University of California, Davis Department of Animal Science

CALIFORNIA CA AQUACULTURE

CALIFORNIA OYSTER CULTURE

History of the Industry

1850-1878: California's oyster fishery and oyster aquaculture industry have had a rich and colorful tradition. The fishery began in the 1850's when Eastern immigrants with an appetite for oysters were attracted to California by the prospect of gold and new opportunities. The dramatic increase in population and resulting market pressure for oysters had immediate impact on the state's shellfish resources. Natural occurring populations of the only native oyster, *Ostrea conchaphila* (*Ostrea lurida*), declined rapidly because of intensive fishing. In response, native oysters were transported from Shoalwater Bay, Washington (Willapa Bay) and later from other bays in the Pacific Northwest and Mexico. This represented the initial attempts at oyster culture on the West Coast. The oysters were transplanted into San Francisco Bay where they were maintained on oyster beds and then marketed throughout central California.

The Shoalwater Bay trade of Olympic oysters dominated the California market from 1850 through 1869. Market demand for a larger, half-shell product stimulated experiments in transporting the Eastern oyster (*Crassostrea virginica*) from the Atlantic states to the West Coast. Several failed attempts were made to establish transport of the Eastern oyster to California by sailing ships. Successful transport of oysters was achieved only after the completion of the transcontinental railroad.

1875-1899: In 1875, transcontinental trade for Eastern oyster seed was established. Shipments of market-sized oysters were transported by rail in barrels of sawdust and ice and transplanted into San Francisco Bay. However, cool summer water temperatures prevented successful natural reproduction of the Eastern oyster. As the demand for oysters increased, small one-inch seed oysters from the East Coast were transplanted for further growth in San Francisco Bay. The Shoalwater Bay trade for Olympic oysters was gradually terminated and, from 1872 until the early 1900 's, California 's San Francisco Bay Eastern oyster industry was the largest oyster industry on the West Coast. Maximum production was reached in 1899 with an estimated 2.5 million pounds of oyster meat produced.

1900-1939: With California's population and industrial growth came a degradation of water quality in San Francisco Bay. By 1908, Eastern oyster production fell by 50 percent. By 1921, the quality of oyster meats produced declined to the extent that shipments of seed

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from the East Coast were terminated, and by 1939, the last of the San Francisco oysters were commercially harvested. Oysters were still transported and held in Tomales Bay until they could be marketed in San Francisco, but the industry, based on the Eastern oyster, did not recover. The industry and state began re-examining earlier experimental plantings with the Pacific oyster.

Introduction of the Pacific Oyster: In 1929, the California Department of Fish and Game (CDFG) and commercial companies made experimental plantings of Pacific oysters (*Crassostrea gigas*) in Tomales Bay and Elkhorn Slough. In the 1930's, experimental plantings continued in a number of bays, including Drakes Estero, Bodega Lagoon, Morro, Newport, and San Francisco Bays. Humboldt Bay was excluded from plantings as the CDFG was trying to re-establish natural populations of native oysters. Several Pacific oyster plantings proved successful, demonstrating that imported Pacific oyster seed could be grown commercially in California.

1940-1980: The initial shipments of Pacific oyster seed from Japan that began in the 1930's were suspended from 1940 through 1946. Shipments of oyster seed from Japan were reinitiated in 1947. The seed was inspected in Japan by CDFG personnel who were looking for organisms considered harmful if introduced into state waters. Boxes containing old oyster shells (mother shell; cultch) with attached young oysters (spat) were shipped by boat and the industry began its recovery on the West Coast. The CDFG lifted its restriction on Pacific oyster seed in Humboldt Bay in l953, and in the next thirty years, the California industry showed rapid growth. Production was centered in Humboldt Bay, Drakes Estero, Tomales Bay, Elkhorn Slough, and Morro Bay.

1980-Present: In the early 1980's, the oyster industry initiated other significant changes. These included the development of U.S.- based shellfish hatcheries and the ability to ship advanced oyster larvae for setting on cultch in heated tanks at remote growout locations. Currently, over 98 percent of the oysters grown in California are Pacific oysters produced from hatcheries in Washington and Oregon and from several smaller specialty hatcheries located within the state. Oyster larvae shipped by millions are set on the mother shell, or as cultchless seed where the larvae is set on a loose substrate such as sand or crushed shell. The latter, a prime California product, results in oysters grown as individuals instead of clusters attached to a mother shell.

