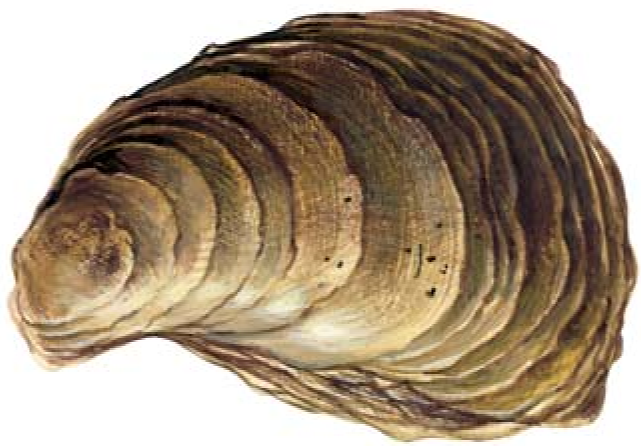
Seafood Watch
Seafood Report

MONTEREY BAY AQUARIUM®

Farmed Oysters



Crassostrea virginica, Illustration © Scandanvian Fishing Yearbook

Worldwide

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 1-877-229-9990.

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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I. Executive Summary

Oysters are filter-feeding bivalves that inhabit most oceans in the world except near polar extremes. Aquaculture production of oysters accounts for 95% of total global production (capture and aquaculture). Although oysters are cultured in 46 countries, the main areas of aquaculture production are China, Korea, Japan, the United States, and France. Oyster seed can be reared in hatcheries or collected from the wild, depending on technical sophistication, practicality, and tradition.

Grow-out of oysters is accomplished in natural, inter-tidal or sub-tidal waters. Grow-out techniques involve suspension of oysters in the water column, via rafts, floats racks or trestles, or bottom culture, in which oysters are grown directly on the seabed. Because oysters are filter feeders, oyster aquaculture facilities generally improve coastal water conditions by converting nutrients and organic matter to biomass. Moreover, the water requirement for oyster hatcheries is low, thus only a small amount of effluent is discharged. Farming of oysters is not entirely benign, however, as oysters can be introduced inadvertently to non-native areas, where they can impact native oyster populations. Aquaculture has played a role in some introductions of non-native oysters and subsequent disease transfers, but there are also ongoing attempts to restore coastal areas with non-native oysters (and stimulate aquaculture production of those species in these areas), and this is also cause for concern. Additionally, there are growing concerns regarding impacts of genetically altered oysters being raised in the wild.

Oysters are non-motile at the adult stage and there is no true “escape” of these organisms from culture plots; however, there can be instances where oysters are overlooked by producers and left to grow and reproduce in the wild. Management regimes and codes of conduct have been formed by the shellfish industry and generally these codes and practices go above and beyond laws governing the culture activity.

Dredging of oysters to collect spat or to harvest market-size oysters after grow-out can also have negative environmental effects; however, dredging of cultured oysters results in less impact per unit production than dredging of wild oysters. At present, farming of oysters pose substantially less risk to the environment than culturing many other finfish or crustacean species. For oysters grown in suspended or off-bottom culture, only ‘Risk of Escapes’ and ‘Risk of Disease Transfer’ are considered of moderate conservation concern (whereas the other criteria are of low concern). This results in an overall recommendation of ‘Best Choice’ for oysters grown with this method of culture. For oysters that are grown on the seafloor and subsequently dredged, the sub-criteria ‘Potential to Impact Habitats’ receives an additional ‘Moderate’ ranking but the overall recommendation is also ‘Best Choice’.,

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√			
Risk of Escapes to Wild Stocks		√		
Risk of Disease and Parasite Transfer to Wild Stocks		√		
Risk of Pollution and Habitat Effects	√			
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

Off-bottom cultured oysters:

Best Choice Good Alternative Avoid

Dredged oysters:

Best Choice Good Alternative Avoid

II. Introduction

Basic biology

Oysters are found in all marine waters of the world except those near the north and south poles. The widespread distribution and dispersion of oysters is possible because they have a 1 to 4-week planktonic stage during which they may travel long distances. Species of oysters also have been introduced outside their native range for aquaculture purposes. There are several genera of oysters cultured in the world, but *Ostrea*, *Crassostrea*, and *Saccostera* are the most important genera in aquaculture (FAO 2005). The classification of oysters is based on the form and structure of larval shell, mode of reproduction, life history, adult shell morphology, and foot shape. Oysters in the genera *Ostrea* are called flat oysters while the *Crassostrea* are known as cupped oysters.

Figure 1. The Pacific oyster (*Crassonstrea gigas*). Photo credited to CSIRO Marine Research.

