probably were unable to spawn.

In nature, usually only male haliotid spawning is noticed. The spermatozoa are released through the respiratory pores in cloudlike white puffs. Eggs are also ejected through the respiratory pores but are not readily recognized because they are green and blend with the color of the sea. During extrusion of the sexual products, the shell is often lifted and the muscle contracted rapidly. Once started, spawning continues without interruption. Great quantities of sperm are produced and the ova are scattered so densely that sometimes the shell is hidden. Medem (1948) could neither stimulate males into discharging sperm when females were present nor *vice versa*. However, he did find that by dipping a water glass in the tank at rhythmic intervals, imitating the natural muscular spawning contractions, he was able to stimulate the animals into discharging their sex products. Medem stated that Haliotis spawning is not brought about by a chemical but by a specific physical stimulation. Ino (1952) said that only a simple mechanical stimulation or an increase in water temperature was needed to cause spawning in mature individuals. Carlisle (1945) exposed red abalones to the air for 1 hour and 15 minutes before the males gave off large quantities of sperm. When these were washed over the females and all individuals placed in well-aerated salt water tanks, the females spawned within six to eight hours.

From sampling the gonads of the abalones along the California coast, I found that a protracted period of spawning occurs from late spring and into the early fall. Gonadal tissue generally decreased in late fall and winter and increased in early spring. Leighton (1959) reported that male black abalones preceded the females in gonadal ripening in the spring and became spent first in the fall. He suggested there may be a maturation stimulus which acts upon the female.

Spawning activity among red abalones in central California (San Luis Obispo County) is generally greatest during the late spring and early summer. However, the spawning periods of groups of red abalones living within relatively short distances of each other, often were separated by weeks or even months. These differences may have been due to variations within the local habitat or to inherent genetic population differences.

Extensive spawning periods are also indicated by collections containing mixed sizes of young haliotids. Crofts (1929), in April 1927, found H. tuberculata with shells 2 to 11 mm long and in August of the same year she found them with shells 2.5 to 11 mm long. This suggests

at least two separate spawning periods, one in early spring and another in the middle of summer.

In October 1955, a sample of black abalones collected at White Point, California, contained 69 individuals 1.0 to 8.5 mm long. All were judged to have resulted from spawning in the spring and early summer.

3.12.2. Development

There have been numerous studies of the anatomy, physiology, morphology and taxonomy of Haliotis but comparatively little work has been attempted on their propagation and embryology. Abalone fertilization experiments are difficult to conduct because of the problems of obtaining mature specimens in spawning condition (Ino, 1952) and of rearing the young larvae, particularly during their swimming stages. Kishinouye (1894, 1895), working with Japanese haliotids was the first to attempt fertilization studies but his experiments failed. Boutan (1899) was the first to report on the embryology of the European H. tuberculata. He described the trochophore larva and shell development but was unable to determine the time of metamorphosis. Stephenson (1924), working with the same species, got swimming trochophores at 44 to 46 hours and carried them to more than 60 hours but they did not develop further. Murayama (1935) fertilized Japanese H. gigantea artificially and carried them for about six weeks. Crofts (1929, 1937) gave accounts of H. tuberculata spawning in the sea and of following their organogenesis through two months. Carlisle (1945) was able to carry H. rufescens from fertilization through seven days, when they appeared close to metamorphosis.

Ino (1952) was the first to obtain a complete ontogenetic sequence for two Japanese abalones, H. seboldii and H. discus, carrying the development of H. seboldii to 20 days and H. discus for 13 months. He successfully reared approximately 100 young haliotids during 1960 and 1961, and in 1962 was engaged in commercial production on a pilot scale (Ino, pers. corres.).

Ino's developmental stages were very smiliar to the identical stages as reported by other workers (Boutan, 1899; Crofts, 1929 and 1937; Murayama, 1935; Carlisle, 1945) so there probably is not much difference in this phase of their life history between Japanese and California abalones. Ino (1952) uses 58 figures to illustrate successive developmental stages from the time the second polar body appears (7 to 8 minutes after the egg is fertilized) until the young abalone is 10 months old and has a shell 18 mm long.

3.12.3. Growth

When they are three months old young abalones average about 1 mm. When the first respiratory pore starts to form, their growth rate increases and by the time they are six months old they are approximately 6 mm long.

Young H. discus reared in the laboratory reached 18 mm by the end of one year (Figure 12) (Ino, 1952). He found young H. gigantea, 19 to 35 mm long on a floating buoy which they could have reached only as free-swimming larvae 10 months earlier. The smallest of these was almost identical to the sizes of those he reared in the laboratory. Ino

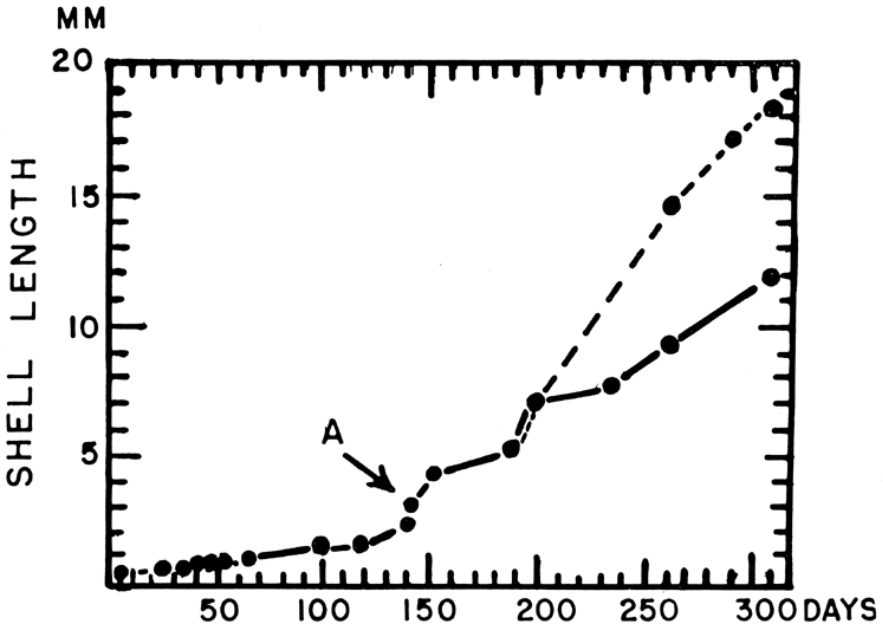


FIGURE 12. Growth of young Japanese abalone, *Haliotis discus hannai,* raised in the laboratory. By the end of approximately one year they averaged 18 mm (data from Ino, 1952). Point A is where the first respiratory pore appeared. Growth of those eating diatoms is depicted by the solid line, those eating calcareous algae by the broken line.

FIGURE 12. Growth of young Japanese abalone, Haliotis discus hannai, raised in the laboratory. By the end of approximately one year they averaged 18 mm (data from Ino, 1952). Point A is where the first respiratory pore appeared. Growth of those eating diatoms is depicted by the solid line, those eating calcareous algae by the broken line

believed, however, that neither the buoy nor the laboratory represented ideal conditions and a length of 40 mm, as reported by Higurashi (1934), might be attained in a year under natural conditions. California black abalones collected in October 1955 ranged from 1.0 to 8.5 mm and from 17 to 35 mm. The smaller specimens were from 1955 spawning and those 17 to 35 mm long were from the previous year (Fitch, pers. corres.).

Growth during the first two years is believed to be fairly uniform among all species depending on the amount and kind of food available. Sakai (1960), investigating annual spawning ring formation in the shells of H. discus hannai, found that individuals 50 to 60 mm long grew approximately 30 mm in 13 months, January through August (Figure 13).

Curtner (1917) was the first to use rings on the shells of red abalones in an attempt to determine age and growth. His work was based on three specimens recovered from a lot of 350 he had marked 13 months previously. He assumed that growth slowed or ceased during winter and commenced in spring or summer leaving an annual ridge or ring on the shell. He interpolated the three recoveries into a growth series of unmarked shells collected at the same time and divided these according to age. He estimated a one-year-old abalone was 1.2 inches in diameter and calculated growth at approximately one-half inch per year. Thus, a two-year-old abalone would be 1.6 inches long, a three-year-old, 2.15 inches, etc. He figured a red abalone 8 inches in diameter, was 13 years old.

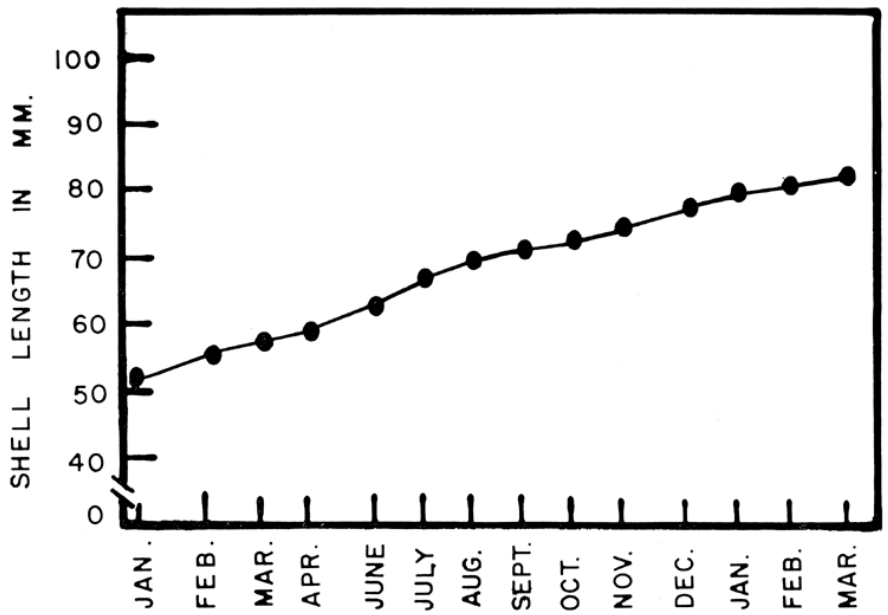


FIGURE 13. Growth of young *H. discus hannai* from about 50 mm (at age 16 months) to approximately 80 mm during 13 months (data from Sakai, 1960).

FIGURE 13. Growth of young H. discus hannai from about 50 mm (at age 16 months) to approximately 80 mm during 13 months (data from Sakai, 1960)

Curtner's estimates of age and growth were accepted until recently when tagged abalones recovered by the author showed many differences. These latest recoveries indicate that growth is not constant and varies considerably (Table 5) . Leighton (1959) reported that variability in growth seemed a rule rather than an exception with black abalones.

Sakai (1960) found that a characteristic annual spawning ring was formed on the shell of H. discus which he attributed to a temporary cessation in growth during gonad maturation and spawning. He offered this annual ring as a method of aging the species but mentioned that other rings were formed several times a year. These disturbance rings were caused by changes in the environment, such as exposure to air and temporary cessation of feeding. Using annual rings to determine age was also attempted by Bolognari (1953) on H. lamellosa. Neither of these species grows much larger than four or five inches and probably does not live more than six or seven years.

Red abalones—which attain lengths exceeding 11 inches, although most are between 7 and 9—cannot be aged by counting shell rings. These are usually crowded and obscure and it has not been possible to distinguish a true annual ring if such exists. In addition, no one has proven that a mature red abalone will spawn each year. If they do not, spawning rings would not be accurate indicators of age.

Field observations showed that growth among red abalones is not regular throughout the year; it is most apparent during the winter when their entire annual increment may be attained within a few weeks.

TABLE 5

Summary of Recoveries of 101 Tagged Red Abalones; 18 from Morro Bay (M), 6 from Ft. Ross (R), and 77 from Ft. Bragg. Numbers in Boldface Indicate Years/Months at Liberty for Morro Bay and Ft. Ross. Recoveries Time at Liberty for Ft. Bragg Recoveries Are in Table 10

(Measurements in mm)

Length when tagged		Length when recovered	Increment
1/0	150	162	+12
1/1	160 M	186	+26
2/4	168 M	184	+16
3/10	169	204	+35
2/7	178 R	180	+ 2
3/1	179 M	204	+25
	184	186	+ 2
1/8	185 R	185	0
2/3	185	196	+11
2/7	187 R	188	+ 1
	187	189	+ 2
1/3	187 R	187	0
	189	191	+ 2
	190	190	0
	190	191	+ 1
	190	194	+ 4
	192	192	0
1/1	193 M	198	+ 5
	194	196	+ 2
	194	196	+ 2
1/2	194 M	197	+ 3
1/6	194 M	194	0
	195	194	− 1
	196	196	0
1/2	197 M	197 M	0
	197	197	0
	197	197	0
	197	197	0
	197	199	+ 2
	198	198	0
	198	199	+ 1
	199	198	− 1
1/11	199 M	194	− 5
0/9	199 R	197	− 2
	199	203	+ 4
	199	206	+ 7
5/7	200 M	210	+10
	200	198	− 2
	200	201	+ 1
	200	203	+ 3
	200	206	+ 6
	201	201	0
0/10	202 M	202	0
4/0	203 M	197	− 6
	204	203	− 1
	204	204	0
0/5	204 M	204	0
	204	204	0
	204	205	+ 1
	205	205	0
1/2	205 M	205	0
	205	206	+ 1
	205	206	+ 1
	205	207	+ 2
	206	205	− 1
	206	206	0
0/2	206 M	206	0
	206	207	+ 1
3/2	206 R	210	+ 4
4/1	206 M	209	+ 3
	207	207	0
	207	209	+ 2
	208	207	− 1
	209	205	− 4
	209	208	− 1
	209	209	0
	210	212	+ 2
	210	212	+ 2
	210	209	− 1
	211	210	− 1
	211	213	+ 2
1/0	213 M	213	0
	213	209	− 4
	213	215	+ 2
	214	214	0
	214	212	− 2
	214	215	+ 1
	215	213	− 2
	215	214	− 1
	215	217	+ 2
	215	216	+ 1
	217	216	− 1
	218	217	− 1
1/0	218 M	218	0
	218	218	0
	219	214	− 5
	219	216	− 3
	219	218	− 1
	220	219	− 1
	221	220	− 1
	222	222	0
	222	222	0
	222	220	− 2
	222	221	− 1
	224	224	0
	224	224	0
	228[1]	239	+11
	229	228	− 1
	232	228	− 4
	232	230	− 2
	235	232	− 3

[1] Probable error (10 mm) in measuring.

TABLE 5

Summary of Recoveries of 101 Tagged Red Abalones; 18 from Morro Bay (M), 6 from Ft. Ross (R), and 77 from Ft. Bragg. Numbers in Boldface Indicate Years/Months at Liberty for Morro Bay and Ft. Ross. Recoveries Time at Liberty for Ft. Bragg Recoveries Are in Table 10

Analyses of tag returns (Table 5) have offered additional evidence that their growth rate is highly irregular and that size, among adult red abalones, and probably among other species as well, is not directly related to age. From approximately 150 to 190 mm, red abalones generally grow more rapidly than they do at larger sizes.

Other methods of aging red abalones and determining their growth have also been investigated. Shells have been sectioned as described by Sakai (1960) and they have been burned to induce cracking at the annual rings as described by Takayama (1940) but without success.

That growth is directly dependent upon the availability of food has been dramatically demonstrated. In 1957, an influx of warm water along the California coast destroyed practically all of the beds of brown kelp, Macrocystis and Nereocystis (Radovich, 1961), the abalone's principal food. During the nearly two years this condition persisted, growth practically ceased and body tissues appeared to shrink. The commercial divers reported a shortage of the young, legal-sized abalones which customarily appear in their catch at the beginning of each season. Because of this, minimum size limits for red abalones were reduced from 8 to 7¾ inches in 1959 but the expected benefits from this measure were partly canceled because of the reduced amount of meat in the smaller abalones.

During 1960, water temperatures began to decline and the kelps started to grow again. The immediate effect was a rapid increase in abalone growth. Abalones were recovered which had apparently added as much new shell in a few months as had formerly taken them three to five years (Table 6) . New growth could be recognized at the edge of the shell because it had not been obscured by barnacles or other marine growth (Figure 14). Most of this increment appeared to take place during the winter.

3.12.4. Food and Feeding

Haliotids are selective plant feeders. During their free-swimming stages, and until they commence a benthic existence their diet consists of pelagic plankton which are conveyed into the mouth by ciliary action (Ino, 1952). During metamorphosis from the creeping stages to the adult form, they feed upon diatoms attached to the substrate. These benthic diatoms, Navicula sp., Nitzchia sp. (Ino, 1952; Leighton, 1959), are scraped off by the radula which becomes functional at this stage of their development. On attaining the adult form, which occurs when the first respiratory pore appears and the shell is approximately 1.9 to 2.4 mm long (Ino, 1952; Leighton, 1959), a further change in diet takes place. Coralline algae replace diatoms as the principal food and the shell color, which is generally white on the diatom diet, changes abruptly and the new increment is reddish because of the pigments in the coralline algae. This color is maintained until the young abalone changes its diet to macroalgae; black abalones start eating macroalgae when they are about 10 mm long (Leighton, 1959) and reds change when about 25 mm. Their shells then become dark green and eventually blue-black for black abalones (Leighton, 1959) and dull brick-red for red abalones. often the shells of young red abalones have a mottled appearance with blue-greens, whites and reds predominant.

Ino (1952) found that different species of Japanese abalones secreted different colored shells when fed the same species of algae. Leighton (1959) reported that giant kelp, Macrocystis sp., gave black abalones the characteristic dark blue color of the adult. The same kelp produces a dull, brick-red color in red abalone shells and a dull green to reddish-brown color in pink abalones.

In California, the two most important abalones, in both the commercial and sport fishery, are reds and pinks; their diets and food habits are of special significance because of this.

The main food of red abalones is bull kelp, Nereocystis lutekeana, although in its absence other seaweeds are eaten. North of Pt. Conception bull kelp is predominant and red abalones are found only

TABLE 6

Greatest Increment (in mm) on Shells of 100 Red Abalones, 195 to 239 mm Long, Delivered to Processing Plants at Morro Bay, October 18, 1961. Abalones Taken by Divers From Morro Bay Area.

Total Shell Length	New Growth	Total Shell Length	New Growth	Total Shell Length	New Growth
195	20	202	10	208	15
195	22	202	14	208	19
		202	47	208	21
196	14			208	22
196	23	203	17	208	30
196	29	203	18	208	33
196	43	203	23	209	38
196	46	203	25		
196	47	203	27	210	11
		203	34	210	15
197	10			210	15
197	15	204	14	210	16
197	21	204	18	210	17
197	21	204	18	210	18
197	27	204	21		
197	29	204	26	211	7
197	30	204	32	211	10
197	37	204	69	211	21
				211	22
198	15	205	14	211	32
198	33	205	15		
198	35	205	19	212	27
		205	21		
199	5	205	26	213	2
199	15	205	30		
199	16	205	30	214	9
199	25	205	31	214	15
		205	32		
200	15	205	35	215	16
200	15			215	35
200	23	206	25	215	38
200	30			215	40
200	36	207	3		
200	46	207	5	216	5
		207	10	216	18
201	7	207	25		
201	20	207	32	218	39
201	21	207	37		
201	23	207	48	223	3
201	48				
				229	15
				239	29

TABLE 6

Greatest Increment (in mm) on Shells of 100 Red Abalones, 195 to 239 mm Long, Delivered to Processing Plants at Morro Bay, October 18, 1961. Abalones Taken by Divers From Morro Bay Area.

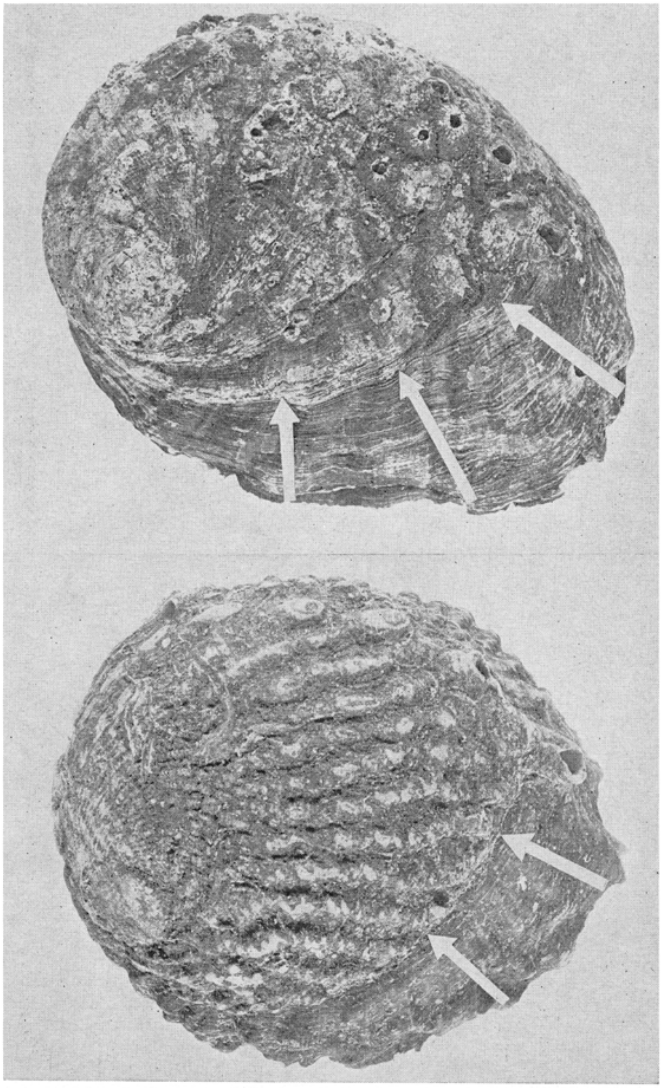


FIGURE 14. Shell increment on adult red and pink abalones during 1960-61. Red abalone (a) was taken by a commercial diver at Morro Bay, October 1961 (total length 208 mm, increment 48 mm). Pink abalone (b) was taken by a commercial diver at San Clemente Island, September 1961 (total length 153 mm, increment 30 mm). Photographs by Willis Photo. Lab., Palo Alto, 1962.

FIGURE 14. Shell increment on adult red and pink abalones during 1960–61. Red abalone (a) was taken by a commercial diver at Morro Bay, October 1961 (total length 208 mm, increment 48 mm). Pink abalone (b) was taken by a commercial diver at San Clemente Island, September 1961 (total length 153 mm, increment 30 mm). Photographs by Willis Photo. Lab., Palo Alto, 1962

where it is growing. South of Pt. Conception they feed primarily on giant kelp, the dominant brown algae in that region. In deeper waters, where bull kelp and giant kelp grow only sparingly, elk kelp, Pelagophycus porra, usually constitutes the main item of diet. Pink abalones which are not found north of Pt. Conception, feed principally on giant kelp. The greatest numbers of pinks are found around the two islands, Santa Barbara and San Clemente, where there are large beds of giant kelp. Abalones inhabiting shallower waters have more varied diets, primarily because neither bull kelp nor giant kelp grow well in turbulent water close to shore. The stomachs of these animals usually contain a wider assortment of seaweeds, including species of red algae, than do those of abalones in deeper water.

Leighton (1959) found that macroalgae constitute the principal food of black abalones. Gut content examinations had led former workers to conclude that diatoms were their main item of food.

The diets of pinto, flat, and threaded abalones probably contain greater amounts of diatomaceous and coralline algae than do the diets of the other species. This is suspected because the shells of these three species exhibit the typical mottling produced by this diet.

White abalones, which are found in deep water only, have been observed feeding on elk kelp, the principal deep-water kelp. Green abalones inhabit shallow water where feather boa kelp, Egregia laevigata, is found; they have been observed browsing on this species as well as on strands of giant kelp. Leighton (1959) stated that experimentally fed blacks exhibited a definite preference for feather boa kelp, although their growth was most rapid when they fed upon Macrocystis pyrifera, Pelvetia fastigiata and Gigartina canaliculata (a red alga).

Red abalones exhibit remarkable dexterity at capturing and manipulating strands of kelp. They extend the anterior epipodium from both sides of the head region, grasp a piece of kelp and pull it back to the mouth. If a large portion of kelp has been captured, they pass it back under the foot where it is held in a convenient position for feeding.

Experiments with rope, eel grass, probes, and other materials indicate that abalones can discriminate between food items and nonfood items. Touching the epipodium with any substance other than macroalgae causes an abalone to withdraw exposed body portions. When touched with a piece of kelp, however, an abalone will extend its epipodium, grasp the kelp and pull it towards its mouth.

The most commonly observed feeding attitude assumed by red abalones is one in which the animal clings to the substrate with the posterior part of its foot and raises the remainder of its foot and body at an angle. When a piece of drifting kelp comes in contact with the epipodium, it is immediately grasped by the forward outer edges of the epipodium and passed under the foot. The piece is passed posteriorly until it is covered by the body of the abalone which then proceeds to feed on the imprisoned kelp.

Red abalones have been observed feeding on palm kelp, Postelesia palmaeformis, and in some instances climbing the stem to browse on the growing plant. They also have been observed climbing the stipes of bull and giant kelp.

3.12.5. Habitat

Abalones live on rocks in and among the seaweeds which are their food.

The largest species of Haliotis are found in the cooler currents along the shores of the continents where brown seaweeds predominate. In warmer waters, where red algae are most common, haliotids are numerous but small.

