Seafood Watch
Seafood Report

MONTEREY BAY AQUARIUM®

Farmed Clams

(Illustration © Monterey Bay Aquarium)

All Regions

Final Report
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About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives", or "Avoid". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Fisheries Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling (831) 647-6873 or emailing seafoodwatch@mbayaq.org.

Disclaimer

Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Executive Summary

Aquaculture accounts for approximately 3.8 million metric tons (mt) of clams, 33% of total world bivalve aquaculture production in 2003. Clams have a broad, worldwide distribution and can be cultured in many countries. The United States produces the majority of clams consumed within the country, and the main foreign source of cultured clams is Canada.

Clam "spat" for aquaculture are captured from the wild by manual collection or dredging, or are produced in hatcheries and transplanted to sites in coastal waters for grow-out. The capture of wild clam spat for use in aquaculture does not appear harmful to natural clam populations because spat are transplanted to sites that are generally superior to those where spat would settle naturally. On-bottom culture of clams is the most common method for grow-out.

Fertilizers and feeds are not applied at grow-out sites for clams, so nutrient additions do not occur. Antibiotics, drugs, and other chemicals used in some other kinds of aquaculture for disease control are seldom used in clam grow-out activities.

Clams are filter feeders and remove particulate matter from the water. Thus, they remove organic matter and nutrients from the water column and can improve water quality. Clams also remove viral and bacterial particles from the water and thus can accumulate algal toxins, pesticides, heavy metals, and other toxic substances. Clams cultivated at polluted sites or in waters with toxic algal blooms may be contaminated with disease organisms or toxins.

Dredging of clams from culture plots can have negative impacts on the seabed and cause benthic diversity to decline and presents a moderate risk for environmental degradation. However, the effects are typically short-lived and biodiversity in culture plots is restored within a short period of time. Management is generally considered effective, where Best Management Practices (BMPs) are thought to reduce environmental impacts and effectively control the use of unapproved therapeutants. Farmed clams present relatively few threats to biodiversity and ecological integrity and thus are considered a Best Choice by Seafood Watch®. If possible, consumers and businesses should seek out clams harvested without the use of mechanical dredges.

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√			
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√ hand-raked	√ dredged		
Management Effectiveness	√			

About the Overall Seafood Recommendation

- A seafood product is ranked "**Avoid**" if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.
- A seafood product is ranked "**Good Alternative**" if the five criteria "average" to yellow (Moderate Conservation Concern) OR if four criteria are of Low Conservation Concern (green) and one criteria is of High Conservation Concern.
- A seafood product is ranked "**Best Choice**" if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.

Overall Seafood Recommendation

Best Choice ▮   Good Alternative ▮   Avoid ▮

Introduction

Most concerns about the possible negative environmental impacts of aquaculture have focused on culture of freshwater and marine fish in cages, flow-through systems, and ponds, and the production of marine shrimp in ponds (Goldburg and Triplett 1997; Naylor et al. 2000). There has been much less discussion of the potential negative effects of the culture of bivalve shellfish as a result of the comparatively low impacts of producing them. Bivalves are filter feeders that obtain their nutrition by removing suspended particles from water. Because it is not necessary to apply feeds to stimulate production, bivalve farming does not increase nutrient inputs to coastal waters. In fact, an increase in abundance of shellfish in an area is usually considered to have a positive benefit on water quality (Shumway et al. 2003).

Bivalve aquaculture includes the production of oysters, clams, mussels, and scallops. Statistics from the United Nations (UN) Food and Agriculture Organization (FAO) reveal that clams are a popular seafood item and that the harvest from the sea cannot meet the demand. The culture of these organisms increased from 1.1 million mt in 1993 to nearly 3.0 million mt in 2003 to account for about 89% of world clam production.

Shumway et al. (2003) discussed the environmental virtues of bivalve culture in comparison to other types of aquaculture. They state that bivalve aquaculture has great potential for increasing seafood production without causing negative environmental impacts.

Clams are an expensive and increasingly-popular member of the bivalve group. There is rapid expansion of the clam aquaculture industry and as demand grows production practices of this activity require analysis.

Basic biology

The term clam is a broad classification of a number of species in the order *Bivalvia*. Clams are recognized easily by their bilateral symmetry. The organism is completely enveloped by a mantle which is divided into two lobes. Each lobe secretes a shell, and the two halves are held together by a ligament and a hinge. The head is rudimentary without eyes, tentacles, or radulae. The margin of the mantle is the main contact with the environment. Because of this feature, the mantle often develops sensory organs. The foot is without a crawling surface, but is well adapted for movement in mud or sand. It also can serve as a digging mechanism. Two large gills on the mantle are used for both gas exchange and feeding. Bivalves feed on fine plankton, bacteria, and detritus. The particles are ingested through the incurrent siphon and captured by mucus-coated cilia on the gills. The particles then pass to the digestive system. When the valves are closed periodically, water is forced out of the exhalent opening or siphon taking wastes along with it.

Ark shells and cockles often are grouped with clams. Cockles and ark shells are close relatives of clams and for all practical purposes can be considered clams (Dore 1991). Furthermore, FAO combines production data for cockles and ark shells with clams. The common trait that links the numerous clam species is their ability to burrow (Gosling 2003). The major species of clams significant in aquaculture are the Manila clam (*Venerupis philippinarum*), the razor clam (*Sinonovacula constricta*), the blood cockle (*Anadara granosa*), and the hard shell clam or northern quahog (*Mercenaria mercenaria*). The Manila clam is native to the western Pacific Ocean including Japan, China, Korea, and the Philippines. It has been introduced to the eastern Pacific coast of North America and to the waters of the North Atlantic with varying success. The natural habitat of the Manila clam is bays and protected coasts. This species inhabits intertidal and shallow tidal zones, and it can burrow up to 10 cm in the seabed. Razor clams are native to the coasts of Japan and China. The razor clam inhabits intertidal areas with flat, muddy or sandy to muddy bottoms. The blood cockle, native to Malaysia, is a commercially important species in Thailand and Malaysia. It prefers to inhabit muddy bottoms in intertidal flats. The blood cockle typically burrows to shallow depths with part of the shell exposed. The hard shell clam is native to the eastern coast of the United States. This species can burrow up to 10 cm deep and prefers sandy to muddy intertidal zones.

Clam species all have a similar reproductive pattern. Once individual clams are ripe, some stimulus, often a rapid rise in temperature or exposure to the spawn of another clam, will trigger spawning. Eggs and sperm are released into the water where fertilization occurs. The fertilized eggs develop into straight-hinge, free-swimming larvae within 1 to 2 days. The shelled larva is called a veliger larva because of the velum with which it swims and eats. The microscopic clam feeds on phytoplankton. The veliger stage lasts for about 2 weeks. At this point, it becomes a pediveliger. A larva in this stage crawls with its foot and swims with its velum looking for a suitable habitat for adult growth. As the clam grows larger it hangs onto substrate by byssal threads similar to those generated by mussels. This gives some protection against being washed away by waves or currents. The early reproductive development of clams is depicted in Figure 1. The natural predators of clams include birds, fish, starfish, crabs, snails, and humans.

