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September 1988

TR EL-82-4.84

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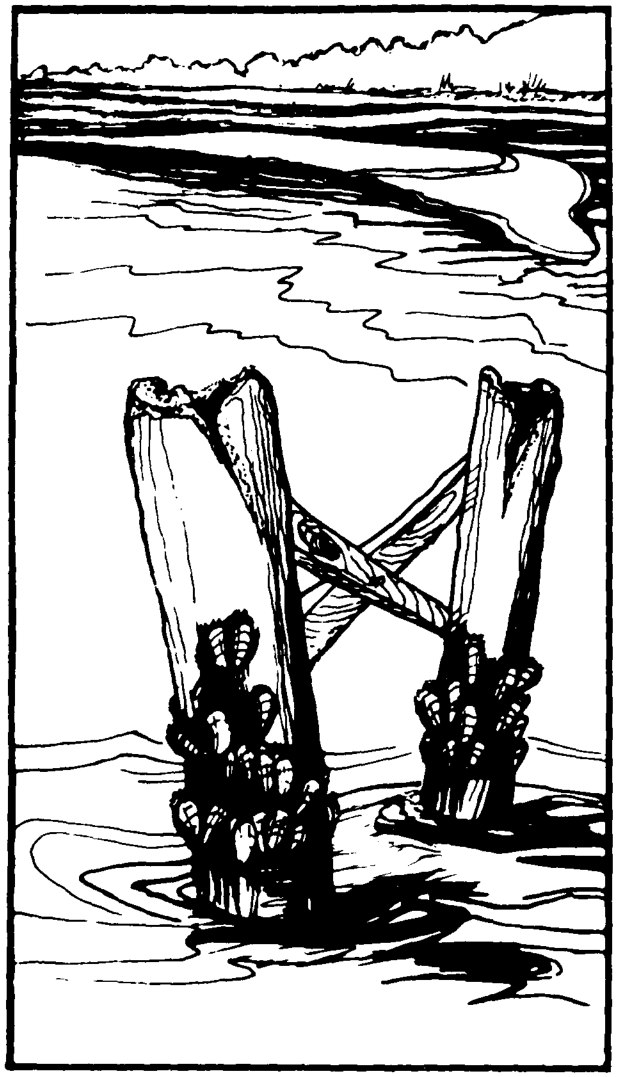

Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

CALIFORNIA SEA MUSSEL AND BAY MUSSEL

by

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

CONTENTS

ACKNOWLEDGMENTS

We acknowledge the reviews by James Peterson, Los Angeles County Natural History Museum, and Michael Martin, California Department of Fish and Game.

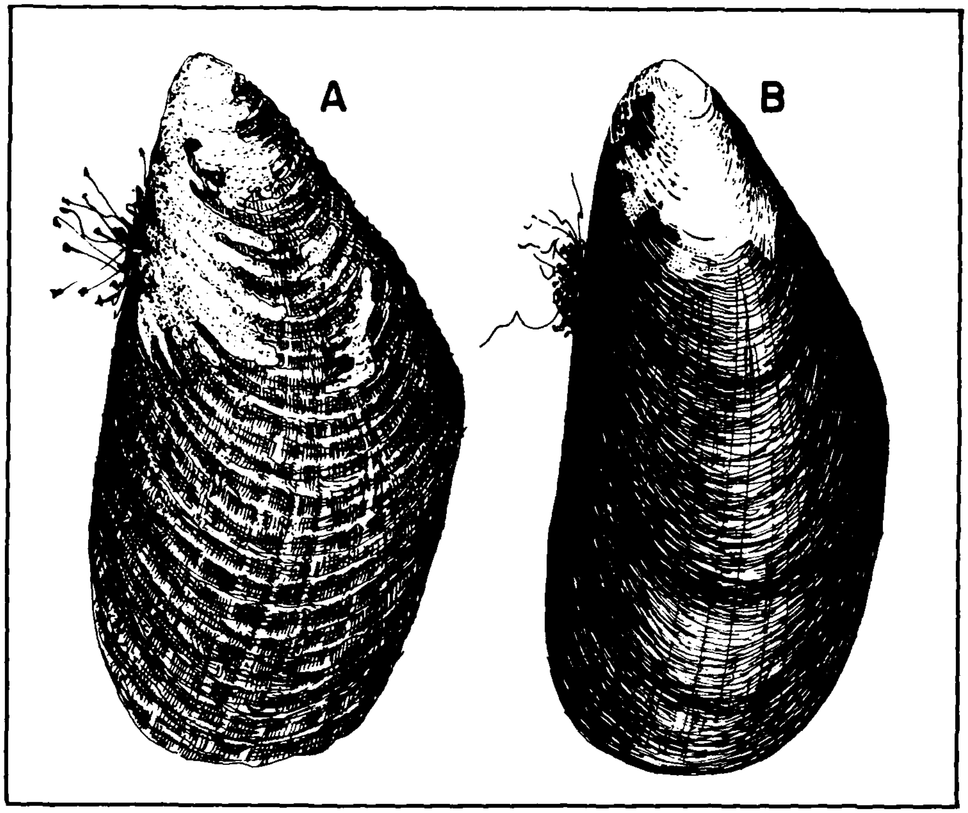

Figure 1. Shells of the California sea mussel (A), and bay mussel (B).

