18 Culture of Abalone, *Haliotis spp*.

Red abalone (*Haliotis rufescens*) cultivated at the Department's Granite Canyon Laboratory. Photo credit: Peter Haaker.

History

Pioneering efforts to mass cultivate abalone in California began about 35 years ago. Three abalone species, red (*Haliotis rufescens*), green (*H. fulgens*), and pink (*H. corrugata*) have been farmed, and research into cultivation techniques has been conducted on black (*H. cracherodii*) and white abalone (*H. sorenseni*). The red abalone, however, is the mainstay of the industry and comprises more than 95 percent of total production.

Abalone are grown in either land based tanks or in cages suspended in the water column. The cages are typically tethered to a raft but have also been suspended beneath a wharf. Aquaculturists that operate these in-water systems typically obtain small seed abalone from land based hatcheries for grow out.

In a typical hatchery operation, ripe broodstock abalone are induced to spawn using hydrogen peroxide or ultraviolet light treated seawater. Fertilized eggs that successfully develop to the veliger swimming stage are transferred to flow through larval rearing tanks. In about 6 days at 59ºF (15ºC), larvae are ready to settle from the planktonic to the benthic stage. They are transferred to nursery tanks, and commence to feed on diatoms. After six months of growth, 0.5 inch (13 millimeter) abalone are then transferred to larger tanks. At this point, the abalone begin feeding on macroalgae. An additional 6 to 8 months are required before they reach the size where they are transferred to grow out tanks or in-water systems. After growing in these tanks or in-water systems for 20 months or longer, they attain the typical 3 to 4 inch (76 to 101 millimeter) shell length preferred by the market.

The number of participants in the abalone industry and their total production were correlated over time prior to the first peak in production in 1997 (Figure 18-1). Following this peak, production declined and then increased as the number of industry participants declined. In 1991, 15 registered abalone aquaculturists in California produced an estimated 175,000 pounds (79 metric tons) of abalone in the shell worth $2.3 million. By 1996, 27 registered abalone aquaculturists produced over 292,000 pounds (132 metric tons) of product. Participation then declined slightly to 22 aquaculturists in 1998 while production increased to an industry high of 395,890 pounds (180 metric tons) of product valued at $5.3 million. Only 13 of the 22 abalone aquaculturists registered in 1998 were actively producing abalone and most of the production came from 4 or 5 growers. As of 2008, the number of industry participants has shrunk to total of 7 growers, with 3 to 4 large growers producing most of the state's cultured abalone. Production is expected to remain around 500,000 pounds (227 metric tons) per year but the global financial downturn and greatly increased production and competition from foreign abalone producers will force the industry to pull back from the export markets and develop more lucrative domestic markets.

