University of California, Davis Department of Animal Science

CALIFORNIA CA AQUACULTURE

CALIFORNIA ABALONE AQUACULTURE

The Abalone Fishery

Abalone, marine snails of the genus *Haliotis*, have occupied the rocky intertidal and subtidal areas of the Pacific coast from Alaska to Baja California for at least 100 million years. Since human occupation of North America these mollusks have been important to the lifestyle and economy of all Pacific coast populations. Native Americans valued the abalone, using the meat as a source of food and the shell for implements, trade material and decoration.

Each successive human culture immigrating to the Pacific coast has recognized the value of abalone. Pacific coast commercial fishing for the eight species of abalone began in the mid-nineteenth century (Table 1). By the mid-twentieth century abalone populations had come under intensive fishing pressure as coastal population grew and fishing technology improved. Commercial fishing peaked at an annual harvest of over 2500 tons in 1957. About 2000 tons were harvested annually from 1957 to 1969, followed by a serious and continuing decline in commercial landings and abalone abundance since 1969. Commercial abalone landings for 1992, 1993 and 1994 were approximately 260, 230 and 140 tons, respectively. The red, pink and green abalone comprise most of the commercial take, but all California abalone species are in serious decline. Both commercial and sports fishing are regulated by specific size limits for each species of abalone, and a bag limit for each category of harvest. The black abalone fishery was closed in 1993 because of mortalities caused by Withering Syndrome, a disease that affects the abalone's foot. The disease has reduced black

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Table 1. Abalone (Genus *Haliotis*) found in California coastal waters.

Common Name	Species Name
Red abalone	*H. rufescens*
Pink abalone	*H. corrugata*
Green abalone	*H. fulgens*
Black abalone	*H. cracherodii*
White abalone	*H. sorenseni*
Threaded abalone	*H. assimilis**
Pinto abalone	*H. kamtschatkana*
Flat abalone	*H. walallensis*

* Considered by some to be a subspecies of the Pinto abalone. Several hybrid crosses of abalone have been reported from California waters.

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abalone populations near the Channel Islands to 10 percent of their 1986 levels. The decline in abalone abundance in California parallels the decline of abalone populations internationally. Overfishing has impacted the world abalone catch among the major fisheries, including that of Japan, Mexico, Australia, South Africa, and Korea. These declines, coupled with the value of abalone meat on the world market, have promoted the concept of abalone aquaculture internationally, both to supplement the world supply of abalone meat and as an enhancement tool to mitigate the damage to the fishery.

Abalone Aquaculture

Abalone culture in California was first attempted at Stanford's Hopkins Marine Station at Pacific Grove in 1940. Initial efforts focused on spawning adult red abalone and studying the larval stages. California's commercial abalone industry began as industry research and development (R&D) near Morro Bay in 1964. For over 20 years commercial R&D efforts continued, with additional research being conducted by the California Department of Fish and Game and the University of California. By the late 1980s the first commercial abalone farms were in transition from R&D to commercial viability, and currently there are about ten commercial operations in California.

Abalone growers have cultured nearly all of the California species. However, because of their value and adaptation to culture technology, the red abalone and, to a lesser extent, the pink and green abalone are the principal species grown in California aquaculture facilities. The pink and the green abalone are of greatest interest to growers in southern California because they can be grown at relatively higher water temperatures.

The Abalone Hatchery

Eggs and Larvae: Adult male and female abalone are maintained as broodstock, and then induced to spawn using either ultraviolet irradiated seawater or a solution of hydrogen peroxide. Both methods stimulate mature female abalone to release unfertilized eggs (called ova) and males to release sperm. An 8 inch mature female abalone may release in excess of 11 million ova of which 6 to 8 million will be fertilized and become viable eggs. Each ova is about 200 µ (1.0 µ = one micron = 0.001 mm = 0.000039 inch). The ova are mixed with a concentration of sperm and seawater, and the fertilized eggs begin cell division within two hours.

