20 Culture of Mussels (*Mytilus spp*.) and Mussel Fisheries

A bed of sea mussels, *Mytilus californianus*, in the intertidal zone at Trinidad State Beach (Humboldt County). Photo credit: John Mello.

History

The use of mussels of the genus *Mytilus* for food in California extends back over 10,000 years as they are the most common shellfish found in island and coastal middens. More recently, mussels have fluctuated in importance in California's commercial and recreational shellfish fisheries for food and bait since the early 1900s. The extent of the recreational harvest has largely remained unknown but commercial landings have been recorded since 1916. Experiments in culturing wild seed stock and in developing hatchery and grow out methods in the 1980s have greatly increased the importance of aquacultural mussel production, particularly the Mediterranean mussel, *Mytilus galloprovincialis*, which occurs primarily in southern and south central California. A related species, the Baltic mussel, *M. trossulus*, is recreationally harvested in northern California and hybrids of the two species are commonly found between Cape Mendocino (Humboldt County) and Monterey Bay.

The California mussel, *M. californianus*, is of minor economic importance in California at present, though it is taken by recreational harvesters. It is primarily used as bait along the west coast, but in the 1980s, wild harvested sea mussels, highly esteemed by gourmet chefs in Oregon, were sold to fine restaurants in Portland. More recently, landings of sea mussels for food have been negligible.

Between 1916 and 1927, the commercial fishery landed a total of over 470,000 pounds (213 metric tons) of mussels, ranging from 9000 pounds (4 metric tons) to 69,000 pounds (31 metric tons) per year in California. After 1927, most areas were closed to harvest by the California Department of Health Services [now Department of Public Health (DPH)] due to a major outbreak that year of paralytic shellfish poisoning. Mussel landings declined to 1600 pounds (7 metric tons) in 1928 and stayed depressed until 1972, when a record 111,000 pounds (50 metric tons) were landed, primarily for

bait. Bait sales continued to be the most significant type of commercial activity for mussels until improved methods of harvesting wild stocks were developed, new culture methods were adopted, and west coast markets began developing for this tasty shellfish in the early 1980s. After the development of the aquaculture industry for mussels, commercial landings of mussels became a minor part of total mussel production and have dropped to below 1000 pounds (0.5 metric tons) in 2007 and 2008 (Figure 20-1).