CALIFORNIA SEA MUSSEL AND BAY MUSSEL

NOMENCLATURE/TAXONOMY

Scientific name . . . . *Mytilus californianus* Conrad
Preferred common name . . California sea mussel (Figure 1A)
Other common names . . . Rock mussel, big mussel, California mussel, sea mussel
Scientific name . . . *Mytilus edulis* Linnaeus
Preferred common name. . . Bay mussel (Figure 1B)
Other common names . . .Edible mussel, black mussel, blue mussel, pile mussel

Geographic range: The California sea mussel ranges from the Aleutian Islands to Socorro Island, Mexico (California distribution is shown in Figure 2) and the bay mussel from the Arctic Ocean to Cape San Lucas, Baja California (Fitch 1953).

MORPHOLOGY/IDENTIFICATION AIDS

California Sea Mussel

Umbo at extreme anterior end of shell. Shell covered with a heavy, black periostracum. Older specimens, from which this covering is worn off, are blue and have an eroded appearance. Exterior of shell with radiating ridges and concentric growth

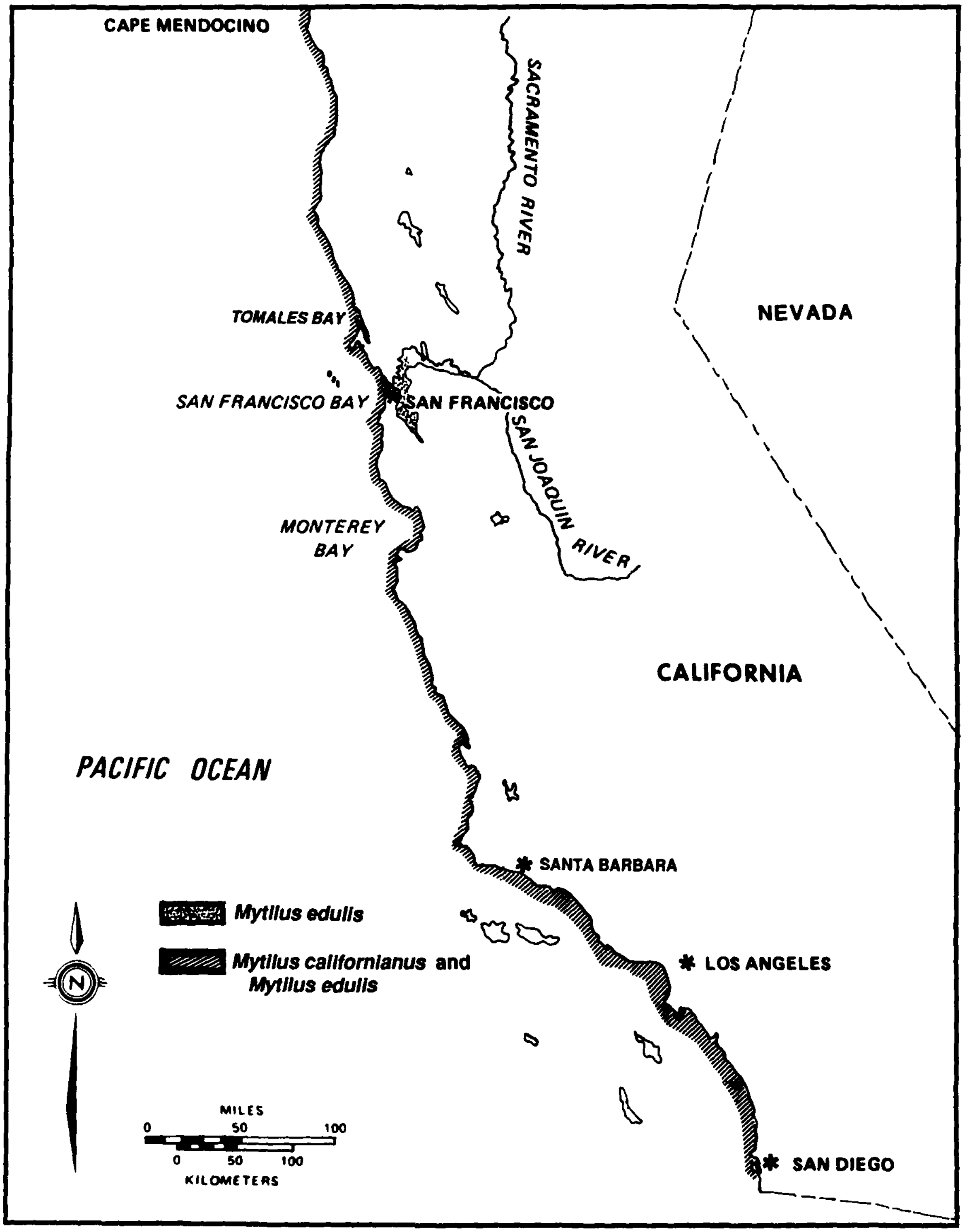

Figure 2. Coastal distribution of the California sea mussel and bay mussel in California.

lines. Interior of shell bluish-black iridescence shows in reflected light. Length to 25 cm. Differs from the bay mussel in having up to a dozen broad radial ribs (Fitch 1953).