During the hatchery phase, the fertilized eggs are hatched and reared through the trochophore and veliger, free-swimming larval stages. The larvae are contained in flow-through water systems equipped with screens to prevent their escape. To protect the young abalone hatcheries use filtered and UV-treated water for all sensitive, early life stages. During this period the developing eggs and larvae derive nutrition primarily from yolk reserves. Some nutrient material is obtained from dissolved organic materials in the seawater. Eggs and larvae are reared in seawater at a temperature of about 15°C (59°F). The rate of development is temperature-dependent. Warmer water temperatures increase the rate of larval development, but increase the risk of bacterial infection in the culture systems.

At 15°C the eggs hatch and release ciliated, free swimming trochophore larvae within 16 to 20 hours. Within 26 to 30 hours after fertilization, the trochophore larva secretes a protective larval shell and transforms into the veliger stage. The veliger is characterized by a retractable velum, a ciliated leaf-like organ used

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for locomotion and respiration. As the veliger continues to develop, it forms an apical cone, undergoes a "typical" gastropod torsion (twisting of the body), the larval foot begins to form, eyespots develop, and the tentacle buds can be seen. Hatchery operators use these observations to judge the development and health of the larvae. When the veliger larva begins to "test" the substrate with its larval foot, the hatchery operator knows that it is ready to leave the water column and begin the crawling phase of its life cycle. Once settled, the veliger sheds its cilia and develops the juvenile shell and body form and characteristic abalone foot.

Juvenile Abalone: The first two months following settlement are the most critical to survival of juvenile abalone in culture systems. Juvenile abalone are reared in flow-through tank systems, and control of the environmental conditions such as temperature, water quality, and feed are essential. In general, water temperature is species-dependent, but usually range between 15 to 18 C. Water quality is determined by initial site selection in an area with an oceanic influence and water of 30 to 35 ppt (parts per thousand or g/liter) salinity. It should be free from harmful contaminants and monitored for temperature, pH, oxygen, and ammonia, and only filtered and UV-treated water used during these early life stages.

Natural Diets: Because all postlarval abalone are grazers, the animals are fed benthic (bottom growing) microalgae that is cultured at the facilities and seeded into the tank prior to introduction of the abalone. These diatoms form a thin surface film in the tank that is grazed by the young abalone. Maintaining a continuous supply of these diatoms in volumes sufficient to feed commercial densities of abalone is critical to a successful commercial operation. The abalone aquaculture industry has traditionally fed microalgal (benthic diatoms) diets to young juvenile abalone. Research suggests that the abalone also derives nutrition from bacteria, yeast and other microorganisms associated with the diatoms. Commercial operations producing ½ million to 1 million seed abalone per year sometimes have difficulty sustaining a healthy diatom growth in the culture tanks.

Artificial diets: Because of the uncertainty that always exists when feeding living diets to aquaculture animals, there is great interest in recent research in abalone nutrition and development of artificial abalone diets. The essential ingredients for an abalone diet are fairly well established. Developmental diets contain about 30 to 50 percent protein, 30 to 40 percent carbohydrate, and about 5 to 6 percent each of fat, fiber, and ash. The protein source can be fish meal or milk by-products, and the carbohydrate is usually from seaweed. Sometimes minerals and vitamin supplements are added. Research is also being conducted to determine the value of the combination of benthic algae and artificial diet as feed for young abalone.

All abalone-producing countries have one or more university research groups or commercial businesses involved in the development of abalone diets. Many California producers have found the artificial diets particularly useful for abalone between 3 and 6 months of age.

Abalone Intermediate or Weaning Systems

When juvenile abalone are about 4 to 6 months of age and about 6.4 to 13.0 mm (¼ to ½ inch) in shell length they are called "seed abalone". The seed abalone are transferred from the hatchery to intermediate culture systems, usually consisting of tanks with floating plastic mesh baskets containing fiberglass or PVC structures on which the abalone crawl.

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This stage of culture is sometimes called "weaning" since the abalone are weaned from their earlier diets to a diet of the giant kelp, *Macrocystis pyrifera*, or other large brown kelp such as *Nereocystus luetkeana*. Kelp is a natural food of the species of California abalone, and at this size the abalone's mouth parts are sufficiently developed to graze on the thicker, tougher fronds of the kelp. The abalone are held at high densities, and kelp is literally stuffed into the baskets around the internal structures, thereby providing the abalone with easy access to the new food. From this point forward, the abalone are maintained on a diet of kelp. The seed abalone are held in the intermediate system for 2 to 6 months or until they reach about 15.0 to 25.0 mm (½ to 1.0 inch) in shell length. At this point they may be sold as seed abalone to another company or transferred to a growout system within the parent company.