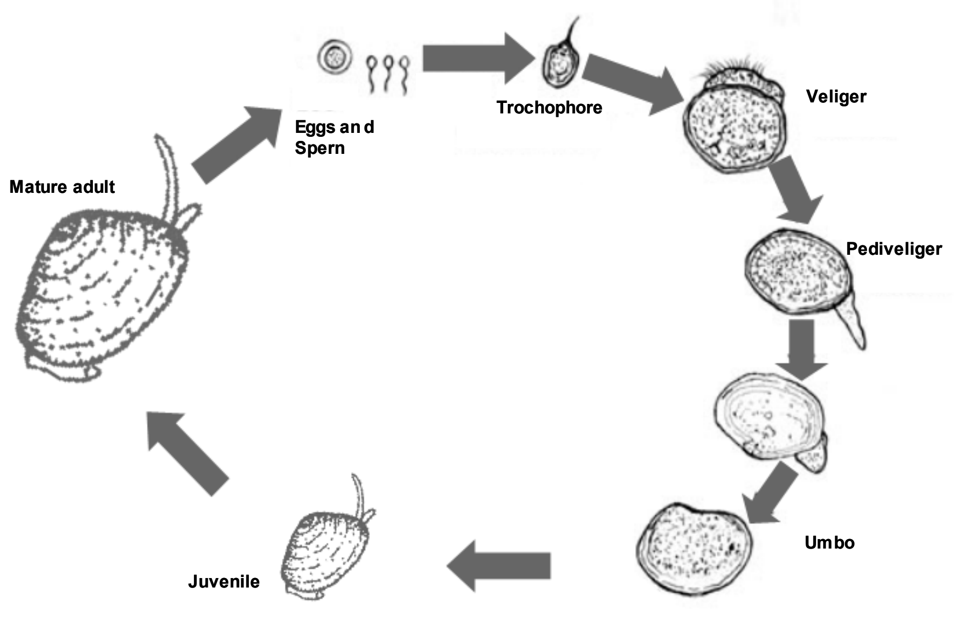

Figure 1. Early developmental stages of the clam. Image adapted from International Marinelife Alliance, Philippines.

Aquaculture production

The demand for clams has exceeded natural production, thus aquaculture is the main source for global clam production (Figure 2).

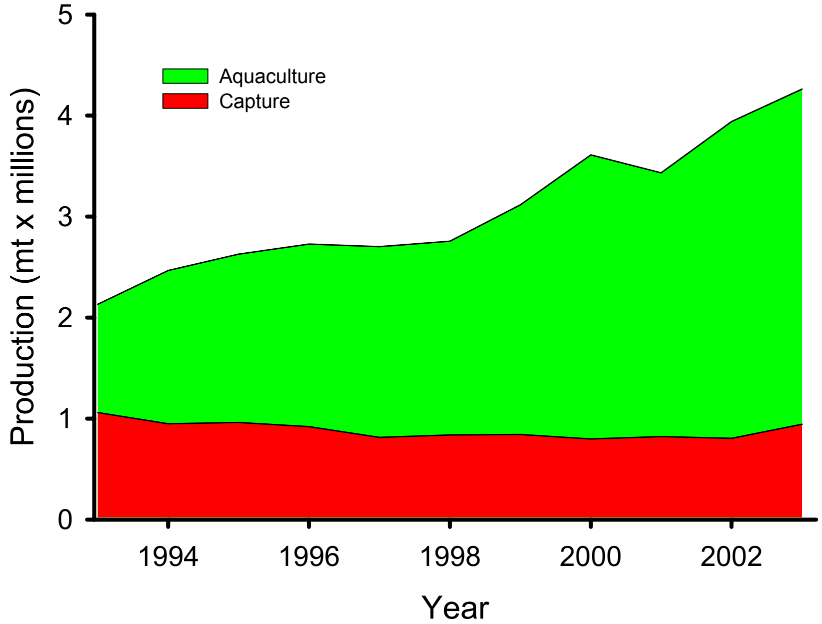

Figure 2. Comparison of clam aquaculture and wild capture of clams. Source: FAO 2005.

The value of world clam aquaculture production has increased from $1.8 billion in 1993 to $4.2 billion in 2003 (Figure 3).

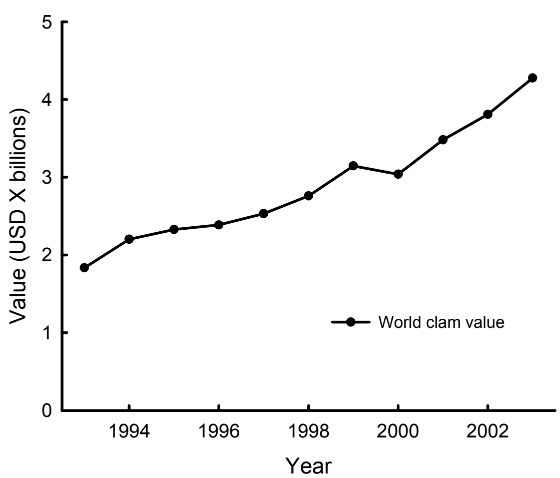

Figure 3. The economic value of farmed clams. Source: FAO 2005.

The major producer of clams is China, followed by Malaysia, Thailand, the United States, Korea, Taiwan, and Italy (Figure 4).

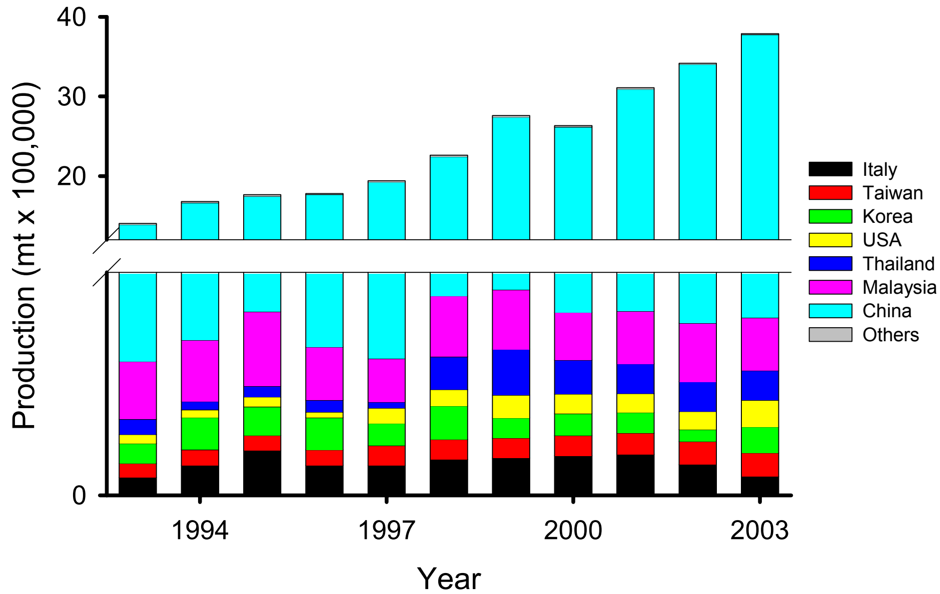

Figure 4. The major countries producing cultured clams. Source: FAO 2005.

China
In China, hatchery-rearing of clam spat is seldom practiced and most of the seed for grow-out is collected by hand from natural habitats. The major species of clams produced in China are the Manila and razor clams. In Chinese clam aquaculture, spat are transferred to nursery ponds in the intertidal zone, where the clams are held for several months before being transferred to grow-out plots in mud flats. China produced 3.5 million mt of clams via aquaculture in 2003. This value dwarfs the clam production of other nations (Figure 3). Additionally, China increased clam aquaculture production by over 0.5 million mt from 2000 to 2001. This increase is enormous and elicits questions about the reliability of the data.