Bay Mussel

Shell wedge-shaped, with umbos at extreme anterior tip. Periostracum usually heavy, smooth, satiny black. Interior of shell smooth, blue-black around margin, and showing some iridescence in reflected light. Flesh a dull brownish-orange. Length to 10 cm. Differs from the California sea mussel partly in having a smooth exterior unmarked by radiating ridges and grooves (Fitch 1953).

REASONS FOR INCLUSION IN SERIES

The California sea and bay mussels are relatively common along the rocky coastline and in bays and estuaries. They support a small commercial bait fishery and are cultured for food on a small scale in Tomales Bay and just north of San Diego.

The areas of greatest potential for the commercial harvest of *M. edulis* in California for food, in descending order of importance, are Humboldt Bay, Tomales Bay, Drakes Estero, San Francisco Bay, Elkhorn Slough, Morro Bay, San Diego Bay, and Tijuana Bay (Chalfant et al. 1980).

Mussels are an important food item throughout the world. There is a potential for culturing both of these species for food more extensively in California. Problems associated with such culturing are seasonal closures caused by pollution and paralytic shellfish poisoning (PSP), finding appropriate culture sites, and obtaining public acceptance to use these sites.

Man's manipulation of the coastal zone could provide additional habitats for mussels. Piers, floating marinas, jetties, and pilings for oil rigs are examples of surfaces ideal for settling mussels. In fact, in Humboldt Bay, California, the only substantial population of *M. edulis* occurs on the under surfaces of floats in a newly constructed marina.

LIFE HISTORY

Spawning

The California sea mussel continually spawns throughout the year at a very low level (Suchanek 1981), with breeding peaks in July and December (Morris et al. 1980). In northern California, Edwards (1984) found no definite spawning cycle. Ripe mussels were seen from February to May and from December to February. Spawning was observed in January, February, May, and December.

The bay mussel has a single massive spawning output each year (Suchanek 1981) which can occur in late fall and/or winter along the central California coast (Morris et al. 1980). In northern California spawning was first observed in May and again from July through November (Edwards 1984).

In the laboratory, spawning has been stimulated by raising and lowering the water temperature, adding single cell algae, using water treated with ultraviolet light, adding mussel sperm, and using water containing hydrogen peroxide. Breese et al. (1963) found 4% Kraft mill effluent to be a highly effective stimulus in triggering mussel spawning. In the natural environment, temperature does not seem to provide a major stimulus for spawning. Mechanical stimuli, such as pulling on the byssal threads, may initiate the release of gametes. Also, spawning of one animal may stimulate others to spawn (Morris et al. 1980).

During spawning the eggs and sperm are discharged through the excurrent chamber. The eggs, which appear as orange ribbons, are fertilized in the open water.

Larval Stage

The embryos develop into trochophore larvae (60-80 micrometers) about 24 h after fertilization. The veliger (straight-hinge stage) develops 24 h later (Figure 3A). A ciliated velum forms and helps the larva swim and maintain itself in the water column. Larvae feed on phytoplankton and are about 0.17 mm long after 1 week. The veliger, which develops an umbo, may reach a length of 0.20 to 0.24 mm in 2 weeks. Loosanoff and Davis (1963) found that the size of mussel larvae (M. edulis) at metamorphosis varied by almost 0.09 mm; lengths ranged from 0.21 mm to almost 0.30 mm in length (Figure 3K). Just before metamorphosis, the larva develops an eyespot and foot.

The larvae of M. californianus have been reared in the laboratory to metamorphosis in 17-24 days after fertilization. Eyespots were observed when the larvae were 0.23 to 0.24 mm long (Skidmore and Chew 1985).

Breeding success or failure is frequently determined during the critical larval stage. The larvae are at the mercy of currents and may be carried away from setting areas and die.

Postlarvae and Recruitment

Mytilus edulis sets on the byssal threads of adults, on a variety of algae, and on newly exposed hard surfaces; M. californianus sets on barnacles, old mussel shell, and newly exposed hard surfaces (Petraites 1978). In California, M. edulis settled immediately on scraped, bare substrate (i.e. no succession occurred) in winter and spring; it did not settle in summer and fall (Reish 1964). Density of newly settled M. californianus was highest on filamentous algae (Peterson 1984). The author observed in the laboratory that M. edulis larvae avoided adult M. californianus. Investigators disagree about settling behavior. For example, the presence of adult M. edulis may inhibit larval settlement. Seed mussels appear to set elsewhere, and then migrate to adult beds, where they attach to byssal threads of the adults wherever there is space (Jamieson et al. 1975). M. californianus preferred to set on byssal threads from adults (Trevelyan and Chang 1983).

In southern California M. edulis settles in massive numbers in some years, but sparsely in others (Morris et al. 1980). In areas where both species have settled, M. edulis was the more mobile and was generally found on the outer part of the colonies. It was also more susceptible to wave action. Mytilus californianus holds its position more strongly than does M. edulis (Harger 1970a).