Abalone Growout or Production Systems

California growout systems have evolved from modifications of a number of designs pioneered by early California growers and other abalone growers internationally. Growout systems have included near-shore submerged and screened concrete pipe culverts, fifty-five gallon plastic barrels, and off-shore cage culture. Contemporary growers primarily use cage culture and land-based, flow-through tank systems.

Cage culture system: The cage culture system evolved from early barrel culture methods. Rectangular cages have proven more efficient, easier to handle, and give better survival rates than barrels. The cage culture system is used by several commercial operations in California and in Mexico's Baja California.

Many abalone cages are built by abalone growers, but commercially constructed cages (SeaCage™) are available. Cages are often constructed from PVC frames covered with heavy gage plastic mesh. Additional surface area is provided to the abalone by securing plastic or fiberglass plates in the cages. The cages are suspended from longline systems or from floating docks that provide access. Additional economic considerations should include costs for boat, motor, fuel, access time, and hydraulic wench to lift the cages for feeding, maintenance, and harvest.

Land-based, flow-through tank systems: Land-based growout production systems usually consist of reinforced concrete or fiberglass tanks of 1000 to 2000 gallon capacity that are plumbed for flow-through seawater and forced air. They should include secondary back-up systems for pumped seawater and forced air to provide the necessary oxygenated water essential to abalone survival. Energy expenditures to operate the seawater pumping and aeration systems are a major cost for land-based systems.

In both cages and flow-through tanks, it takes 3 to 4 years for abalone to grow to a commercial marketing size of about 7.6 to 8.9 cm (3 to 3 ½ inches). This is the most capital intensive and time-consuming portion of abalone aquaculture, and labor and feed costs are a major consideration for both types of culture systems.

Source of kelp: Kelp for abalone intermediate and growout production is harvested from California's offshore kelp beds, and regulated under permits issued by the California Department of Fish and Game (CDFG). An abalone farm has the option to harvest kelp using its own vessel and operators or to purchase kelp from a licensed kelp-harvesting company. Kelp is harvested for use in a number of products ranging from ingredients used to culture bacteria to stabilizers for ice cream. About

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half of the kelp beds in California off-shore waters are designated as "open" by the CDFG, and anyone with a permit can harvest kelp from these beds. Several abalone farms lease specific kelp beds from the State and have exclusive harvesting rights on these beds. The harvest of kelp is highly regulated and monitored by the Fish and Game Commission. Whether harvested from open or leased beds, kelp can only be cut at a depth of four feet below the surface. Regulations are designed to maintain a sustainable resource. Commercial growers also collect, dry and store kelp to prepare for feeding during times when seas are too rough to collect fresh kelp.

Abalone Production and Marketing

Production: Estimated California abalone aquaculture production for 1992 was 132,000 pounds of live abalone valued at $2 million. In 1994 estimated production was 242,000 pounds valued at about $3.1 million.

Marketing: Abalone products are marketed as an up-scale product. Its high international market value allows growers to recoup an expensive and relatively long-term production investment. In general, the demand for abalone exceeds the supply. For example, in 1993 Japanese harvest of their native abalone was approximately 2,000 tons, but Japanese demand for abalone product was about 4,000 metric tons. The Japanese import abalone from China, Korea, Australia and California.

Most California abalone aquaculture operations include a marketing partner for product development. Abalone are primarily marketed live to domestic and international markets, and shipment of live abalone is presently considered the most cost effective and desirable market for growers. In 1994, 60 percent of cultured abalone were sold live, 30 percent were sold as shucked meat, and 10 percent were sold in other forms including as seed. Major international markets are Japan, Taiwan and Hong Kong. Domestic markets include white tablecloth restaurants, seafood markets, sushi bars, and resorts throughout the continental United States

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