Thailand and Malaysia
In Thailand and Malaysia, the cockles *Anadara granosa* and *Anadara* spp. are produced by aquaculture. *Anadara* spp. is the most common clam produced in Thailand, but there are no natural spatfall of *Anadara* in Thailand. Thus, Thai clam producers depend on Malaysia to provide wild seed for the grow-out activity centered in Satun province in southern Thailand. Malaysia is also in the native range of the Manila clam, and this species is cultured in Malaysia in addition to cockles.

There has been a steady decline in production of clams in Thailand. In 1999, the production was close to 62,000 mt, but by 2003 production declined to 40,000 mt. Clam and cockle culture in Thailand has been hindered because of the absence of a naturally reproducing, profitable clam species. Although clam hatcheries have been constructed in Thailand, most small farmers still are reliant on the seed from Malaysia. Malaysia was one of the top producers of clams and cockles in the 1990s, but there has been a significant decline in production in Malaysia as well, from 99,000 mt in 1995 to 71,000 mt in 2003. The decline may have resulted from overexploitation of natural stocks through capture for seed and for the market.

Italy
The major clam culture area in Europe is the northern Adriatic Sea, Italy, and the main species is the Manila clam. In Europe, over-fishing and irregular yields of the native, grooved carpet shell (*Venerupis decussates*) led to introductions of the Manila clam in the 1970s and 1980s (Gosling 2003). The Manila clam has had limited reproductive success in European waters, and this has led to increased efforts to establish hatcheries. However, in Italy, there are no commercial clam hatcheries; consequently seed stock is imported from the United Kingdom, Spain, and France. Over the past decade, Italy has doubled its aquaculture production of clams primarily through the culture of the Manila clam. Italy is the largest aquaculture producer of clams in Europe, and as a result, much of their product is exported to other European countries.

Korea
Aquaculture of bivalves is a large industry in Korea, and numerous species are cultured. In 2001 approximately 45,000 hectares (ha) of the coastal area devoted to marine aquaculture, or mariculture, were used for molluscan aquaculture (Bai and Kim 2001). Oysters represent the largest portion of the industry, but clams, primarily blood cockles (*Anadara* spp.), Manila clam, and the short-necked clam (*Tapes japonica*) are important species. The production of clams in Korea has decreased over the past decade from 93,000 mt in 1992 to 35,000 mt in 2003. Korean hatcheries began producing oyster seed in 1990 for commercial sale. The high availability of oyster seed is thought to have decreased efforts to culture clams, as oyster is a more profitable species.

Taiwan
The primary clam species cultured in Taiwan is the hard clam (*Meretrix lusoria*) (Cover page image). The hard clam industry in Taiwan has been somewhat variable because of water pollution. During periods of heavy rain, water carrying industrial pollutants is flushed from rivers into estuaries. These industrial chemicals are toxic to clams, and mortalities up to 50% were observed in the 1980s (Chen 1990). Clams are raised in hatcheries and stocked into either estuarine plots or tidal ponds. Taiwan is still recovering from the pollution effects of rapid industrialization; however, it is making efforts to adopt more environmentally sound industrial techniques to lesson water pollution. Aquaculture is benefiting from these efforts, as production in Taiwan has increased gradually from 19,000 mt in 1991 to 32,100 mt in 2003.

United States
The United States (US) has a well-developed clam farming industry on both the Pacific and Atlantic coasts. The US produces both Manila clam and hard shell clam, but the most productive species has been the hard shell clam. The hard shell clam lives in sandy-bottomed bays and coves, and along beaches from Canada to Texas; however, it is found only sporadically north of Cape Cod. Most of the original US clam culture was centered in the New England states, but the industry spread southward to Virginia, North Carolina, and South Carolina. Since 1984, clam culture in Florida has been expanding rapidly, particularly in the Indian River Lagoon. This appears to be the new frontier for hard shell clam mariculture in the United States.

The United States has increased clam production markedly in the past decade. In 1992, production was 8,528 mt, and in 2003 it was 35,700 mt. The US still imports more clams than it exports, however. In 2003, the US imported 4,353 mt of clams between January and June, while it exported only 2,030 mt (Aquaculture Magazine 2004).

Canada

Although Canada is not as large a clam producer as the US, there is significant importation of clams into the US from Canada. Manila clam is the dominant species raised on Canada's west coast, while hard clam and soft shell clam are the dominant species cultured on its east coast.

Aquaculture systems

Clam culture consists of two major activities: capture or hatchery production of seed stock; and grow-out of seed stock to marketable size. Mature clams are spawned under hatchery conditions. Fertilized eggs are incubated until hatching and transferred to nursery tanks for larval development. When larval clams reach juvenile size they are transferred to the grow-out location. Grow-out of juvenile clams is typically conducted in the intertidal zone of a bay or estuary. Both the production of seed stock and the grow-out phase of clam production are similar regardless of species cultured.

Seed stock production

Capture

Spat for clam culture can be obtained from the wild by sieving sediment from areas of heavy settlement with hand tools or with mechanical, hydraulic devices (Spencer 2002). However, wild spat capture is not commonly practiced except in Asia. In the rest of the world, clam spat usually originate from hatcheries.

Hatcheries

The success of a hatchery is related directly to the availability of sufficient amounts of good quality water. Temperature and salinity play an important role in spawning and larval development. Therefore, to reduce costs of adjusting temperature and salinity, hatcheries should be located where water quality is nearly optimal. Hatcheries typically are located near the shore of a bay or estuary where sufficient quantities of water can be pumped into the facility. In some instances, water for hatcheries is pumped from a greater distance offshore to avoid pollution and ensure adequate water quality. Continuously-flowing seawater is not necessary in a hatchery because both larvae and algal food are cultured in standing water (Castagna and Manzi 1989). Brood stock management requires small amounts of water exchange.

Hatchery design depends on the method of algal culture. The Glancy method requires sunlight for algal production, and consequently, solaria and greenhouse-type structures are employed (Glancy 1965). Recent innovations have caused a shift from the Glancy method to a more controlled hatchery environment consisting of artificial light sources, insulation, and heat exchangers for water temperature regulation (Figure 5). In newer hatcheries, pipes and tanks are constructed almost solely from fiberglass and plastic. These structures allow easy manipulation of hatchery organization, and they also typically are cheaper than concrete tanks and metal pipes. The constant challenge of reducing fouling in pipes and tanks requires rearing units and plumbing that can be rapidly disassembled for cleaning and easily reassembled. Antifoulant chemicals are not used in the hatchery because larval tolerance to such chemicals is typically low (Castagna and Manzi 1989).

Brood stock management

Clams for brood stock are usually selected from wild stocks for optimal color and morphological traits as well as rapid growth rates and high fecundity and survival. Because most modern clam hatcheries can control the rearing environment, spawning can take place at any time of the year. Clams of 35-80 mm in shell length are optimal size for spawning (Spencer 2002). After an adequate brood stock is established, it can be used in gamete production for several years. Clams collected from the wild for brood stock are quickly transferred to the hatchery where they are cleaned and placed in holding tanks where final selection can be made. Once final selection has been completed, the adult clams are transferred to conditioning tanks where they are kept until they are ready to spawn. The clams are placed on a mesh screen suspended in a stream of flowing water of about 35 parts per trillion (ppt) salinity (Spencer 2002). Early gonadal development can be stimulated in several days to several weeks by holding mature clams in warm seawater and providing ample supplies of food (Loosanoff and Davis 1963).

There are several feeding methods that rely on food provided by natural seawater or controlled algal production in the hatchery. Most modern molluscan hatcheries use algae produced on-site to reduce introductions of disease and fouling organisms common in natural water. Algae typically are cultured from pure cultures of commercially available algae. An initial nutrient solution is made using sterile water and inoculated with the algal culture. Following initial inoculation, the algae are incubated in containers of increasing size as the population of algae grows. Aeration is used to provide adequate dissolved oxygen and mixing to stabilize algae blooms. Input of algae as food for clams is based on abundance of cells in algal cultures.