Most of California's rocky shoreline supports an abundance of marine growth. The substrate of the littoral zone, extending between the upper limit of the high tides and the lowest point reached by low tides, is generally covered by seaweeds of various colors, shapes and sizes. The sublittoral area lying beyond the low tide limits, is inhabited principally by larger kelp. These marine algae flourish from just below the low water mark to depths exceeding 100 feet; they are in greatest profusion between the mid-littoral and 40 feet. At depths greater than 80 to 120 feet where little sunlight penetrates, smaller species of algae are inhibited. The giant kelps, with their holdfasts on the bottom but most of their bulk buoyed on the surface, grow in these depths. This coastal band of seaweed is abalone habitat.

In northern California, the shoreline drops off rapidly, forming steep underwater banks. As a result, the seaweed zone is narrow and abalones are close to shore. In central and southern California, the slope of the shoreline is more gradual and the band of marine growth is wider, extending a mile offshore in some localities. Abalones tend to distribute themselves vertically in this zone according to species, although there is some intermixing at both the shallowest and deepest margins of a species-selected depth. It is believed that a species' vertical distribution is directly related to water temperature. In Alaskan waters, H. kamtschatkana, is common intertidally (Livingson, 1952), while at its southern distribution, it is rarely found shallower than 35 feet. H. rufescens in northern California is concentrated in 10 to 20 feet of water, while off San Diego red abalones seldom are encountered at depths of less than 50 feet. Kishinouye (1894) studied the vertical distribution of several Japanese Haliotis and found that H. discus was common in water 4 to 5 meters deep, H. sieboldii was abundant in 12 to 13 meters, and H. gigantea was most numerous in water deeper than 15 meters.

The South African H. midae, is reported to range from just above low water of spring tides into water 50 feet deep with greatest abundance between 10 and 25 feet. Although haliotids will move about, they seldom travel outside of their chosen zones. Species that prefer depths between 10 and 25 feet, for example, seldom are found in 40 or 50 feet of water.

The substrate on which abalones live usually reflects the rocky character of the shoreline. In northern California, their habitat is extremely rough and rugged. The bottom consists of huge boulders and rocks, some piled one on another. Great cracks and crevices lead out into deep water from the shore and these are often filled with rubble and sand. The shoreline drops steeply into deep water and abalones are found in the narrow band of vegetation growing on this slope.

In northern California, Fort Bragg and vicinity, there are isolated localities where abalones are abundant. Abalones are often quite numerous

around the mouths of small streams and rivers entering the ocean along this stretch of coastline. There are, however, long stretches where there are no abalones. In deeper water (over 40 feet), they are extremely rare.

In the central California region (San Luis Obispo County), where the bottom slopes gently from the shore, abalones are most numerous. In these areas, boulders protrude from a sandy, more-or-less-level bottom. There are often smaller rocks scattered on the bottom and small ravines and crevices extend in several directions. There is sufficient surface for the abalones to live on without undue crowding, an adequate food supply, and protection for the young. Young abalones, after metamorphosing to the benthic stage, settle on the substrate where, because they are light-sensitive, they seek cracks and crevices in which to live. Until they are three or four inches long, they are seldom seen in the open. Previous investigators (Edwards, 1913; Bonnot, 1948) were concerned because young abalones were never seen in the areas being fished by commercial divers. The young abalones have since been found deep in cracks and on the undersides of rocks partially buried in sand and gravel. As many as 12 young ranging from 0.5 to 5.0 inches, have been found clinging to the underside of a rock partially buried in sand and gravel.

Abalones prefer areas where there is sand although they cannot attach themselves to or travel across a pure sand bottom. They have been observed at times moving over what appeared to be pure sand; however, in such cases, the sand consisted of a very thin layer over a hard bottom on which the abalones were actually moving.

Partial or temporary burial in sand apparently does not affect them. Abalones clinging to the bases of rocks set in sand frequently have only a small part of their shell and body exposed above the sand. Apparently they suffer no distress in this situation. However, when sand completely covers a rock or reef where abalones are established, they must find another habitat.

3.13. Enemies, Parasites and Other Abalone Problems

3.13.1. Sea Otters

Fisher (1939), Boolootian (pers. corres.) and others have said that various species of Haliotis are eaten by California sea otters, Enhydra lutrus neres. The extent of sea otter predation on the abalone stocks has been the subject of considerable controversy and debate. Although only limited observations have been made to determine the effects of their predation, all evidence indicates they pose a threat to human exploitation when the two are competing in the same area.

Divers, examining areas where sea otters have been observed eating abalones, have found many empty shells on the bottom showing characteristic breakage patterns (Figure 15). It is difficult to estimate the extent of these depredations because it has not been possible to obtain an accurate abalone count on a bed of any size. The original abalone population can only be estimated and after a visit by sea otters the empty shells recovered may not be complete. In areas which were inspected before and after sea otters had arrived (Carmel Cove and Stillwater Cove), the number of empty shells on the bottom indicated large numbers had been taken but the beds were not "wiped out."

FIGURE 15. Hole in the top of a red abalone shell characteristic of damage done by sea otters using rocks. Photo by Glen Bickford, 1958.

FIGURE 15. Hole in the top of a red abalone shell characteristic of damage done by sea otters using rocks. Photo by Glen Bickford, 1958

The California sea otter population consists of a number of scattered herds distributed from Monterey south to Piedras Blancas. The number of sea otters in all the herds is estimated at 690 to 700 animals (Boolootian, 1961). Except for the southernmost herd, most of them live in areas where abalones have seldom been reported; however, any further southerly expansion by the population could conceivably place sea otters in an area where they would be competing with commercial abalone fishermen. Boolootian (pers. corres.) observed that sea urchins, Strongylocentrotus spp, made up about 60 percent of the sea otter's diet, mussels, Mytilus californianus, approximately 35 percent, and red abalones about 5 percent. They also ate a few crabs, and an occasional fish or strand of kelp.

How sea otters remove abalones from rocks is not known. In deeper water where there is little or no surge, abalones may be found clinging to the substrate by the posterior third of their foot, waiting for food to drift by. When they are in this position, with the forepart of the body raised, they could be dislodged easily by a sharp blow from the

paw of a sea otter. A skindiver at Carmel said he has seen sea otters remove abalones from rocks essentially in this manner. Usually, however, abalones grip the rocks tightly and can be removed only by prying with a flat iron bar. Many of the abalone shells found where sea otters have been feeding have a large piece broken out of the top or off the side. From the condition of these shells, it is suspected that sea otters use a rock to knock out a hole and then reach in and strip the viscera, leaving the abalone clinging to the rock. After a short period, the abalone would weaken and the sea otter could descend, pull it off the rock, take it to the surface and eat it. I obtained evidence that the sea otters were doing essentially this at Point Lobos in June 1958.

In approximately 50 feet of water, on a relatively flat bottom I found an abalone with a large piece broken out of the top of its shell and the viscera removed. The abalone was still clinging to a rock. About four feet away was a stone about the same size as the abalone. The lower half of the stone was clean where it had been buried in the sand and the upper portion, which had been exposed, was covered with coralline algae. I felt certain that one of the many sea otters in the area had just attempted to gather this abalone by picking up the stone, smashing the abalone's shell and removing its viscera (Figure 16), My presence had probably frightened it off before it could descend and remove the abalone.

That sea otters possess considerable dextral ability is confirmed by many observers. Kenyon's (1959) account of a captive sea otter's strength and dexterity indicates that removing an abalone by smashing

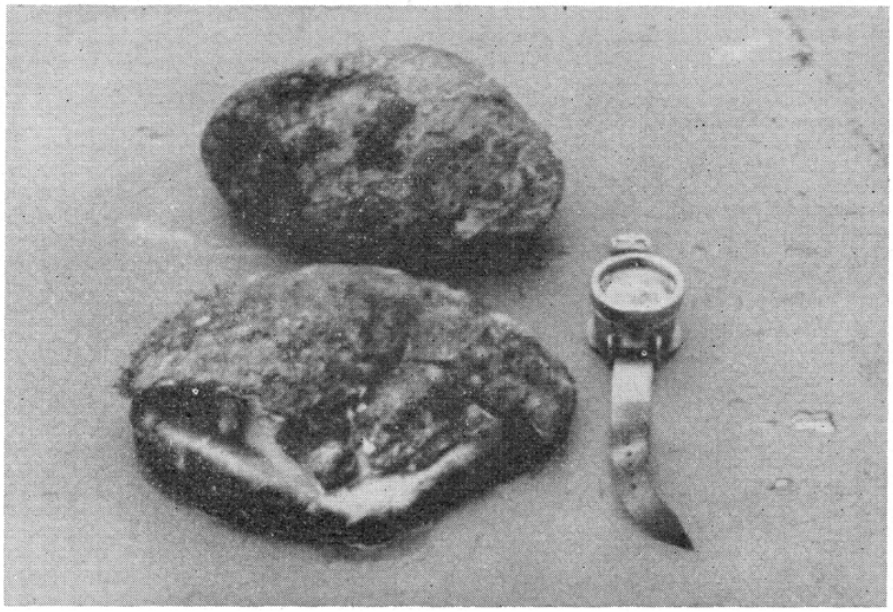


FIGURE 16. Abalone with shell broken and viscera removed by a sea otter at Carmel Bay in 50 feet of water. Rock used by otter is in background. Underwater compass (right) is for size comparison. The abalone is about eight inches across and the rock weighs about six pounds. Photo by the author, June 1958.

FIGURE 16. Abalone with shell broken and viscera removed by a sea otter at Carmel Bay in 50 feet of water. Rock used by otter is in background. Underwater compass (right) is for size comparison. The abalone is about eight inches across and the rock weighs about six pounds. Photo by the author, June 1958

the shell with a rock would be a relatively simple task for these animals. "The drain in the zoo pool was covered by metal mesh which fitted snugly in place. This the otter promptly removed when she entered the pool. Apparently the dark hole beneath fascinated her. Since food scraps plugged the open drain, her keeper secured a band of strap iron over the mesh with a bolt that projected above it. Undaunted, the sea otter pounded the bolt with a rock until she succeeded in dislodging it."

3.13.2. Fishes

In northern and central California, cabezons, Scorpaenichthys marmoratus, include abalones in their diet. O'Connell (1955) examined the stomachs of 15 cabezons taken in the Monterey area and found whole shells and fragments, several over 3 inches across, of flat and pinto abalones. The absence of blacks and reds was puzzling since these are the two most common species in the Monterey region.

Black abalones live higher in the intertidal zone, often in cracks and crevices. These two factors would tend, as suggested by O'Connell (1955), to protect them from cabezons. However, cabezons in southern California have been taken with black abalones up to 5 inches in diameter in their stomachs. Young red abalones, until they are between 3 and 4 inches across are apparently sensitive to light and remain on the undersides of rocks and deep in cracks and crevices. As a result, they are seldom in the open where a cabezon or other fish could capture them. Young and adult flats and pintos, on the other hand, are found in the open, on the tops and sides of rocks where they would be accessible to a cabezon.

Adult haliotids, unless they have become dislodged from the substrate, are not ordinarily vulnerable to fish predation. If displaced and unable to right themselves quickly, they usually fall victim to the always-present fish. Fish immediately swarm around upturned abalones and tear pieces from the foot. Three or four sheepheads, Pimelometopon pulchrum, can completely clean the meat from the abalone shell in a few minutes. Although a dislodged abalone may right itself, if attacked by fish its chances for survival are small. There is no clotting mechanism in abalone blood and if its wounds are extensive, it will bleed to death. In waters south of Pt. Conception, abalone divers often are accompanied by clouds of fish, largely sheepheads, which immediately attack any legal abalone inadvertently dropped from the diver's basket or an undersized one which fails to attach itself to a rock as the diver puts it back. Abalones in southern California and Baja California waters are frequently preyed upon by moray eels, Gymnothorax mordax, which are considered pests by the abalone divers.

3.13.3. Crabs

A commercial abalone diver, R. Owens (pers. corres.) observed rock crabs, Cancer antennarius (Figure 17), in the Morro Bay area actively preying on red abalones. His appears to be the first account of crabs attacking live abalones although they are often seen eating dead ones.

On one occasion, Owens found an actual battle in progress. The crab had grasped the edge of the abalone's shell with both claws in an attempt to pry it off the rock. Another time he saw a crab that had succeeded in insenting one of its claws underneath the abalone's shell

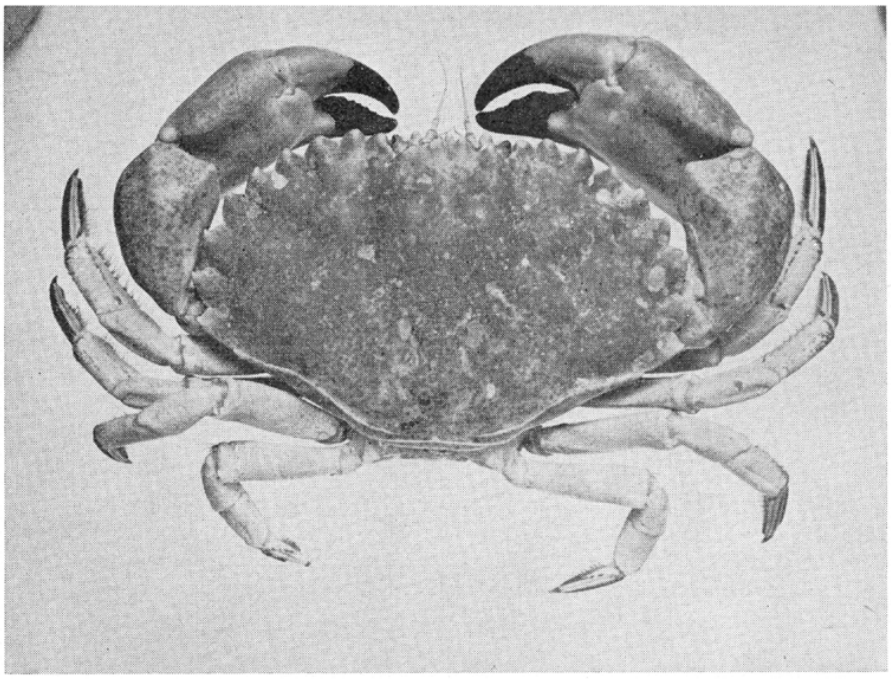


FIGURE 17. Rock crabs, *Cancer antennarius*, prey on abalones in the Morro Bay area. They have been observed grasping the edge of an abalone's shell with their claws and prying it off a rock. Photo by J. B. Phillips, August 1938.

FIGURE 17. Rock crabs, Cancer antennarius, prey on abalones in the Morro Bay area. They have been observed grasping the edge of an abalone's shell with their claws and prying it off a rock. Photo by J. B. Phillips, August 1938

and was tearing off portions of the foot and viscera, while maintaining a hold on the shell with its other claw.

The shell of an abalone that has been attacked by a rock crab has characteristic notches and scratches along its right edge (Figure 18). Although the initial contact has not been observed, a crab probably grasps the edge of the shell when the abalone is raised up waiting for food to drift by. The amount of force applied by a crab must be considerable judging from the size of the pieces broken out of the edge of the shell. Empty shells up to 9 inches across have been found with characteristic crab notches in their margins. These silent battles between crabs and abalones may last from one-half to three-quarters of an hour.

In the Morro Bay area, where these encounters were observed, the rock crab population has apparently increased greatly in the last few years. This has resulted in more intensive predation and it is possible in this area that C. antennarius may become a serious threat to the abalones.

3.13.4. Octopuses

Octopuses (or octopi) also prey on abalones. Pilson and Taylor (1961) reported that Octopus bimaculoides and O. bimaculatus drill holes in the shells of abalones with their radulae and inject a paralyzing venom through the hole into the body of the abalone. The venom causes the abalone to relax its hold on the substrate and it can be easily

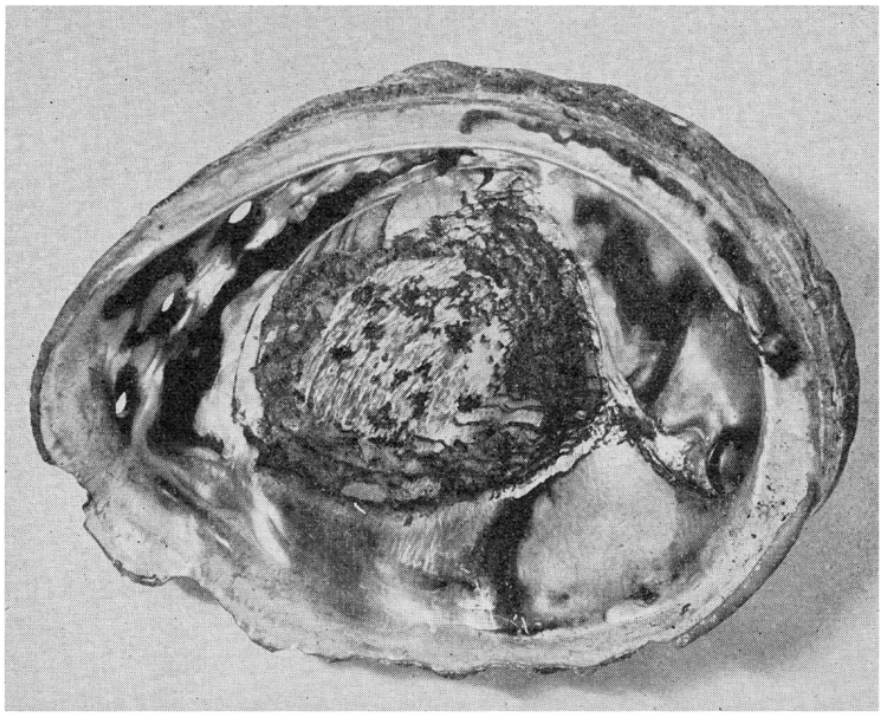


FIGURE 18. Shell of a red abalone eight inches long attacked by a rock crab, showing characteristic broken edge where a crab grasped the shell. This shell was picked up in 25 feet of water by R. Owens, April 1962, Morro Bay, California. Photo by Willis Photo. Lab., Palo Alto, April 1962.

FIGURE 18. Shell of a red abalone eight inches long attacked by a rock crab, showing characteristic broken edge where a crab grasped the shell. This shell was picked up in 25 feet of water by R. Owens, April 1962, Morro Bay, California. Photo by Willis Photo. Lab., Palo Alto, April 1962

removed by the octopus. The hold drilled by an octopus has a characteristic shape; it is tiny, slightly oval and although narrowing at the bottom it is fairly straight-sided. A hole, drilled by an octopus weighing 48 grams through a shell 1.4 mm thick, measured 0.8 by 0.6 mm at the top and narrowed to 0.3 by 0.2 mm at the bottom. The size of the hole is dependent upon the size of the octopus and the thickness of the shell. However, even a large octopus produces a hole which is generally smaller and less tapering than those drilled by small carnivorous snails. Octopuses also remove abalones by pulling, and Phillips (1934) reported that abalone divers occasionally would find an octopus patiently exerting pressure on an abalone. An octopus may try to pull an abalone off a rock first but failing in this it may then drill a hole.

Octopuses probably are not a serious threat to the abalone population.

3.13.5. Starfish

According to MacGinitie and MacGinitie (1949), small abalones are preyed upon by starfish but large abalones successfully resist the starfish attacks even though the starfish are larger. The actual amount of depredation on young abalones by starfish probably is quite small. Feder (1956) reported that when young abalones in an aquarium were

first presented to starfish, Pisaster sp., they moved away rapidly; however, as they became accustomed to the starfish they moved less and eventually they ignored them completely. In many years of diving, I have never observed a young abalone being attacked by a starfish. Actually, the two are seldom in the same habitat; young abalones tend to remain under rocks and in cracks and crannies while starfish are more often found in the open. On several occasions when an apparent starfish attack was investigated, the starfish was feeding on the barnacles and other marine growths on the abalone shell. Although the tube feet of the starfish would be in direct contact with the body of the abalone, the abalone showed no indication of alarm and did not try to escape. Starfish have been seen feeding on abalones that had died of other causes.

3.13.6. Parasitic Snails

Among the various marine organisms living on red abalone shells in the Monterey Bay area are many small gastropods, Odostomia evalea phanea. These minute (up to 5 mm long) snails are ectoparasites. They were first observed sucking blood from the mantles of oysters (Abbott, 1954). Since then they have been found parasitizing several other species of mollusks, so they probably are also parasitic on abalones. Because of their smallness, their effect on an abalone is probably negligible.

3.13.7. Parasitic Worms

In California waters, a parasitic worm, Echinocephalus pseudouncinatus, frequently is found encysted in green and pink abalones. This worm apparently seldom infests the other species of California abalones and has been reported only from the shallower water haliotids. Neither the means by which it invades abalones nor the other stages of its life history are known at present.

In some areas, infestation is heavy and an individual abalone may harbor many cysts. The encysted worms are primarily in the musculature (foot), but are often found in the lining of the digestive tract, in the gonadal tissue and in the liver. Although they are unsightly, they apparently have no adverse effect on the abalones.

3.13.8. Boring Clams

The shells of most haliotids support considerable growths of marine plants and animals. Oldroyd (1911) reported on mollusks collected from the shells of red, green, black and pink abalones landed by Japanese divers at White Point near San Pedro. He listed 59 species of gastropods he found inhabiting the shells of these abalones. Kelsey (1922) examined several pink and green abalone shells taken at the Coronado Islands, Mexico, and found 94 specimens including 25 species of mollusks. Only two species of mollusks, piddocks, Penitella conradi, and date mussels, Lithophaga subula, actively bore into abalone shells; however, piddocks enter from the outside and drill at right angles to the shell surface. When a piddock has drilled deep enough to come into contact with the abalone's mantle, the mantle secretes a protective layer of nacre over the borer, preventing entry into the abalone's body or musculature. By continuing to deposit nacre, the intruding borer is effectively walled off and a blister pearl is formed. Date mussels bore

in by secreting an acid which dissolves the abalone's shell. Where piddocks drill in at right angles to the shell surface, date mussels may enter at an acute angle; in some instances, one is found in a burrow almost parallel to the surface of the abalone shell. When infested by borers, the shell of the abalone becomes thick and heavy and shells an inch thick are common in areas where boring mollusks are abundant.

3.13.9. Boring Sponges

Many abalone shells are attacked by boring sponges, Cliona celata californiana. These yellow, encrusting sponges spread over an abalone's shell and dissolve tiny holes in it to increase their attached surface (MacGinitie & MacGinitie, 1949). Shells infested with boring sponges are often quite frail and easily broken.

3.13.10. Pearls

Occasionally a small foreign body may become lodged between the abalone's shell and mantle. When this happens, the abalone deposits nacre around the foreign substance, producing a "free" pearl. These are usually irregular in shape and of value only as novelties. Free pearls have also been recovered from the gonads and digestive tracts of abalones but how they have arrived in these locations is unknown.

Boutan (1925) tells of a method he developed in 1898 for producing pearls in haliotids. His method was adapted by the Japanese to the pearl oyster, Pinctada martensii, and is the basis for their present-day artificial pearl industry. A few attempts have been made to culture abalone pearls but apparently the work involved has been too great for the results obtained.

3.13.11. Sea Urchins

Purple and red sea urchins, Strongylocentroutus purpuratus and S. franciscanus, regarded as enemies of abalones, are in many areas vigorous competitors. In most localities, abalones and sea urchins are not intermixed but the edge of one population will overlap that of the other. At these contact points there is competition for food and living space. Once sea urchins have gained a foothold, they seldom leave. Although both feed on algae, sea urchins are more intensive grazers than abalones and they crop the rocks almost completely bare. When this occurs, the abalones are forced to move to another area to find food.

The largest sea urchin populations are in the deeper waters offshore where the algal growth is not as thick as it is inshore. However, sea urchins appear to move rather freely, both inshore and off. When a population moves inshore and enters established abalone habitat, it may completely replace the abalones in that area.

Since sea urchins are probably one of the most numerous benthic marine organisms living along our coast (there are literally hundreds of acres of them), competition for food and living space is so intense they apparently are forced to move into any suitable territory that becomes available.

3.13.12. Commensal Shrimp

A purple shrimp, Betaeus harfordi, has been found living in the mantle cavity of all of the species of California abalones. This crustacean

resembles a tiny, laterally flattened, Maine lobster (Figure 19). A single abalone may harbor more than one shrimp but four is the maximum observed. They move over the surface of the mantle and epipodium apparently without causing discomfort to the host. They usually lie along the folds of the epipodium and when disturbed, dart beneath the shell. As a general rule, the largest abalones will host the largest shrimps. When an abalone is removed from the water these shrimp quickly abandon their host and swim rapidly away. As a result, they are not often encountered in abalones which have been brought ashore. No one knows whether or not this association benefits abalones. The shrimps, however, enjoy the protection of a relatively stable home safe from enemies.

3.13.13. Storm Losses

After an unusually heavy storm along the northern California coastline and in some parts of the central coast (Monterey County), abalones frequently wash up on the shore in great numbers. Many are so broken and crushed that they have died even after being returned to the water. Sportsmen and conservationists have been concerned and have speculated as to the actual cause of these losses associated with heavy storms. Runoff from the storms often introduces quantities of fresh water, silt, debris and other materials and these combined with the violent wave action can drastically change the marine environment in the immediate shore regions.