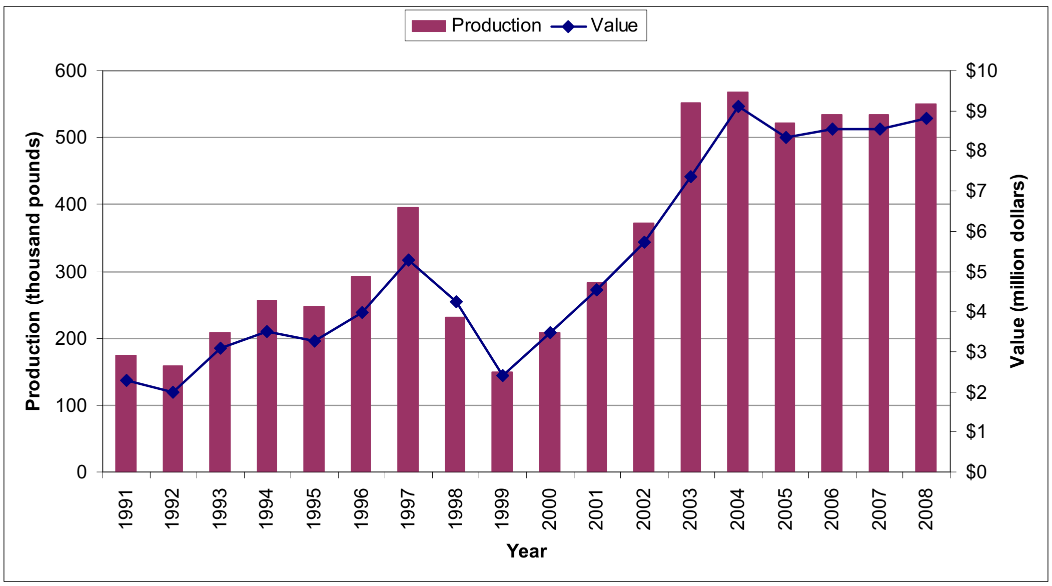

Figure 18-1. Abalone production and value, 1991-2008. Data Source: California State Tax records (royalty reports) and Department Aquaculture Harvest Survey Database. Production includes human consumption only; value includes both seed production and human consumption.

The long term decline in participation and two-year drop in production after 1997 are attributable, at least in part, to disease impacts exacerbated to some extent by a significant El Niño event. Until recently, cultivated abalone had been considered relatively disease free. The bacterium *Vibrio sp*. infected larval cultures, but it was typically suppressed by using filtered, ultraviolet treated seawater. That perspective changed with the introduction of a parasitic sabellid polychaete worm from South Africa. By the mid 1990s, the parasite had spread to virtually every abalone aquaculture facility in the state. The worm induces the infested abalone to form a tube for it out of nacreous (shell) material. With heavy infestations, the abalone shell is brittle and very deformed and abalone growth is stunted. Impacts to the industry included loss from voluntary stock destruction and reduced income from marketing deformed product. Cooperative efforts by the industry, the California Department of Fish and Game

(Department), and Sea Grant-sponsored university researchers have almost completely eradicated the parasitic worm from California.

Unfortunately, the industry also started experiencing elevated losses of cultured product from withering syndrome (WS) during this same time frame. This disease is characterized by a drastic shrinkage of the abalone's foot. The disease has been shown to be caused by a unique bacterium or Rickettsiales-like prokaryote that infects cells lining the gut, and is now sometimes referred to as 'abalone rickettsiosis'. Abalone can be infected by the bacterium without showing clinical signs of disease, especially in cooler water temperatures. For example, in one study no farmed red abalone infected with the causative agent of WS and held at 58°F (15°C) for nine months experienced mortality or signs of disease, while 33 percent of corresponding animals held at 65°F (18°C) died while showing signs of the disease. Similarly, during the 1997-1998 El Niño event, many facilities experienced elevated water temperatures that triggered WS, resulting in elevated mortality in their cultured stock. Research has shown that the disease can be controlled by oral or bath administration of the antibiotic oxytetracycline, but this is generally practical only for treating small numbers of important animals such as broodstock.

In September 2007, a large red tide event caused by the dinoflagellate *Cochlodinium sp.* led to large scale mortality at one facility. Toxic algal blooms have become more common in nearshore waters off of California in recent years. The dinoflagellate impacted the abalone by causing gill damage and by also lowering the amount of dissolved oxygen in the seawater. Growers working with a number of agencies and groups that monitor oceanographic and weather patterns were able to successfully predict another red tide event and avoid potential mortality by lowering the cages containing abalone to the bottom where dissolved oxygen was high and concentrations of toxic algae were low.

The dedicated entrepreneurs at the core of this industry have achieved their successes despite these challenges and interest in abalone aquaculture remains high, prompted in part by the closure of the commercial abalone fishery in 1997. Presently, abalone are available to meet market demands only through importation or the purchase of cultured abalone (Table 17-1). Consequently, there is a high market demand and a good price to growers for the farmed product. The large amount of illegally harvested wild abalone remains a problem worldwide since this product is sold at a reduced price impacting the legal wild harvest and cultured abalone sectors. In 2002, the Department estimated the illegal commercial take of abalone to be 265,000 pounds (120 metric tons) per year. In South Africa the illegal take is so large that if poaching continues at the current rate, abalone there may be fished to extinction.