Brood stock are typically fed unicellular, marine algae. There is, however, some debate over the optimal amounts and proportions of algal species offered to the brood stock. Thus, different hatcheries may offer quite different amounts of algae. Practical experience, availability of algae, and species cultured will dictate the algal feeding regimes employed in a specific hatchery.

Spawning

Clams chosen to spawn are taken from conditioning tanks and transferred to spawning troughs. Spawning troughs are shallow tanks fitted with a dark material on the bottom so eggs and sperm can be observed easily (Spencer 2002). Some hatcheries use serotonin 5HT to stimulate spawning (Gibbons and Castagna 1984), but this practice is not common and normally is used only for reluctant spawners. Temperature cycling is the most common method to induce spawning (Loosanoff and Davis 1963; Spencer 2002). The trough is partially filled with cool water to stimulate the extension of the clam's siphon. After 15 to 30 minutes, the water is drained and replaced with warmer water. Sometimes gonads from sacrificed clams are ground and injected into the water near the intake siphon of each clam. This process is repeated for 1 to 6 hours. After several hours, if there are some clams that do not spawn, they are returned to the conditioning tank. If some males spawn before the females, they are taken out of the water to impede gamete expulsion. If mass spawning is desired, males are left in rearing tanks until there is sufficient egg production; however, some culturists prefer to control the amount of eggs and sperm in the environment (Castagna and Manzi 1989). In this method, clams can be isolated in containers and appropriate quantities of sperm and eggs combined.

Fertilization of Manila clam eggs occurs within 60 to 90 minutes in waters at 25°C with salinity greater than 28 ppt (Spencer 2002). Fertilized eggs are collected and gently washed through mesh screens to separate them. Egg incubation requires the highest quality water, so water should be filtered to remove fungi and bacteria. Modern facilities use ultra violet filters to sterilize water (Figure 5). Utting and Helm (1985) recommended adding 1 mg/L of ethylenediaminetetraacetic acid (EDTA) to water in incubation containers to complex potentially toxic heavy metals. Aeration is not used during embryonic development. Within several days, eggs develop into D-larvae (the D is used in reference the shape of the larvae).

Larval development
After the D-larval stage, densities are reduced to ensure adequate growth. Aeration or induced upwelling necessary to keep the larvae in suspension is provided by oil-free pumps (Helm and Spencer 1972). Water quality requirements are similar to those of the incubation vessels. Feeding of prepared algal culture is begun at the D-larval stage. Water is exchanged several times per week in the larval rearing tanks. During cleaning, organisms can be graded and deformed larvae discarded. Because clam larvae are planktonic during the first 10 days of development, feeding is increased during this period, but as the larvae reach the pediveliger stage, the feeding rate is lowered.

Procedures for rearing pediveligers vary greatly and usually involve transfer at 2 to 3 weeks to a system that can hold them in suspension. An airlift pump normally is used to force water down through the culture unit. This action suspends healthy pediveligers away from dead or sick larvae, which collect on the bottom of the tanks. Algae are applied to culture units as food for the pediveligers. Once metamorphosis has taken place, clams can no longer swim. They are able to move up and down the sides of the containers by use of the foot. Because spat are quite mobile, they can migrate above the water surface of the rearing unit. They should be placed back in the water or mortalities may occur because of over-exposure to the air (Spencer 2002). The metamorphosis process can be accelerated by the addition of L-dopa or epinephrine (Coon et al. 1985).

Nursery
There are three common types of nursery systems. The upflow method suspends spat on mesh screens in the water column while water is forced up from the bottom of the rearing unit. This method allows for constant water flow to bring food organisms to the juvenile clams (Spencer 2002). A less common nursery system uses wooden trays lined with plastic and with a thin layer of sand on the bottom. Spat are placed in the trays, which are then placed in a fiberglass raceway. The third type of nursery is a land-based system more common in Asia where there are sufficient natural spatfalls year round. The land-based system usually involves creating an intertidal pond in which spat can be placed in trays with sand. The ponds are filled with seawater and clams are allowed to feed on natural organisms. Algal cultures are not added to these ponds, but manure may be added to ponds to stimulate algal blooms.

Grow-out
After reaching appropriate size, clams are transferred to grow-out plots in the intertidal zone of bays and estuaries (Loosanoff and Davis 1963). The grow-out activity is simple but requires constant monitoring to ensure adequate production. Siting of grow-out plots is also critical

because excessive siltation or excessive periods of air exposure between tides can impede growth and survival (Spencer 2002).

The two most common methods of grow-out are ground plots and tray culture. The ground plots can be prepared by removing large stones and debris to smooth the bottom in the culture area. Mesh screens can be installed to prevent over-burrowing and suffocation of clams in soft substrate. Where substrate is more densely packed, there is no need for a mesh barrier and clams can be set directly on the bottom. At locations where the substrate is too compact for burrowing, trays can be used. Trays vary in size depending upon equipment available at harvest. Typical trays have a fine mesh bottom which allows water to pass but excludes soil and reduces the weight of trays at harvest. A firm sand or soft mud is desirable for tray culture, although gravel can be used. Trays are only popular where sediment is not of good quality, because clam production is highest in natural sea bottom (Spencer 2002).

Manila clams are typically seeded at 500 to 1,000 spat/m^2, and a plastic mesh, usually with 5-mm openings, is placed on top of clam beds to protect against predation by fish and crabs (Spencer 2002). This mesh also prevents the loss of clams from plots, and it is particularly important where non-native species are cultured. Trays are also covered with netting and placed in culture plots. Regardless of which method is used, the principle is the same: clams must be provided a sediment substrate in which they can burrow. Nets at clam grow-out plots must be cleaned and repaired frequently to allow adequate water exchange, food availability, and protection from predators. Cleaning is performed with brushes or brooms, but in areas of France where the substrate is sandy, tractors can be equipped with roller brushes to clean the clams.

Grow-out periods for hard shell clams depend on temperature and food availability, but typically range from 18 to 36 months (Kraeuter and Castagna 2001). In Europe, Manila clam plots usually are harvested after 24 to 36 months (Gosling 2003). The Taiwanese can achieve marketable size clams in 18 months by using intertidal ponds (Chen 1990).

Clams are commonly harvested from ground plots by hand in the US and Canada, yet there are some producers who use dredging devices to accomplish harvest. In Taiwan, rakes with nylon bags attached are used to disrupt the soil and remove the clams. Another mechanical aid to harvesting is a plow-type collector, which is pulled behind a tractor. The device has an angled blade to dig under the clams and lift them and the sediment onto a series of graders which lets smaller clams and sediment drop back to the plots (Spencer 2002). Boats equipped with suction devices can also be used to suck clams into mesh bags. As the water, clams, and sediment are pumped into the bags, water pressure cleans the shells. If hydrogen sulfide is present in grow-out plots, shells can become discolored, which will reduce market value, and thus some farmers wash shells with bleach (Chen 1990). Trays are removed manually and are often placed on tractor-drawn platforms.

At typical stocking densities, 3-year-old plots of Manila clams can yield between 10 and 15 kg of meat/m^2. Manila clams in Europe can yield up to 20 kg meat/ m^2 (Spencer 2003).