When excessive fresh water is introduced into salt water it decreases salinity. This causes the osmotic pressure of the marine organisms in the area to increase and they take on excessive amounts of fluid. When

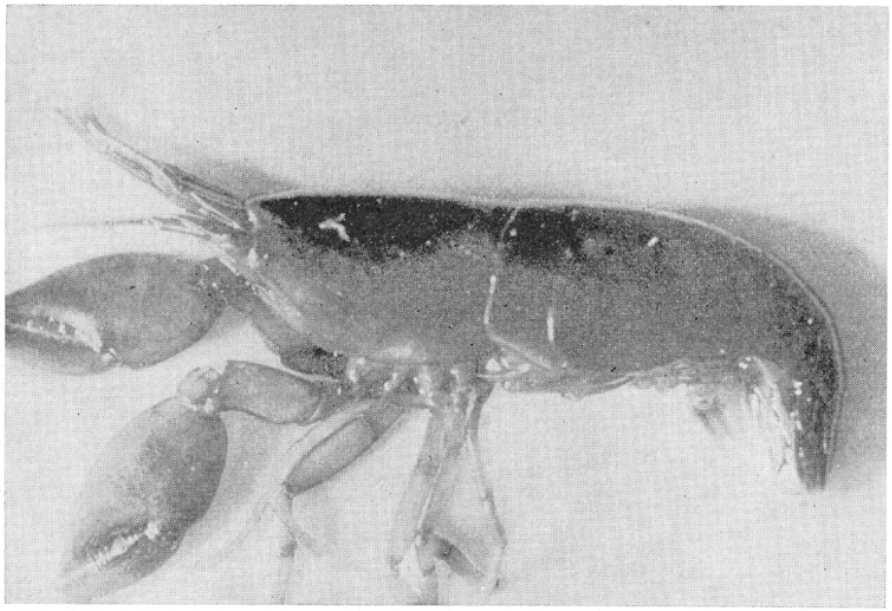


FIGURE 19. ***Betaeus harfordi,*** **a commensal shrimp that lives between the mantle and shell on all species of California abalones. They are usually one-half to almost two inches long and purple in color. Photo by Verne Peckham, September 1961.**

FIGURE 19. Betaeus harfordi, a commensal shrimp that lives between the mantle and shell on all species of California abalones. They are usually one-half to almost two inches long and purple in color. Photo by Verne Peckham, September 1961

this happens, their systems must work overtime to eliminate the excess. If the situation persists for lengthy periods an abalone's efforts to maintain its water balance becomes too much, its grip on the rock weakens and it is washed ashore.

How silt and other debris affect abalones can only be surmised because no experimental or field data are available. Silt, if it accumulates rapidly, could smother abalones. To avoid being smothered abalones may move and in doing so, be washed from the rocks by the violent wave action accompanying the storm.

In some coastal regions, the immediate offshore area contains numerous boulders of many shapes and sizes on which abalones live. Ordinarily these boulders provide a stable substrate; however, during violent storms they are tumbled about by the wave action. Any abalones clinging to these rocks would be crushed or knocked from them and tossed ashore.

Any one or combination of storm-caused conditions could account for the numerous abalones washed up on beaches during violent storms; the tumbling of rocks and boulders probably causes the greatest loss.

4. HISTORY OF ABALONE FISHERIES

4.1. Indian Fisheries

Ethnological and anthropological evidence indicates that an abalone fishery flourished for many years among the Indians of the coastal regions and the Channel Islands.

Whenever abalones were in sufficient quantities, they were the main shellfish item in the Indian's diet and among the Channel Island dwellers they were the principal food. This is attested to by the enormous quantities of abalone shells in the middens and shell mounds found along the coast from Monterey Bay south and among the Channel Islands.

Recently, radiocarbon dating techniques have been used to obtain fairly precise ages for these ancient fisheries. Orr (1956, 1960), reported that red abalone shells from several sites on Santa Rosa Island (Figure 20) were 5,370 to 7,400 years old (Figure 21, Table 7). All shells were from middens (Figure 22) with the exception of a sample which the Indians had placed in a cemetery containing over 100 skeletons. These skeletons had been buried in sitting positions with knees drawn up under their chins. Each skull had been painted a brilliant red which gradually faded on exposure to the air. Three of the skeletons were from strong people over 7 feet tall (Figure 23).

The Santa Rosa Island archaeological sites appear to be the oldest which have been radiocarbon dated on the Pacific coast, but Orr (1956) states, "We feel confident that there are many middens much older than these on both the [Channel] Islands and the Mainland, which are as yet undated."

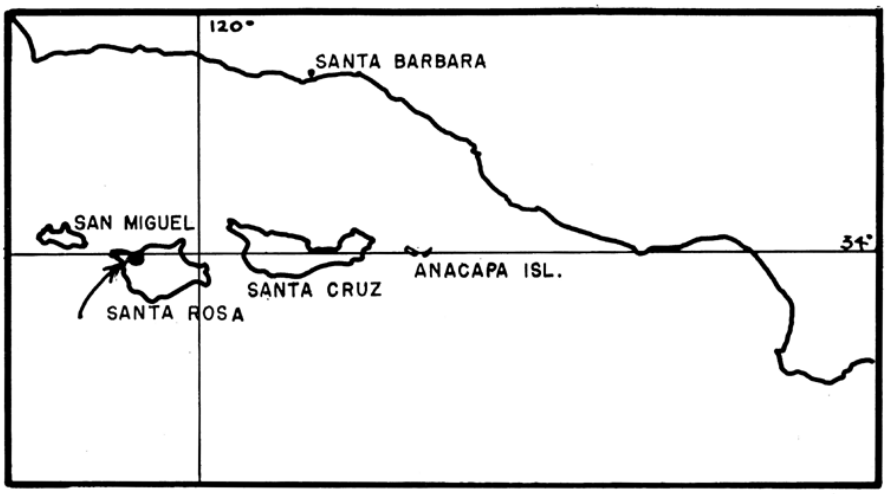


FIGURE 20. Location of archaeological site on Santa Rosa Island yielding abalone shells gathered by Indians as long ago as 7,500 years.

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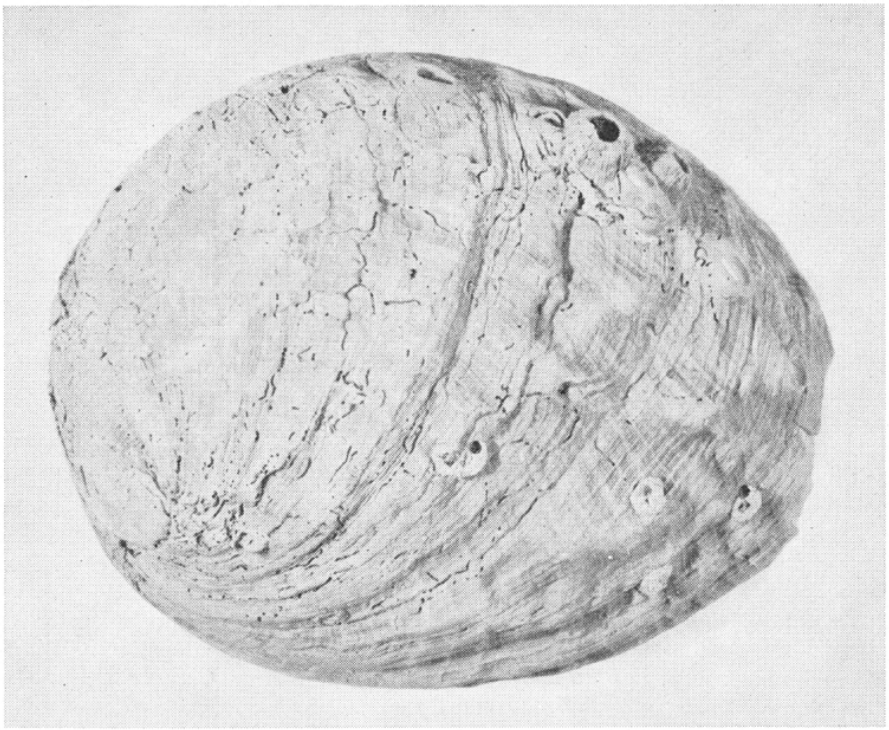

FIGURE 21. Red abalone shell an estimated 7,400 years old, taken from Indian midden on Santa Rosa Island. Photo courtesy of Santa Barbara Museum of Natural History, 1959.

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TABLE 7

Ages of Red Abalone Shells From Archaeological Sites Santa Rosa Island, California [1]

Location	Time Culture	Age in Years
From bottom of shell midden at a depth of 18 to 24 inches	Highlander	5,370 ± 150
From midden under 12 feet of alluvium exposed in the face of the sea cliff	Dune Dweller	6,820 ± 160
From burial ground at depth of 10 feet in clean sand covered with 3 feet of black midden	Dune Dweller "Red Head"	7,070 ± 300
From shell midden at a depth of 15 feet under water-laid sediments exposed in face of sea cliff	Dune Dweller	7,400 ± 200

[1] From Orr (1960).

TABLE 7

Ages of Red Abalone Shells From Archaeological Sites Santa Rosa Island, California

Not only were the abalones used by the local Indians for food, the shells because of their size and brilliance, were of considerable value for barter. Abalone ornaments and shell fragments have been discovered great distances inland.

Brand (1938) stated that abalone shells, fragments and artifacts have been recovered from prehistoric grave ruins in Utah, Arizona, New Mexico, Texas and southwest Colorado and are in the remains of

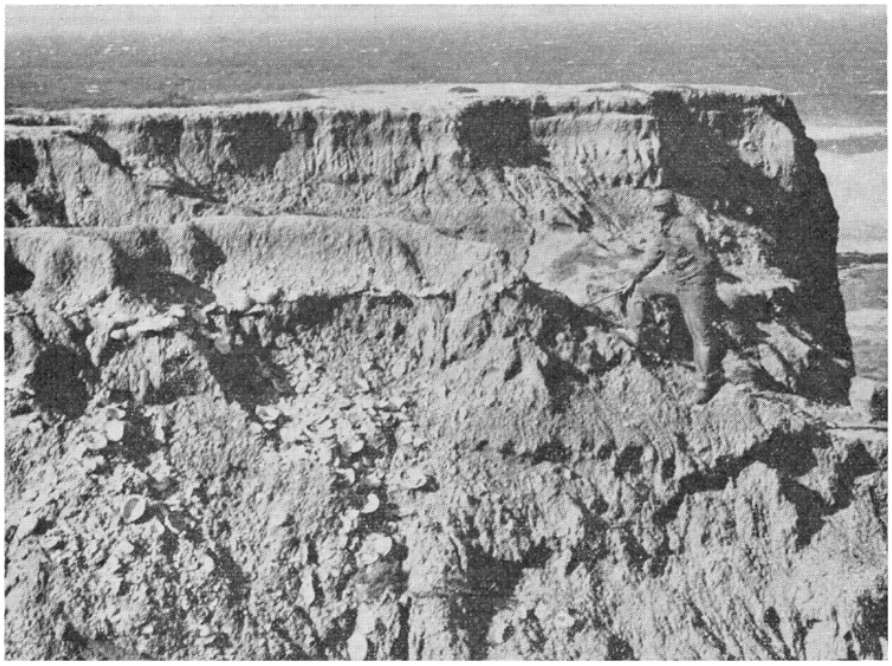

FIGURE 22. Part of Indian shell midden covering several hundred square feet on Santa Rosa Island. A red abalone shell found under 12 feet of water-laid sediments was an estimated 6,800 years old. Photo courtesy of Santa Barbara Museum of Natural History, 1959.

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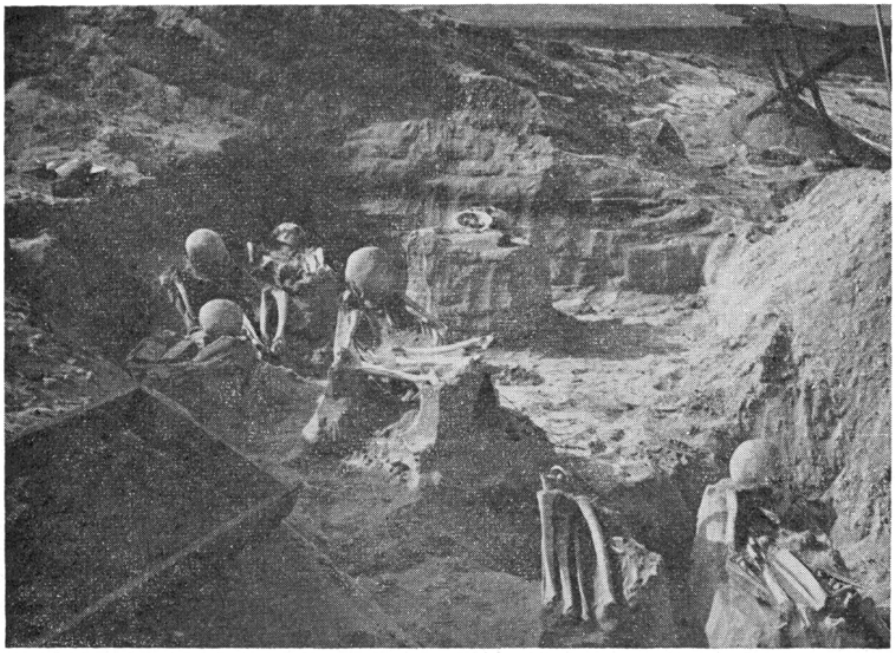

FIGURE 23. Indian cemetery, Santa Rosa Island, containing abalone shells radiocarbon dated at 7,070 years. Tops of skulls were painted red, several skeletons measured over seven feet tall. Photo courtesy of Santa Barbara Museum of Natural History, 1959.

FIGURE 23. Indian cemetery, Santa Rosa Island, containing abalone shells radiocarbon dated at 7,070 years. Tops of skulls were painted red, several skeletons measured over seven feet tall. Photo courtesy of Santa Barbara Museum of Natural History, 1959

all cultures from the Basket Makers to the Pueblo Cliff Dwellers. Abalone ornaments found in Basket Makers' graves are an estimated 1,500 years old and are believed to have arrived from southern California, Baja California or both via ancient, established trade routes (Figure 24). These West Coast sea shell trade routes extended throughout the southwest and met with trails and routes from the Gulf of Mexico.

Two main routes, one originating in southern California near the site of present-day San Diego and the other in Sonora, Mexico, on the Gulf of California, carried most of the traffic. These two routes forked into secondary routes which in turn branched into minor trails. The shells carried eastward on the northern routes were mostly from abalones, some of which, according to Ives (1961), have been recovered in numerous sites east of the Mississippi. These trade routes are believed to have existed 2,000 to 3,000 years ago.

Indians in the central and northwest central regions of California used abalone shells to manufacture jewelry, fish hooks, scrapers and knives. They called abalone shells uhello, the same name they used for the money they fabricated from them (Figure 25). The value of the

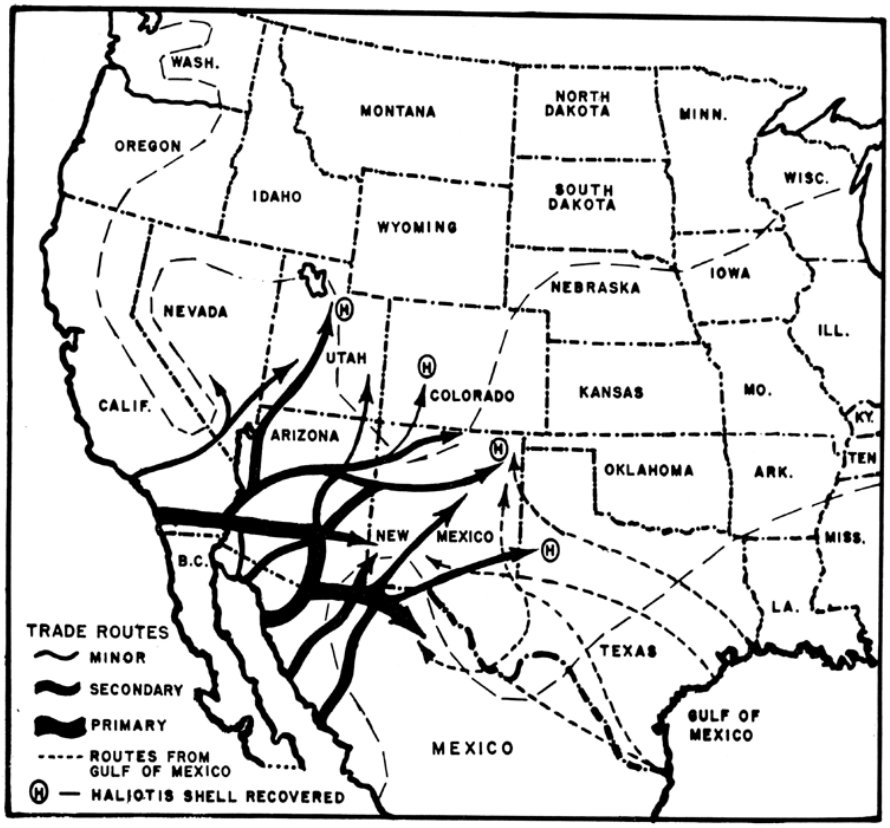

FIGURE 24. Aboriginal seashell trade routes in the southwest. Trails from the Pacific coast and Gulf of California met with those from the Gulf of Mexico. The northern and southern limits of the area in which abalone shells and artifacts were trade items are indicated by the thin, broken lines. (Based on data in Brand, 1948, and Ives, 1961.)

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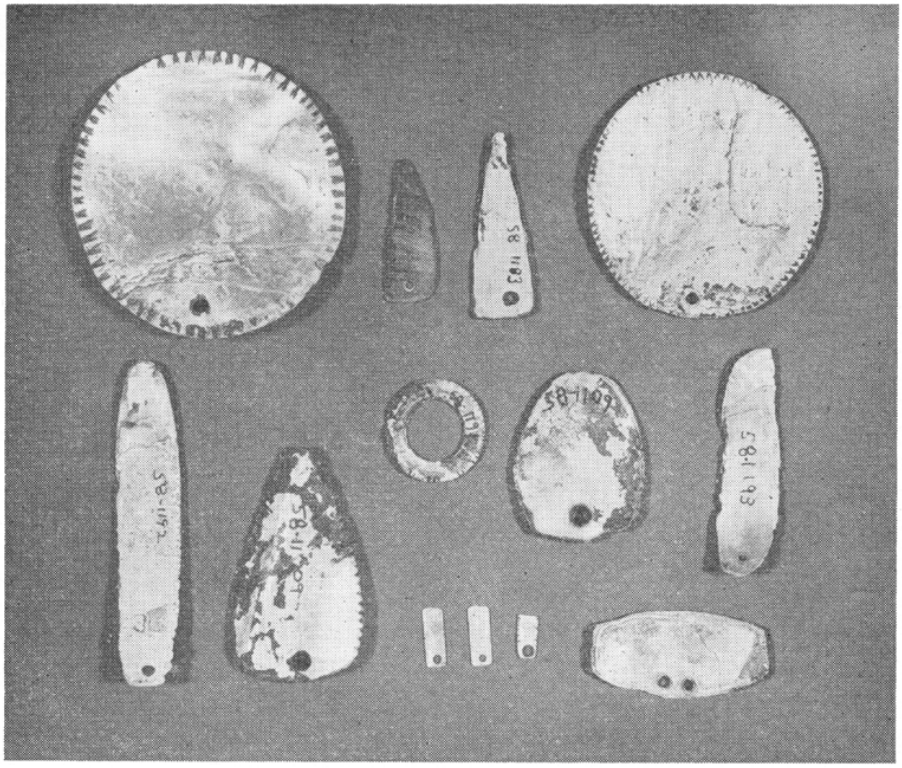

FIGURE 25. Abalone shell artifacts and money from the Castro Shell Mound, Palo Alto, California, an estimated 1,500 years old. Note incised edges of large circular money pieces. Articles courtesy of Department of Sociology and Anthropology, Stanford University. Photo by Glen Bickford, 1958.

FIGURE 25. Abalone shell artifacts and money from the Castro Shell Mound, Palo Alto, California, an estimated 1,500 years old. Note incised edges of large circular money pieces. Articles courtesy of Department of Sociology and Anthropology, Stanford University. Photo by Glen Bickford, 1958

money, which was usually circular, depended upon shell brilliancy and size. Individual pieces ranged from roughly the size of a quarter to a silver dollar and were perforated and strung on leather thongs. When not being traded, they were sometimes worn in necklaces. Many were incised around the edges in patterns believed by some to represent various constellations. Pieces of abalone shells were also used for inlay work on pots and bowls and as decorations on wooden and bone knives and spears. Whole shells were used as dishes and containers by plugging the holes with asphalt (Figure 26).

The coast Yuki, who lived in what is now Mendocino County, used a special hardwood tool for removing abalones and mussels from rocks. This tool was approximately a yard long and had a flat chisel-like end, which if broken off in use, was resharpened with a mussel-shell knife. When a stick became very short it would be driven under an abalone with a stone.

Perhaps the main problem the Indians had with shellfish, was preparing the ones for storage that could not be eaten immediately. This probably was done by sun drying them or smoking them over a fire. The impracticality of transporting fresh seafood over long distances is reflected in the taboo the Hupa (Hoopa) of northern California had against bringing it into their valley; all such products had to be

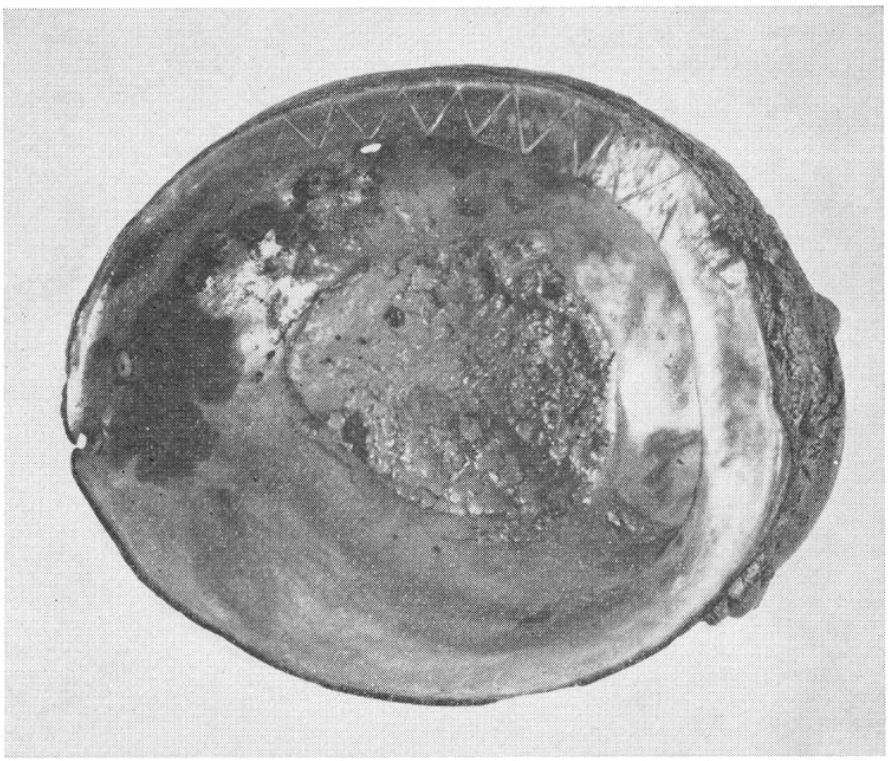

FIGURE 26. Black abalone from Santa Barbara area used as a dish. Holes plugged with olive snail *(Olivella)* disc beads and asphalt. Note inscribed edge. Age uncertain but estimated late Canaliño, (500 to 2,000 years old). Photo courtesy of Santa Barbara Museum of Natural History, 1960.

FIGURE 26. Black abalone from Santa Barbara area used as a dish. Holes plugged with olive snail (Olivella) disc beads and asphalt. Note inscribed edge. Age uncertain but estimated late Canaliño, (500 to 2,000 years old). Photo courtesy of Santa Barbara Museum of Natural History, 1960

dried. often the food was cooked before drying. The Tolowa of present-day Del Norte County, when they had a quantity of museels, clams, or barnacles to be dried, would build a fire on the beach, scoop out the coals, bury the shellfish in the hot sand and re-cover the spot with the coals. When a portion of the dried product was to be eaten, it was soaked overnight in fresh water, boiled, and then consumed with acorn mush.

Although eaten fresh, abalones also were sun dried and in this form they could be transported and stored for future use. Non-coastal Indian groups would sometimes travel half the width of the state in order to enjoy the benefits and delights of fresh seafood as well as to preserve some to transport home. On such trips they traded for shells and other articles with the coastal groups.

Kreiger (1928) recovered many artifacts from excavations in a pit-house village site on the Columbia River at Wahluke, Grant County, Washington. Among these were an incised pendant made from a piece of red abalone shell and a small, circular disk from a pinto abalone shell. These artifacts probably arrived at the site, which is over 200 miles from the Pacific Coast, via a trade route over the mountains or up the Columbia River.

According to Heizer (1940) the "California abalone," identified as H. rufescens by Leechman (1942), was known to several tribes of the Pacific Northwest (Washington, British Columbia, and Alaska) and was accepted by them (as trade goods) from the early Spanish explorers. Father Peña, who traveled with the Santiago Expedition in 1774, relates, "our people bought several of these articles (otter skins, painted rush caps, capes, etc.) in exchange for old clothes, and [abalone] shells, which they had brought from Monterey."

Although abalones are known from the Pacific northwest, the predominant species, H. kamtschatkana, is small and the shell is quite thin compared to the "California abalone." Consequently, the latter was in great demand by the local tribes for inlay and other decorative work. The Tlingets on Vancouver Island called abalones *gu'nxa*, the Haida called them *gu'lgu* and at the mouth of the Straits of Juan de Fuca they were known as *g'uindu*.