Table 17-1. World Abalone Production (short tons live weight) for the years 2004 and 2005.			
Country	**Culture**	**Legal Harvest**	**Illegal Harvest**
China	4960		
Taiwan	3307		
South Africa	661	261	2039
Japan	220	2425	591
USA	287	0	132
Australia	320	5653	1102
Chile	220		
Mexico	55	1175	606
New Zealand	3	1188	441
Other	33	487	121
Total	10,067	11,189	5033
Grand Total: 26,290 short tons (live weight)			

Data source: Trends in World Production, Rodney Roberts, Paua Industry Council, New Zealand, 2005.

A more recent positive development in abalone aquaculture is the production of cultured abalone pearls. The product is produced by inserting a nucleus into the abalone. Given time, nacre is laid over the nucleus to form a semi-spherical pearl that has all the lustrous hues of the shell interior. Once extracted, these pearls are set in jewelry and the meat is processed for sale to restaurant trade as either a fresh or frozen product.

Status of Biological Knowledge

A considerable amount of research on abalone aquaculture has been accomplished by the private sector, particularly with respect to systems design and overall technology. University and Department scientists have also made major contributions. Sea Grant-funded research has greatly increased our understanding of abalone developmental biology. Spawning induction procedures, larval settlement inducers and larval rearing systems were developed by researchers funded through this program. Sea Grant-funded research has also contributed significantly to our understanding of abalone diseases.

The Department began abalone culture investigations in 1971 at its Granite Canyon Laboratory near Monterey. That effort led to the development of a flow through larval rearing system and the development of a flush-fill tank system that was adopted by the industry. The Department subsequently developed a pilot production hatchery at Granite Canyon that provided training opportunities and resulted in the production of seed abalone for enhancement research.

The Department's Shellfish Health Laboratory in Bodega Bay has expanded our knowledge of the biology of the parasitic sabellid worm contributing significantly to the success that has been achieved in the cooperative eradication efforts. The laboratory also identified the causative agent for WS and has conducted extensive research into questions related to transmission and control of this pathogen.

Two principle areas for research, nutrition and genetics, may provide significant benefits to the industry in the future. Prepared diets have been developed and are being used widely for juvenile stages. However, most prepared feeds are expensive and not readily accepted by adult abalone in comparison to giant kelp. Recently one of the Monterey growers has been working with California Sea Grant looking at raising red algae as a food supplement and studying its effect on growth rate, shell color and product taste. Results are promising at feed rates of just 6 percent of the diet. Less progress has been made in genetics research. Most growers use a selection process where broodstock is selected based on growth rates. Wild broodstock is also used to maintain genetic diversity in cultured stocks. Some research has been done with triploidy (3 sets of chromosomes) as a means of enhancing abalone growth rates. While encouraging, the results have not been applied broadly within the industry. Recent successful research on the cryopreservation of abalone sperm may greatly benefit controlled breeding programs to assist the development of strains of red abalone that are optimized for domestic production.

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Further Reading

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Abalone production and value, 1991-2008.					
Year	**Pounds**	**Value**	**Year**	**Pounds**	**Value**
1991	175,000	$2,275,000	**2000**	208,300	$3,466,088
1992	157,900	$1,976,000	**2001**	283,000	$4,528,000
1993	208,589	$3,072,358	**2002**	372,577	$5,728,593
1994	256,582	$3,500,541	**2003**	551,600	$7,373,600
1995	248,050	$3,256,251	**2004**	568,793	$9,100,688
1996	292,000	$3,971,177	**2005**	522,000	$8,352,000
1997	395,891	$5,280,910	**2006**	535,000	$8,560,000
1998	231,442	$4,246,607	**2007**	535,000	$8,560,000
1999	150,000	$2,398,457	**2008**	551,000	$8,816,000

Data Source: California State Tax records (royalty reports) and Department Aquaculture Harvest Survey Database. Production includes human consumption only; value includes both seed production and human consumption.