Chalfant et al. (1980) stated that settlement of M. edulis was generally gregarious; in Maine, for example, mussel spat densities exceeding 300,000/m^2 have been found in shallow, subtidal areas.

The cleaning of surface areas ("brushing the flats") has increased recruitment. Also, the placement of pilings, stakes, or poles is a common commercial method of collecting seed mussels. In the Santa Barbara Channel, natural sets of M. californianus are collected from the legs of oil drilling platforms. Setting areas are prepared by cleaning unwanted growth or wrapping areas with special materials that attract wild spat.

It probably takes many years for Mytilus to become established in the high intertidal zone at approximately +1.8 to +2.4 m above mean lower low

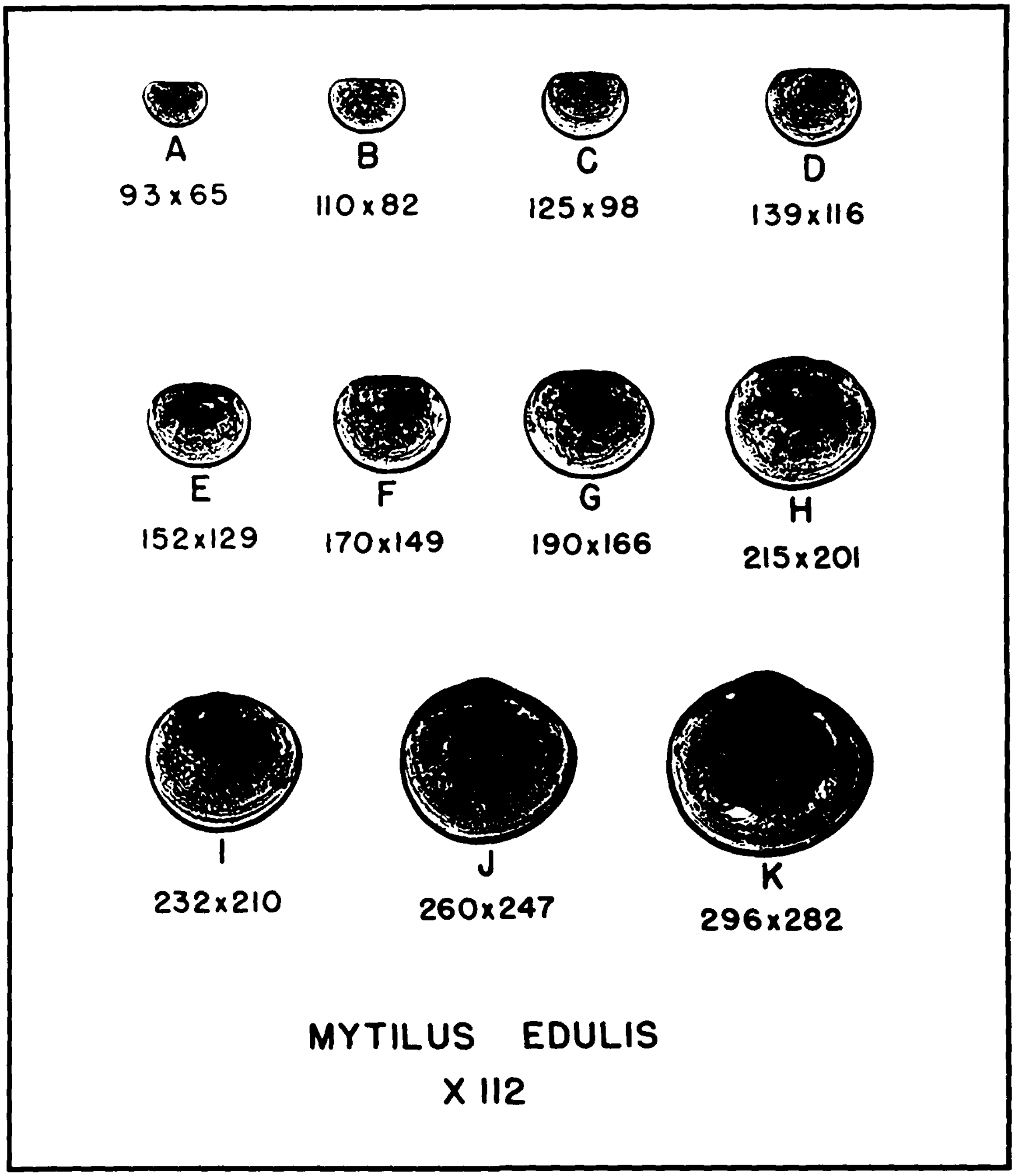

Figure 3. Larval development of the bay mussel, size (height and length) in micrometers.

water (Dayton 1971). Establishment is faster at lower levels (Dayton 1971).

Maturity

Sex ratios are generally equal and there is no indication of sex change with age. Some sexually mature mussels were only 4 months old or 25 mm long. Viable sperm was observed in mussels 30 mm long. Spawning occurred near the end of the first year or when the mussels were 70 mm long (Coe and Fox 1942).