4.2. Mexican Fishery

The Mexican *aulone* fishery, like that in California, was started by the Chinese, who began operating in the 1860's in Baja California using San Diego as a base (Croker, 1931). The bulk of the catch came from the Coronado Islands and from the mainland near Ensenada south to Cedros Island. Abalones were collected intertidally and sent to San Diego to be dried. In the more distant camps, processing was carried out at the campsite and dried meats and shells destined for the Orient were shipped to San Francisco either directly from the camps or by way of San Diego. For years, almost the entire harvest was dried and shipped to the Orient; however, because of increasingly heavy export taxes on dried abalones, canning plants were established at various sites and part of the catch went out in one-pound cans. Manufactured products such as canned abalones are not taxed in Mexico. To protect the Mexican canners, their government passed a law in 1929 prohibiting exporting fresh abalones. This was done to prevent shipping fresh abalones to San Pedro and San Diego for canning; before this law was passed considerable quantities were processed in these cities.

The amount of abalones imported into California from Baja California increased from 3.8 million pounds in 1923 to 7.4 million in 1929. By 1929, the Japanese controlled the drying industry and one of the two Mexican canning plants; the other was controlled by German residents in Mexico (Croker, 1931).

The important fishing areas in 1929 were along the mainland and islands from San Geronimo Island to San Hipolito Pt., Baja California. During rough weather, diving was carried on along the mainland between Turtle Bay and San Hipolito Pt. In summer, camps were established on the more northern islands of San Geronimo, Cedros, and Natividad. The diving boats, each approximately 29 feet long, were equipped with air compressors but not motors; they were towed to the fishing grounds. Each boat crew consisted of one diver and four other men.

In 1960, the main commercial fishing grounds were between Santa Rosalia and San Juanico Point, near Magdalena Bay (Figure 27). Their diving methods have been adapted from the Japanese, who until World War II, controlled the Mexican abalone industry. Today the

resource is reserved for Mexican Fishermen's Co-operatives. There is a closed season each year from January 14 to March 16, coinciding with the California season. Pink and green abalones must be 12.5 cm (ca. 5 inches) to be legal (de Buen, 1960).

In central Baja California, a diver and three helpers work from a large skiff equipped with an outboard motor and compressor.

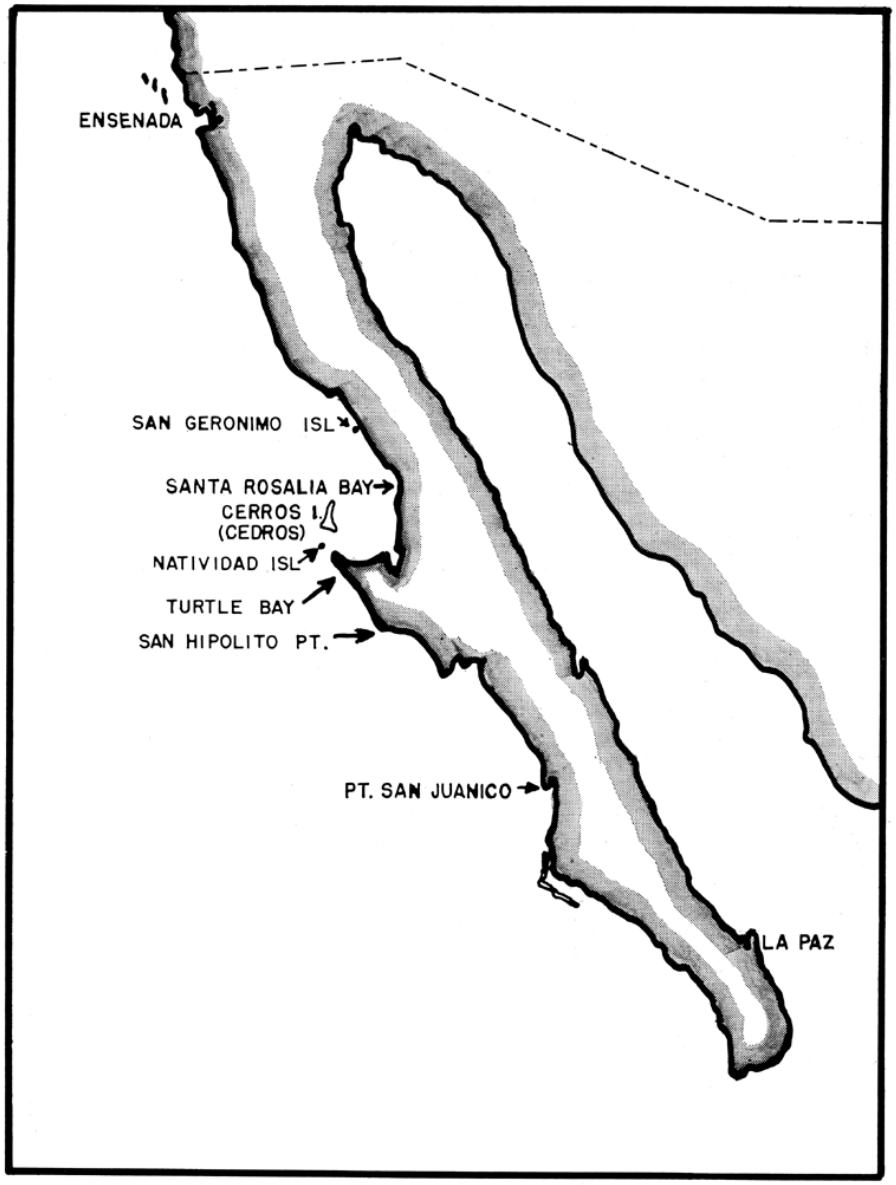

FIGURE 27. Mexican commercial abalone fishing areas on the west coast of Baja California. Principal abalone fishing areas today are between Santa Rosalia and San Juanico Pt. In summer, camps are established on San Geronimo, Cedros, and Natividad Islands.

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At Cedros Island, the diving fleet works from a large mother ship which accommodates approximately 15 divers and 50 crewmen. The diving boats working from the mother ship are each about 18 feet long, flat-bottomed and have a central inboard gasoline engine which drives the propeller and supplies power for the compressor. The propeller can be raised above the transom when not rotating; this keeps it from becoming entangled in the heavy kelp. The boat is kept above the diver by one of the crewmen using a long pair of oars. The second man tends the diver's hose and the bag line, pulling in full baskets and sending back empty ones. The third man empties the abalones from the bag, removes their shells and places the shucked meat in a sack. Late in the day, tenders pick up the sacks of abalone meat from the diving boats. The divers usually work for 10 days, living on the mother ship, then spend 5 days ashore in the village on Cedros Island. Aboard the mother ship, the divers have separate quarters and galley; ashore they live with their families in pleasant homes equipped with modern conveniences.

In northern Baja California, around the Coronado Islands, two divers usually work from a large open whaleboat with a crew of six to eight men (Figure 28); the divers alternate shifts on the diving.

According to de Buen (1960) four species make up the catch, but pinks (called yellow abalones by the Mexicans) and greens predominate. Green abalones are most abundant in the southern Baja California fishery, while pinks are most plentiful in the middle area. Dried black abalones are used for bait by lobster fishermen and reds, the fourth species, are rarely taken.

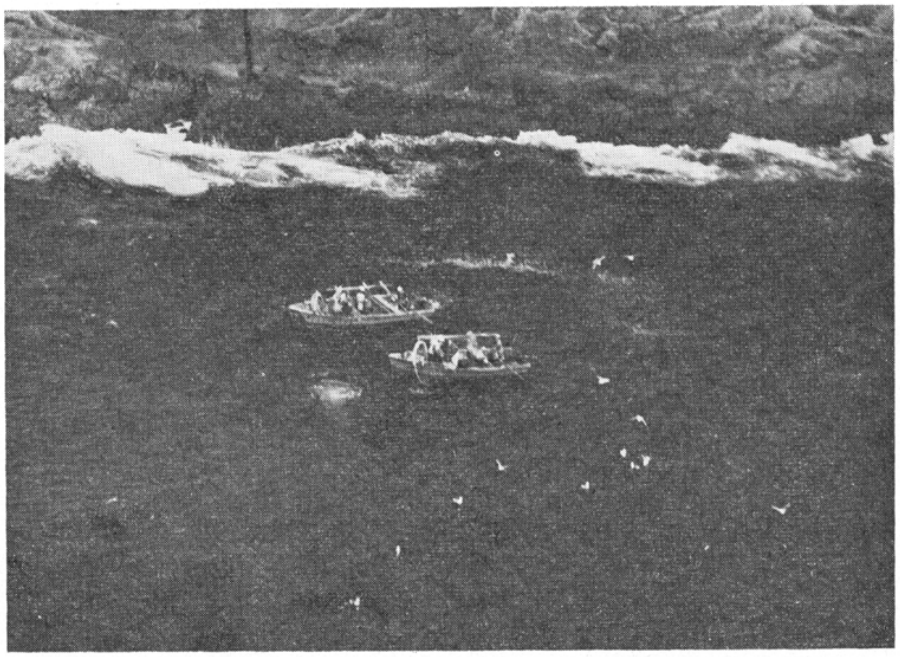

FIGURE 28. Mexican abelone divers at the Coronado Islands. Both boats are anchored and are kept in position by the oarsmen in the stern. The diver for the nearest boat is down. His exhaust bubbles can be seen in front of the bow. The diver for the second boat is still on board. Photo by the author, 1958.

FIGURE 28. Mexican abalone divers at the Coronado Islands. Both boats are anchored and are kept in position by the oarsmen in the stern. The diver for the nearest boat is down. His exhaust bubbles can be seen in front of the bow. The diver for the second boat is still on board. Photo by the author, 1958

In the Cedros Island cannery, according to de Buen, the abalones are washed in a mechanical mixer, trimmed, placed in cans, sealed and refrigerated. In other canneries, abalones are put up *al natural* in cylindrical cans containing 16 ounces net. The 1959 pack is reported to have been canned in six plants: two at Ensenada and the rest scattered south along the coast to Magdalena Bay (U.S.F.W.S., 1961).

Almost all the canned abalone, one of Mexico's chief seafood exports, is re-exported from the United States to the Philippines and the Orient. The 1960 catch was approximately 6 million pounds. In 1959, approximately 170,000 pounds of fresh frozen fillets were exported; however, the product was improperly prepared and in 1960 fillet exports dropped to 128,000 pounds. Properly handled, this product could become an important export item for Mexico (U.S.F.W.S., 1961).

4.3. California Fishery

Not until the Chinese arrived in the early 1850's were California's abalones gathered by other than Indians. Brought to this country as cheap labor to help build railroads and to work mines, the Chinese were quick to associate local abalones with those of their native land where they were important food items. It is these people to whom the credit must be given for originating our abalone fishery. In their own country, Chinese peasants were forbidden by law to gather abalones (Albrecht, 1917); in this country no such regulations existed. There was soon a thriving industry and by 1879 California commercial landings of abalone meat and shell were over 4.1 million pounds per year. Green and black abalones were the predominant species in these early years.

These early abalone fishermen worked the intertidal area from skiffs. According to Keep (1890), they would row among the rocks at low tide searching the cracks between exposed boulders and examining the submerged rocks. Using a long pole with a wedge on one end, they would knock an abalone off a rock and then draw it up with a boat hook (Figure 29).

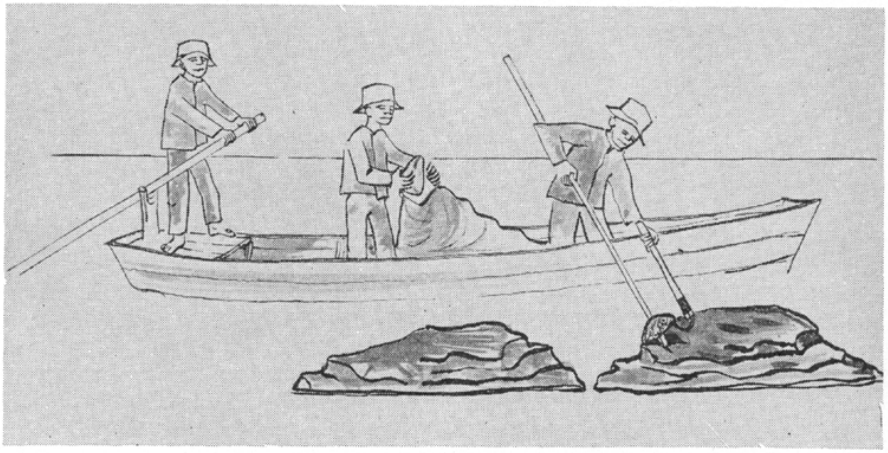

FIGURE 29. Chinese fishermen gathering abalones off California in the early 1800's. Abalones were knocked off rocks by a wedge on the end of a pole and drawn up with a gaff. This method is still used in parts of the Orient. Brush drawing by R. B. Lucas, 1961.

FIGURE 29. Chinese fishermen gathering abalones off California in the early 1800's. Abalones were knocked off rocks by a wedge on the end of a pole and drawn up with a gaff. This method is still used in parts of the Orient. Brush drawing by R. B. Lucas, 1961

Although these methods were primitive, they seem to have been quite effective. These fishermen who were concerned only with numbers soon stripped the shores and seriously depleted the abalone stocks. When this happened, the fishery, which had been centered at San Diego, was extended into Baja California and abalone camps were also established on San Clemente, Santa Catalina and several other Channel Islands. In 1880, the Mexican government became so concerned at the efficiency of the Chinese operations in Baja California they set a license fee of $60 per boat and established a consulate at San Diego to keep records on the fishermen. The California coastal counties also became alarmed at the rate these mollusks were being taken and in 1900 ordinances were passed making it unlawful to fish for abalones except in deeper water. Since the Chinese were not divers, having done their harvesting in the intertidal zone and from skiffs, these ordinances effectively eliminated them from the fishery. Their place was then taken by Japanese "sake barrel" divers (Albrecht, 1917), who worked the offshore waters that could not be reached by the Chinese pole fishermen. The name for this type of diving was derived from the barrels, originally containing the Japanese sake or rice wine, shipped to this country from the Orient. The divers used them as floats to rest on between dives. This float method is still used in parts of Japan and the Orient by the shellfish and seaweed divers.

Apparently the sake barrel divers were not too successful for their place was taken by Japanese hard-hat divers and the fishery moved from shallow into deeper waters. The technique of hard-hat diving for abalones was jealously guarded by the Japanese and the few white divers who wanted to learn the trade spent many hours peering through binoculars observing their methods. Even then it was not until 1929 that Caucasian divers had any measure of success. Gradually, however, they mastered the technique and in some ways improved upon it. The Japanese method is still used by most of today's divers who fish for red abalones and much of their equipment (helmets, hoses, suits, etc.) is of Japanese manufacture (Figures 30 and 31). Japanese divers operated along the rocky coasts of Monterey and San Luis Obispo Counties (Figures 32 and 33), and continued to monopolize the fishery until World War II when many were moved inland to relocation centers.

4.3.1. Commercial Fishery

4.3.1.1. Diving Methods

A Japanese diving boat crew originally consisted of five men: a diver, a line tender, a kelp cutter, a pump operator and a boat operator. Diving boats today are equipped with compressors, eliminating the necessity of a pump operator. A crew today consists of a diver, a boat operator and line tender who also cuts the kelp. The boat is not anchored but follows the diver as he walks over the bottom and through the kelp searching for abalones. As he walks he cuts interfering kelp with a knife tied to his wrist. As the cut kelp floats to the surface, strands become entangled in the diver's air hose and life line. The line tender using a special knife, a sickle blade fastened to the end of a 10-foot pole, reaches into the water near the air hose and with a quick upward jerk of the knife cuts the kelp draped over the hose. The movement

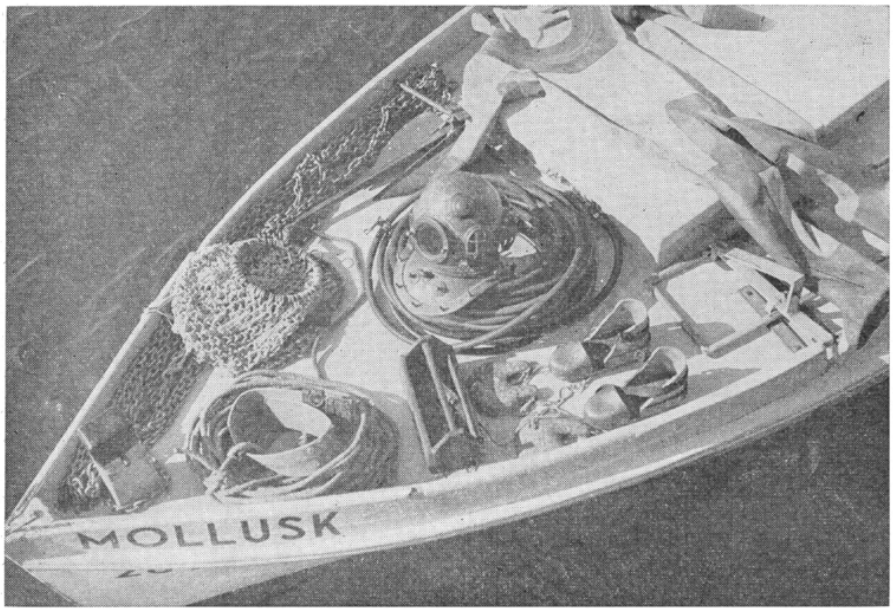

FIGURE 30. Gear used by hard-hat abalone divers in the red abalone fishery. Helmet is of Japanese manufacture, weights and shoes are often cast by the divers themselves, suit of canvas and rubber is similar to that used by Florida sponge divers. Photo by Verne Peckham, 1961.

FIGURE 30. Gear used by hard-hat abalone divers in the red abalone fishery. Helmet is of Japanese manufacture, weights and shoes are often cast by the divers themselves, suit of canvas and rubber is similar to that used by Florida sponge divers. Photo by Verne Peckham, 1961

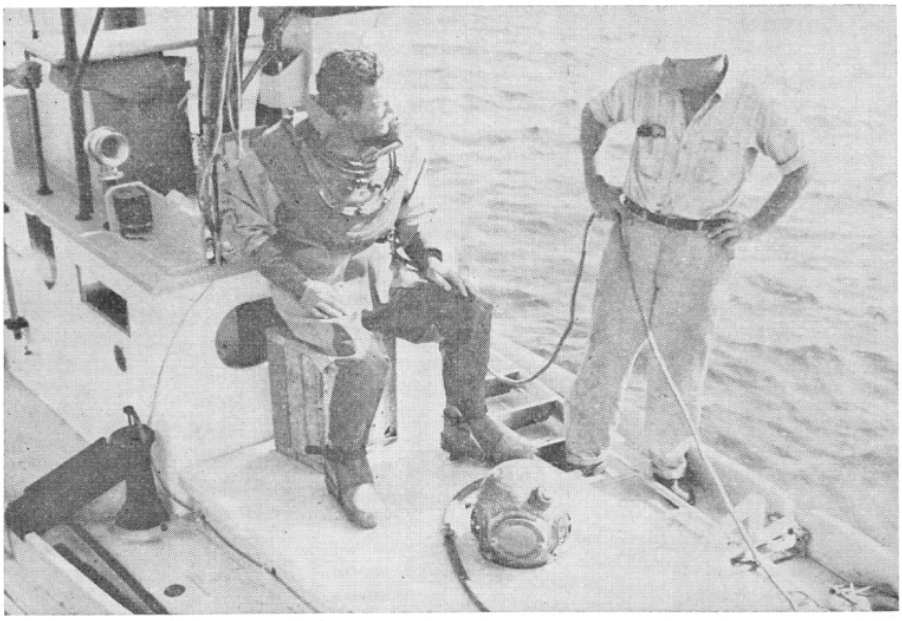

FIGURE 31. Diver dressed except for weights and helmet, ready to descend. Photo by Verne Peckham, 1961.

FIGURE 31. Diver dressed except for weights and helmet, ready to descend. Photo by Verne Peckham, 1961

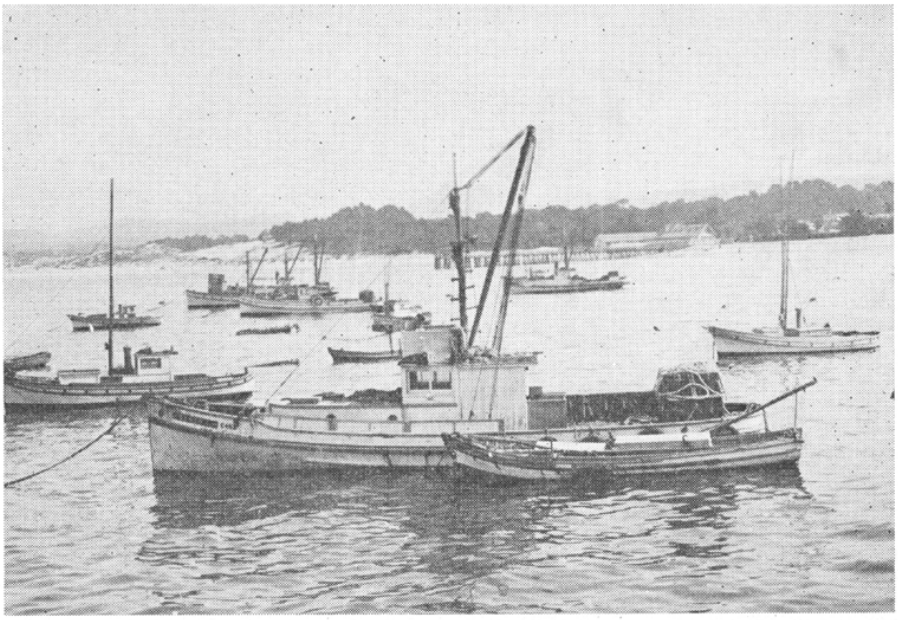

FIGURE 32. Japanese diving boat and mother ship anchored at Monterey Harbor, 1931. These boats and crews operated as far south as Pt. Conception. The abalones were kept in live-boxes and returned to Monterey for processing. Photo by J. B. Phillips, 1931.

FIGURE 32. Japanese diving boat and mother ship anchored at Monterey Harbor, 1931. These boats and crews operated as far south as Pt. Conception. The abalones were kept in live-boxes and returned to Monterey for processing. Photo by J. B. Phillips, 1931

FIGURE 33. Japanese divers working off the California coast between Carmel and San Simeon, Sept. 1938. Photo by J. B. Phillips, 1938.

FIGURE 33. Japanese divers working off the California coast between Carmel and San Simeon, Sept. 1938. Photo by J. B. Phillips, 1938

of water, caused by the diver's exhaust bubbles rising to the surface, helps separate the cut ends and move the kelp away from the hose. This keeps the hose free and the diver proceeds along the bottom, collecting abalones while the boat follows his path through the kelp. Because the kelp is so thick, the boat's propeller must be kept uncaged so it can cut itself free from entangling kelp. Although a caged propeller would be safer for the diver by preventing his air hose from being cut by its rotating blades, a cage becomes so entangled in kelp the boat cannot operate. Considerable skill is required of the boat operator who not only must keep the boat close to the diver but must keep it from being smashed against the various rocks and submerged reefs where the diver works (Figure 34).

To take advantage of relatively smooth water, diving usually starts in the early morning and continues until late afternoon or until winds put an end to operations. The divers usually work in depths of 25 to 100 feet but most diving is in 25 to 60 feet of water. A diver may walk from 1 to 8 miles a day searching for abalones on the floor of the sea. He carries a woven net "basket" in which he places the abalones as he removes them from the rocks (Figure 35). When the basket is filled, he signals the line tender either by jerking on his rope or by telephone—an innovation the Japanese did not have. The line tender then fastens an empty bag to a weighted line and throws it overboard as close as he can to the diver who detaches it and fastens the full one in its place. The line tender pulls the full bag to the surface and the diver continues his search.

In southern California, a new diving method was introduced in the late 1950's. Rather than invest in the expensive and heavy gear normally used by abalone divers, some of the operators started using lightweight frogman-type suits and swim fins. Instead of a metal helmet, divers wear a light mask to which air is supplied from a compressor in the diving boat. Two or more divers may work from a single, anchored boat. Swimming along the bottom, they are restricted only by the lengths of their air hoses, normally 200 to 300 feet. Some of these divers carry larger abalone baskets than divers using heavy equipment and tie a canvas bag to the upper rim. When the basket is filled and is too heavy to be carried, the diver allows some of his exhaust air to fill the canvas bag, inflating it just enough to float the basket of abalones off the bottom. Then he swims with it to a line hanging from the boat, fastens it to a snap, takes an empty one in exchange and swims away. By this method, considerable expensive equipment and manpower is eliminated; one man can look after as many as three divers and the boat whereas with heavy gear two men are required for one diver. By 1962, a number of divers in central California were using this method.

The number of individuals engaged in the fishery while never very large has increased considerably. In 1928, there were 11; all were Japanese and all were working out of Monterey. In 1937, 27 diving permits were issued and in 1947, 130, all to Caucasians. Diving permits are required of all persons engaged in taking abalones commercially including boat crew members, so the actual number of divers in 1937 was probably 9 or 10 and in 1947, 35 or 40. In 1954, 294 permits were issued and in 1960 the total was 505. of these 505, approximately one-third were divers; the others were line tenders and boat operators.