The West Coast hatcheries produce several species and varieties of oysters including the Miyagi variety of the Pacific oyster (*Crassostrea gigas*) and, to a lesser extent, the Pacific Kumamoto oyster (*Cassostrea sikamea*). Other minor species produced by hatcheries over the years include the European oyster (*Ostrea edulis*) and the Eastern oyster (*Crassostrea virginica*). The ability to ship oyster larvae long distance and set the spat at the growout areas has significantly reduced the cost of seed. Although the industry as a whole uses domestic seed, small shipments of Japanese seed were periodically imported to maintain these trade channels as insurance against problems in the domestic hatchery system. The last shipments of Japanese oyster seed were received in 1989.

Production Bays

The production activity within the various bays has varied throughout the years, primarily based on water quality, site selection, and the financial viability of oyster operations. Growing areas are leased from the state through the Fish & Game Commission, Harbor Districts,

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and Navigation Districts. Current production is primarily in Humboldt Bay, Drakes Estero, Tomales Bay and Morro Bay. The industry periodically tests the feasibility of offshore culture of oysters in the Santa Barbara Channel and cultchless oyster production in San Diego Bay. Tomales Bay has recently experienced a resurgence of production by growers using cultchless seed and targeting the half-shell markets. At present, about 90 percent of the state's oyster production is based on cultched oyster seed and occurs in Humboldt Bay and Drakes Estero.

Culture Techniques

A variety of oyster culture methods are being used within the oyster producing areas. Each production method depends upon the physical characteristics of the production bay and the need to protect the younger oysters from predators such as bat rays, rock crabs, and drills (snails). Culture methods are influenced by factors such as substrate type, current velocity, tidal range, and phytoplankton productivity. California oysters are grown from spat to market size in 13 to 18 months, depending on the bay and the method of culture.

The primary culture technique used in Humboldt Bay is bottom culture. In bottom culture, cultch with attached spat are spread over selected areas in the bay and the oysters grown to a size of about four inches. The oysters are then harvested by hydraulic dredge. Some off-bottom techniques are used, including bags of oysters supported by low racks and oyster bags attached to longlines.

Drakes Estero has one of the largest off-bottom, rack culture systems in the country. Off-bottom culture is used primarily to avoid predators. Other advantages include greater use of the water column and less silt accumulating on the oyster. The system of rack culture uses mother shells containing spat that are strung on lines. Each mother shell is separated by a tube spacer and the lines are secured to hang over the rails of racks that are positioned in the bay. Another method, stake culture, consists of three mother shells separated by spacers and threaded on a solid stake that is driven into the substrate. This method is used in selected shallow areas within the bay.

Tomales Bay growers use a variety of off-bottom techniques including rack-and-bag, stake culture, bag and longline, and Stanway tube culture. Rack-and bag culture uses cultchless seed that is first grown in trays and then transferred to mesh bags that are positioned on low racks placed in the bay. Bag and longline culture use cultchless seed in mesh bags that are attached to an anchored line which suspends the bags in the water or secures the bags on a stable, hard bottom, intertidal area. Stanway tube culture consists of mesh tubes containing oysters that rotate as they pivot about an axle as the tides change. This method reduces the labor involved in hand moving the containers to maintain the more uniform shape of the cultchless oyster.

Production techniques in Morro Bay include bottom, rack-and bag, and stake culture. Producers in the Santa Barbara Channel have used a system of longlines with attached bags of oysters suspended from offshore racks in the deep waters. San Diego Bay producers have used rack-and-bag culture for oysters, but have switched to the culture of mussels.

Oyster Production and Markets

Total annual oyster production for the state was about 1.5 million pounds of shucked meat in 1995. Shucked oysters are marketed as meat packaged in gallon containers and in 8-and 10-oz jars. The shucked product is marketed as small (200/ gallon), medium (140/gallon), and large (100/gallon).

Oysters are also marketed in the shell as shell-

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stock. Prime markets for shellstock include the half-shell and barbecue oyster markets. Shellstock is marketed as small (2.5-3.5 inches), medium (3.5-4.5 inches), large (4.5+ inches), and clusters (attached, mixed). Premium shellstock include "selects," which are individuals chosen from the production lines of producers that grow cultched products, and from cultchless oyster production companies.

The demand for oyster products far exceeds the state's production level, and the majority of shellfish products consumed in the state are imported from the Pacific Northwest and, to a lesser extent, the Atlantic and Gulf states. The California product is considered prime and the production areas are among the best in the country.

Shellfish Safety

The safety of shellfish products is part of the market attraction of the California product. The California Department of Health Services (CDHS) has regulatory authority over the commercial shellfish industry. The Department conducts regular monitoring programs that determine growing area sanitation and safety conditions. Two essential programs are the monitoring of the bays for indications of contamination by human sewage and for the occurrence of natural biotoxins, such as paralytic shellfish poison produced by toxic phytoplankton. These two monitoring programs provide a safe product for the consumer and also provide an early warning system for people sport-harvesting shellfish in noncommercial areas. The water and meat quality monitoring programs also provide an assessment of the biological condition of the natural resources of the bays in the hope of preventing a repetition of events that led to the contamination of San Francisco Bay.