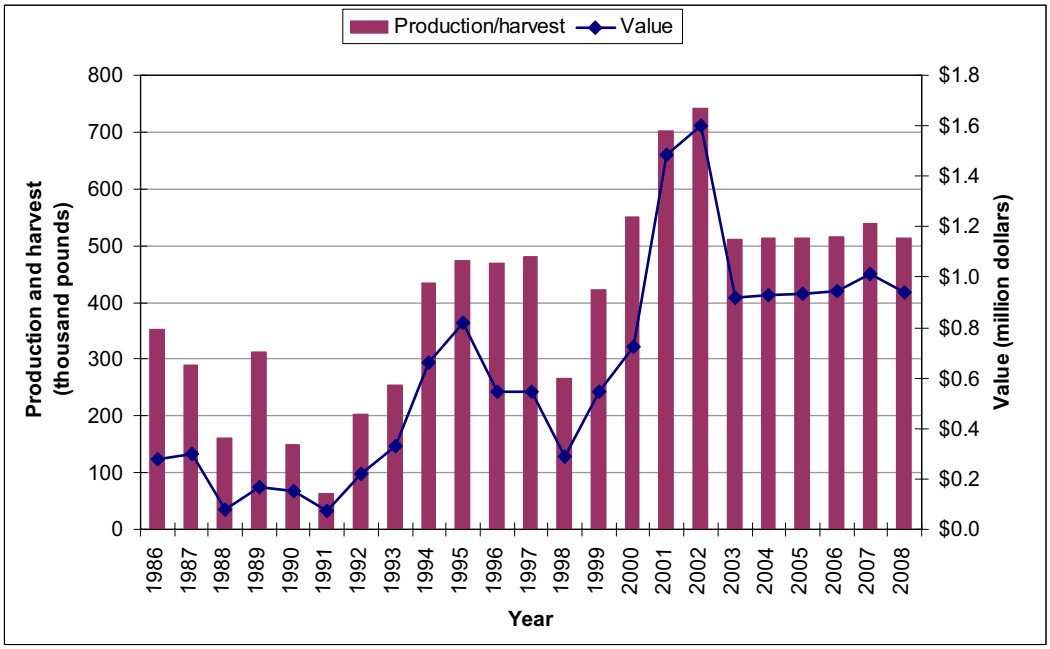

Figure 20-1. Mussel production, harvest and value (cultured mussels and commercially harvested wild mussels), 1986-2008. Data Source: Production - California State Tax records (royalty reports) and Department Aquaculture Harvest Survey Database. Harvest - CFIS data, all gear types combined.

Research on harvesting naturally set Mediterranean mussels from offshore oil production platforms for food was initiated in the Santa Barbara Channel in 1979. Divers routinely removed fouling organisms from the submerged support structures of offshore platforms at considerable expense to oil companies. An ecological consulting firm, hired to suggest ways to control the biofouling, found that various stages of the succession of organisms included settlement and growth of edible mussels, both Mediterranean and California. Recognizing the potential for food production and increasing market demand for high quality shellfish, the owners of the firm contracted with various offshore oil companies to test the feasibility of harvesting and marketing the mussels. The harvest of mussels from oil platforms became significant in the 1980s but because of internal problems, the harvesting company stopped production in recent years. While mussels taken from oil platforms have been counted as a component of aquaculture mussel production, this source of mussels might be more properly categorized as part of the commercial fishery landings. Although the structures are man made, they are not designed nor intended for aquaculture purposes.

Experimental mussel, oyster and clam culture also began in 1983 in Aqua Hedionda Lagoon near Carlsbad. Taking advantage of excellent natural mussel settlement in the lagoon and relatively fast growth of juveniles, the shellfish firm began to culture mussels in 1985. It obtained a 5 acre lease for use of the lagoon and began a commercial operation following modified Italian long line techniques. Mussel seed was placed in a tubular net "stocking" designed specifically for mussel growing (Figure 20-2). The stocking or "reste" was originally imported from Italy, but is now available to growers from U.S. suppliers. The stockings were suspended from long lines 50 yards long and supported by small buoys to keep the stockings off the bottom. Mussel production at the Carlsbad farm peaked in 1989, second only to the offshore platform harvest in the Santa Barbara Channel. However, the following year DPH decertified the shellfish growing area due to rising coliform counts in the lagoon. Production ceased in 1990 and remained static until a certified depuration system, required by the state, was put into operation in 1992.

Figure 20-2. Cultured mussels grown on aquaculture sock lines. Credit: Department of Fisheries and Oceans Canada.

In 1985, approximately 104,000 pounds (47 metric tons) of mussels were harvested, primarily from offshore platforms, but by this time a farm in Tomales Bay also had begun to utilize European long line methods to grow mussels. Over the next 7 years, three to five other Tomales Bay oyster growers diversified into mussel production. These growers utilized wild caught and hatchery reared seed, with the latter being relied upon more in the late 1980s, as natural recruitment during this period was often erratic and unreliable. After a brief period of expansion, several Tomales Bay growers ceased all but minimal production in the mid 1990s to concentrate on oyster culture. By the fall of 2000, only one company was producing commercial quantities of mussels and this trend continued until 2008 with sporadic production by one other company. These mussels are sold exclusively to local restaurants around Tomales Bay. At least 3 other growers have the capability to produce commercial quantities and one had begun in 2008 to scale up their operations using the Bouchot culture technique which originated in France in the 13th century. This technique uses tubular mesh nets with mussel seed inside that are wound around tall poles set in rows into the seabed. With the current increased demand and price, this grower plans to sell to the wholesale market rather than restaurants.

