Culture of Mussels

History

Mussels of the genus *Mytilus* have fluctuated in importance in California's commercial and sport shellfish fisheries for food and bait since the early 1900s. Experiments in culturing wild seed stock and in developing hatchery and grow-out methods in the 1980s have increased the economic potential of mussels, particularly *Mytilus galloprovincialis* (the Mediterranean mussel), which occurs primarily in southern and south-central California.

A related species, *Mytilus trossulus* (the "foolish mussel") is sport-harvested in northern California and hybrids of *M. trossulus* and *galloprovinciallis* are commonly found between Cape Mendocino and Monterey Bay.

The sea mussel, *Mytilus californianus*, is of minor economic importance in California at present, though it is taken by sport harvesters and it is periodically sold by a southern California harvester to restaurants. 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 and still may have a future in California.

Between 1916 and 1927, a total of over 470,000 pounds of mussels, ranging from 9,000 to 69,000 pounds per year, were landed in California. After 1927, most areas were closed to harvest by the California Department of Health Services due to a major outbreak that year of paralytic shellfish poisoning. Mussel landings declined to 1,610 pounds in 1928 and stayed depressed until 1972, when a record 111,000 pounds were landed, primarily for bait. Bait sales continued to be the most significant commercial activity for California 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.

Research on harvesting wild-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 *M. galloprovincialis* and *M. californianus*. 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.

Experimental mussel, oyster, and clam culture also began in 1983 in Aqua Hedionda Lagoon near Carlsbad. Taking advantage of excellent natural mussel spatfalls in the lagoon and relatively fast growth of juveniles, the shellfish firm began to culture mussels in 1985. It obtained a five-acre lease for use of the lagoon and began a commercial operation following modified Italian longline techniques. Mussel seed was placed in a tubular net "stocking" designed specifically for mussel growing. The stocking or "reste" was originally imported from Italy, but is now available to growers from U.S. suppliers. The stockings were suspended from longlines fifty 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 the State Department of Health 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.

In 1985, approximately 104,000 pounds of mussels were harvested, primarily from offshore platforms, but by this time a farm in Tomales Bay also had begun to utilize European longline methods to grow mussels. Over the next seven 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. These are sold exclusively to local restaurants around Tomales Bay. At least three other growers have the capability to produce commercial quantities and may scale up their operations again if market conditions improve.

On the north coast, an oyster grower operating in Mad River Slough, Humboldt County, 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 have been the primary source of seed. The mature mussels are 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.

The total state mussel production tripled in 1986, reaching more than 334,000 pounds, with over 90 percent harvested from platforms in the Santa Barbara Channel and the remainder from Tomales Bay. Statewide produc-

tion dropped slightly in 1987 to approximately 286,000 pounds and decreased further in 1988 to 151,000 pounds, due to major winter storms, which dislodged market-ready mussels from platform structures. Production jumped to over 300,000 pounds in 1989 but dropped to 130,000 pounds in 1990 when the Carlsbad firm ceased production, continuing a slide in 1991 to a low of only 47,000 pounds. During the next six years (1992 through 1997), with the Carlsbad firm 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 to 471,000 pounds. 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, 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 has been encouraging to growers.

Mussels harvested during the five years between 1986 and 1990 provided a return of $1.17 million to California growers. Steady expansion of production during the following five years between 1991 to 1995 increased statewide returns to $2.06 million. Return to growers dipped in 1996 and 1997 to about $500 thousand per year with a critical drop in 1998 to $280 thousand.

The wholesale price has not changed significantly over the past 15 years still ranging from $1.10 to $1.25 per pound. Retail/restaurant prices have increased slightly from $2.00 in 1990 to $2.25 in 2000. Direct sale prices to the public at farmers markets and retail shellfish farms has increased, varying between $2.50 per pound in southern California and $4 per pound in the Tomales and San Francisco Bay area. The retail/restaurant price in Humboldt County is slightly higher at $2.50 per pound and direct sales at farmers' markets are intermediate at $3.00 per pound.

California growers continue to face stiff competition from mussels imported from eastern Canada, New Zealand, Maine, and Washington due to the advent of low cost air transport of fresh shellfish and individual flash freezing methods. Competing on the world market is a challenge to California producers, because of massive production of mussels in China, Korea, New Zealand, Australia, and other Pacific Rim countries. 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 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 at different densities. A wide range of results, from zero survival to excellent survival and growth were reported. 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 as growers continued to utilize natural seed.