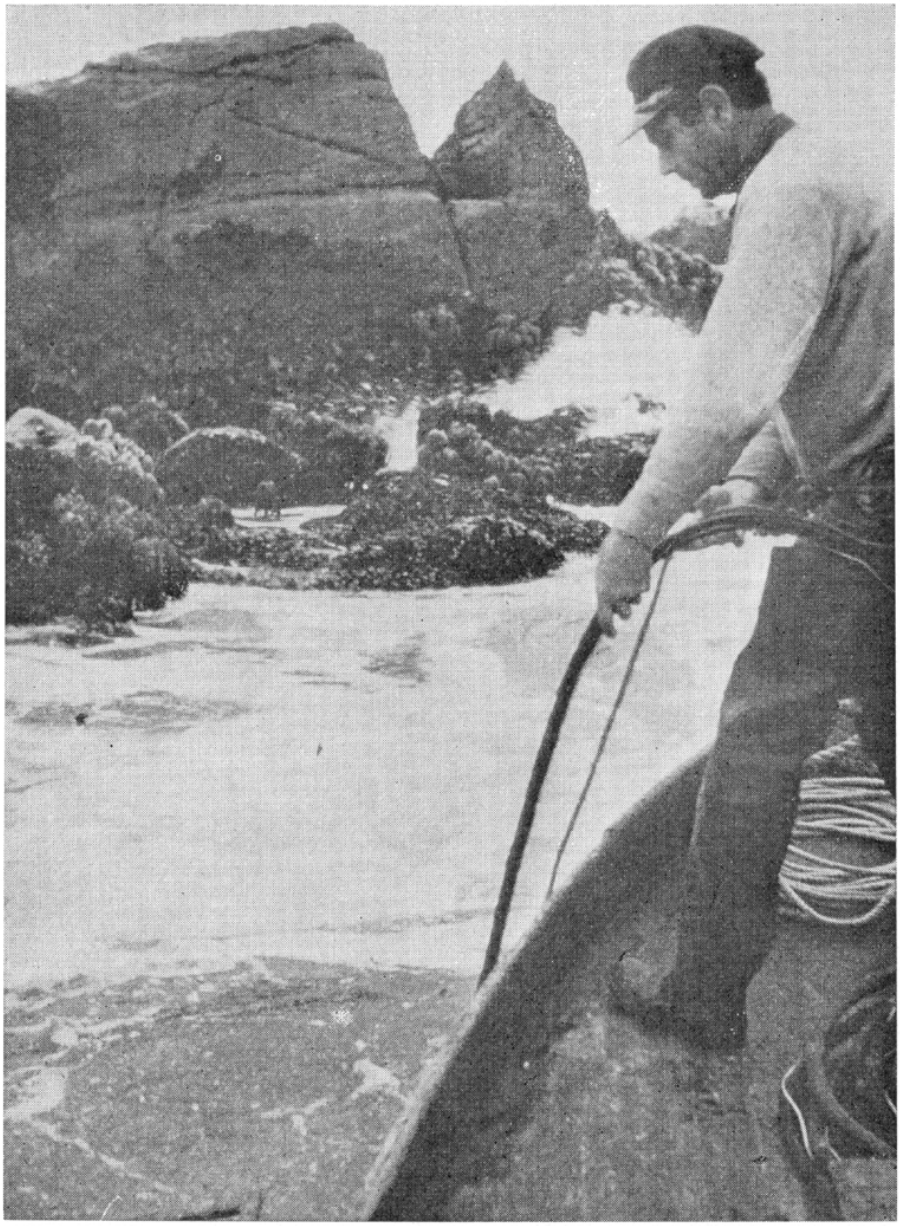

FIGURE 34. In some areas, abalones are near reefs which make diving a rugged business. Photo by D. H. Fry, Jr., 1952.

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The increase in the fishery can be attributed to opening the mainland south of Pt. Conception and the Channel Islands for diving and the consequent development of the pink abalone fishery (Figure 36). Some who purchase permits might not engage in the fishery for various reasons, others who begin a season may not remain to the end and still others may start late and drop out after a short while. There is a fair

turnover among crew members and boat operators but the fleet is usually composed of 50 to 60 boats. Because of the nature of the fishery, not all boats, divers and crews operate at the same time. Boats are laid up for hull and engine repairs, divers or crew members become ill and diving gear becomes damaged or worn and must be replaced or repaired. These difficulties, plus natural hazards, tend to limit the number of divers in the water at any one time.

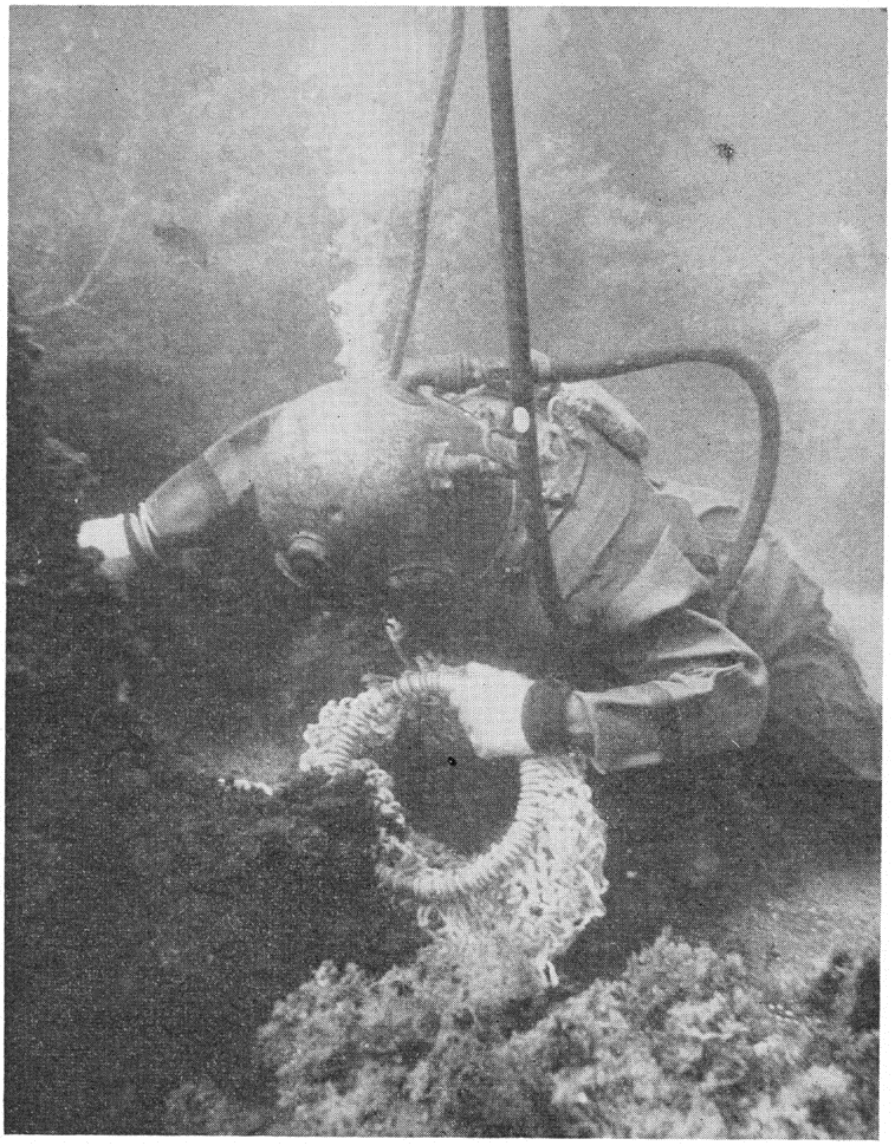

FIGURE 35. Diver in hard-hat gear gathering abalones. Woven basket holds 25 to 30 reds. Photo by Glen Bickford, 1957

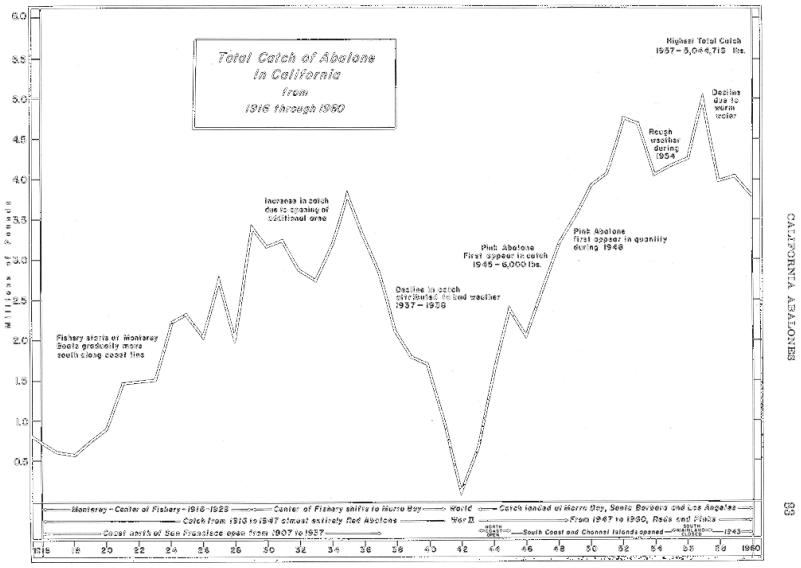

FIGURE 36. Total catch by year of abalones taken in California from 1916 through 1960. Significant changes in the fishery are indicated on the chart; dates and extent of other important influences on the fishery appear on the lines below the graph

4.3.1.2. Catch

Although a commercial abalone fishery had existed in California for many years, not until 1916 were records of the landings collected by the Department of Fish and Game. Between 1916 and 1929, almost the entire abalone catch, over 2 million pounds per year, was taken by Japanese crews and landed at Monterey (Figure 36). During the first few years, the catch was taken around Pt. Lobos and the south shore of Monterey Bay by fishermen who worked from skiffs and hooked the abalones off the rocks with gaffs and spears. After diving suits were introduced, the coastline as far south as Point Sur was harvested from 1920 to 1925. Trips were generally for one day but boats stayed out two days if difficulties were encountered. From 1925 to 1929, trips usually lasted two days and the boats worked as far south as Lopez Point; the catch continued to increase during this period. In 1929 the area south of Cape San Martin, from Cambria to Pt. Buchon, was opened at the request of the industry and a number of Caucasian divers started operating out of Morro Bay. The Japanese divers continued to land their catch at Monterey, and from 1930 until World War II they worked as far south as Pt. Conception. Some of the catch was landed at Avila for processing but most was taken to Monterey by the boats. In 1930, divers commenced using liveboxes (Figure 32). Since it took an average of three days from the time a boat left until it returned to Monterey, abalones picked on the first day became soft unless kept in liveboxes. Abalones harvested around Pt. Conception were landed at Avila and Santa Barbara.

The industry gradually moved south from Monterey to Morro Bay and by the beginning of World War II this area, which was closer to the fishing grounds, had become its center.

During the war years, 1942 through 1946, only a few thousand pounds were taken. The Japanese were moved inland by the government and the few Caucasian divers who were not in the armed services were gathering gelidium, a seaweed used in agar-agar.

Due to the wartime demand for additional protein foods, the mainland between Pt. Conception and San Diego, including the Channel Islands, and from San Francisco to Humboldt Bay was opened to commercial diving. The north coast catch was small (525,000 pounds in 3 years) and public opposition to commercial diving in the area was so great it was closed in 1945 and has remained closed despite sporadic efforts by commercial interests to have it reopened.

The present commercial fishery is divided into two general areas: one north and the other south of Pt. Conception. North of Pt. Conception there are no pink abalones—the fishery is entirely for reds. This northern fishing area extends roughly from Cape San Martin to Cayucos, a distance of 35 to 40 miles (Figure 37). It has been harvested continuously since 1929 and is the main source of the red abalones landed in California. Abalones from these beds are of top quality and bring a better price to the divers than those from any other area in California. The red abalone catch averaged two million pounds per year from 1916 through 1960 and almost all came from this region. Most of the catch is landed at Morro Bay; however, fishery statistics for Morro Bay are included with those for the Santa Barbara area (Figure 38).

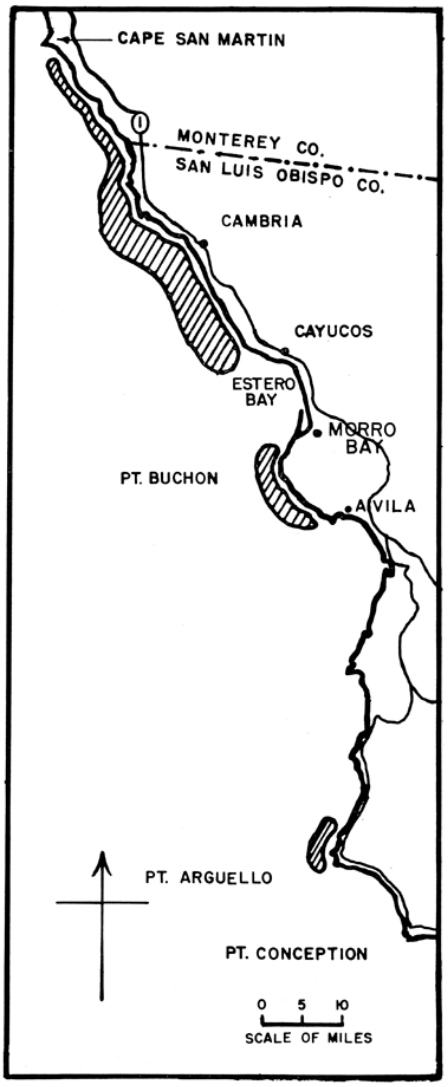

FIGURE 37. Most of the red abalones landed in California today come from between Cape San Martin and Pt. Conception and most of these are taken between Cape San Martin and Cayucos, an area that has been in continuous production since 1929.

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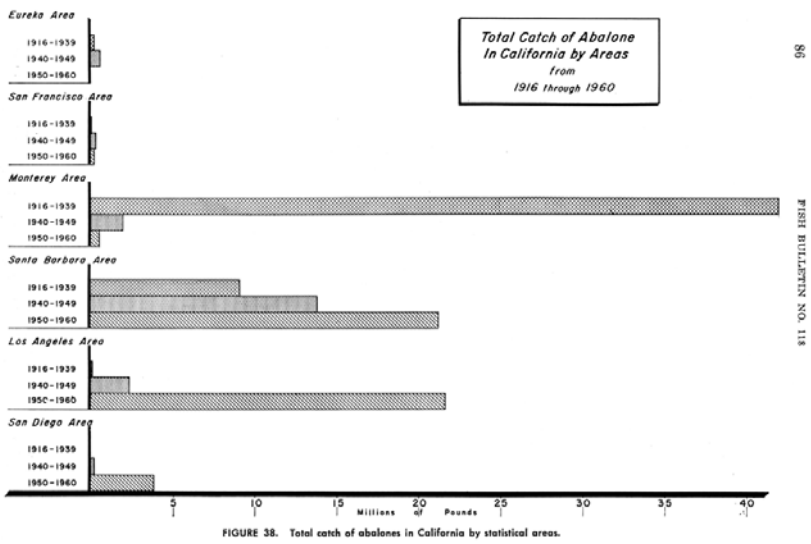

FIGURE 38. Total catch of abalones in California by statistical areas.

FIGURE 38. Total catch of abalones in California by statistical areas

South of Pt. Conception, except for a few reds taken at San Miguel Island and off San Diego, the fishery is primarily for pinks although a few thousand pounds of greens, whites and blacks also enter the catch. This area first opened in 1943 but did not begin to produce abalones in appreciable quantity until 1948 (Figure 39). The catch quickly mounted and reached a peak of 3.5 million pounds in 1952. Approximately 2.4 million pounds of the 1952 catch came from two of the Channel Islands, Santa Barbara and San Clemente.

After 1952 the pink abalone catch declined and 1960 landings were approximately one-half those of the reds. During the first few years after they were opened, the Channel Islands were heavily fished and the catch consisted primarily of accumulated stocks of large (older) individuals. Within a few years, the older abalones had been harvested and the divers had to depend on the younger abalones as they grew to marketable size. Pink abalones apparently do not grow rapidly so the take has diminished.

The warm water in 1957, 1958 and 1959 contributed to the decline of the pink catch by destroying much of their food supply, kelp. Because of the shortage of food not many abalones grew to legal sizes. In addition, the flesh of the abalones that did reach legal size was shrunken and watery, reducing the amount of salable meat.

Almost the entire catch at present (1962) is from Santa Cruz, San Clemente, Santa Barbara and Anacapa Islands, with Santa Barbara and San Clemente contributing the most. San Nicolas Island, because it is further from the mainland, does not contribute much to the total catch. Landings from Santa Catalina Island are small as are those from

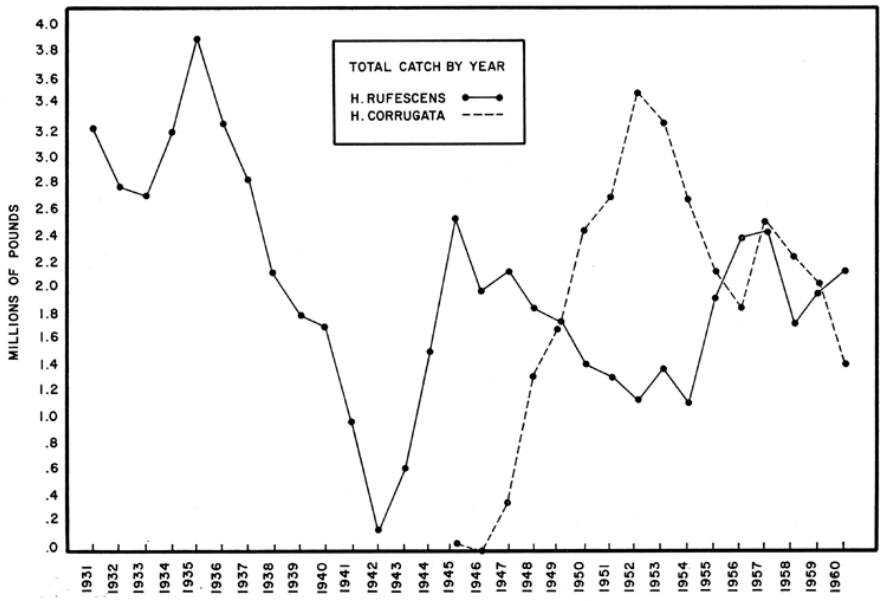

FIGURE 39. Until World War II the entire abalone catch consisted of reds, almost all from the Morro Bay area. The pink fishery began in 1943 when the Channel Islands were opened but catches were small until 1948. Many of the red abalone divers entered the pink fishery, which helps to account for the spectacular increase in the catch. As harvesting continued and legal-sized abalones became scarce, many divers returned to the red abalone fishery.

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San Miguel Island. San Miguel Island produces mostly red abalones while all the others produce pinks. Along the mainland, most pinks are taken near Pt. Conception. Most abalones are landed at Santa Barbara, San Pedro, Newport Beach and San Diego where they are processed. Divers can always sell red abalones because of their high quality and when reds are plentiful many processors place limits on the quantity of pinks they will accept.

Landings of both species are greatest during the first few months after the season opens when the divers are harvesting the abalones that have reached legal size during the two-month closed period. Rough weather during the early summer generally restricts diving and the catch declines. Landings usually increase slightly during the fall; decline again as early winter storms prevent diving and increase for a few weeks in December.

A month-by-month comparison of red and pink abalone landings (Figure 40) shows a somewhat similar curve for both. The catch of pinks, however, has been determined primarily by market demand; their fishery has not necessarily been influenced by the same factors that affect the reds. Many divers who fish for pinks work on a part-time basis, concentrating their efforts at the beginning and end of the season.

Although pink abalones have been important, the fishery for red abalones has been the mainstay of the industry (Figure 41).

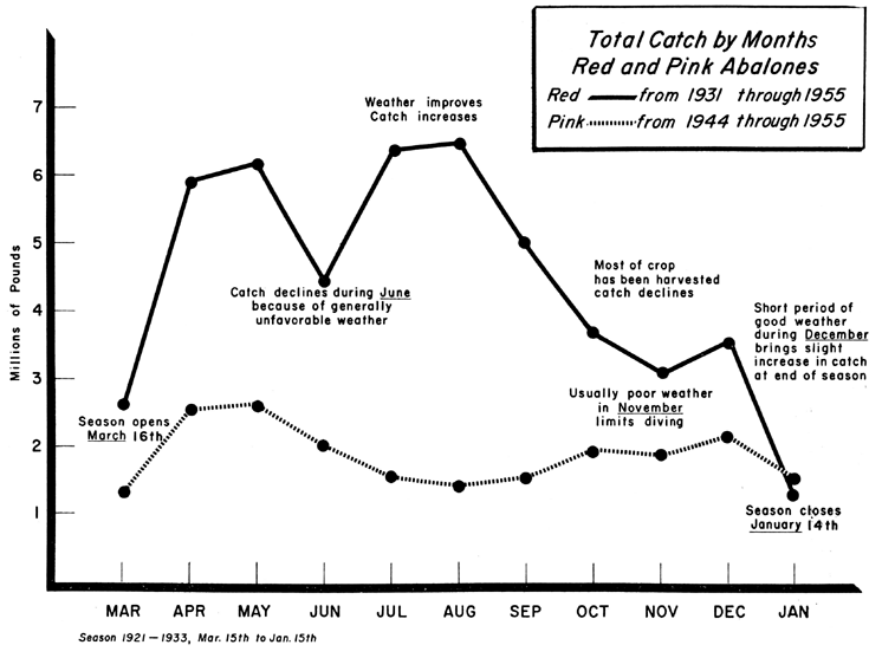

FIGURE 40. Although landings for both pinks and reds have followed the same general trends, fluctuations in red catch have been caused primarily by weather while those affecting pinks were caused by market vagaries.

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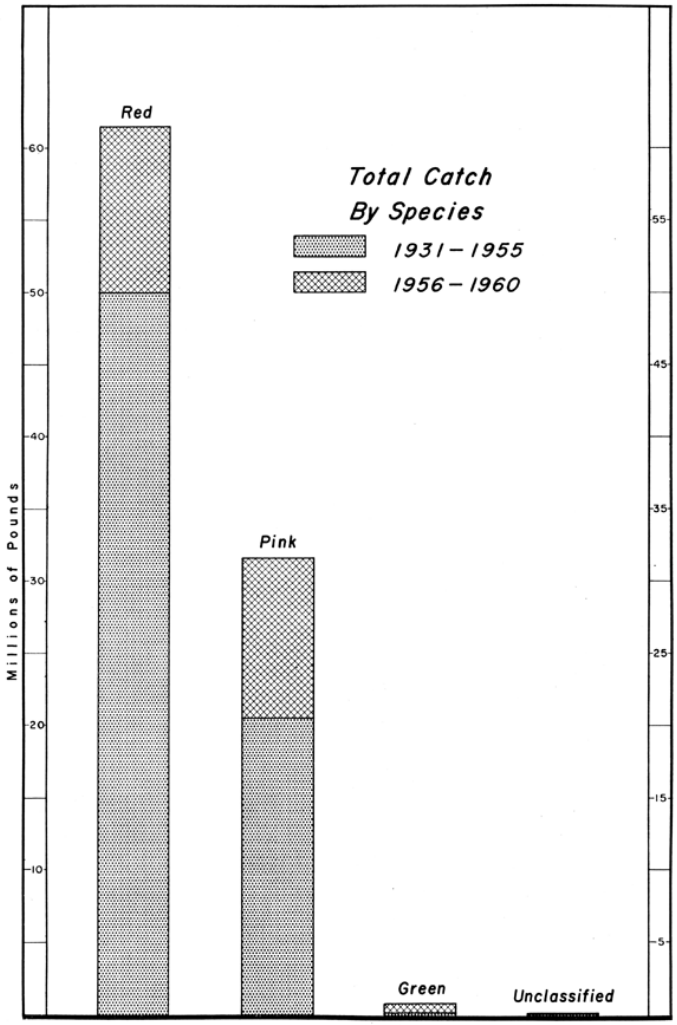

FIGURE 41. The California abalone industry has been established on the fishery for red abalones. The fishery for pinks, in existence since World War II, has contributed almost half of the landings since 1948. Green abalones are taken only incidentally, and are of minor importance in the fishery.

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4.3.1.3. Processing

Market operators report the abalone catch in dozens and we convert their figures into poundages for our statistical and biological records. All of the department's published figures and records are based on weight in the round and for a dozen abalones the following conversions are used: reds (minimum size 8 inches) = 50 pounds pinks (minimum size 6 inches) = 25 pounds Prior to 1959, the conversion factor for pinks was 35 pounds per dozen.

A diver's pay is based on the amount of salable meat that can be recovered from his catch. From one-fourth to one-third of an abalone's live weight is usable meat, so the price a diver receives usually varies from load to load. The price received for reds in 1961 ranged from $5 to $10 per dozen and for pinks from $1.50 to $5.50 per dozen. The reds, because of the larger minimum size, are easier to process and have more usable meat than the pinks. The minimum legal size for pinks is 6 inches but abalones that small are seldom accepted by the processors because of the excessive labor costs involved in handling them.

The early Chinese fishermen in California gathered abalones for their own use or for local markets at first. Later they dried the meats and exported them to the Orient but this practice was prohibited in 1915. The first processing of fresh abalones—slicing into steaks—was started in Monterey in 1913 by the Japanese. After laws were passed to prohibit drying abalones, there was some difficulty educating Californians to eat the fresh product.