On California's north coast, an oyster grower operating in Mad River Slough, a tributary to Humboldt Bay, began farming mussels in 1992 using the floating raft culture method. Seed mussels, attached to a line inside flexible plastic mesh netting, are suspended from the raft during grow out. Cultured mussels from Humboldt Bay were

initially used, but since the mid 1990s, wild juvenile mussels collected from the bay were the primary source of seed. The mature mussels were sold locally at farmers' markets and restaurants. One other Humboldt Bay operation began experimenting with mussel grow out in 2001, using wild seed stock and following the raft culture method used in Mad River Slough. However, as of 2008, no aquaculturists are raising mussels in Humboldt Bay.

The total state mussel production tripled in 1986, reaching more than 334,000 pounds (152 metric tons) (Figure 20-1), with over 90 percent harvested from platforms in the Santa Barbara Channel and the remainder from Tomales Bay. Statewide production dropped slightly in 1987 to approximately 286,000 pounds (130 metric tons) and decreased further in 1988 to 151,000 pounds (68 metric tons), due to major winter storms, which dislodged market-ready mussels from platform structures. Production jumped to over 300,000 pounds (136 metric tons) in 1989 but dropped to 130,000 pounds (59 metric tons) in 1990 when a major producer ceased production, continuing a slide in 1991 to a low of only 47,000 pounds (21 metric tons).

During the next six years (1992 through 1997), with the major producer back in production, increasing harvest from offshore platforms in the Santa Barbara Channel, and steady production in Tomales Bay, the statewide total rose from 187,000 pounds (85 metric tons) to 472,000 pounds (214 metric tons). Strong winter storms following warm El Niño seawater conditions in the fall of 1997 caused havoc to mussel production throughout the state the following year. An economically devastating drop in production of nearly 50 percent, to 256,000 pounds (116 metric tons), occurred in 1998. One of the large southern California growers stated that spawning and recruitment were both affected by these events. A colder water regime in 1999-2000 improved the recruitment situation and harvests increased. Combined harvests from producers and offshore oil platforms pushed production to a new record high of 740,000 pounds (336 metric tons) in 2002. In the period from 2003 to 2008 loss of offshore platform harvest has reduced annual production to slightly over 500,000 pounds (227 metric tons). Recently a new grower in the Santa Barbara area has expanded mussel production on a nearshore open ocean lease. Significant losses due to sea duck predation on mussels, a problem for mussel growers in Tomales Bay as well, has limited Santa Barbara production as of 2008.

Mussels harvested during the five years between 1986 and 1990 provided an average annual return of $188,000 to California growers. Steady expansion of production during the following five years (1991 to 1995) increased statewide annual returns to $412,500. While production and return to growers dipped in 1998 due to El Niño conditions, the five year period from 1996 to 2000 still saw an increase in return to producers of $524,500 annually (Figure 20-1). Annual mussel production reached a historic peak in 2002, boosting annual returns to $1.2 million. Following the 2002 peak in production, oil platform harvest ceased and as of 2008, has not been a component of state production. Production stabilized during the period 2006 to 2008 with annual returns averaging $965,000.

The wholesale price did not change significantly until the late 1990s. The prior 15 years saw the price range from $1.10 to $1.25 per pound ($2.43 to $2.76 per

kilogram). Competition with low priced imported mussels kept the price low, reducing the profit margin for state producers. Increased public acceptance of mussels as a quality shellfish food item has led to increased demand and allowed state producers to raise wholesale prices, as the price of imported mussels rose. Wholesale prices have averaged over $1.80 per pound ($3.97 per kilogram) since 2000. Retail/restaurant prices have increased from $2.00 in 1990, to $2.25 in 2000, to around $3.00 per pound as of 2008 ($4.41, $4.96, and $6.62 per kilogram, respectively). Direct sale prices have always been higher to the public at farmers markets and retail shellfish outlets with the price varying between $2.50 per pound in southern California and $4.00 or more per pound in northern California ($5.51 and $8.82 per kilogram, respectively).