Age and Growth

The age of mollusks is determined by three methods: (1) size-frequency studies; (2) the interpretation of growth interruption lines on the shell; and (3) experimental methods involving the release and recovery of marked individuals (Haskin 1954). Jamieson et al. (1975) reported that growth rates of mussels in any given population were so variable that year classes could not be determined from size. Most workers have attempted to age mussels through interpretation of growth interruption lines, although some have studied marked individuals. Lutz (1976) aged mussels by using acetate on polished longitudinal shell sections.

Factors influencing growth of M. edulis were divided into two categories by Jamieson et al. (1975): biological (age, size, and genotype), and physical (light, temperature, depth, food, salinity, and current). Of these, water temperature was the only factor which influenced growth throughout the mussel's geographic range. In some areas (e.g., Maine), growth was seasonal, whereas in California, where the annual temperature range was relatively narrow, there was no obvious seasonal variation in shell growth rate (Chalfant et al. 1980). Lutz and Porter (1977) reported that water temperature above 25 ^{o}C not only seriously decreased growth, but also caused mortalities of 89%-100%.

In extensive growth studies conducted in Puget Sound, Washington, by Skidmore and Chew (1985), sets of M. edulis in four of five experiments attained market size (50 mm) within 12 to 13 months. The growth rates of M. edulis and M. californianus were also compared at two sites in Puget Sound. Mytilus edulis grew the fastest for the first three months, but size differences between the two species were small by the end of 9 months.

In southern California (Scripps Institution of Oceanography dock, San Diego) M. californianus sometimes grows as much as 7 mm per month. This species may reach a length of 80-86 mm within a year of settlement, 120 mm after 2 years, and 140-150 mm after 3 years (Coe and Fox 1942). Maximum size is 200-250 mm (Harger 1972). Growth is fastest during the colder months and slowest (sometimes nil) in mid-summer or above 20 ^{o}C.

Mytilus edulis does not grow as large as M. californianus (Figure 4). In southern California, the bay mussel grew to a length of 66 to 76 mm after 1 year and 90-99 mm after 2 years (Coe 1945). Thereafter, growth was very slow (Table 1). Maximum size ranges from 120-150 mm (Harger 1972).

Mussels eat a variety of organisms, such as dinoflagellates, organic particles, small diatoms, zoospores, minute ova and spermatozoa, flagellates and other protozoans, various unicellular algae, and detritus (consisting of particles from the cytolysis of cells of a large variety of plants and animals). Growth rates are related to the abundance of dinoflagellates (Coe and Fox 1942). Mytilus californianus from southern California grew 100% faster in height and 50% faster in width at +0.1 m (the plus sign in this report indicates vertical height above mean

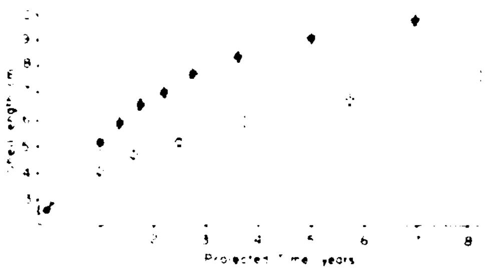

Figure 4. Projected growth curves for Mytilus edulis (open symbols) and Mytilus californianus (closed symbols) based on data obtained from undisturbed populations of mussels at Santa Barbara Harbor, California (Harger 1970b).

lower low water) than at +0.3 m where feeding time was shorter (Dehnel 1956). Males grow faster than females the first 1.5 years (Coe and Fox 1942).

Food particles, drawn through an inhalent aperture by ciliary action, are caught on sheets of mucus and carried along the sides of palps to the mouth. Some particles are ingested but others, if excessive, are discharged from the mantle cavity as pseudofeces. The most common food is the dinoflagellate Prorocentrum micans, at a size of 57 x 30 µm (Fox and Coe 1943).

Table 1. Growth of Mytilus edulis in relation to size (Coe 1945).

Size (mm)	Average increase per month (mm)
11-20	11.3
21-30	11.1
31-40	9.9
41-50	8.0
51-60	5.9
61-90	2.8
91-103	0.75

COMMERCIAL AND SPORT FISHERIES AND AQUACULTURE

Both species of mussels were once commercially important in California. Over 69,000 pounds were landed in 1917 (Table 2), but in 1927, and thereafter, most areas were closed to fishing by the California State Board of Health, due to mussel poisoning. No mussels can now be sold for human consumption from May 1 to October 31 because of the presence of paralytic shellfish poisoning. The consumption of mussels that have concentrated large amounts of the poison-producing microscopic dinoflagellate Gonyaulax catenella sometimes causes serious illness (Nishitani and Chew 1983). In 1980, for example, poisoning was recorded in 98 residents of Marin and Sonoma counties, California, of whom two died (Estes and VanBlaricom 1985).

A limited sport fishery, where mussels are usually removed from piling or rocks by hand, now exists during the open season. A daily harvest of 25 pounds is allowed.

Four companies have shown interest in farming mussels for human consumption in Tomales Bay, California, because the demand for a year-round supply of quality mussels has outgrown the supply from native beds. They hang ropes from longlines supported by floats to collect a natural set. The seed is then placed in plastic netting, which is then hung from the longlines.