Abalone canning was started at Cayucos in 1905 and soon other canneries were established at San Diego, San Pedro, and Point Lobos near Monterey. Although five canning plants were operating in 1917, by 1928 there were only three. There was never much demand for canned abalones because they not only were more expensive to can but the fresh product could take care of the market. When exporting abalones from California was prohibited, the last cannery at Point Lobos closed in 1931. Since then, the entire product has been marketed either fresh or frozen. Only the trimmings can be canned.

Although details may differ, the general method for preparing and processing abalones is essentially the same in all the California processing plants. The methods described and illustrated here are most commonly used to prepare red abalones.

Abalones are usually delivered to the plants in the afternoon when the divers are usually forced to return to port because of winds. The abalones are placed in boxes and unloaded from the boats at the processor's dock (Figure 42). Inside the plant they are placed either on the cement floor or on tables (Figure 43) where they remain until the next morning or until they have relaxed sufficiently for easier handling by the workers. The processing begins when a shucker inserts a flat, semicurved iron bar between the shell and flesh and forces it forward to where the muscle is attached. He then exerts a strong, quick force to the bar (Figure 44) and pops the animal cleanly from the shell.

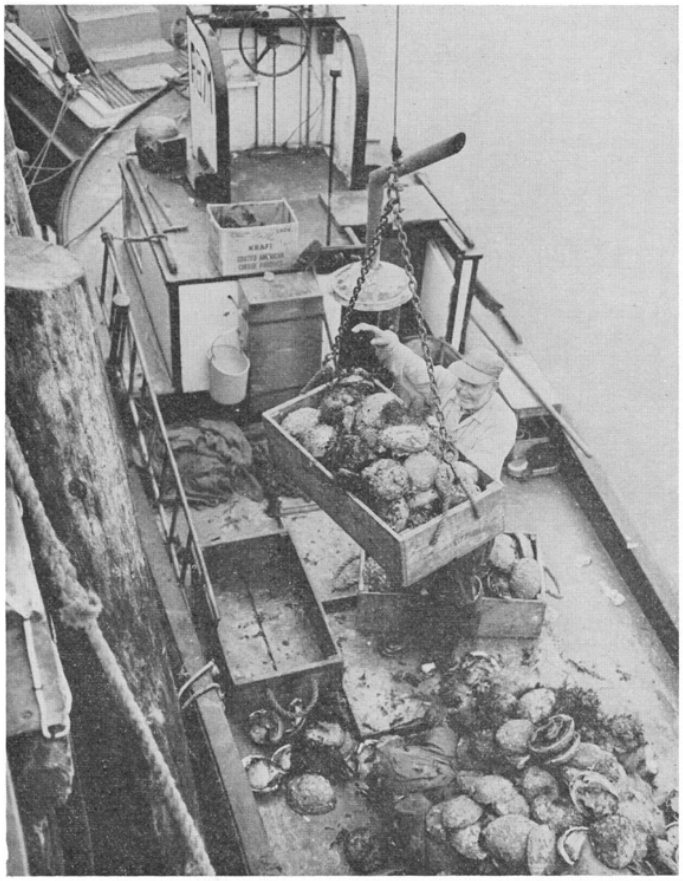

FIGURE 42. Unloading red abalones from a diving boat at the processor's dock. The diving helmet on the forward deck has been equipped with an extra-wide face plate. Photo by Verne Peckham, 1961.

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FIGURE 43. These abalones have just been delivered to the processor's shop. They will remain on the table until they have relaxed. Photo by Glen Bickford, 1960.

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Most of the viscera are removed and discarded; however, in some plants they and the gonads are frozen for fish bait.

After shucking, the abalones are washed either by hand or in a modified cement mixer (Figure 45). After washing, they are spread in a single layer on a cement table and allowed to stand for several hours to let the muscle tissues relax. When the abalones no longer curl around the edges, the epipodium, which contains a black pigment, is trimmed off either with a knife or by using a motor-driven circular blade (Figure 46). Usually some of the black pigment remains but when the tough fascia around the columellar muscle is peeled off, all residual epipodial pigment is also removed (Figure 47). Almost the entire processing operation is done by hand labor so it is necessary to recover a maximum of salable meat from each abalone. The trimmers and peelers must be quite skillful to keep waste at a minimum and assure the processor of a profit for his product. Shucking, trimming and peeling reduces an abalone to about one-third of its round weight (Figure 48). The peeled abalones are sliced into steaks approximately one-half inch thick, usually with a slicing machine (Figure 49).

The steaks have to be pounded to break down their tough connective fibers (Figure 50). If this is not done, the meat retains the consistency

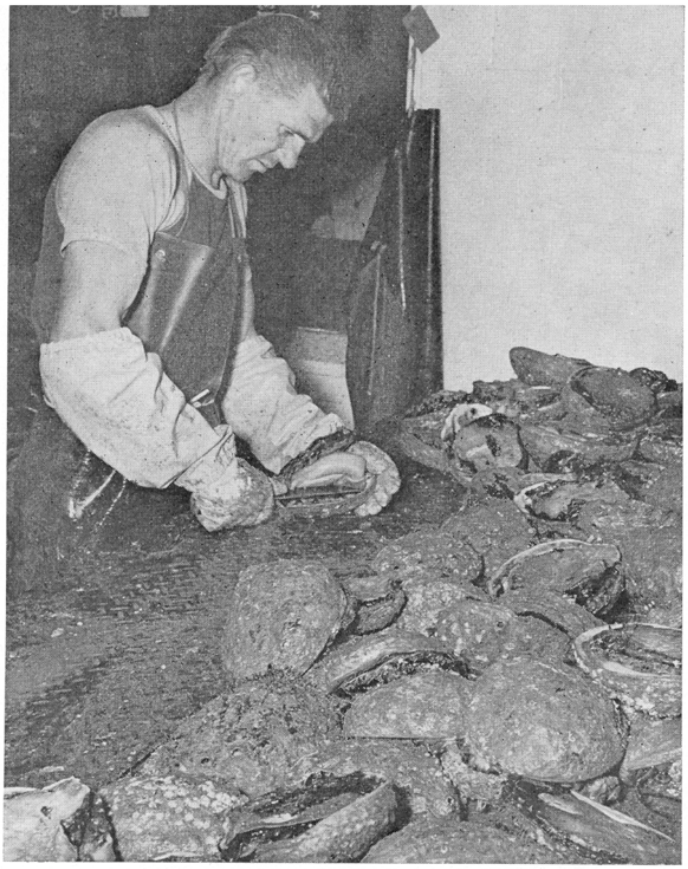

FIGURE 44. The "shucker" separates the muscle from the shell in one continuous movement with his "shucking bar." Photo by Glen Bickford, 1960.

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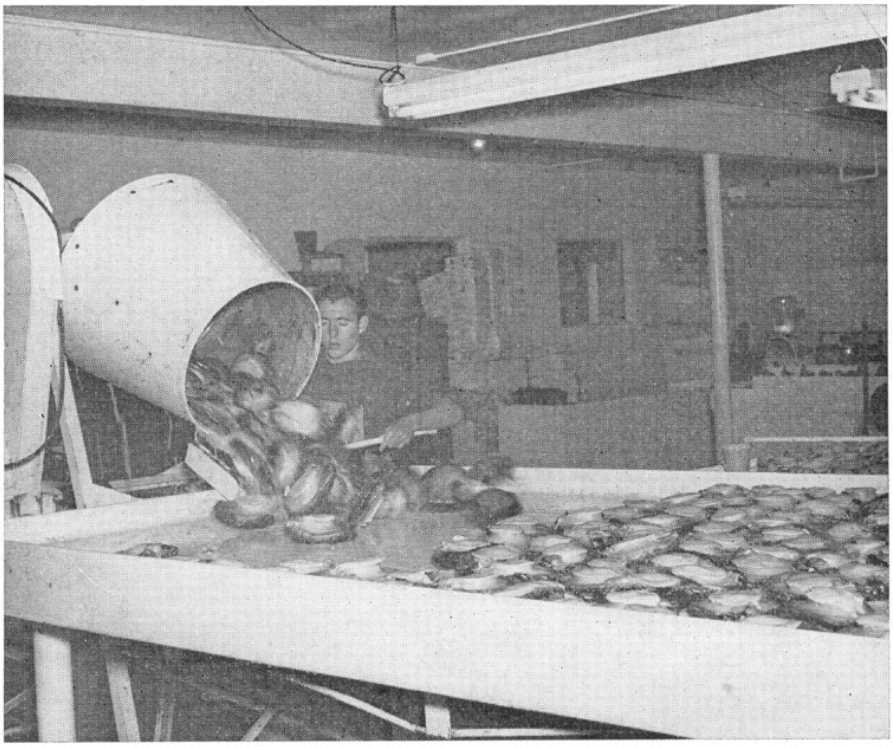

FIGURE 45. Before the advent of the mechanical washer, abalones were scrubbed by hand with stiff brushes. Photo by Glen Bickford, 1960.

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of truck tire rubber, making chewing a difficult task. Although many methods have been tried, no satisfactory substitute has been found for hand-pounding the steaks. This operation, too, calls for skill; the slices must be struck hard enough to break their fibers but not so hard the tissues are crushed and the slice shattered.

The finished product is sorted according to steak size and color, packed in 5- or 10-pound cartons (Figure 51), and placed in a freezer.

Premium prices are received for the large, white-meat steaks so abalones which will produce the whitest meat and the largest steaks are eagerly sought by both diver and processor. Occasionally, abalones will have greyish-colored meat. They taste every bit as good as the white meated abalones but because they are dark they bring a lower price.

Most of the processed catch is quick-frozen and distributed to restaurants. There is always a market for a first-quality product; lower grade abalones (darks) may not sell as readily, but usually all the red abalones harvested can be marketed.

Some processing plants grind dark abalone meat with trimmings and produce abalone patties. These are packaged, frozen and distributed to

markets. The largest and most decorative shells are usually sold to collectors and the rest are thrown away (Figure 52).

4.3.2. Sportfishery

The abalone laws passed by the coastal counties in the early 1860's were indirectly responsible for establishing the sportfishery. Prior to that time, no distinction was made between gathering abalones to sell and gathering them for recreation. By prohibiting their sale when gathered from the littoral zone, the commercial fishery was moved offshore and the shoreline was left for those who sought abalones for recreation. The first abalone law enacted by the State (in 1901) established a minimum size on all species of 15 inches, measured around the rim.

Most subsequent regulations applied only to the commercial fishery and not until 1913 were laws directly affecting the sportfishery adopted. At that time spearing abalones was prohibited (this is still in effect) and a bag limit of 10 was established in southern California. In 1917, identical minimum sizes were set on reds, greens, pinks and blacks for both commercial and sport fishermen but controversy soon developed

FIGURE 46. Preliminary trimming with a slicing machine removes most of the epipodium containing the black pigment. This process was formerly done by hand using a knife. Photo by Glen Bickford, 1960.

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FIGURE 47. Removing the tough fascia covering the top and columellar muscle and the residual pigment requires great skill. Not only must the "peelers" work rapidly, they must be careful not to remove too much meat. Photo by Glen Bickford, 1960.

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over these. Sportfishermen argued that commercial divers in deep water were taking abalones that would move inshore and replace the intertidal population they depended upon. In 1921, the sport size limit for red abalones was left at seven inches but the commercial limit was raised to eight on the assumption that a one-inch differential would allow plenty of abalones to move inshore for the sportsmen. Our tagging studies have proven this does not happen; adult abalones seldom travel more than a few feet in any direction.

Until the end of World War II, almost all abalone sport fishing was during low tides; the fishermen waded among the rocks removing abalones uncovered by the tide. Only a few hardy individuals dived for abalones, particularly in the cold waters of central and northern California. With the advent of rubber skindiving suits shortly after the end of World War II, part of the sportfishery moved offshore into the deeper water.

The abalone sportfishery is limited to small portions of the total coastline. of California's nearly 1,300 miles of open coastline, 75 percent is privately owned and access is permitted or denied according to the owner's pleasure. Most of the 10 percent controlled by the federal

government (lighthouses, military establishments, etc.) is closed to the public. The remaining 15 percent (about 175 miles) is owned by cities, counties and the State and constitutes most of the shoreline legally accessible to the public. About half of this 175 miles is sandy and unsuitable for abalones, leaving about 80 to 85 miles of rocky shoreline accessible for fishing. However, not all of this 80 to 85 miles of rocky shoreline is good abalone habitat.

Since shorepickers and skindivers compete for abalones in the same areas, occasional disagreements have occurred. Their conflicts have developed over the same issues that started the argument between sportfishermen and the commercial divers nearly 50 years ago. On some beaches, there have been pitched battles between skindivers and shorepickers.

There is little or no reason for conflict between sportfishermen, either skindiver or shorepicker, and commercial interests today because the same areas are not fished by both groups. The principal commercial fishing areas are generally inaccessible to sportfishermen. In central California, most of the commercial diving is offshore from private land not open to the general public. In southern California, almost the entire commercial catch is from offshore islands beyond the reach of all but a few sportsmen.

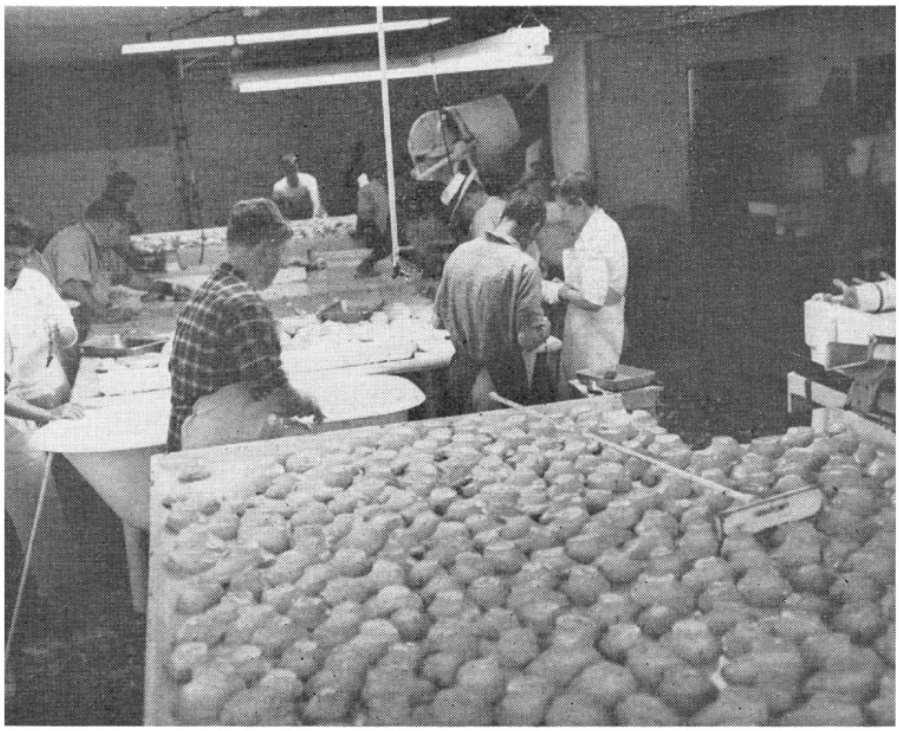

FIGURE 48. After peeling off black pigment and tough muscle fascia, abalones are ready for slicing into steaks. Photo by Glen Bickford, 1960.

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FIGURE 49. Slicing peeled abalones into ½ to ⅜ inch thick steaks.
Photo by Glen Bickford, 1960.

FIGURE 49. Slicing peeled abalones into ½ to # inch thick steaks. Photo by Glen Bickford, 1960

Most of the abalone sportfishing in the expanse from Oregon to Pt. Arguello is done in the stretch between Monterey and Ft. Bragg. All of the shorepickers and most of the skindivers appear during periods of low tides and attempts have been made to count them at these times and to estimate their catch.

Among the earliest tallies were those taken by Fish and Game wardens examining the catches of abalone fishermen as they left the beach. Later, counting stations were established at strategic locations during periods of low tides to obtain more comprehensive estimates. The coastal area from Fort Ross to Point Arena has been one of the most heavily fished. During three days in 1949, 3,902 fishermen took 15,514 abalones from this area (Table 8) . Both fishermen and abalones were counted on the beach from 1946 through 1952. However, in 1960, the fishermen were counted from an airplane but their catch was estimated from averages based upon numerous shoreside samples.

By using aircraft, a greater length of coastline can be surveyed during a single low tide and by counting the people on the beaches and in the water, the number of abalone fishermen can be estimated with reasonable accuracy. The average catch per shorepicker ranges

TABLE 8

Abalone Fishermen and Their Catch in the Area Fort Ross to Point Arena, 1946-1960

Year	Number of Abalones	Number of Fishermen	Abalones per Fisherman	Number of Cars
1946 (3 days)	2,037	1,070	1.9	385
1949 (3 days)	15,514	3,902	4.0	1,334
1951 (1 day)	2,496	660	3.8	--
1952 (1 day)	1,355	680	2.0	248
1960 (1 day)	1,080 (est)	540	2.0	--

TABLE 8

Abalone Fishermen and Their Catch in the Area Fort Ross to Point Arena, 1946–1960

FIGURE 50. Pounding the steaks to break down the tough muscle fibers, a process that has resisted mechanization. Many methods have been tried, but only pounding by hand has proven satisfactory. The mallets are usually oak and weigh two or three pounds. Photo by Glen Bickford, 1960.

FIGURE 50. Pounding the steaks to break down the tough muscle fibers, a process that has resisted mechanization. Many methods have been tried, but only pounding by hand has proven satisfactory. The mallets are usually oak and weigh two or three pounds. Photo by Glen Bickford, 1960

from 1.5 to 4.5 abalones depending upon the time of day, height of tide, amount of surf, etc. By adjusting averages to the fishing conditions observed, one can roughly estimate the number of abalones taken by fishermen counted during an aerial survey. However, such estimates vary considerably and should only be used to approximate the sport catch.

FIGURE 51. The pounded steaks are graded according to quality (color) and size, packed in cartons, weighed and quick frozen. Photo by Glen Bickford, 1960.

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In general, tides lower than minus 0.5 feet are best for shorepicking but legal abalones can be found whenever the tides approach 0.0 feet. The amount of littoral zone exposed, however, depends upon the condition of the surf; when the surf is high, fewer abalones are taken regardless of the height of the tide. The time of low water is important since many of the lowest tides occur before sunrise in the spring or after sundown in the fall and abalone fishing is restricted to the period from one-half hour before sunrise to one-half hour after sunset.

Between 2,200 and 2,500 skindivers averaging 14 to 17 diving days each in the area between Oregon and Pismo Beach, landed 53,700 red abalones in 1960 according to information collected during a 4-year survey of northern California's marine sportfisheries (Table 9) .

In southern California, sportfishermen gather abalones from Santa Barbara to San Diego and, to a limited extent, around Santa Cruz and Anacapa Islands, and along the mainland side of Santa Catalina Island. Most of their catch consists of pinks and greens but a few blacks, reds and whites are also taken. SCUBA is permitted for abalone fishing in southern California and fair numbers are taken by divers using this gear.

Abalones are no longer abundant along the southern California coast. Pollution has destroyed some of their habitat as have high-school biology classes, shell collectors, aquarium enthusiasts and the general public who indiscriminately overturn rocks in the intertidal zone at every opportunity.

Weather and water temperatures are mild and abalones can be sought during almost any low tide; however accurate figures on the catch either by skindivers or shorepickers are not available. From limited observations, it appears that in southern California fewer abalones are

FIGURE 52. Pile of empty shells from part of a day's work. Most of these will be discarded; shell collectors will purchase the best. Photo by Glen Bickford, 1960.

FIGURE 52. Pile of empty shells from part of a day's work. Most of these will be discarded; shell collectors will purchase the best. Photo by Glen Bickford, 1960

taken per fisherman but their total catch is equal to or exceeds that of northern California because there are more shorepickers and skindivers after them.

Young (1961) in discussing the take of skindivers from California party boats states that abalones were their prime targets. In northern California (mainly Carmel Bay and the Farallon Islands), 112 divers bagged 200 red abalones, while in southern California (mostly around the offshore islands) 1,725 divers gathered 2,450 abalones of several species.

TABLE 9

Effort Expended for and Catch of Red Abalones by Skindiving, Oregon to Pismo Beach, 1960 [1]

Area	Diving Days	Hours Diving for Abalones	Number of Red Abalones	Abalones per Hour
Oregon-Fort Bragg	1,300	--	1,460	--
Fort Bragg-San Francisco	15,200	11,000	33,000	3
Sharp Park-Santa Cruz	5,900	4,180	8,700	2
Monterey-Point Sur	15,000	2,350	4,900	2
Point Sur-Pismo Beach	2,300	1,660	4,800	3
Totals	38,700	19,200	52,860	

[1] Figures from D. J. Project F12R.

TABLE 9

Effort Expended for and Catch of Red Abalones by Skindiving, Oregon to Pismo Beach, 1960

5. RESEARCH

5.1. Northern California

In 1951, the State Legislature directed the Department of Fish and Game to determine if the north coast could support a commercial abalone fishery without endangering the sport fishery. A program was inagurated and asked to answer four questions:

1. Is the resource sufficient for a commercial abalone fishery in northern California?
2. If so, how would a commercial fishery affect the sport fishery?
3. Is the resource maintaining itself in present commercial areas?
4. Is the resource maintaining itself in present sportfishing areas?

A preliminary report was presented to the Assembly Interim Committee on Fish & Game in August 1955, and additional information was published in *Outdoor California* in May 1957.

An original plan called for surveying the entire coastline from San Francisco to the Oregon border but it could not be done accurately with the time and manpower available, so efforts were concentrated in the coastal waters of Marin, Sonoma, and Mendocino counties.

To establish a commercial abalone fishery, certain basic requirements are necessary. There must be sufficient abalones in the area and these must meet required size and quality standards. Adequate and safe shelter must be available for the diving boats, the fishing area must be accessible to the fleet and the weather must be calm enough to permit diving sufficiently often to make the operation profitable. Water clarity (underwater visibility) and bottom terrain, while not as critical, must also be considered.

Any one of these requirements, if lacking, would seriously deter establishing a commercial abalone fishery. Since none of the north coast areas investigated met any of the criteria, a commercial fishery there is impractical. Thus, the question as to the effect of a commercial fishery on the sport fishery is academic.

At best the north coast, San Francisco to Oregon, could support a weak marginal fishery such as at Half Moon Bay where one or two divers occasionally land four to six dozen abalones on a weekend or when other fishing is slow. Such a marginal operation is occasionally attempted in the Monterey Bay area, but usually after a short trial it is abandoned and the divers either quit the business or move to the established areas in central or southern California. Although the entire mainland coast from San Diego to San Francisco, except for a few short stretches, is open to commercial abalone diving, most of the catch comes from a very small area between Cape San Martin and Point Conception. The department has twice surveyed the area from Monterey to Avila and commercial divers make periodic excursions into it, yet the results have always been the same as for the north coast—there are not enough abalones for a commercial fishery.

Commercial diving was permitted on the north coast from 1909 to 1937 and from 1943 through 1945. Records, compiled by the Department of Fish and Game since 1916, reveal that only 166,340 pounds of abalones were taken from the north coast between 1916 and 1937, approximately 7,500 pounds-per-year. During the same 22-year period, landings from the rest of the State, almost all from central California (Monterey County), totaled 48,370,000 pounds or 2,200,000 pounds-per-year. From 1943 through 1945, 525,460 pounds were taken from the north coast and 4,470,000 pounds from the rest of the State. The two main problems encountered by commercial divers on the north coast were the same two that hindered our investigation: too many days of rough weather, and too few abalones.

5.1.1. Number of Abalones

Our first task was to determine, as nearly as possible, the number of abalones in the area. We tried many methods of making counts but all were abandoned as impractical and inaccurate. Abalones usually live in groups or "beds" and these may vary from an area the size of a small room to one of several acres. The visible individuals are 5 to 9 inches across but most are between 7 and 8. The small abalones live under rocks and are seldom seen. Such grouping by size tends to make all abalones in a bed, with a few obvious exceptions, appear identical to each other. Because of the limited visibility underwater, due both to turbidity and to restricted vision imposed by diving equipment, it is difficult for a diver to tell which abalones he has counted and which he has not. Attempts to mark the abalones as they were counted met with little success because the growths on their shells rendered the marks invisible at a few feet. However, the biggest difficulty, and the main reason for abandoning direct numerical counting, was an inability to take into consideration the multitude of abalones on the undersides of rocks, in cracks and crevices and inside caves and caverns. A diver counting in rough, jumbled terrain could not possibly locate or see all of the abalones and his tally would be low. There is no formula for equating such a count to one made where the bottom is flat or consists of smooth-sided rocks.

The most satisfactory method and the one we employed was to compare visually the north coast areas with the commercial grounds of central California. To do this, we first intensively explored the beds the commercial divers had been working for over 30 years. Two members of our investigation were former commercial abalone divers, each with over 20 years experience. Armed with the knowledge of how productive beds "looked" our next step was to make comparisons on the north coast.

North of San Francisco we made our first exploratory dives where we felt certain we would find abalones, and we were not wrong. In fact, the greatest numbers of abalones we saw on the north coast were on these first dives. Additional exploration failed to reveal commercial concentrations of abalones except in a few, small isolated areas.