California growers continue to face strong competition from mussels imported from eastern Canada, New Zealand, Mexico, Maine and Washington state due to the advent of low cost air transport for fresh shellfish and individual flash freezing methods. Competing on the world market is a challenge to California producers because of the massive production of mussels in China, Korea, New Zealand, Australia and other Pacific Rim countries. All but one company in Tomales Bay ceased or minimized their mussel operations, citing competition from low cost imported mussels as the reason. Expansion of the industry is dependent on the maintenance of clean growing areas, a supportive regulatory environment, aggressive marketing and dependable sources of seed. Climatic and oceanographic events have also had significant impacts on the economic health of this industry.

Until 1986, all mussels grown commercially in California were set or collected as wild spatfall or natural seed. In 1985, a cooperative effort was initiated by a Humboldt County shellfish nurseryman to produce the first commercial quantities of hatchery reared mussel seed on the west coast. Growers utilized a variety of substrates and set the spat (seed) at different densities. A wide range of results, from zero survival to excellent survival and growth were reported. The five participating growers in Tomales Bay purchased larger (0.5 to 1.0 inch; 1.3 to 2.5 centimeters) seed, which could be grown to market size in 6 to 9 months. The methods of growing out seed evolved and matured in Tomales Bay and in the Puget Sound area of Washington state but were not proven on a commercial scale in south central and southern California until the late 1990s. Growers there now use a combination of wild and hatchery seed. As of 2008, no in-state source of cultured mussel seed is currently available and growers now must purchase seed from out of state hatcheries. Availability of hatchery mussel seed is a limiting factor for producers when capture of natural spatfall is limited or fails.

Predation on maturing mussels by surf scoters and other sea ducks and predation on small natural-set seed by schools of surfperch, has over time proved burdensome to most of the shellfish growers who were concentrating on oysters as their primary product. However, recent market interest and increased prices for mussels has led to the use of some innovative and successful techniques by producers in Tomales Bay and Santa Barbara to foil the duck and fish predators.

Both southern and northern California mussel companies also must cope with water quality fluctuations, especially in nearshore areas or embayments. One south coast aquaculturist has built a depuration system for bivalve shellfish, one of the first in

California. The grower has been able to use a protected lagoon to grow mussels, which are relayed to the onshore depuration system prior to sale. By utilizing seawater treated with ultraviolet light to eliminate harmful bacteria, the grower can produce wholesome, high quality mussels.

Status of Biological Knowledge

Early studies of California mussels identified the blue mussel, *M. edulis*, as a common species, but genetic studies utilizing protein electrophoresis in the late 1980s showed that there were two forms of mussels on the west coast that are distinct from the blue mussel and morphometrically similar. One of these forms is electrophoretically indistinguishable from the Mediterranean mussel which is known to have recently colonized many disparate shores around the world. The other form was designated the Baltic mussel, which was originally described from specimens collected in Oregon but is also found in eastern Canada and the Baltic Sea. Along eastern Pacific shores it is found from Alaska to central California. The two forms occur together and hybridize with one another. Several genetic studies in the late 1990s have confirmed that the Mediterranean mussel is found principally south of the Monterey Peninsula and the Baltic mussel is found primarily north of Cape Mendocino (Humboldt County). A zone of hybridization has been documented between these two distinct coastal features but studies using DNA markers have found hybrids as far north as Whidbey Island, Washington (near Seattle) and as far south as San Diego Bay.

The hybridization and geographic range issues regarding the Baltic mussel in central and northern California confound the interpretation of earlier life history studies of mussels taxonomically classified as blue mussel, but, regardless of the taxonomic issue, all mussels share many common biological traits as they are all members of the bivalve class Pelecypoda (hatchet feet). Mussels have separate sexes, though some hermaphrodism occurs. There is evidence that changes in water temperatures, physical stimulation (such as disturbance by winter storms), variation in light levels, or phytoplankton blooms may stimulate spawning.

Spawning in the California mussel occurs throughout the year at a very low level, with peaks in July and December but reproductive output can be up to eightfold greater for sites south of Point Conception relative to more northerly sites. The spawning and recruitment of the Mediterranean mussel also occurs year round, although it is heaviest in February, March and April and again in September and October in southern California. Mussels reaching 1.6 inches (4.1 centimeters) in shell length are found to have gonads in various stages of development and are able to spawn.