One company cultures mussels from the legs of oil drilling platforms in the Santa Barbara channels. Seed, placed in plastic netting, is wrapped around the legs. When the mussels reach maturity divers scrape them off the legs. The mussels are conveyed to the surface through suction hoses and are cleaned, packaged, and shipped fresh to market.

The ratio of meat to total weight is high in mussels. The composition

Table 2. Yearly landings of mussels in California.

Year	Landings (lb)
1916[a]	53,799
1917	69,042
1918	49,154
1919	35,095
1920	33,112
1921	9,196
1922	43,872
1923	60,026
1924	49,223
1925	25,942
1926	14,614
1927	29,631
1928	1,610
1929	1,028
1930	325
1931	1,800
1932	230
1933	465
1935	10
1936	750
1937	1,490
1938	150
1939	1,800
1940	100
1942	50
1946	639
1947[b]	530
1972[c]	111,799[g]
1974[d]	81,642[g]
1975[e]	53,691[g]
1976[f]	47,336[h]

[a]Years 1916-1947 (Bureau of Marine Fisheries 1949).
[b]No commercial landings between 1948-1971.
[c]Pinkas 1974.
[d]McAllister 1976.
[e]Pinkas 1977.
[f]Oliphant 1979.
[g]Bait.
[h]2,357 pounds for human consumption; rest for bait.

of cultured M. edulis, analyzed by Slabyj et al. (1978), is moisture, 71.1%-75.7%; protein, 14.1%-21.0%; crude fat, 2.6%-3.5%; ash, 2.0%-2.7%; and carbohydrate, 1.2%-5.8%.

ECOLOGICAL ROLE

Feeding

Mussels are suspension feeders, are considered to be scavengers, and collect anything in the plankton that is small enough to ingest. Digestion is intracellular (Coe and Fox 1944).

Competitors

When a resource is potentially limiting (as in the case of living space for sessile organisms in the rocky intertidal zone) one species of competitor may potentially dominate the others in procuring or holding the resource. Predation or physical disturbance may cause mortality of the dominant competitor sufficient to prevent the exclusion of the other competitors, allowing several species to coexist. Such phenomena occur in the rocky intertidal zone of the Pacific coast of the United States, where significant insights into such processes of community function have been obtained especially from studies done on the coast of Washington. As shown in the following discussion, the distribution of M. californianus is controlled by predation and physical disturbance, while the distribution of M. edulis is controlled by these two factors and competition as well.

On Washington's exposed outer coast, M. californianus is the dominant competitor for available space and will form dense monospecific stands unless deterred (Paine 1966). Mytilus californianus is one of the most consistent occupants of space in the intertidal barnacle-mussel association there, along with the barnacles Chthamalus dalli, Balanus glandula, and B. cariosa, and the sea anemone Anthopleura elegantissima (Dayton 1971). The name "California sea mussel" was given to M.

californianus because of its restriction mostly to the outer coast. Mytilus californianus will settle among Balanus and completely cover the barnacles (Dayton 1971), eventually excluding them (Paine 1966). Mytilus californianus denies space to M. edulis on the open coast, but it seems to offer protection from wave action to those M. edulis that do become attached (Harger 1970c). Mytilus edulis is called the "bay mussel" because it has long been thought to be common mostly in quiet waters, but it is now known to be common on the outer coast as well (Suchanek 1978). Mytilus edulis on the exposed outer coast of Washington usually occupies a band 0.3 m in vertical height (at about +2.9 to +3.2 m) above the M. californianus zone, which is at about +0.5 to +2.9 m (Suchanek 1978). The lower limit of M. edulis zone is probably set by competitive exclusion by M. californianus and by predation (Suchanek 1978).

Predators

A number of predators prey on mussels in California. Harger (1972a) reported that M. edulis was preferred over M. californianus by nine invertebrate predators: two sea stars, Pisaster giganteus and P. ochraceus, five species of muricid gastropods, Thais emarginata, Acanthina spirata, Ocenebra poulsoni, Ceratostoma nuttalli, and Jaton festivus, and two species of crabs, Cancer antennarius and Pachygrapus crassipes. A third crab, Pugettia producta, ate mussels but showed no preference for a particular species. Harger and Landenberger (1971) observed greater losses from predation in shallow water compared to deep water.

Mytilus californianus occupies only about 4% of the space (between about +3 m and a depth of about -27 m) that it would occupy under physically mild and predator-free conditions (Paine 1976b). The sea star P. ochraceus may clear patches of M. californianus (Dayton 1971), one of its preferred prey (Paine 1966). In an experiment in Washington, P. ochraceus was removed and the area eventually became a monospecific stand of M. californianus (Paine 1966). Pisaster ochraceus controls the abundance of the dominant mussel and thus allows other species to coexist (Paine 1966). Mytilus californianus escapes predation from whelk predators (Thais spp.) by attaining a variable minimum size of invulnerability (Dayton 1971). This mussel escapes predation by P. ochraceus by growing to a minimum size that increases as the size of the sea star increases (Paine 1976b). Mean density of P. ochraceus may vary locally by at least two orders of magnitude, affecting local abundance of M. californianus (Paine 1976b). In Washington, areas of low M. californianus abundance and high P. ochraceus density occur side-by-side with dense stands of large M. californianus that have low P. ochraceus density; the mussels had probably escaped predation by attaining an invulnerable size (Paine 1976b).