The largest concentrations are at Fort Ross, Sonoma County and near Fort Bragg, Mendocino County. North and south of these areas abalones are extremely scarce except for small, isolated groups (Figures 53 54 55 56 57).

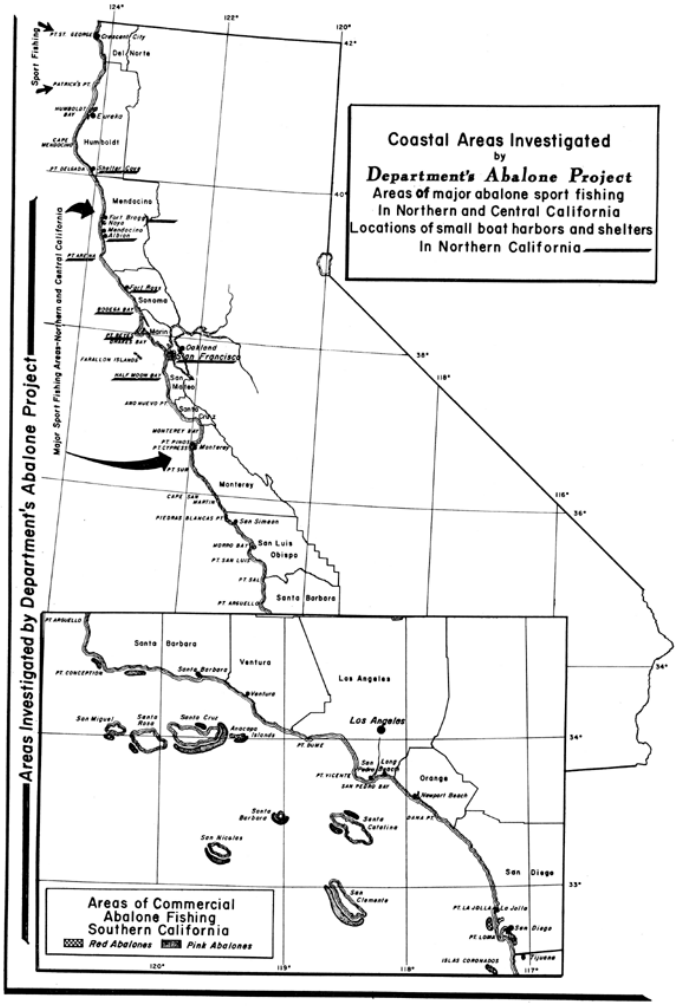

FIGURE 53. Area investigated by Department's abalone program covered the coastline from above Ft. Bragg to the Mexican border, including the Channel Islands. Also shown are principal small boat harbors and coastal ports. The southern California abalone fishery is conducted almost entirely among the Channel Islands (enlarged insert).

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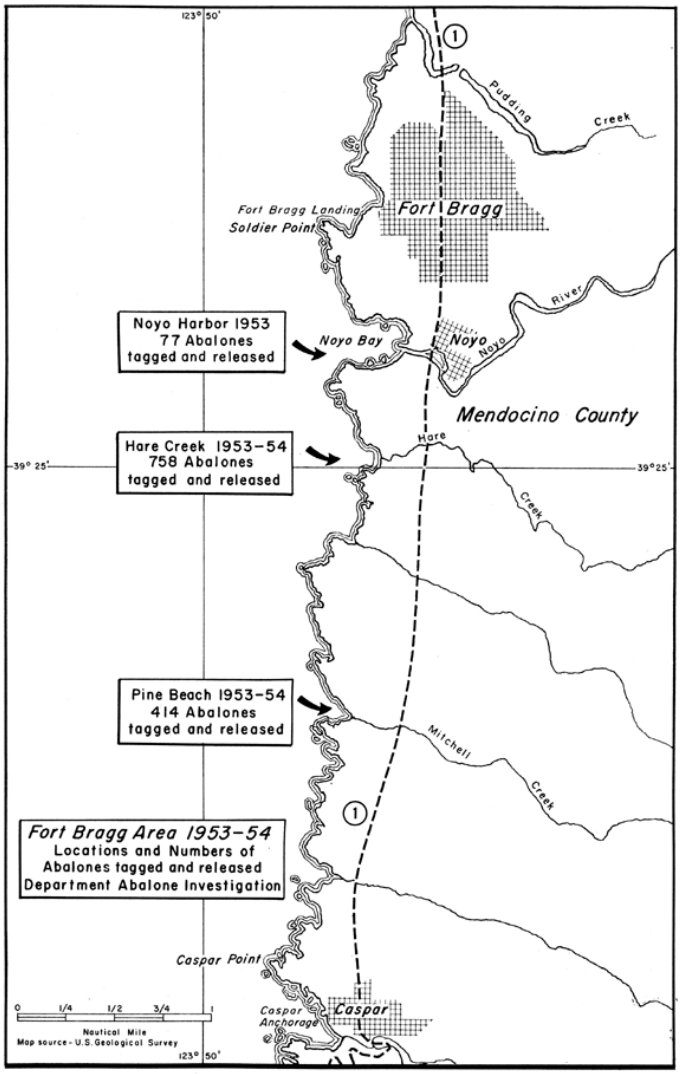

FIGURE 54. Ft. Bragg area of the Mendocino County coast showing where tagged abalones were released.

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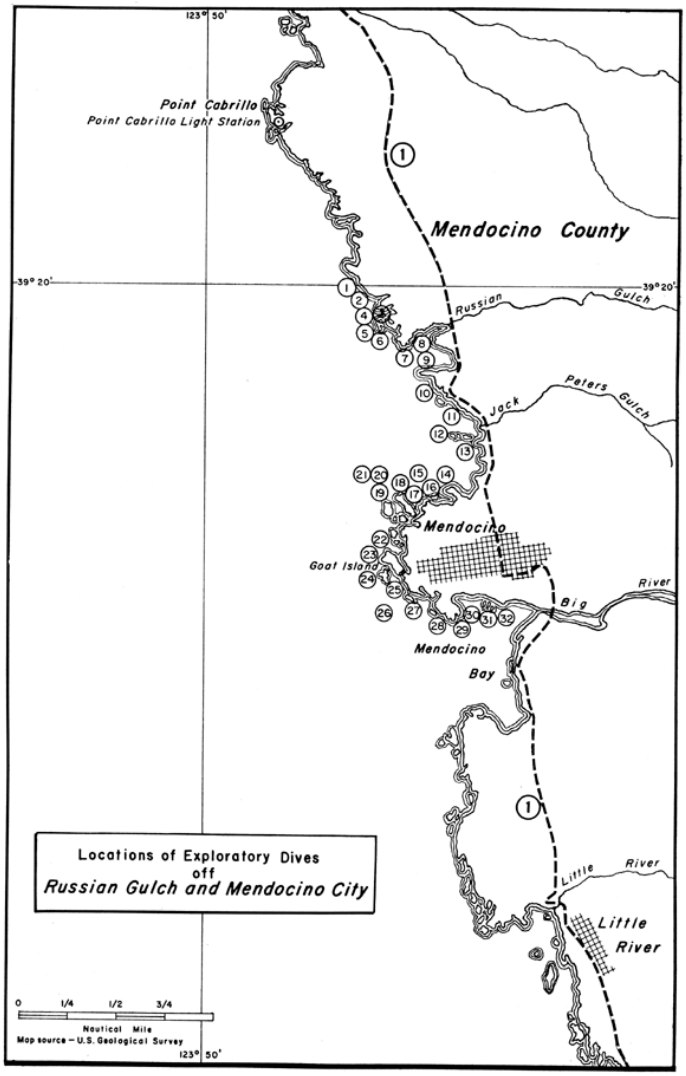

FIGURE 55. The Russian Gulch area of Mendocino County showing where some of the exploratory dives were made by the Department's investigation. Nowhere in this area were there enough abalones to warrant a commercial fishery.

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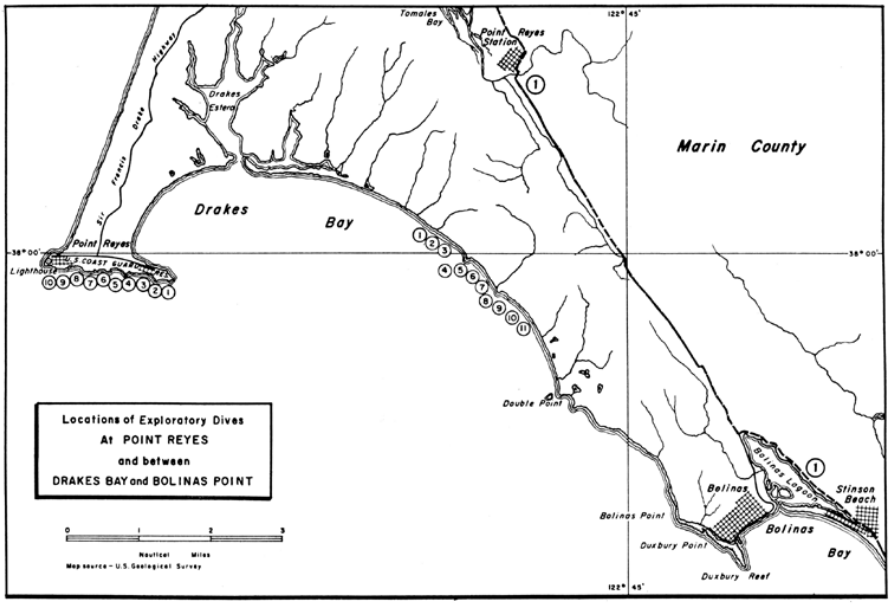

FIGURE 56. Locations of exploratory dives near Pt. Reyes, Marin County—an area worked by commercial divers during World War II. Only a few scattered abalones were found by Department divers.

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5.1.2. Ports

None of the small boat harbors or weather shelters between Eureka and San Francisco can be considered adequate (Figure 53). The entrance to Eureka Harbor, for example, is extremely hazardous for small boats during a storm or when a strong swell is running. At Shelter Cove, approximately 54 miles south, there is fair protection from northwesterly weather but it is exposed and dangerous during southerly or westerly winds and there is nearly always a swell running. Since there are no docks or piers, landings must be made on the beach where some supplies are available; the nearest town is Garberville, 24 miles away over a winding mountain road.

Some 35 miles south of Shelter Cove, is Noyo Harbor, Ft. Bragg, a small cove open to the west. The Noyo River enters at the head of the cove and its lower ¼ mile is navigable for small craft. Inside the river is shelter from any wind or sea condition and there are numerous docks along the channel, all operated by commercial fish houses. This is the only safe, all-weather harbor between San Francisco and Eureka but during storms or heavy swells the entrance is extremely dangerous. The only shelter between Noyo and Bodega Bay is Area Cove, 33 miles south of Noyo, an open bight affording some protection from northerly storms.

Bodega Harbor, 85 miles south of Noyo, is a triangular lagoon or inner bay lying between Bodega Peninsula and the mainland. It offers good protection from northwesterly storms but is open to southerly winds which sweep across the lagoon and on occasion blow anchored vessels onto the beach. Pt. Reyes, a rocky headland at the western end

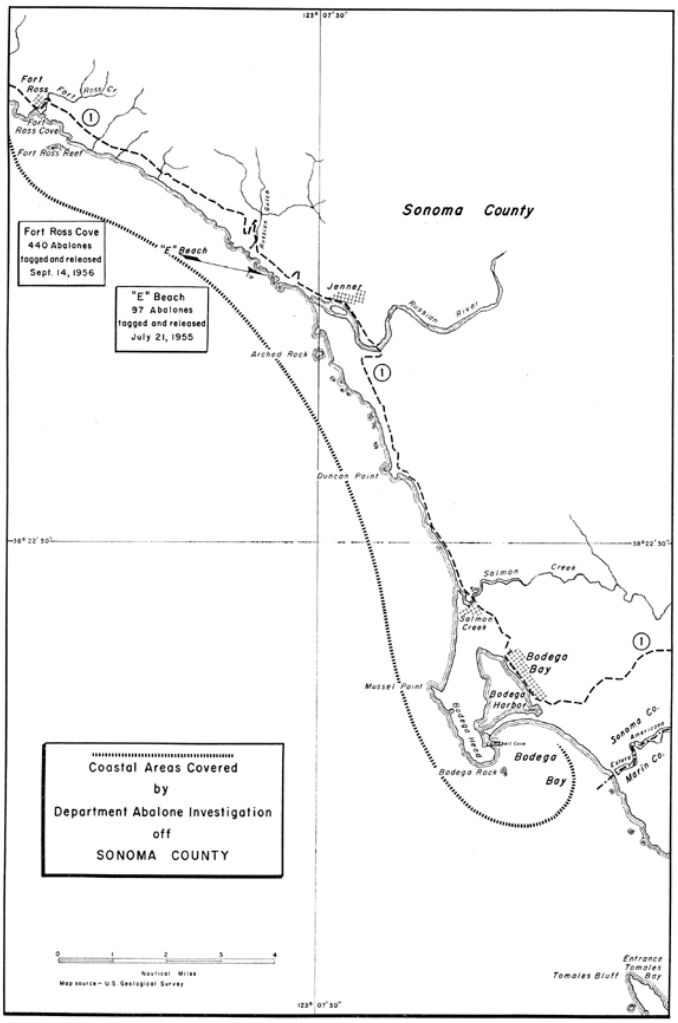

FIGURE 57. The Ft. Ross area in Sonoma County is one of the most popular sportfishing localities along the northern California Coast. During low tides the beaches are crowded with abalone pickers.

FIGURE 57. The Ft. Ross area in Sonoma County is one of the most popular sportfishing localities along the northern California Coast. During low tides the beaches are crowded with abalone pickers

of Drakes Bay 28 miles south of Bodega Harbor, offers protection in northerly and westerly weather and some shelter from southerly to southwesterly weather. Prevailing winds and swells are from the northeast but during the winter there is frequently a heavy swell from the south. Bolinas Bay, 10 miles south of Pt. Reyes, is another open bight affording some protection from the northwest. The entrance to San Francisco Bay is 10 nautical miles south of Bolinas.

The paucity of harbors along the north coast would restrict the operating ranges of diving boats to within a short radius of each shelter and the abalone populations in these limited areas would sustain the pressure of the entire north coast commercial fishery. Such practices are not good for any fishery and would be particularly bad for a sedentary one, such as the abalone. A commercial abalone fishery established in this region would be short-lived.

Boats built for abalone diving generally have "V" bottoms, plywood hulls, are powered with marine engines and are 27 to 30 feet long. They are equipped with bunks and some cooking facilities but conditions are crowded and only a few stay at sea more than a day or two at a time (Figure 58). In central California, where the fishing grounds are close to port, most of the trips are for one day only; the boats return to port each night. In southern California, almost the entire catch is taken around the offshore islands where anchorages are numerous and shelter usually can be found within a short run of the abalone grounds. Some of the processors in southern California have tender boats pick up abalones from their diving boats on the fishing grounds. In these cases, the diving boats can stay out for extended periods (Figure 59).

FIGURE 58. Part of the abalone diving fleet anchored at Morro Bay.
Photo by Verne Peckham, 1961.

FIGURE 58. Part of the abalone diving fleet anchored at Morro Bay. Photo by Verne Peckham, 1961

FIGURE 59. A pickup boat used to collect pink abalones from divers working the Channel Islands. These boats are about 50 feet long and can haul several tons of abalones per trip. Photo by Glen Bickford, 1959.

FIGURE 59. A pickup boat used to collect pink abalones from divers working the Channel Islands. These boats are about 50 feet long and can haul several tons of abalones per trip. Photo by Glen Bickford, 1959

5.1.3. Weather

The greatest handicap to the department's investigation in the north coast region was the lack of suitable diving weather. This alone would practically eliminate any chance for a commercial abalone fishery to flourish. For all practical purposes, diving along the north coast is limited to the summer months only and even then it is impossible to dive during long stretches because of adverse weather. The region is characterized by violent winter storms which last well into spring. In the summer, heavy fogs are common, usually into September. On most days the fog will clear by noon but by then the prevailing westerly wind has set in, building up the swell which lasts into the night. If the wind is strong, as is usually the case, the swell lasts two or three days or longer. When the swell diminishes, the water is turbid because of the disturbed bottom sediments and although diving may be possible it is not practical because the diver cannot see. There are days when the ocean is smooth, little, if any, swell is running and the water is clear. Such days are ideal for diving but they rarely occur and cannot be predicted.

During our investigation, we found the maximum number of days a diver could work on the north coast averaged three per month or about 30 for the 10-month abalone season. The average for central California is about 10 days per month during the season and in southern California

it is higher yet. Although most of the favorable weather along the north coast occurs during summer, divers cannot depend on it. In some years, there are long stretches of unfavorable diving weather during the summer. Because of this, it would be extremely risky to attempt setting up production schedules to take advantage of the expected good weather.

For example, we were able to dive on only 11 days between June and September 1954 and even though we remained until the end of November, no further diving was possible. Even on the 11 days we worked we had to return to port by noon or earlier because of wind and the rising swell.

5.1.4. Bottom Conditions

One of the most striking features of the north coast region is its extremely rough and rugged bottom terrain. In most locations, the bottom drops off so sharply it has the appearance of a giant, steep-sided, underwater quarry. Rocks and boulders, ranging in size from a basketball to a small house, cover the bottom and are piled one on top of the other making it difficult for a diver to traverse an area. To travel in a straight line for more than a few feet is impossible.

All of the abalones in this region are close to shore, most in 20 to 40 feet of water. Along the Mendocino County coast where the bottom drops off very abruptly, the abalones are especially close to shore. This situation and the rough weather make diving extremely difficult and dangerous. Rough bottom not only slows a diver down but close to shore, wave action is intensified and the water is rought and turbulent. In a heavy surge a diver constantly has to brace himself to prevent being knocked over.

Many small streams and several large rivers empty into the ocean along the north coast. During the winter, when flood conditions usually prevail, they transport large amounts of sediment to the sea where they settle out on the bottom. Because of these sediments and the intensified wave action close to shore, there are few days when underwater visibility is satisfactory for diving.

5.1.5. Abalone Movements

When abalones are removed from the intertidal zone other abalones eventually will move in and replace them. One of the problems confronting us was to determine from how far offshore and from what depths these replacements travel. With answers to these questions, one could decide how close to shore and at what depths commercial abalone divers can operate without harming the shore fishery. In an effort to solve this problem, we started tagging abalones and releasing them at different depths and distances offshore. In the Ft. Bragg area, we placed over 1,200 tagged abalones where we felt there would be a good chance of their being recovered by shore fishermen. At Fort Ross, more than 440 were released and at "E" Beach, 97 abalones were placed in 10 feet of water approximately 15 feet from shore.

When we checked at Pine Creek and Hare Creek approximately one year after tagging, all of the tagged abalones we recovered were still within the same general area in which they had been released. Most had grown only a little and many did not grow at all (Table 10) .

TABLE 10

Growth Data for 77 Tagged Red Abalones Recovered by Department's Divers From Ft. Bragg Area (Pine Beach), August 29, 1955. All Were in the Area of Release.

The measurements which were greater when tagged than when recovered, may have been due to chipped edges at time of remeasurement, to some form of marine growth inadvertently included in the original measurement that was missing upon recovery or to human error.

Tag No.	Date tagged	Days at liberty	Length (mm) when tagged	Length (mm) when recovered	Increment (mm)
509	6–13–53	807	185	196	+11
335	7–10–53	779	204	203	− 1
438	8–21–54	373	150	162	+12
447	"	"	187	189	+ 2
604	"	"	189	191	+ 2
645	"	"	190	191	+ 1
622	"	"	190	194	+ 4
434	"	"	194	196	+ 2
423	"	"	195	194	− 1
603	"	"	196	196	0
613	"	"	197	197	0
441	"	"	197	199	+ 2
639	"	"	198	198	0
440	"	"	198	199	+ 1
425	"	"	199	203	+ 4
607	"	"	199	206	+ 7
636	"	"	200	201	+ 1
602	"	"	200	203	+ 3
626	"	"	204	205	+ 1
627	"	"	204	204	0
437	"	"	205	205	0
450	"	"	205	207	+ 2
634	"	"	205	206	+ 1
635	"	"	206	206	0
632	"	"	206	205	− 1
446	"	"	207	209	+ 2
615	"	"	210	212	+ 2
620	"	"	210	212	+ 2
429	"	"	211	213	+ 2
658	"	"	211	210	− 1
630	"	"	213	215	+ 2
639	"	"	214	214	0
621	"	"	215	214	− 1
432	"	"	219	218	− 1
647	"	"	219	216	− 3
653	"	"	220	219	− 1
255	7–18–54	322	207	207	0
261	"	"	213	209	− 4
271	"	"	232	230	− 2
803	8–20–54	355	190	190	0
451	"	"	197	197	0
419	"	"	198	200	+ 2
483	"	"	205	206	+ 1
415	"	"	209	209	0
500	"	"	214	215	+ 1
813	"	"	215	217	+ 2
854	"	"	218	217	− 1
807	"	"	222	222	0
809	"	"	222	222	0
489	"	"	224	224	0
855	"	"	224	224	0
488	"	"	228[1]	239	+11
824	"	"	229	228	− 1
408	"	"	232	228	− 4
864	8–21–54	356	200	206	+ 6
1350	"	"	201	201	0
886	"	"	209	205	− 4
1614	"	"	210[1]	200	−10
1585	"	"	210	209	− 1
899	"	"	217	216	− 1

TABLE 10
Growth Data for 77 Tagged Red Abalones Recovered by Department's Divers From Ft. Bragg Area (Pine Beach), August 29, 1955. All Were in the Area of Release.

TABLE 10—Continued

Tag No.	Date tagged	Days at liberty	Length (mm) when tagged	Length (mm) when recovered	Increment (mm)
872	8–21–54	356	218	218	0
860	"	"	235	232	− 3
1238	8–31–54	366	206	207	+ 1
1140	"	"	199	198	− 1
1330	9– 1–54	367	184	186	+ 2
1297	"	"	209	208	− 1
1613	9–16–54	383	192	192	0
1617	"	"	197	197	0
1578	"	"	204	204	0
1634	"	"	208	207	− 1
1616	"	"	214	212	− 2
1577	"	"	215	216	+ 1
1661	"	"	215	213	− 2
1598	"	"	219	214	− 5
1619	"	"	221	220	− 1
1574	"	"	222	220	− 2
1590	"	"	222	221	− 1

[1] Length probably misread by 10 mm.

TABLE 10—Cont'd.

Tagged abalones were recovered by sportsmen at Pine Creek, Hare Creek, "E" Beach and Ft. Ross (Table 11) . None of our tagged abalones except number 360 (Table 11) moved from the general area in which it was released. Abalone number 360, collected in deep water and released in shallow, had moved back into deep water, a distance of approximately 50 feet; in four years it had grown 35 mm. No abalone released in water deeper than 8 or 10 feet has been recovered in the intertidal zone; in fact, none has moved horizontally toward shore more than 4 to 5 feet.

5.1.6. Quality

Although there may be quantities of abalones in a given area, unless they can meet commercial quality requirements a fishery would not be practical. Commercially processed abalones are graded and sold according to color; highest prices are obtained for the whitest meat with lower prices for the "darks," usually shades of grey. The price differential between "whites" and "darks" is such that a processor cannot operate profitably should he have a consistent run of dark-meat abalones. Since the market will absorb only a limited amount of dark meat, processors cannot make up in quantity what is lacking in quality. About two-thirds to three-quarters of an abalone's weight is lost in trimming. Such low recovery coupled with high operating costs, result in a narrow range of profit for the commercial abalone processor. He must have sufficient numbers of top quality abalones to stay in business.

In 1953, we sampled 164 commercial sized abalones in the Ft. Bragg area for quality. After measuring, the animal was removed from the shell and cut through the body so the color of the exposed meat could be recorded. Sixty-three of the 164 abalones, about 40 percent, were "darks," and would not have been acceptable to the processors (Table 12) .

TABLE 11

Growth Data for 32 Tagged Red Abalones Recovered by Sportsmen; 25 From Pine Beach; 1 From E Beach and 6 From Ft. Ross

Pine Beach

Tag No.	Date tagged	Date recovered	Days at liberty	Length (mm) when tagged	(mm) when recovered	Increment (mm)	Depth of recovery
1406	8–25–54	12– 7–54	104	185	na[1]	--	Intertidal
1415	"	"	104	190	na	--	"
1447	"	"	104	191	na	--	"
1368	"	"	104	205	na	--	"
395	"	"	104	211	ha	--	"
368	"	12– 8–54	105	200	202	+ 2	"
201	"	"	105	204	216[2]	+12	"
365	"	"	105	207	201	− 6	"
391	"	12– 9–54	106	188	na	--	"
392	"	"	106	189	na	--	"
380	"	"	106	204	na	--	"
358	"	"	106	206	na	--	"
356	"	"	106	213	na	--	"
379	"	"	106	216	na	--	"
665	"	12–10–54	107	182	na	--	"
670	"	"	107	190	na	--	"
682	"	"	107	195	na	--	"
683	"	"	107	200	na	--	"
1398	"	12–11–54	108	182	na	--	"
1432	"	"	108	195	na	--	"
1402	"	"	108	198	na	--	"
1404	"	"	108	198	na	--	"
1428	"	"	108	204	na	--	"
1454	"	"	108	218	na	--	"
360	"	10–14–58	1511	169	204	+35	20 feet

E Beach

187	7–21–55	5–12–56	180	210	216	+ 6	Intertidal

Fort Ross

5003	9–14–56	6–29–57	180	199	197	− 2	Intertidal
4703	9–14–56	12– 57	455	187	182	− 5	"
4865	9–14–56	5– 5–58	705	185	185	0	"
4718	9–13–56	4– 59	900	178	180	+ 2	"
4950	9–14–56	4–26–59	950	187	188	+ 1	"
4720	9–13–56	11– 59	1162	206	210	+ 4	"

[1] na = not available.
[2] Probably misread by 10 mm.