The five participating growers in Tomales Bay purchased larger (0.5-1.0 inch) seed, which could be grown to market size in six to nine months. Excessive predation on maturing mussels by scoter ducks and on small natural-set seed by schools of perch over time proved burdensome to most of the shellfish growers who were concentrating on oysters as their primary product. All but one company in Tomales Bay ceased or minimized their mussel operations, citing competition from low-cost imported mussels as the reason.

Southern California mussel companies also face stiff competition from imports, and 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 violet light to eliminate harmful bacteria, he can produce wholesome, high quality mussels.

Status of Biological Knowledge

Genetic studies utilizing protein electrophoresis in the late 1980s showed that there were two distinct forms of *edulis*-like mussels on the West Coast that are morphometrically similar. One of these forms is electrophoretically indistinguishable from *M. galloprovincialis*, the Mediterranean mussel, which is known to have recently colonized many disparate shores around the world. The other form is also distinct from the Atlantic *M. edulis* and was designated *M. trossulus*, the Pacific Northwest mussel. It was found from Alaska to central California. The two forms occur together and are reported to hybridize with one another. Several genetic studies in the late 1990s have confirmed that *M. galloprovincialis* is found principally south of the Monterey Peninsula and *M. trossulus* is found primarily north of Cape Mendocino. A zone of hybridization has been documented between these two distinct coastal features.

The hybridization and geographic range issues regarding *M. trossulus* in central and northern California confound the interpretation of earlier life history studies of mussels taxonomically classified as *M. edulis*, 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 *M. californianus* occurs throughout the year at a very low level, with peaks in July and December. The spawning and recruitment of *M. galloprovincialis* 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 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 (seed).

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 *M. galloprovincialis* and *M. californianus* have been reported to be at least 0.25 inch per month and as high as 0.5 inch 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 two-inch shell length in six to eight months.

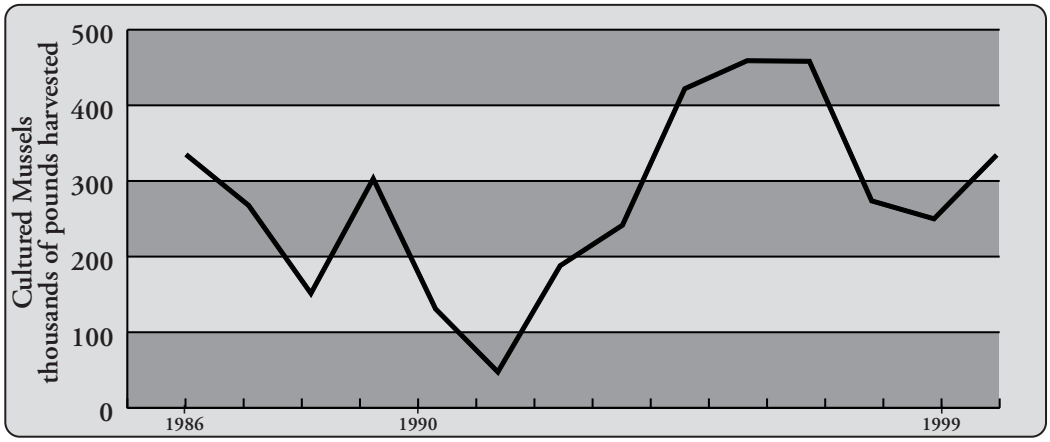
Food consumed by mussels includes dinoflagellates, organic particles, small diatoms, zoospores, protozoa, unicellular algae, bacteria, and detritus. Phytoplankton is considered to be the main food item providing energy for rapid growth.

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.

Predators of California mussel species are abundant. They include two sea stars, five species of muricid gastropods, and three crabs. Scoter ducks, the black oyster- catcher, shiner perch, and the sea otter are also important predators in coastal waters.

An invasive species of algae, *Caulerpa taxifolia*, recently found in a southern California lagoon is another concern of both mussel growers and resource managers. Known for its progressive smothering of the Mediterranean seafloor, the alga is the focus of an intensive effort by state and federal regulators to eradicate the species before it spreads.

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 California Department of Health Services utilizes mussels as bio-toxin indicators in a statewide monitoring program staffed by volunteers. A quarantine on sport harvest is imposed between May 1 and October 1 when the probability of toxic phytoplankton uptake in mussels is high. However, commercially grown mussels may continue to be harvested during this period as long as constant testing assures that only a safe, wholesome, and non-toxic product is available to the consumer.



Commercial Harvest 1986-1999, Cultured Mussels
Annual pounds of cultivated mussels landed by State aquaculture producers. Harvest data for 1997-1999 include only mussels cultivated in Tomales Bay and Drakes Estero. Data Source: California State Tax records (royalties reports) and DFG Aquaculture Harvest Survey Database.

Management Considerations

See the Management Considerations Appendix for further information.

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