Where coastal waters are polluted, clams bioaccumulate metals, potentially toxic substances, viruses, and bacteria (see Appendix 2). The cleansing or expulsion of these contaminants generally is referred to as depuration. Depuration takes place after removing clams from final grow-out. Clams can be reset in natural areas that are less productive, yet the water is of better quality, or clams can be transferred to an enclosed system that purifies water before it is exposed to the clams. Purification of water in enclosed systems is conducted usually by chlorination treatment, ozone treatment, or UV filtration (Blogoslawski 1989). Although depuration is a beneficial practice, cracked and chipped shells resulting from the handling and transporting of clams during depuration can be a serious problem.

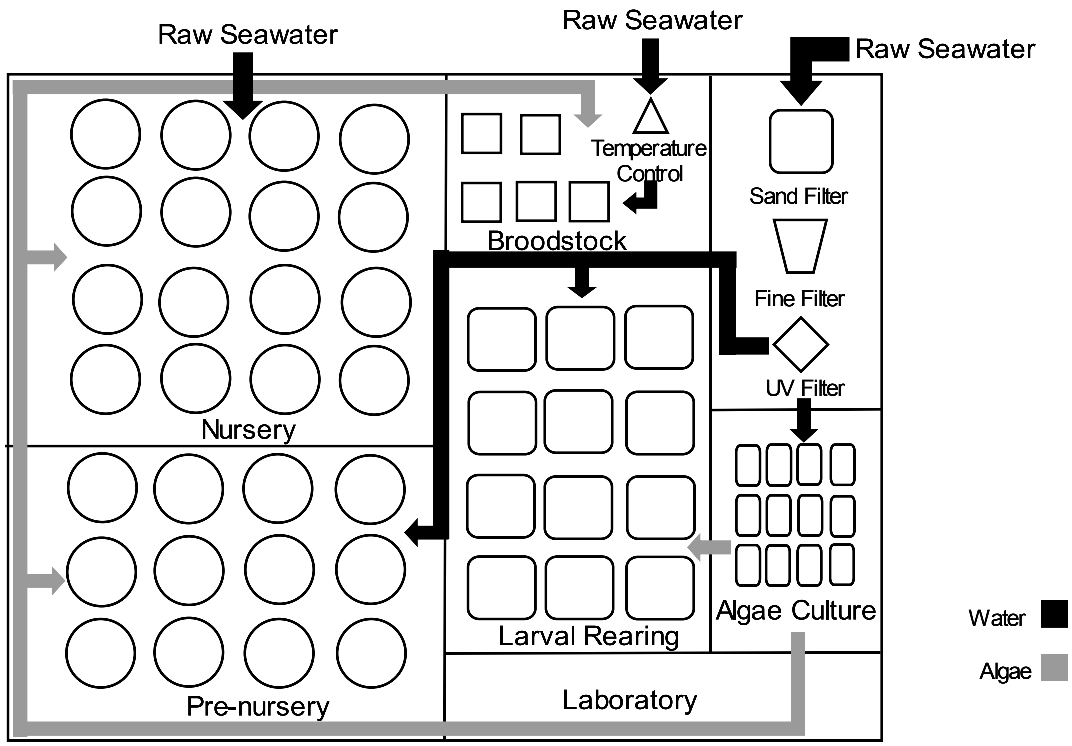

Figure 5. Schematic drawing of a modern clam hatchery. Source: Boyd and McNevin 2004.

Availability of Science

There is considerable scientific and grey literature on clam aquaculture. The FAO provides a wealth of information on aquaculture and capture production, as well as commodity reports. For more technical information, the National Shellfisheries Association and the Journal of Shellfish Research encompass a broad spectrum of shellfish species biology, ecology, and aquaculture production. Because the impacts of shellfish farming, in general, are small compared to finfish and shrimp aquaculture, much of the industry promotes the environmental benefits of clam culture. Aside from FAO and NACA (Network of Aquaculture Centers in Asia-Pacific) documents, information on clam culture in Asian countries is not readily available to the public.

Market Availability

Common and market names:
Clams are also known as cockles and ark shells.

Seasonal availability:
Farmed clams are available year-round, but fresh clam availability may be limited in specific regions for food safety reasons (see Appendix 2).

Product forms:
Clams are typically served cooked in or out of the shell and available fresh or frozen. Additionally, clams are available raw for sushi.

Import and export sources and statistics:
The US produces the majority of domestically consumed clams; however, there is importation of clams to the US market from a variety of countries. The main country that produces clams by aquaculture and exports product to the US is Canada.

Analysis of Seafood Watch® Sustainability Criteria for Farmed Species

Criterion 1: Use of Marine Resources

Clams require no wild fish in the form of fishmeal or fish oil in aquaculture production or natural production, thus there is no direct effect on wild fish populations by the aquaculture of clams. Because clams rely on natural production of food organisms in grow-out, there will be a reduction of nutrients, phytoplankton, zooplankton, and bacteria in the water column as a result of the aquaculture activity. There is little information to suggest that this has a detrimental effect on larval fish and natural bivalves that rely on this source of food, or that they limit primary productivity because most coastal systems are eutrophic (Boesch and Brinsfield 2000).

When spat are collected by hand, there is no bycatch of fish and shrimp. Spat for some clam culture may be dredged, however, which will cause benthic damage in areas with sensitive habitat (see Criterion 4).

The removal of spat from the wild for culture of bivalves typically does not have a negative effect on the natural stocks. In the US and Canada hatchery production of clam spat is a common practice and reliance on wild spat is being reduced. Quantifying the amount of spat produced in hatcheries in Asia is difficult because of the lack of information on the number of producers that rely on hatchery seed.

Synthesis
Formulated feed is not used in grow-out of clams, thus fishmeal and fish oil are not used. Additionally, the majority of clam spat collected from the wild in the US and Canada do not appear to pose a significant risk to wild clam stocks. Therefore, the use of marine resources ranks low for cultured clams.

Use of Marine Resources Rank:

Low	Moderate	High	Critical

Criterion 2: Risk of Escapes to Wild Stocks and Ecosystems

Clams undergo a planktonic larval stage and can be introduced to other areas of the world with relative ease. For example, many different larval bivalves and other organisms are discharged when cargo ships dispose ballast water into the local environment (Carlton 2001).

Manila clams are not native to the Pacific coast of Canada and the United States; however, introduction of the species dates back to the early 1900s where specific laws and cautionary procedures were not in place to prevent the spread of exotic species.

Although clams are more mobile than mussels and oysters, there is little risk of escape from culture plots as netting or bags are generally used to secure clams. Moreover, the species of clams cultured in the US and Canada are already established and there is little evidence to suggest any escape of cultured species would negatively affect the wild population.

Synthesis
Clams produced by aquaculture and consumed in the US are primarily grown domestically or imported from Canada. There is little information to suggest that escapes of cultured clams in either country have had a negative effect on the wild stocks. Thus, as with all other forms of bivalve culture the risk of wild stock detriment by escape of culture species ranks low.

Risk of Escaped Fish to Wild Stocks Rank:

Low	Moderate	High	Critical

Criterion 3: Risk of Disease and Parasite Transfer to Wild Stocks

There are few diseases that affect clam grow-out; however, clam larvae and spat are relatively susceptible to disease organisms. The most important disease is brown ring disease (BRD) of Manila clams. This disease, most prevalent in spat, causes degeneration of the digestive gland and mass mortalities have been observed (Gosling 2003). Noel et al. (1996) found that the most effective treatment for BRD in the hatchery was 10 mg furazolidone/L for 3 days. Jones et al. (1993) provided the alternative of a mild chlorine dip to kill bacteria clinging externally to the shells.