Pisaster ochraceus may indirectly enhance recruitment of M. californianus by the following series of events: 1) P. ochraceus consumes limpets (less preferred prey) and may reduce their abundance; 2) as shown experimentally, a reduction in limpet density would consequently enhance the abundance of one of the limpet's major foods, the red alga Endocladia; and 3) mussel recruitment may be enhanced because Endocladia is the major settling substrate for M. californianus larvae (Dayton 1971).

On the outer coast of Washington, M. edulis will become established in a patch cleared by physical disturbance or predation in the M. californianus zone (which is at about +0.5 to +2.9 m) only if the patch diameter is greater than about 40 cm (Suchanek 1978). Smaller patches expose settling M. edulis (and the filamentous algae used as settling substrate) to removal by grazers (limpets, chitons, and the opisthobranch gastropod Onchidella borealis) that move in from the edge of the patch (Suchanek 1978). Those M. edulis that do invade the M. californianus zone grow quickly but are preferred over M. californianus by whelk predators, Thais spp. (Suchanek 1978). On the outer coast, the lower limit of M. edulis band (about +2.9 m) is probably determined partly by predation by gastropods, birds, and sea stars (Suchanek 1978). Pisaster ochraceus has more time to feed and thus can eat more mussels at lower intertidal levels. The abrupt lower limit of M. californianus band (about +0.5 m) is almost certainly the most conspicuous feature of the rocky intertidal community (Paine 1976) and is probably set by predation by P. ochraceus (Paine 1966, 1974).

The sea otter (Enhydra lutris) is known to eat both M. californianus and M. edulis (Estes and VanBlaricom 1985), but mussels form only a small portion of its diet in California. Consumption of mussels by sea otters appears to be sufficiently scattered in time and space to preclude the regional depletion of harvestable stocks. The exposure of much of the central California coast to heavy surf probably provides an important refuge for mussels from foraging sea otters. Predation by the black oystercatcher, Haematopus bachmani, and dislodgement by storm waves are probably at least as important as sea otter predation in limiting the availability of mussels for human consumption in California.

Diving ducks, especially scoters, are mussel predators. Three species of ducks are responsible for most of the losses--the surf scoter, Melanitta delgandi, white-winged scoter, M. perspicillata, and black scoter, Oidemia amereicana. In feeding, the ducks dive underwater, remove a clump of mussels, return to the surface, shake the clump, and dislodge one mussel and swallow it whole. The other mussels in the clump sink to the bottom (Skidmore and Chew 1985).

Commensals, Parasites, and Encrusting Epifauna

The commensal crab, Pinnotheres sp., has been found in M. edulis. The crabs eat the food mussels have filtered out and decrease the pumping rates of mussels. Mature female crabs can reduce the meat yield by as much as 26% (Pregenzer 1981).

In California the parasitic copepod Mytilicola orientales was found in 13 of 20 M. californianus and in 24 M. edulis (Chew et al. 1964) Bradley and Siebert (1978) found Mytilicola in M. edulis from San Francisco Bay (incidence range, 36.8%-48.5%); they believed the parasite was imported with the Japanese oyster (Crassostrea gigas). The gonads of one M. californianus, from Humboldt Bay, were heavily parasitized with trematode cercariae of the family Bucephalidae (Edwards 1984), and trematode sporocysts were found in the digestive gland and gonadal tissue of M. edulis (Brousseau 1983).

Subtidal M. californianus may be overgrown by sponges, barnacles, anemones, and other epifauna (Paine 1976a). Heavily encrusted mussels weighed less (in tissue weight) than those less encrusted (Paine 1976a).

ENVIRONMENTAL REQUIREMENTS

Temperature and Salinity

Temperature plays an important role in growth. Coe and Fox (1944) found that the growth of M. californianus was most rapid at 17-20 °C and decreased sharply above 20 °C. Growth continued (but at a lower rate) at 14 °C or lower but less rapidly. Feeding continued at 7-8 °C and 27-28 °C. Filtration rate and oxygen consumption were highest at 20 °C (Coe and Fox 1942).

In California the optimum temperature range for growth was 10-20 °C (Morris et al. 1980). Feldmeth and Alpert (1977) found that the mean wet weight of mussels from the cooler waters of Alamitos Bay, California (14.8-15.8 °C) was four times greater than those from San Gabriel River (22.7-25.0 °C).

In nature, *M. californianus* is rarely found in bays and estuaries--perhaps because eggs, sperm, and larvae cannot withstand dilutions below 75% sea water (Robertson 1964). In contrast, *M. edulis* can accommodate a wide salinity range (Bayne 1965)--an interspecies difference that explains its wider distribution both in the open coastal waters and in protective bays.

Habitat

Mytilus edulis is sensitive to the effects of waves (Harger 1970a). It appears that *M. californianus* holds its position more strongly than does *M. edulis*.