The Biology of Oysters

Oysters are bivalve mollusks that exhibit a variety of sizes, shapes, shell textures and colors, and vary in their mode of reproduction and sexual expression. These biological and physical features influence such aspects as where they grow and how they reproduce, which in turn influence commercial aspects such as culture practices and marketing strategy. Individual oysters conform to the shape of the substrate to which they are attached and are therefore highly variable in shape. Shape is also influenced by other oysters or substrates pressing on their shells. Shell shape, texture, and color are all influenced by the oyster's genetic makeup and the physical environment such as salinity, attachment substrate, and food. They feed on phytoplankton and nutrient-bearing detritus by pumping water over their gills, which filters the food material and passes it into the oyster's mouth.

All oysters have typical molluscan trochophore larvae that develop into a veliger larval form capable of filtering food, swimming, and selecting a suitable substrate for attachment. The microscopic veliger settles, cements its left valve to the substrate, and undergoes metamorphosis into an oyster spat. For the rest of its life, the attached spat will compete for space and nutrients and, if it survives, will grow into the adult form. The four oysters now found in California all belong to the same family. They represent two groups characterized by biological variations, including different modes of sexual expression, reproduction, and dispersal of young. The exact temperature at which the oysters will spawn and the rate of larval development and growth depend on a variety of factors, including the genetics of the species and variety and the latitude of the breeding population. Natural spawning is also influenced by lunar periodicity and tides.

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Native and European Oysters (Genus *Ostrea*)

Native and European oysters are rhythmical consecutive hermaphrodites; they can change sex either annually or within a closer interval. In their first year, they are strongly protandric (i.e. the first expression of sex at maturity is male). They may become female in the same year or in the following year if the environmental conditions are good and food is plentiful. They are also larviparous (brooders); fertilization of eggs is internal and the larvae are held for awhile before release. Mature, egg-carrying females spawn at about 59-63° F. The eggs are released into the female's own mantle cavity and are fertilized as she takes in water containing the male's sperm. When the eggs hatch, the veliger larvae are held by the gillblades and incubate for about 10 days before release. Once expelled, the advanced larvae swim freely and feed on phytoplankton for an additional period before settlement and metamorphosis (Native, 14-18 days; European, 10-14 days).

Native Oyster: The Native oyster is California's only indigenous oyster species, and occurs along the Pacific Coast from Sitka, Alaska to Cape San Lucas, and Baja California. The largest concentrations occur in the Pacific Northwest along the coast of Washington's Puget Sound and in Willapa Bay. Although still grown commercially in Washington in specially constructed beds, natural concentrations are not abundant enough to support a commercial fishery. In California, populations of the Native oyster are still relatively low and it is a protected species.

The adult Native oyster is about two-to three-inches in length and more often irregular in shape. Shell textures vary from smooth to rough with concentric growth lines and the exterior has purple-brown to brown axial bands. The two shell valves are symmetrical; their interior is colored as shades of olive-green or with a metallic sheen. The adult internal shell's muscle scar is usually centrally located and not pigmented.

In California, the Native oyster is found in many of the state's coastal inlets, especially mud flats and gravel bars located near the mouth of small rivers and streams. It cannot withstand high temperatures or frost when exposed and does not survive low salinity or turbid water conditions. In bays, the natural beds are invariably located in the subtidal zone where the oyster is better protected from both prolonged hot summer surface water temperatures and extreme cold winter water conditions. They are often found clinging to rocky outcroppings or other structures that offer protection from rays and other predatory fish.

European Oyster: European oysters are hatchery produced on the West Coast. Adults are about three-to four-inches in length, with a poorly developed beak that gives the valves an oval to round shape. The left or attachment valve is larger and deeper-cupped than the right valve, with 20 to 30 ribs and irregular, concentric lamellae. The upper, smaller valve is flat, with numerous concentric lamellae but no ribs. The hinge ligament consists of three parts: a middle flat part on the left valve and two projections on the right. The internal valves are white and the muscle scar is eccentrically positioned and not pigmented.