TABLE 11

Growth Data for 32 Tagged Red Abalones Recovered by Sportsmen; 25 From Pine Beach; 1 From E Beach and 6 From Ft. Ross

Nowhere along the north coast did we find abalone beds that would meet the quality standards required for a commercial fishery.

5.2. Southern California

During the first years most of our investigative efforts were in the northern and central California abalone areas. We limited our activities in southern California primarily to exploratory diving and a general survey of commercial and sport fishing localities. In 1956, 1957 and 1958, we transplanted large numbers of red and pink abalones to determine if this technique could be used to build up abalone populations. In 1956, about 800 red abalones were transplanted from San Miguel Island to Santa Catalina. Warm water the following year destroyed the kelp and most of these abalones did not survive. A few, however, moved

TABLE 12

Quality Data (Color of Meat) for 164 Red Abalones Taken by Department's Divers From Ft. Bragg Area, May and June 1953

Shell length (mm)	Meat color	Shell length (mm)	Meat color	Shell length (mm)	Meat color	Shell length (mm)	Meat color
157	gray	200	lt. gray	212	gray	221	white
		200	dark	212	white	221	white
172	white	201	white	212	white	221	dark
		201	white	212	dark	221	dark
180	gray	201	gray	213	white	222	white
180	white	201	gray	213	white	222	black
183	gray	202	white	213	white	222	white
185	white	202	white	213	white	223	white
185	white	202	white	213	dark	223	white
186	white	203	white	213	white	223	white
186	white	203	white	214	white	223	dark
187	gray	203	gray	214	white	223	white
189	gray	204	white	214	white	224	lt. gray
		204	dark	214	white	224	white
190	dark	205	gray	214	gray	224	white
191	white	205	white	215	white	224	white
192	gray	205	dark	215	dark	225	white
192	gray	206	gray	215	white	225	lt. gray
192	gray	206	white	215	white	225	white
192	dark	206	white	216	dark	225	dark
194	white	206	white	216	white	225	dark
194	medium	206	white	217	white	225	white
195	dark	207	white	217	dark	225	dark
195	white	208	white	217	gray	226	gray
196	gray	208	dark	217	dark	226	white
196	gray	209	white	217	white	226	white
196	white	209	white	217	dark	226	white
196	white			217	white	227	white
196	white	210	white	218	white	227	white
196	white	210	dark	219	white	227	white
197	white	210	white	219	white	228	lt. gray
197	white	210	white	219	white	228	white
197	gray	210	white	219	lt. gray		
198	white	210	lt. gray	219	white	230	gray
198	gray	210	dark	219	dark	230	lt. gray
198	gray	210	white	219	white	231	white
198	white	210	white	219	dark	232	dark
199	white	211	white			233	white
		211	white	220	gray	233	dark
200	white	211	white	220	dark	235	white
200	white	211	white	220	white	238	dark
200	white	211	gray	220	white		
200	white	212	gray	220	white	244	white

TABLE 12

Quality Data (Color of Meat) for 164 Red Abalones Taken by Department's Divers From Ft. Bragg Area, May and June 1953

into deeper, colder waters and managed to establish themselves. Elk kelp appears to be their main food in the deeper water but none of the transplanted abalones has grown appreciably.

In April 1956, black abalones were transplanted from White Point to Catalina Harbor and black abalones from Catalina Harbor and Bird Rock were moved to White Point in an attempt to determine the effect of changes in environment. The bodies of the White Point abalones were shrunken and their shells were eroded, presumably from the effects of the millions of gallons of pollutants being flushed into the sea each day through Los Angeles County's submarine sewer outfall at White Point. The black abalones from Catalina Harbor, the controls, were normal in appearance.

Two months later those recovered at Catalina Harbor had all gained weight. The average weight gain was 12 percent and individual gain ranged from 8 to 71 grams. The same month, of those recovered at White Point after having been transplanted there from Catalina Harbor and Bird Rock, approximately half had gained weight while the other half had either lost or remained the same (Fitch, pers. corres.).

In 1957 several lots of pink abalones were moved from the west end of Santa Catalina Island to the harbor at Avalon (Figure 60). Most survived the transplant but the tags corroded and it was impossible to measure growth or to trace individual movements.

Because pink abalones had become important to the abalone industry, our research on them was expanded in 1958. Diving stations were established along the mainland and among the Channel Islands to investigate representative populations and to assess the effects of commercial and sportfishing. Age, growth and other biological studies were started and a successful tag was developed.

The influx of warm water in 1957 destroyed most of the kelp in the areas where we had established stations and made transplants. The abalones were affected by the kelp loss and we were unable to collect complete data from the stations; however, there were indications that pink abalones remain in the same location for at least a year and some

FIGURE 60. Tagging pink abalones aboard the vessel *Nautilus*, used as a mother ship by the Department's abalone investigation. Plastic disc tags were fastened to the abalones by threading wire through the holes in their shells. The discs were later replaced by stainless steel tags when it was discovered that the plastic discs corroded. Photo by Glen Bickford, 1957.

FIGURE 60. Tagging pink abalones aboard the vessel Nautilus, used as a mother ship by the Department's abalone investigation. Plastic disc tags were fastened to the abalones by threading wire through the holes in their shells. The discs were later replaced by stainless steel tags when it was discovered that the plastic discs corroded. Photo by Glen Bickford, 1957

remain in one place during their entire adult lives. Growth is believed slow, but again accurate growth could not be determined. Where the kelp had returned, some pink abalones almost doubled their shell lengths in relatively short periods, indicating their growth, like that of red abalones, is dependent primarily on the food supply. Abalones in areas fished by commercial divers also suffered from the lack of kelp; this was reflected in the decline in the catch (Figure 36).

In 1960, the abalone program was curtailed and field activity reduced from ten months a year to two. During these two months we confined our activities to checking conditions at established stations. Along the mainland, the kelp has been slow returning and the abalones showed little growth. Among the islands at stations where the kelp had returned, the abalones were growing rapidly, even those which had not grown for a long time were adding new shell.

The red abalones along the mainland side of Santa Cruz Island appear to be increasing. Where formerly red abalones were rarely encountered, in 1961 approximately one abalone out of every ten was a red.

6. SUMMARY

Abalones are marine snails belonging to the genus Haliotis (family Haliotidae) and are related to clams, oysters, mussels and squids. They are distinguished by their ear-shaped shells, by rounded shell perforations overlying the respiratory cavity and by their enormous shell apertures. Worldwide there are about 130 species and subspecies plus a number of hybrids.

6.1. History

Haliotids were mentioned as early as the fourth century B.C. by Aristotle and Japanese records describe an incident in their abalone fishery that took place in 425 A.D. Linnè in 1740 was the first to apply the generic name Haliotis while Cuvier in 1817 was the first to publish a detailed account of their anatomy. Since then numerous other workers have published various details of their anatomy, physiology, taxonomy, morphology, and embryology, plus accounts of the fisheries and fishing methods.

6.2. Fossils

There are fossil haliotids in the upper Cretaceous, Eocene-Oligocene, Miocene and Pliocene. Fossils recovered in California closely resemble living forms. Fossil abalones have also been recovered in Europe, Africa, Japan, Australia, Asia Minor and the Mediterranean area.

6.3. Geographic Distribution

Haliotids live throughout the world, among many islands in the Pacific and the Indian oceans, and along the shores of the Mediterranean Sea. There are more kinds in the Australia-New Zealand region than anywhere else but the largest ones live off the coasts of California, Japan, and South Africa. None has been found on the west coast of South America nor in the Arctic or Antarctic.

6.4. Anatomy

Abalones are primitive forms so their anatomy is not complicated. They have simple digestive, nervous, excretory, respiratory, reproductive and circulatory systems.

Most of the body consists of the left shell muscle, which is attached to the shell by microvilli.

The sexes of abalones are separate.

6.5. California Species

Eight species of California abalones, reds, pinks, greens, blacks, whites, flats, pintos and threaded are described and a key is provided for their identification.

6.6. Life History

Haliotids usually spawn in the spring or summer, depending upon water temperature. They usually will not spawn unless water temperatures reach approximately 20°C. California red abalones mature when they are about 4 inches long.

6.7. Development

Development of Haliotis is believed similar for all species; only minor morphological differences have been observed in the larvae.

Fertilization takes place in the water after eggs and sperm have been emitted. The fertilized egg develops into a free-swimming larva which lasts from one to two weeks. A shell starts to form during the latter part of the swimming stage. The shell gradually increases in weight and the young abalone sinks to the bottom. After settling to the bottom the young begin to feed on minute algae. On about the 12th day they start final metamorphosis which is completed in about two months. The first respiratory pore forms about 130 days after settling and by the 140th day the shell is approximately 3.5 mm long. Red abalones are about 20 to 25 mm long when a year old.

6.8. Growth

During the first few years growth is fairly regular and most California abalones will be 3 to 4 inches long within 4 or 5 years. Their growth is irregular and is influenced by environmental changes; there is no reliable way to determine abalone ages.

6.9. Food and Feeding

Young haliotids feed principally on minute algae; as they mature they commence eating the larger seaweeds. In California their main items of diet are giant kelp and bull kelp although other varieties are also eaten.

6.10. Habitat

Abalones live along rocky shores among the seaweeds. In California, they range from the high tide zone to depths over 500 feet; most, however, are found in the littoral zone. They prefer the open coast and are not found in bays or estuaries. They tend to distribute themselves vertically according to species.

6.11. Predators, Parasites, and Similar Problems

Abalones are preyed on by sea otters, crabs, octopi, and fish. Their shells are attacked by boring clams and sponges. Sea urchins compete with them for food and living space, small snails suck their blood, a shrimp makes his home under their shells, and a parasitic worm often encysts in their flesh.

During heavy storms, abalones are often crushed by rolling boulders and tossed ashore.

6.12. Indian Fishery

Radiocarbon dated abalone shells from Santa Rosa Island show that the Indians gathered them over 7,000 years ago. They were also important for food and in the culture of other aborigines. Shells, traded with Indians of the east and northwest were carried over trade routes for many hundreds of miles.

6.13. Mexican Fishery

The Mexican fishery was started in the 1860's by the Chinese, who also started the California fishery. Most of the catch was taken at the

Coronado Islands and along the shore in the intertidal zone and was dried and sent to the Orient.

Before World War II the fishery was controlled by the Japanese and Germans. It is now controlled by Mexican Fishermen's Cooperatives. The catch primarily of pinks and greens is taken by divers, canned and shipped to the Philippines and the Orient. In 1960, 6 million pounds were taken between Ensenada and Magdalena Bay.

6.14. California Commercial Fishery

This fishery started by the Chinese in the early 1850's at San Diego, was taken over by the Japanese who introduced the diving suit in the 1900's and moved the center of the fishery to Monterey. The Japanese dominated the industry until World War II. Caucasian divers took over after World War II. Divers work from unanchored boats tended by two crew members. The crew follows the diver with the boat as he walks through the kelp, keeps his airline free, and supplies him with baskets for the abalones he gathers.

In 1960, 505 abalone permits were issued, approximately one-third to divers and the others to crew members.

From 1916 to the beginning of World War II almost the entire catch consisted of red abalones taken between Monterey and Morro Bay. The fishery, which started around Monterey gradually spread southward and by World War II it was centered at Morro Bay. During World War II, the southern coastline and the Channel Islands were opened and pink abalones were taken in quantity for the first time. Catches average between two and three million pounds per year.

During the last few years abalone landings have averaged between 4 and 5 million pounds per year. They are usually heaviest at the beginning and end of each season, primarily because of weather.

Red abalones are the mainstay of the California abalone industry. They are cleaned, trimmed, sliced, pounded and marketed as fresh frozen fillets. The bulk of the catch is sold to restaurants. The trimmings are mostly ground and made into patties but some are canned and sold as chowder. Little use is made of the shells, some are taken by collectors, others are used to manufacture jewelry and the rest are discarded.

6.15. Sportfishery

Sportfishing for abalones, until World War II, was carried out almost entirely in the intertidal zone; however, with the advent of rubber "skindiving" suits, much of the fishery moved into offshore waters. Sportsmen are no longer dependent on low tides to collect abalones.

The abalone sportfishery is limited to approximately 85 miles of publicly owned shoreline. In northern California, most activity is between Fort Bragg and Monterey; however, in southern California, the sportfishery extends along the coastline from Santa Barbara to San Diego and among several of the offshore islands.

During 1960, 2,200 to 2,500 skindivers gathered an estimated 53,000 abalones, mostly reds, between Pismo Beach and Oregon. The take in southern California, mostly greens and pinks, probably was even greater.

SCUBA is prohibited for taking abalones north of Yankee Point (Monterey County) but is legal south of there.

6.16. Research—Northern California

Directed by the State Legislature the department expanded its abalone investigation in 1951. Research was first concentrated north of San Francisco to determine if this area could support a commercial fishery. Exploratory dives were made, abalone numbers were estimated, tagging for growth and movement was carried out and quality samples were taken. Results showed a commercial fishery would be impractical and undesirable because:

1) Except in a few areas, abalones are not present in sufficient numbers.
2) Most abalones would not meet quality standards.
3) The generally steep bottom provides such a small area for abalones, commercial divers would be in sportsmen's territory.
4) All-weather ports are lacking.
5) The rugged bottom would be difficult for divers to travel over.
6) Poor weather would restrict the number of diving days to three or four per month.

6.17. Research—Southern California

Areas fished by commercial divers and sportsmen were surveyed and numerous red, pink, and black abalones were transplanted.

A tag was developed for pink abalones and tagging experiments were made to determine growth and movement. Growth was slow and depended upon food supply.

In 1960 the abalone program was curtailed to two months per year to investigate conditions at stations established in representative localities.

6.18. California Regulations

The first modern-day abalone laws were passed in 1901 establishing a minimum size limit. Since then, new laws have been enacted, or old laws revised during almost every Legislative session in odd-numbered years.

The commercial fishery has always been regulated by the Legislature as was the sportfishery until 1945 when jurisdiction over it was given to the Fish and Game Commission.

At present, the fishery and fishermen are regulated by a wide assortment of laws applying to size, bag (take), seasons, fishing hours, fishing depths, gear, and numerous other items.

Licenses are required of all participants and these may be revoked in cases of flagrant disregard for the regulations.

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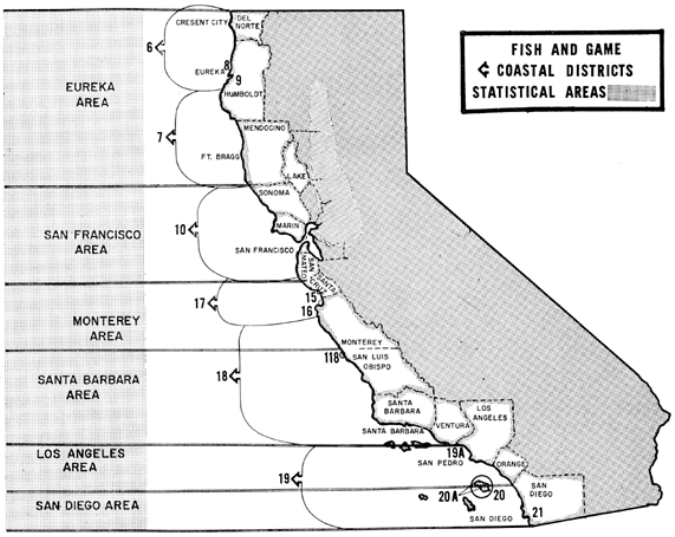

FIGURE 61. Coastal counties included in Fish and Game statistical areas, and locations of coastal Fish and Game districts.

FIGURE 61. Coastal counties included in Fish and Game statistical areas, and locations of coastal Fish and Game districts

APPENDIX
RESUME OF MAJOR CALIFORNIA ABALONE REGULATIONS

* Pertains to Sportfishery only

** Pertains to both Sport and Commercial Fishery

If no asterisk Laws Pertain to Commercial Fishery Only

Legislative Year		*Year Changed*
1901	Size: Minimum 15 inches around the edge of the shell	1905
1903	No change	
1905	Size: Minimum in inches (around shell): blacks 12, all others 15	1909
1907	Diving: Commercial diving prohibited statewide	1909
1909	Diving: Commercial diving permitted statewide	1913
	License: Commercial license required	still in force
	Size: 17 inch minimum for reds	1913
	Possession: Only reds can be possessed	1911
1911	Season: ** Closed between March 1 and July 1	1913
	Possession: Pinks, greens and blacks can be possessed	1933
	Size: Minimum in inches (around shell): reds 17; pinks 14; greens and blacks 12	1913
	Landing: ** Must be landed alive and in the shell	still in force
	Use: Must be for food only	still in force
1913	Season: ** Closed between February 1 and April 30	1915
	Size: ** Minimum in inches (around shell): reds 19; greens 18; pinks 16; blacks 14	1917
	Spearing: ** Prohibited	still in force
	Diving: Prohibited south of Santa Barbara County	1915
	Closed Area: South of Santa Barbara County closed for blacks	1915
	Export: Illegal to export out of the State	1915
1913	Bag Limit: * 10 south of Santa Barbara County	1915
	License: Commercial fishing license $10	still in force
1915	Season: ** Closed for reds in February, March and April	1921
	Drying: Prohibited	still in force
	Export: Permitted in containers of less than one pint	1917
	Diving: Prohibited south of San Luis Obispo County	1917
	Closed Area: South of San Luis Obispo County closed for blacks	1917
	Bag Limit: * 10 south of San Luis Obispo County	1917
1917	Size: ** Minimum in inches (greatest diameter): reds 7; greens 6½ pinks 6; and blacks 5	1921
	Export: Meat and unworked shells illegal	1941
	Diving: Prohibited from Point Santa Cruz to the Carmel River except for small areas at Santa Cruz (Dist. 15) and Monterey (Dist. 16); and in all water south of San Luis Obispo County, except (Dist. 20A) at Santa Catalina Island	1921
	Closed Area: Areas closed for blacks reopened	still in force
	Bag Limit: * 10 south of San Luis Obispo County, 20 from Point Santa Cruz to the Carmel River (Dist. 17)	1921
1919	No change.	
1921	Season: ** Closed from January 15 to March 15	1933
	Closed Area: Commercial diving prohibited Pt. Buchon to Pico Creek;	1929
	Mendocino County to Pt. Santa Cruz;	1937
	and Carmel River to Santa Barbara County	1931
	Bag Limit: * 10 daily from Pt. Santa Cruz to the Carmel River and south of San Luis Obispo County	1925
	10 daily and 20 weekly from Pt. Santa Cruz to the Carmel River, 10 daily in Dists. 15 and 16	1925
	10 daily if taken within 20 feet of extreme low tide line in all other areas south of Mendocino County (Dist. 10 and 18)	1925
	No bag limit elsewhere	1925
	Size: Minimum diameter in inches: 8 for reds in districts 10 and 18	1929
1923	No change.	
1925	Diving: Santa Barbara County opened	1929
	Districts 15 and 16 closed	still in force
	Prohibited between Pico Creek and Pt. Buchon	1929
	Bag Limit: * 10 daily and 20 weekly in the districts where diving was not allowed	1929
	10 daily in districts where diving was allowed (these districts had no bag limit outside a line 20 feet beyond the extreme low tideline; north of Sonoma County there were no bag limits)	1929
1927	No Material Change.	
1929	Diving: Illegal Humboldt Bay to Sonoma County	1931
	Illegal Pigeon Point to Santa Cruz	1945
	Permitted from Pico Creek to Point Buchon	still in force
	Permitted in District 7 in waters 20 feet beyond the extreme low tide line	1931
	Size: Minimum in inches: 8 for reds taken District 7	1945
	7 for reds taken Pigeon Point-Point Santa Cruz	1947
	Bag Limit:* District 7, 10 daily and 20 weekly	1931
1931	Bag Limit:* 10 daily in areas closed to commercial fishing	1935
	License: * Required for sportfishing	still in force
	Closed Areas: Prohibited in waters less than 20 feet deep in Districts 7, 10, and 18. Prohibition of diving inside a line 20 feet beyond extreme low tide requirement was dropped	1937
1933	Laws regulating seasons changed from **Prohibitive** to **Permissive** wording, giving protection to species not named.	
	Possession: ** Possession of other than pink, red, black, and green abalones illegal	1955
	Season:** Closed between January 14 and March 16	still in force
1935	Bag Limit:* Sportfishery, five daily in District 10 (Mendocino County to Pigeon Point) in waters less than 20 feet deep	1945
1937	Closed Area: District 118 (San Simeon Pier to Cambria State Park)	1956
1937	Diving: Illegal Mendocino County to Pigeon Point (District 10)	1943
	Bag Limit:* 10 daily and 20 weekly in District 6 (Humboldt Bay to Oregon)	1945
1939	Permits: Commercial diving conducted only under revocable permits issued under Commission rules and regulations	still in force
1939	Undersize:** Abalones less than legal size must be replaced on the rock by hand	still in force
	Gear:** Measuring device must be carried	still in force
1941	Export: Meal and chowder from trimmings packed in No. 10 cans or larger permitted	1947
	Bag Limit:* 10 daily in Marin Co. District. 2 and 10, five daily	1945

1943	Permits: Commercial diving permits issued only to those with full deep-sea diving gear	still in force
	Diving: Permitted in Districts 7 and 10	1945
1943	Size: Minimum in inches; 8 for reds Districts 10, 18 and 19	1945
	7¼ for greens Districts 18 and 19	1945
	8 for other species District 10	1947
	**reds 7, greens 6½, pinks 6, blacks 5	1947
1945	Regulatory Powers over sportfishery given Fish and Game Commission	still in force
	Bag Limit:* 10 daily	1947
	Diving: Commercial diving north of Point Lobos (S.F.Co.) was prohibited	still in force
	Diving: From Malibu Point to Rocky Point (District 19A) was prohibited	1949
	Size: Commercial, eight inches for all species	1947
	Export: Illegal to export meat	still in force
1[1] 1946	Permits: Master permits issued boat diver and crew as a unit. Supplemental permits issued each crew member. All permits of a crew, boat, and diver can be revoked for a violation by any one of them	still in force
1947	Export: Chowder from trimmings in any pack permitted	still in force
	Gear:** Taking with any device more than 36 inches long except diving equipment was prohibited	still in force
	Bag Limit:* 10 daily but not more than five reds	1949
	Diving: Santa Catalina Island opened (District 20, 20A)	still in force
	Size: Minimum in inches: Commercial: reds 8, greens 7¼, pinks 6, blacks 6	1949
	Sport* : reds 7, greens 6¼, pinks 6, blacks 6	1952
1949	Diving: Prohibited San Francisco to Oregon	still in force
	Permitted Point Lobos to Pigeon Point; Carmel River to San Simeon, Cambria State Park to Malibu Point, and Rocky Point to Mexico, in water over 20 feet deep	1957
	Closed on Catalina Island except between Southeast Rock and the western point of the island	still in force
	Possession:** Black abalones may be taken from Anacapa, Santa Cruz, Santa Rosa and San Miguel Islands at any time without bag limit if used for bait	1955
	Cannot be taken on mainland for commercial use	still in force
	Size:** Five inches for black abalones taken on islands listed above for bait	still in force
1949	Closed Area: To commercial fishing.	
	All waters less than 20 feet deep	still in force
	Oregon to Point Lobos (Districts 6, 7 and part of 10)	still in force
	Pigeon Point to Yankee Point (Districts 15, 16 and 17)	still in force
	San Simeon to Cambria State Park (District 118)	1955
	Malibu Point to Rocky Point	1955
1949	Bag Limit:* Five daily	still in force
1951	No Change.	
1[1] 1952	Diving:** No SCUBA may be used to take abalones north of Yankee Point, Monterey County	still in force
	Size Limit:* Minimum in inches, reds 7, greens 6¼ pinks 6, blacks 5	still in force
1953	Export: Illegal except trimmings ground and canned, frozen, or made into meal or chowder	still in force
1[1] 1954	Gear: Must have surface air pump operated from boat, 100 feet of hose, two baskets and a measuring device	still in force
1955	Possession: Species other than red, green, black, pink may be possessed	still in force
	Size: Minimum commercial in inches: reds 8, greens 7¼, blacks 5, all others 6	1959
	Diving: No commercial diving within 150 feet of shore or in waters less than 20 feet deep	1957
	License: Annual boat registration fee $40	1957
	Closed Areas: Mainland coast from Gaviota Creek (Santa Barbara County) to north city limits of San Diego closed	1957
	Area near Cambria (District 118) opened	still in force
	Bag Limit: No limit on blacks for lobster bait within one mile of Anacapa, Santa Cruz, Santa Barbara, San Nicolas and San Clemente islands. May be taken for bait only during lobster season	still in force
1957	Closed Areas: Mainland coast from Gaviota Creek to north city limits of San Diego opened	still in force
	Diving: Commercial diving prohibited in water less than 20 feet deep	still in force
	License: No boat registration fee required	still in force
1959	Size: Minimum in inches, commercial; reds 7¾	still in force
1961	No important changes.	

[1] Regulations listed for even-numbered years enacted by orders of the Fish and Game Commission.