Mytilus edulis is behaviorally adapted to quiet waters better than *M. californianus*. Mussels may form clumps up to 25 cm thick; juvenile *M. edulis* crawl to the outside of such clumps which may include *M. californianus*, but the latter mussel does not (Harger 1968). This crawling behavior protects *M. edulis* from harmful silt that accumulates inside the clumps in quiet waters. This silt may tend to exclude *M. californianus* there (Harger 1968).

The growth of *M. edulis* was seriously affected by tidal exposure. Little or no growth took place at 80% exposure and the mussels died within 3 months; growth was significantly less at 40% and 60% exposure than at 0% and 20% exposure (Christensen 1984). Morris et al. (1980) stated that *M. edulis* needs to be submerged at least half the time to show significant growth.

Physical Disturbance

Wave action or wave-borne logs in exposed areas may remove whole mats of mussels in the intertidal zone (Dayton 1971). At the edge of a cleared patch, substantial numbers of additional mussels may be removed by wave action (Dayton 1971). Mussels high in the intertidal zone away from starfish predation may survive for a great many years, until some are killed by wave-borne logs, unusual cold, or other physical stresses (Dayton 1971). The upper limit to the *M. edulis* zone in the high intertidal area at Tatoosh Island, Washington, was controlled by extreme summer heat that killed mussels, or made their shells gape and made them easy prey for gulls (Suchanek 1978).

Other Environmental Factors

Because mussels--particularly *M. edulis*--are distributed along the coast, and in bays and estuaries, they are often subjected to sewage and other kinds of pollution (Roberts 1976). The mussels may be unsafe to eat and must be depurated before marketing. In addition, both species of mussels ingest certain dinoflagellates that make them toxic to humans, causing paralytic shellfish poisoning.

Mussels concentrate hydrocarbons in their tissues. The hydrocarbons are rapidly taken up by the gill tissues and eventually are deposited in high concentrations in the alimentary canal (Roberts 1976). Although oil is only slightly toxic to mussels, it may affect the marketing of the animals by tainting them. Clark and Finley (1975) reported that the uptake and loss of petroleum hydrocarbons was related to the magnitude of exposure. When mussels were placed in clean water, most hydrocarbons were lost but significant quantities of No. 2 fuel oil remained for as long as 35 days. Fuel oil and outboard motor oil may inhibit byssal thread formation but at Long Beach Harbor, California, motor boat activity posed little threat (Carr and Reish 1978).

A number of trace metals are found in the soft tissues of mussels, including Ag, Cu, Cr, Mn, Pb, Cd, and Zn. Levels in *M. edulis* from California (Table 3) agreed with those of the same species in New Zealand (Graham 1972).

Since 1977 the California Department of Fish and Game has been monitoring the amount of trace metals in mussels (State Mussel Watch) along the coast (Stephenson et al. 1980a, 1980b). Of the sites investigated, Royal Palms, Corona del Mar, and La Jolla were "hot spots" for silver, copper, lead, and zinc. Silver was especially high in mussels in South San Francisco Bay. Los Angeles Harbor and Santa Catalina Island had the highest concentration of silver and lead while mussels in San Diego had the highest concentration of zinc. The amount of trace metals in mussels, depending on site, were in many instances much higher than those found by Graham (1972).

Table 3. Dry weight (ppm) of trace metals in soft parts of whole bodies of *Mytilus edulis*. Values are approximate means (ranges in parentheses) (Graham 1972).

Location	N	Ag	Cu	Cr	Mn	Pb	Cd	Zn
California	24	1 (<1-1.3)	7 (5-11)	4 (<2-8)	16 (6-28)	5 (2-8)	5 (3-7)	284 (204-341)
New Zealand	6	1 (0.1-1.3)	9 (8-11)	16 (9-24)	27 (12-38)	12 (3-25)	1 (1[illegible]	91 (50-180)

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, distribution, life history, and environmental requirements of coastal aquatic species. They are prepared to assist in environmental impact assessment. The California sea mussel, Mytilus californianus, and the bay mussel, M. edulis, are commonly collected for bait. Some commercial landing and aquaculture occurs at a very low level of production. Both species are distributed along the California coast; the sea mussel is more commonly found on intertidal coastal rocks and the bay mussel on pilings and other hard substrates in bays and estuaries. The eggs of both species develop into a trochophore stage in 12-24 hours after fertilization, and the planktonic larval stage lasts 3-4 weeks. Sexual maturity can occur in one year. Spawning of the sea mussel occurs sporadically throughout the year; the bay mussel spawns in central California in late fall and winter. Maximum length is 120-150 mm for the bay mussel and 200-250 mm for the sea mussel. Both species are regarded as unsafe to eat from May 1 to October 31 due to the possible presence of paralytic shellfish poisoning.

17. Document Analysis a. Descriptors

Life cycles	Feeding habits	Estuaries
Fisheries	Growth	Salinity
Mussels	Competition	Temperature
Aquaculture	Water pollution	Contaminants

b. Identifiers/Open-Ended Terms

Bay mussel	Ecological role
Mytilus edulis	Commercial fishery
California sea mussel	Sport fishery
Mytilus californianus	Ecological requirements

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