In addition to BRD, Brown (1974) implicated *Pseudomonas* as the cause of larval clam mortalities in a hatchery in the northeastern United States; Tubiash et al. (1965) determined *Vibrio* and *Aeromonas* strains could cause mortality to developing clam embryos; and Elston et al. (1982) identified *Vibrio* bacterium as the cause for mortalities in cultured clams in another hatchery in the United States. It should be noted that most bacterial health problems affecting clams are experienced in the hatchery. Protective measures should be taken to sterilize the water before clams are placed in it.

In addition to bacterial organisms, there are a host of fungi, protozoan, and nematodes that can negatively affect clam growth during hatchery and grow-out phase (Gibbons and Blogoslawski 1989). The effects of these organisms can be greatly reduced if precautionary measures are taken to reduce stress, and proper care is taken to keep hatcheries clean and disease free.

In the United States the Minor Use and Minor Species Animal Health Act of 2004 (MUMS) was signed into law on August 2, 2004. This new law is intended to encourage development of new animal drugs for minor species and for minor uses in major species. Policies still are being formed, but concern may be raised about the use of antibiotics in shellfish culture once permits begin to be issued. Nevertheless, the amount of antibiotics used in clam hatcheries would be minute and because the amount of effluent released from hatcheries is also minute there is little threat of chemical contamination from antibiotic use. Moreover, if antibiotics are used, it is only during the short, hatchery phase and chemical contamination of clams by minor use of antibiotics is highly unlikely.

Synthesis
There are few reports of disease outbreaks affecting wild clam populations, thus there is little evidence to suggest there is a major threat to wild clams stocks posed by the culture of clams. Clams are susceptible to disease organisms primarily in the early life stages. Natural recruitment is regulated by the ability of juvenile clams and clam spat to survive natural predators and stressors. Under hatchery conditions, spat and juveniles can be monitored closely and measures can be taken to aid in the survival of seed stock. The risk of disease transfer from cultured clams to wild clams thus ranks low.

Risk of Disease and Parasite Transfer to Wild Stocks Rank:

Low Moderate High Critical

<u>Criterion 4: Risk of Pollution and Habitat Effects</u>

Unlike other forms of aquaculture, molluscs cause a net reduction of nutrients in the water column. However, dredging and other benthic changes may negatively impact the culture environment.

Pelagic effects
Clams feed by filtering particulate organic matter from the water column, and this organic matter includes both phytoplankton and nutrients on which the phytoplankton feed. In this way clam aquaculture can reduce the abundance of phytoplankton in the water, and subsequently reduce the abundance of zooplankton, which feed on the phytoplankton. There are concerns that such a reduction in plankton could lessen benthic and fish production; however, unless clam culture is highly intensive in an embayment with restricted water circulation, clam culture would not be

expected to cause great changes in plankton or fish production. This is not a common problem though as such sites are not optimal for aquaculture activities, especially for shellfish. Additionally, eutrophication is a common problem in coastal waters in most parts of the world; thus, the removal of organic matter and nutrients by cultured mussels can be a positive factor. Clam aquaculture sites can remove excess nutrients from the ecosystem, improving water quality in coastal areas.

Sediment effects

Clams and other bivalves cannot convert all of the food that they filter from the water into harvestable biomass, thus, they excrete wastes into the environment. Soluble or fine wastes will be carried away from the culture site in water currents, but larger, solid wastes will settle to the bottom under and near culture areas.

Spencer et al. (1998) studied the effects of clam culture on the benthic community. The netting and green algae that grow on it caused increased sedimentation. Netted plots, with or without clams, were raised about 10 cm in the center by sediment accumulation. There also was a slight increase in sediment organic matter concentration in netted plots with and without clams. The abundance of worms also increased beneath netted plots whether or not clams were present. Thus, netting appears to have a greater influence on sediment quality than the clams which it covers.

The major benthic effects of clam culture result from harvesting. Spencer et al. (1998) found that harvesting by hand raking caused a 50% decline in benthic species diversity, while suction harvesting caused a 90% reduction in benthic diversity. The suction dredge used to harvest clams also left a 10 cm deep trench in the areas harvested, and there was a fine layer of sediment a few meters wide for about 40 m downstream of the harvester discharge. The trench filled within 3 to 4 months and the fine layer of sediment created by the harvester quickly disappeared. The harvests were conducted in winter, and benthic species diversity and abundance had returned to normal by the following summer (Spencer undated).

Spencer (undated) recommended the following practices to avoid adverse benthic impacts:

- Maintain netting in good repair to prevent escape of non-native species.
- When culturing native clams, remove netting after clams are large enough that predation is no longer a danger.
- Harvest by hand raking.
- Harvest in winter so that benthic communities can recover from harvesting effects during spring and summer.

There is no uniform impact that clam culture has on the habitats the clams are raised in, and site selection is of primary interest, as the negative effects of a clam grow-out facility will be determined by this factor. However, there are few cases where clam culture has caused serious environmental impacts, and moreover the environment has more of an impact on clam culture than the former.

Fouling control

Fouling is a major impediment in clam aquaculture. Bottom netting used in clam culture is quite prone to the fouling and clogging, which restricts water flow through the nets. Constant cleaning is required to remove fouling organisms. There have been many attempts to control predators and fouling organisms in bivalve culture through the use of chemicals such as Victoria Blue B, copper sulfate, quicklime, saturated salt solutions, chlorinated hydrocarbon insecticides, and other pesticides (Loosanoff 1960; MacKenzie 1977; MacKenzie 1979; Shumway et al. 1988; Brooks 1993). A review of predator controls in bivalve culture conducted by Jory et al. (1984) revealed that the installation of exclusionary devices such as netting was more successful than chemical treatment for control of predators and fouling organisms.

Dredging

Spat for seed stock that are not raised in hatcheries are typically dredged and transferred to culture areas. Harvest of clam plots can also be conducted by dredging and effects of this activity are similar to that of other bivalve dredging activities. The influence of bivalve dredging was discussed by Dolmer et al. (2001), who found impacts to include changes in seabed topography and sediment structure, re-suspension of sediment, and reduction in diversity of macrofauna. Dolmer et al. (2001) found the influence of dredging on sediment topography to be insignificant in sandy sediment, but observed furrows up to 5 cm deep in more stable sediment. However, Dolmer et al. (2001) also found sediment texture and organic matter content to be unaffected by dredging. After dredging, sediment was found to have a lower number of species, especially of polychaetes, than undredged areas; however, this effect only lasted for a few weeks.

Water quality

Clams are filter feeders, and they remove particulate organic matter including phytoplankton, detritus, zooplankton, bacteria, and suspended soil particles, from the water. They digest the particulate matter and release feces, pseudofeces[1], and ammonium, phosphate, silicate, and other nutrients back into the water (Dame et al. 1991; Gosling 1992). The growth rate of clams depends on the stocking density and the availability of particulate organic matter.

According to Shumway et al. (2003), the average concentrations of nitrogen and phosphorus in shellfish are 1.4% and 0.14%, respectively. Thus, the harvest of 1 mt of clams would contain 14 kg nitrogen and 1.4 kg phosphorus. The volume of water filtered by clams on a 1-ha culture area would be much greater than the volume of water in a 1-ha natural area, and the removal of nutrients could have a significant effect on slowing the rate of nutrient loading in an ecosystem in which clam culture is superimposed.

Synthesis

The grow-out of clams is accomplished in the natural environment, thus there is a beneficial effect on water quality, though dredging of clam plots may cause moderate harm to benthic organisms and habitat. There are few reports of disease outbreaks at clam grow-out sites, thus there is little need for antimicrobials; however, antimicrobials are sometimes used in hatcheries.