Pacific, Pacific Kumamoto and Eastern Oysters (Genus *Crassostrea*)

The Pacific, Kumamoto and Eastern oysters are alternative hermaphrodites; sex change occurs, but its timing is erratic. They have a tendency for protandry in their first year, but the tendency is not as strong as that of Native and European oysters. They are oviparous (broadcast spawners); the eggs are immediately

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released and fertilization takes place in the environment. Mature, egg-carrying females spawn at about 63-77° F, depending on the species, variety, and latitude. These oysters require higher water temperatures to establish a natural population than are consistently found in California. Since spawning and successful reproduction rarely take place in California, the oysters are spawned and reared in shellfish hatcheries at about 77° F. The eggs hatch into free-swimming trochophores and then into veliger larvae; within three to five days, these settle, attach to a substrate, and metamorphose to the spat.

Pacific Oyster: The adult Pacific oyster averages about four-to six-inches in length. It has large, cup-like shells (valves) with coarse and widely-spaced concentric lamellae. The exterior of the shell has coarse ridges, is thinner than that of Eastern oysters, but is more deeply cupped. The upper valve is flat and smaller than the lower (left) valve. The internal surface is white, often with a faint purplish stain over the muscle scar or near the edges. The edges of the mantel are deeply pigmented.

Introduced from Japan, the Pacific oyster is now grown in Alaska, Canada, Washington, Oregon, and California. It is the most common oyster grown on the West Coast and the most common variety cultured is the Miyagi. Other common names used for the Pacific oyster include Japanese Oyster, Gigas, and Magaki.

Kumamoto Oyster: The adult Kumamoto oyster is about three-to four-inches in length, slightly smaller than the Pacific oyster, and demonstrates slower growth. The shell is dark gray to purple, wrinkled in appearance, and the right valve has ridges running toward the margin that give it a wavy appearance. The Kumamoto is highly valued as it has a deeply cupped left valve and a high ratio of meat weight to total weight.

The Kumamoto oyster was introduced to the West Coast from Ariake Bay, Kumamoto Prefecture, Japan. It was once considered a variety (Kumamoto) of the Pacific oyster, but recently elevated to species status through genetic studies conducted at the University of California, Davis, Bodega Marine Laboratory. Additional studies show that Kumamoto sperm cannot fertilize Pacific oyster eggs, but the opposite cross produces viable hybrids.

Eastern Oyster: Adult Eastern oysters may vary in length from two-to six-inches. The shells are asymmetrical, highly variable in texture and shape. The external shell is usually a shade of gray and the internal valves are white with a variable-colored muscle scar, usually deep purple. The left valve is longer than the right and not deeply cupped. The shell beak is usually elongated and strongly curved. The shell margins are usually straight or only slightly undulating and the inner margins of the valves are smooth.

Although not grown in abundance as that of the Pacific oyster, the Eastern oyster remains a valued aquaculture species on the West Coast. It is primarily a half-shell product and is still popular among West Coast consumers.

Future of the Industry

The rapid growth in California's population has brought increased environmental and social pressures as more people move into the state's coastal zone. Increased population and human activity continue to have negative impacts on the environmental quality of nearshore water and competing interest groups view and value coastal resources differently than that expressed in earlier decades. Nationally, it has been estimated that because of declining water quality, available approved oyster-growing areas are lost at a rate of 1.0 percent annually. In recent years, the actions of the California shellfish industry and environmental groups

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have brought local and state-wide attention to the issue of water quality. This attention has contributed to actions that have reduced the rate of decline in coastal water quality, but the overall trend is still somewhat negative.

One of the strongest arguments for a strong shellfish industry is its position as the "canary in the mine." As long as the shellfish industry exists, the bays and other shellfish growing-areas will be monitored for water quality to assure human health safety. The monitoring programs, including coliform, chemical, and biotoxin analysis, are concentrated to a greater extent in commercial shellfish production areas. These activities are one of the greatest deterrents to resource exploitation by any group using the coastal zone, including the shellfish industry itself. Commercial growers view the maintenance of coastal water quality as the first line of defense against the loss of the industry.

The California oyster industry is the oldest aquaculture industry in the Western United States. Despite its age, California and the Pacific oyster industry have demonstrated some of the most innovative adaptations to changing times and changing conditions. The development of the hatchery system and remote setting of oyster larvae is a West Coast phenomena that has demonstrated economic advantage and has had international impact. Hatchery production has led to the development of broodstock development which will, in turn, result in improved lines of commercial oysters. The diversity of product and production of cultched and cultchless oysters using new production technology has stimulated new growth in the industry and has opened additional growing areas. One of the more innovative adaptations has been the production of polyploid oysters, or sterile oysters with an extra set of chromosomes. Oysters that do not produce eggs or sperm do not develop a strong taste and remain in prime market condition well nto the summer months. These technical advances are designed to make the shellfish industry more competitive within the market place which will result in a stronger industry.

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Fred S. Conte
Department of Animal Science
University of California, Davis