When spawning occurs in the natural environment, eggs and sperm are discharged through the excurrent chamber and fertilization takes place in the open ocean or estuary. Within 24 hours, the embryo develops into free-swimming trochophore larva that grows into a more advanced veliger stage, again, within 24 hours. The development of the ciliated velum (approximately 48 hours after fertilization) gives the larvae more control in swimming and in gathering food. The veliger is also known as the “straight-hinge” stage, denoting the appearance of the first shell. In two to

three weeks, veligers begin metamorphosis, a stage preceded by the development of an eyespot (a photosensitive organ) and a foot. This is the pediveliger stage, during which the veliger changes from a swimming larva to a bottom dwelling juvenile mussel or spat.

Newly settled mussels attach to substrates with proteinaceous threads (byssus or byssal threads) that are secreted by the postlarvae. Young mussels have the unique ability to detach their byssus, crawl to a different location, or drift away in a current to seek a more favorable substrate, and reattach. This trait is considered to be a significant problem for growers, as postlarvae have disappeared from various substrates soon after placement in open water.

Growth rates of both the Mediterranean mussel and the California mussel have been reported to be at least 0.25 inch (0.64 centimeters) per month and as high as 0.5 inch (1.3 centimeters) per month in the Santa Barbara Channel. Growth rate is influenced primarily by the quantity and quality of food, rather than temperature and mussels achieved a 2 inch (5 centimeter) shell length in 6 to 8 months.

Food consumed by mussels includes dinoflagellates, organic particles, small diatoms, zoospores, protozoa, unicellular algae, bacteria and detritus. Phytoplankton is considered to be the main food item providing energy for rapid growth.

Competition for space is an important factor influencing growth and survival of mussels, both in wild and cultured populations. Mytilids of the same and different species compete for limited space in the rocky intertidal and subtidal growing areas. Cultured mussels on artificial substrates also can become overcrowded if seed stocking densities are too high. Crowding causes instability of mussel masses and, when coupled with high current speeds, turbulence and drifting materials, losses frequently occur. Barnacles and sea anemones also compete for space with mussels.

Changes in climate could negatively affect mussel beds, particularly in southern California. Mussel beds have been found to have high numbers of associated organisms but recent studies indicate a dramatic decline in community diversity which might be attributed to climate change. Compared to the mid 1970s and 1980s, mussel beds in southern California have declined in mussel cover, biomass, and bed thickness but similar changes have not been detected in mussel beds of central and northern California.

Predators of mussel species are abundant. They include sea stars, muricid gastropods and crabs. The surf scoter, the black oystercatcher, shiner surfperch and the sea otter are also important predators in coastal waters. The lower limit of mussel populations in the intertidal zone is determined by the activities of predators, primarily seastars of the genus *Pisaster*. Mussel populations on oil rigs occur much deeper than is typical for coastal reefs and are thought to be protected from sea stars by dense populations of sea anemones occurring below the mussel zone.

Mussels are used in California and other parts of the world as sentinel species in “mussel watch” programs to monitor various organic and inorganic pollutants. As filter feeders, mussels also ingest and concentrate toxin producing species of phytoplankton

that periodically bloom along the Pacific coast. The DPH utilizes mussels as biotoxin indicators in a statewide monitoring program staffed by volunteers. A statewide annual quarantine on recreational harvest is imposed between May 1 and October 31 when the probability of toxic phytoplankton uptake in mussels is high. However, commercially grown and commercially harvested wild mussels may continue to be harvested during this period as long as constant testing assures that only a safe, wholesome and nontoxic product is available to the consumer.

Management Considerations

It is recommended that large scale commercial harvesting of wild mussels be prohibited because of the potential for damage to a delicate and highly productive rocky intertidal community. Any harvesting that is done should be size selective and leave a layer of mussels intact. The presence of mussels greatly increases the diversity of rocky intertidal communities but mussel beds can be damaged by human activity. Mussel cover has been negatively impacted by foot traffic and removal of mussels for food or bait in southern California. Large gaps in mussel beds greater than 32 square feet (3 square meters) can take decades to fully recover.