[1] Pseudofeces is material that has not been ingested but rather collected around the mantle. This material is often released into the water column by spasmodic contractions.

If achieved by dredging, harvesting presents a moderate risk of disturbing the habitat, and the activity results in temporary declines in biodiversity. However, harvesting of culture plots is less destructive than harvesting wild clams because harvest is restricted to relatively small plots. This contrasts with dredging of long expansive clam beds for spat collection or capture fishery harvests. Presently, the risk of pollution and habitat effects thus ranks low for hand harvest of cultured clams, while it ranks of moderate concern for clams harvested by dredging.

Risk of Pollution and Habitat Effects Rank:

Hand-raked clams:	**Low**	Moderate	High	Critical
Dredged clams:	Low	**Moderate**	High	Critical

Criterion 5: Effectiveness of the Management Regime

Research of grey and scientific literature suggests that great care is taken to preserve the environment surrounding clam farms. The health of cultured clams depends on habitat quality more so than other species produced by aquaculture because they can quickly bioaccumulate contaminants in their biomass (see Appendix 2). Thus, in developed and even some developing countries there are strict regulations governing water quality and habitat change. Furthermore, according to Shumway et al. (2003), Chile, New Zealand, Ireland, and Canada have environmental codes with Best Management Practices (BMPs) for shellfish culture. Awareness in the industry that the farming practices of clams are of lower impact than other forms of aquaculture has prompted many producers to go above and beyond normal recommendations and regulations for monitoring and averting environmental and social impacts.

In the United States, the Pacific Coast Shellfish Growers Association (PCSGA) has developed BMPs for shellfish production on the west coast. The East Coast Shellfish Growers Association (ECSGA) submitted a pre-proposal to the Northeast Regional Aquaculture Center at the US Department of Agriculture (USDA) for funding the development of shellfish BMPs, but has yet to get funding approved. BMPs also have been developed for the state of Massachusetts. The use of therapeutics in US aquaculture is overseen by the US Food and Drug Administration (FDA) and regulations are quite stringent regarding use of unapproved chemicals. Additionally, the US Environmental Protection Agency (EPA) regulates the use of non-pharmaceutical chemicals used in shellfish culture, and again laws are strict and shellfish producers typically do not use unapproved chemicals. The British Columbia Shellfish Growers Association also is participating in the development of BMPs for production of shellfish.

Effectiveness of Management Rank:

Highly Effective	Moderately Effective	Ineffective	Critical

Overall Evaluation and Seafood Recommendation

Clams are a delicacy and obtain a high price in a growing US market. Clams can be raised through a variety of methods, the most important difference in which, in relation to environmental impacts, is how they are harvested; by hand or by dredging. Operations reliant on dredging can physically disturb the benthos; whereas manual harvest by hand or hand tools generally have milder impacts. At present, disease transfer is not a major risk; clams do not consume marine fish in the form of fishmeal and fish oil; and clams typically make waters less eutrophic by filtering out nutrients. Moreover, capture of wild clam spat typically does not affect the wild populations. Introductions of clams to areas on the east and west coast of North America took place many years before regulations and preventative measures were in place to negate the introduction of exotic species; thus, well-established populations of the Manila clam exist throughout the US and Canada. Overall, farmed clams present relatively few threats to biodiversity and ecological integrity and thus are considered a Best Choice on the Seafood Watch® pocket guide, though, if possible, consumers and businesses should seek out clams harvested without the use of mechanical dredges.

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√			
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√ hand-raked	√ dredged		
Management Effectiveness	√			

Overall Seafood Recommendation

Best Choice ■ Good Alternative ■ Avoid ■

Acknowledgements

Scientific review does not constitute an endorsement of Seafood Watch® on the part of the reviewing scientists; Seafood Watch® is solely responsible for the conclusions reached in this report.

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Appendix 1: Rankings of individual criteria

Factor	Ranking
Estimated wild fish used to produce farmed fish (ton/ton) Green: Low use (WI:FO=0-1.1), Yellow: Moderate use (WI:FO=1.1-2), Red: Extensive use (WI:FO>2)	NA
Stock status of the reduction fishery used for feed for the farmed species Green: Underexploited, Yellow: Close to BMSY, Red: Substantially below BMSY	NA
Source of stock for the farmed species Green: Hatchery or no impact from wild collection, Yellow: Potential impact from wild collection, Red: Wild collection results in depletion	■
Conservation Concern: Use of marine Resources (yellow for China wild caught spat)	■

Factor	Ranking
Evidence that farmed fish regularly escape to the surrounding environment Green: Rarely or never escapes, Yellow: Infrequent or unknown escapes, Red: Regularly and often escapes	■
Status of escaping farmed fish to the surrounding environment Green: Native and genetically and ecologically similar, Yellow: Non-native but widely established or unknown, Red: Non-native and not established or native and genetically and ecologically distinct from wild stocks	■
Where escaping fish is non-native-Evidence of the establishment of self-sustaining feral stocks	■
Where escaping fish is native-Evidence of genetic introgression through successful crossbreeding Green: No evidence of introgression, Yellow: Introgressions likely or unknown, Red: Empirical evidence of introgression	■
Evidence of spawning disruption of wild fish	■
Evidence of competition with wild fish for limiting resources or habitats	■
Stock status of affected wild fish	■
Conservation Concern: Risk of Escaped Fish to Wild Stocks	■

Factor	Ranking
Risk of amplification and retransmission of disease or parasites to wild stocks	■
Risk of species introductions or translocations of novel disease/parasites to wild stocks	■
Bio-safety risks inherent in operations	■
Stock status of potentially affected wild fish	■
Conservation Concern: Risk of Disease Transfer to Wild Stocks	■

Factor	Ranking
Effluent water treatment	
Evidence of substantial local effluent effects (dredged – yellow)	
Evidence of regional effluent effects	
Extent of local or regional effluent effects	
Potential to impact habitats: Location (dredged – yellow)	
Potential to impact habitats: Extent of Operations (dredged – yellow)	
Conservation Concern: Risk of Pollution and Habitat Effects (dredged – yellow)	

Factor	Ranking
Demonstrated application of existing federal, state and local laws to current aquaculture operation	
Use of licensing to control the location (siting), number, size and stocking density of farms	
Existence and effectiveness of "better management practices" for aquaculture operations, especially to reduce escaped fish	
Existence and effectiveness of measure to prevent disease and to treat those outbreaks that do occur	
Existence of regulations for therapeutants, including their release into the environment, such as antibiotics, biocides, and herbicides	
Use and effect of predator controls in farming operations	
Existence and effectiveness of policies and incentives utilizing a precautionary approach against irreversible risks to guide expansion of the aquaculture industry	
Conservation Concern: Effectiveness of the Management Regime	

Appendix 2: Public health

Clams filter large volumes of water to remove food particles. Because they are efficient at capturing food particles, they are also efficient at accumulating potentially toxic or pathogenic organisms that may occur in water. Moreover, heavy metals, pesticides, dioxins, polyphenol bichlorides, dibutyltin, and other potentially toxic substances in water may be absorbed by and accumulated in clams. Thus, clams should not be reared in areas where waters receive significant levels of pollution or where potentially toxic dinoflagellates are abundant. Clams from polluted waters can contain high enough levels of biological or chemical contaminants to represent a health risk to consumers.

Improved detection methods and inspection technology, monitoring programs, and laws and regulations imposed on the shellfish industry have resulted in a decline in illnesses related to shellfish consumption (Shumway 1992). Nevertheless, Shumway (1992) emphasized that outbreaks of shellfish-borne illnesses still occur. However, more outbreaks of shellfish illnesses result from private collection and consumption of shellfish than from commercial suppliers of shellfish. Regulations have little effect on protecting the public from non-commercial sources of shellfish. The human health risk of consuming raw shellfish is much greater than for consuming cooked shellfish. Nevertheless, Shumway (1992) stressed that cooking will not always deactivate infectious particles in shellfish.