The eastern oyster (*Crassostrea virginica*) inhabits intertidal and subtidal locations in estuaries where salinities range from 5 to 18 ppt. The Pacific oyster (*Crassostrea gigas*) (Figure 1) thrives in waters with salinities of 23 – 28 ppt or higher on flats composed of firm mud, sand, or gravel, but they also can grow on rocks. The European flat oyster (*Ostrea edulis*) is typically found in highly productive, shallow, coastal waters with salinities of 20 – 28 ppt. This species can grow on firm bottoms of almost any texture. The Sydney rock oyster (*Saccostrea commercialis*) is native to Australia and is found in coastal zones of Victoria and Queensland. This species occurs on rocks in the intertidal zone in estuaries near river mouths. These oysters can survive salinities of 15 – 55 ppt, but grow best between 25 and 35 ppt. Some oyster species are commonly found in clusters where settlement has taken place on adjacent oysters, while other species of oysters are more solitary.

The major oyster-predators are crabs, oyster drills, starfish, boring sponges, and birds. Intertidal oysters are subjected to less predation than oysters that grow subtidally.

Oysters respire with gills and the mantle. The mantle is lined with many small, thin-walled blood vessels which extract dissolved oxygen from the water and expel carbon dioxide. While under water, oysters feed almost continuously on plankton and microscopic plants and animals by opening their shells and filtering water. Water is drawn into the gill cavity by rhythmic beating of cilia. Minute plants and animals and other particles in the water become embedded in mucus on the gills, and the mucus and embedded particles are concentrated into strings that are passed along to the mouth.

Numerous oyster species are cultured (Table 1). Under natural conditions, oysters spawn as water temperature rises in the spring. Oysters are known as "broadcast spawners" because they release eggs and sperm into the water column. A fertilized egg develops into a planktonic, free-swimming trochophore larva in about 6 hours. The trochophore larva does not feed and develops into a fully shelled veliger larva within 12 to 24 hours. The veliger has a thin shell and actively feeds in the water column. A veliger larva remains planktonic for up to 3 or 4 weeks. Towards the end of this period, it develops a foot and settles to the bottom to seek a hard substrate. When a suitable surface is located, the larva attaches itself by byssal threads and metamorphoses into adult form (Figure 2). Oyster larvae will attach themselves to many types of substrate, but they seem to prefer molluscan shells and other materials which provide hard, firm surfaces. The process of becoming cemented to the substrate is termed "setting," and the oyster is referred to as a "spat" when it has attached to a substrate. Often, a group of 25 or more spat will settle on a few square centimeters of surface, but of these, only 2 or 3 will survive to adulthood.

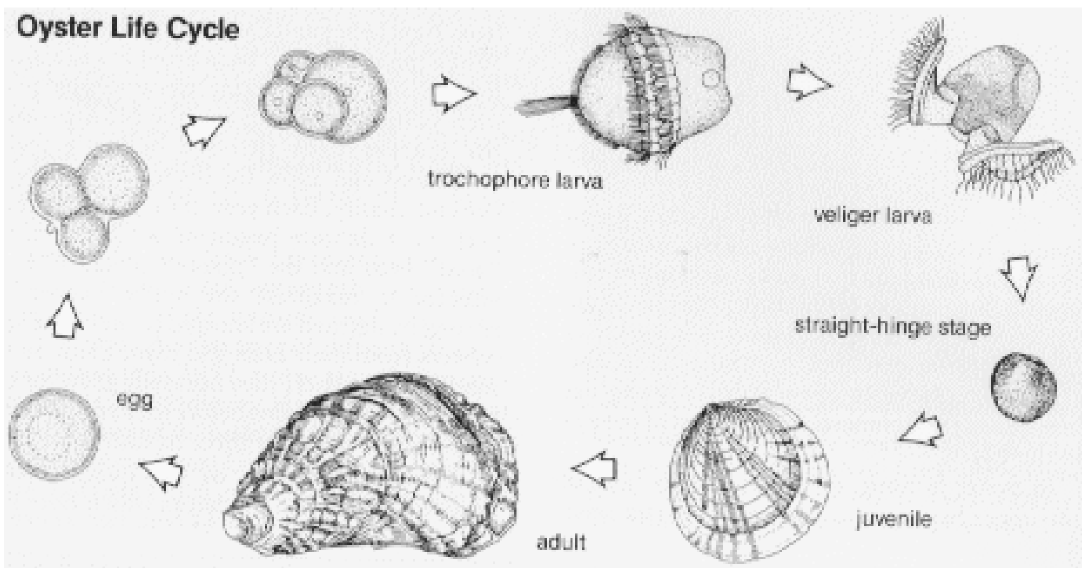

Figure 2. The oyster life cycle. Image credited to South Carolina Department of Natural Resources.