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Further Reading

Blanchette CA, Helmuth B and Gaines SD. 2007. Spatial patterns of growth in the mussel, *Mytilus californianus*, across a major oceanographic and biogeographic boundary at Point Conception, California, USA. J. Exp. Mar. Biol. Ecol. 340:126-148.

Coan EV, Scott PV and Bernard FR. 2000. Bivalve seashells of the western North America: marine bivalve mollusks from Arctic Alaska to Baja California. Santa Barbara Museum of Natural History Monographs No 2; studies in Biodiversity No 2 Santa Barbara, CA 746 p.

McDonald JH and Koehn RK. 1988. The mussels *Mytilus galloprovincialis* and *M. trossulus* on the Pacific coast of North America. Mar. Biol. 79:117-176.

Price RJ. 1989. Paralytic shellfish poisoning and red tides. California Sea Grant Extension Program 89-1, University of California, Davis. 2 p.

Smith JR, Fong P and Ambrose RF. 2006. Long-term change in mussel (*Mytilus californianus* Conrad) populations along the wave-exposed coast of southern California. Mar. Biol. 149(3):537-545.

Smith JR and Murray SN. 2005. The effects of experimental bait collection and trampling on a *Mytilus californianus* mussel bed in southern California. Mar. Biol. 147(3):699-706.

Trevelyan GA. 1991. Aquacultural ecology of hatchery-produced juvenile mussels (*Mytilus edulis* L.) [dissertation]. Davis (CA): University of California, Davis. 242 p. Available from: University of California, Davis library, Davis, CA.

Mussel production, harvest and value (cultured mussels and commercially harvested wild mussels), 1986-2008.

	Culture		Harvest		Total	
Year	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**
1986	334,617	$267,693	16,953	$10,282	351,570	$277,975
1987	286,689	$298,157	1,577	$934	288,266	$299,091
1988	151,399	$70,941	9,203	$5,503	160,602	$76,444
1989	302,958	$164,640	9,619	$5,800	312,577	$170,440
1990	130,867	$139,834	17,928	$10,757	148,795	$150,591
1991	47,468	$65,671	15,953	$9,572	63,421	$75,243
1992	187,945	$210,417	14,214	$8,528	202,159	$218,945
1993	241,534	$325,583	11,567	$6,916	253,101	$332,499
1994	421,980	$652,175	12,417	$7,490	434,397	$659,665
1995	458,955	$808,383	13,986	$10,440	472,941	$818,823
1996	458,252	$535,160	11,231	$8,541	469,483	$543,701
1997	471,556	$536,952	8,690	$6,714	480,246	$543,666
1998	255,967	$284,153	9,064	$6,732	265,031	$290,885
1999	413,697	$541,920	7,785	$5,385	421,482	$547,305
2000	545,692	$723,936	4,603	$1,510	550,295	$725,446
2001	699,079	$1,485,418	2,729	$1,513	701,808	$1,486,931
2002	736,457	$1,601,299	4,522	$1,356	740,979	$1,602,655
2003	506,307	$918,921	4,711	$1,263	511,018	$920,184
2004	508,416	$926,088	3,575	$936	511,991	$927,024

Mussel production, harvest and value (cultured mussels and commercially harvested wild mussels), 1986-2008.						
	Culture		Harvest		Total	
Year	Pounds	Value	Pounds	Value	Pounds	Value
2005	511,460	$934,365	2,033	$1,939	513,493	$936,304
2006	514,378	$943,134	1,620	$73	515,998	$943,207
2007	537,127	$1,011,381	997	$215	538,124	$1,011,596
2008	513,720	$941,160	440	$65	514,160	$941,225

Data Source: Production - California State Tax records (royalty reports) and Department Aquaculture Harvest Survey Database. Harvest - CFIS data, all gear types combined.