"Shellfish watch" programs are common throughout the developed world. In these programs, bivalves, and particularly mussels, are used as sentinel organisms in environmental monitoring programs. According to Widdows and Donkin (1992), the following attributes of mussels make them excellent sentinel organisms:

- They are dominant components of the fauna of most coastal ecosystems and have large, stable populations.

- They are suspension feeders that pump large volumes of water and concentrate many chemicals in their tissues at factors of 10 to 100,000 times seawater concentrations.

- They are tolerant to a wide range of conditions including relatively high concentrations of contaminants in the water.

- They metabolize or excrete contaminants at a low rate compared to fish.

- They can be transplanted in the location desired and they are sessile; thus, they are a better indicator organism of local conditions than fish or other mobile species.

- They are important as seafood, and measurement of contamination is important in protecting public health.

The shellfish watch programs can provide useful information on contaminants and their concentrations in coastal waters and evaluate changes in contaminant concentrations over time. In addition, results of these programs may be used to assess the contaminant concentrations in shellfish and assess the health risk of consuming shellfish from a specific location. Shellfish harvest may be prohibited during periods when microbiological quality is poor or organisms contain high concentrations of potentially toxic compounds.

Microbial quality

Shumway (1992) provided a list of bacterial and viral contaminants identified in shellfish. The list includes many dangerous pathogens including hepatitis and polio viruses, fecal coliforms, fecal streptococci, and *Vibrio*. The source of these contaminants is sewage discharges into coastal waters, and clams and other shellfish concentrate the pathogens to much greater concentrations than found in the water.

Because clams and other shellfish can cause public health concerns, most developed nations have imposed standards for microbial quality of clams. For example, in the United States, the total aerobic viable bacterial count must be $\leq 5 \times 10^5$ cells/mL of shucked meat and the fecal coliform count must be ≤ 230 cells/100 mL of shucked meat (Slabyj 1980). In the United Kingdom, shellfish containing < 230 fecal coliforms/100 mL of meat in all samples are suitable for human consumption. Those containing > 230 but < 4,600 coliforms/100 mL can be consumed by humans if depurated, heated, or re-laid for a short period to reduce coliform loads. If coliforms are between 4,600 and 60,000/100 mL, shellfish must be re-laid at least 2 months. Shellfish with > 60,000 coliforms/100 mL flesh cannot be offered for human consumption.

In the United States, waters for capture or culture of shellfish are monitored. The total coliform median or geometric mean must not exceed 70/100 mL and the estimated 90^{th} percentile must not exceed 230/100 mL. Shellfish from areas not meeting these standards cannot be offered for human consumption. However, shellfish from water containing 71-700 coliforms/100 mL (90^{th} percentile < 2,300/mL) can be eaten following depuration.

The European Union (EU) requires countries to have shellfish monitoring programs and national regulations that are developed using EU regulations as guidelines. Shellfish harvesting (including aquaculture) is classified into three types of waters:

Classification	Status
A	Shellfish grown in these waters can be used for direct sale without any treatment.
B	Shellfish grown in these waters must be purified (depurated) or re-laid before sale.
C	Shellfish grown in these waters must be re-laid in appropriate waters of A or B classification for at least 2 months to allow them time to reach an acceptable bacterial standard.

Algal toxins
Several coastal waters around the world have sporadic increases in the abundance of dinoflagellates and other toxic algae (Shumway 1990). Dinoflagellates of the genus *Gonyaulax* are capable of producing compounds which are highly toxic to humans (Yentsch and Incze 1992). Shellfish are relatively tolerant to algal toxins, but they can concentrate algal toxins and constitute a threat to public health. A number of algal toxins have been identified to include amnesic shellfish poisoning (ASP), paralytic shellfish poisoning (PSP), and diarrhetic shellfish poisoning (DSP). These intoxications can be quite serious or lethal. The symptoms follow:

> ASP – Symptoms of ASP include vomiting and diarrhea, and in some cases this can be followed by confusion, loss of memory, disorientation, and even coma. Chronic effects of ASP may include permanent loss of short-term memory.
>
> PSP – Symptoms of PSP can begin within 5 to 30 minutes after consumption. Initially there is slight perioral tingling progressing to numbness that spreads to the face and neck in moderate cases. Headache, dizziness, nausea and vomiting are also common in the early stages of poisoning. In severe cases, the numb sensation spreads to the extremities. This is followed by incoordination and respiratory difficulty. Acute intoxication can lead to medullary disturbances, which are evidenced by difficulty swallowing, sense of throat constriction, speech incoherence or complete loss of speech, as well as brain stem dysfunction. In very severe cases, complete paralysis can occur in 2-12 hours, followed by death from respiratory failure.
>
> DSP – Symptoms of DSP include diarrhea, nausea, and vomiting and abdominal pain. Onset occurs from 30 minutes to a few hours after eating. The duration is usually short with a maximum of a few days in severe cases. The disease is not usually life threatening. Complete clinical recovery is usually seen within 3 days even in severe cases. The illness is often mistaken as gastro-enteritis and therefore is probably under-reported.

Algal toxins can affect shellfish from both fishing and aquaculture operations. Although it is well known that dinoflagellate blooms are the cause of the algal toxin problem in shellfish, it is difficult to predict when and where these blooms will occur. Of course, some waters have a history of developing dinoflagellate blooms during a particular season, but blooms may sometimes not follow the usual pattern. They also may occur at other places where dinoflagellate blooms have not been reported previously. Thus, the most reliable procedure for protecting public health is the implementation of "shellfish watch" programs in which the abundance of *Alexandium* is monitored, and when blooms begin to develop, mussels and other shellfish are monitored for concentrations of algal toxins. Shellfish fisheries and aquaculture sites are closed when public health authorities conclude that it is potentially dangerous to consume the shellfish.

Chemical contamination
The chemical compounds that may contaminate shellfish originate in pollution and include pesticides, heavy metals, and industrial chemicals. The substances measured in the Mussel Water Program in the United States include trace metals (arsenic, cadmium, copper, lead, nickel,

mercury, selenium, and zinc) and organic compounds (DDT, chlordane, dieldrin, polychlorinated biphenyls, polyeyclic aromatic hydrocarbons, and butyltin).

Shumway (1992) provided a list of action levels for concentrations of several undesirable substances in seafood (Table A1).

Table A1. Action levels, tolerances and other values for poisonous or deleterious substances in seafood. Source: Shumway (1992).

Deleterious substances	Level	Food commodity
Aldrin/Dieldrin	0.30 ppm	Fish and shellfish
Chlordane	0.30 ppm	Fish only
DDT, DDE, TDE	5.00 ppm	Fish only
Endrin	0.30 ppm	Fish and shellfish
Heptachlor/Heptachlor Epoxide	0.30 ppm	Fish and shellfish
Kepone	0.30 ppm 0.40 ppm	Fish and shellfish; crabmeat
Mercury	1.00 ppm	Fish and shellfish
Mirex	0.10 ppm	Fish only
Paralytic shellfish poison	80 μg/100 g of meat	Fresh, frozen, and canned clams, mussels, and oysters
Polychlorinated biphenyls (PCBs)	20 ppm	Fish and shellfish
Ptychodiscus brevis toxins	20 Mouse units/100 g	Shellfish
Toxaphene	5.00 ppm	Fish only