Table 1: Species and area of oyster aquaculture production for 2003. Source: FAO 2005.

Country	Species
Algeria	*C. gigas**
Argentina	*C. gigas**
Australia	*C. gigas*, C. spp, O. spp, Saccostrea commercialis*
Bosnia and Herzegovina	*O. edulis*
Brazil	*C. spp*
Canada	*C. gigas*, C. virginica*
Channel Islands	*C. gigas**
Chile	*C. gigas*, O. chilensis*
China	*C. gigas, C. rivularis, S. cucullata*
Croatia	*O. edulis*
Cuba	*C. rhizophorae*
France	*C. gigas*, O. edulis*
Germany	*C. gigas**
Greece	*O. edulis*
Ireland	*C. gigas*, O. edulis*
Japan	*C. gigas*
Republic of Korea	*C. gigas*
Malaysia	*C. spp*
Mauritius	*S. cuccullata*
Mexico	*C. corteziensis, C. virginica, C. gigas**
Morocco	*C. gigas*, O. edulis*
Namibia	*C. gigas**
Netherlands	*C. spp, O. edulis*
New Caledonia	*C. gigas**
New Zealand	*C. gigas**
Norway	*C. gigas*, O. edulis*
Papua New Guinea	*C. rhizophorae*
Peru	*C. gigas**
Philippines	*C. iredalei*
Portugal	*C. gigas*, O. edulis,*
Senegal	*C. gasar*, C. spp*
South Africa	*C. gigas*, O. edulis**
Spain	*C. gigas*, C. spp, O. edulis*
Taiwan	*C. gigas*
Thailand	*C. spp*
Tunisia	*C. gigas*, O. edulis*
United Kingdom	*C. gigas*, C. spp, O. edulis*
United States of America	*C. gigas*, C. spp, C. virginica, O. conchaphila, O. edulis*, O. spp*

*Non-native species in the area cultured

Aquaculture production
In 1952 wild capture of oysters was approximately 303,000 metric tons (mt) but has since dropped, to roughly 200,000 mt in 2003 (FAO 2005). Much of this can be attributed to advancement in aquaculture, but as with many of the world's fisheries, natural production has not been able to keep up with demand for oysters.

World oyster production (aquaculture and capture) in 2003 was approximately 4.7 million mt, and all but around 200,000 mt were from aquaculture (Figure 3) (FAO 2005). Of the numerous oyster species produced, *C. gigas* overwhelmingly dominates global production (Figure 4).

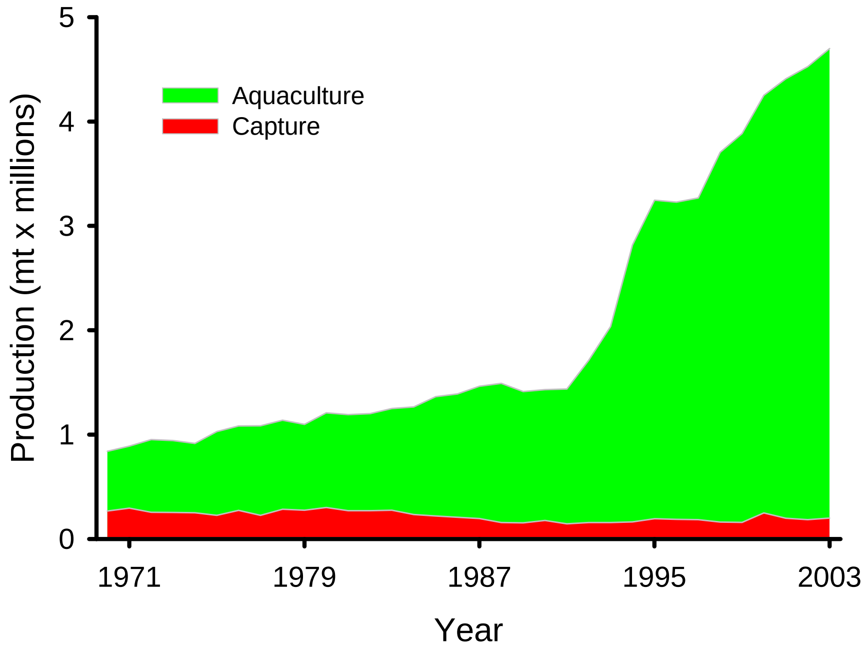

Figure 3. Comparison of oyster capture fisheries and aquaculture production. Source: FAO 2005.

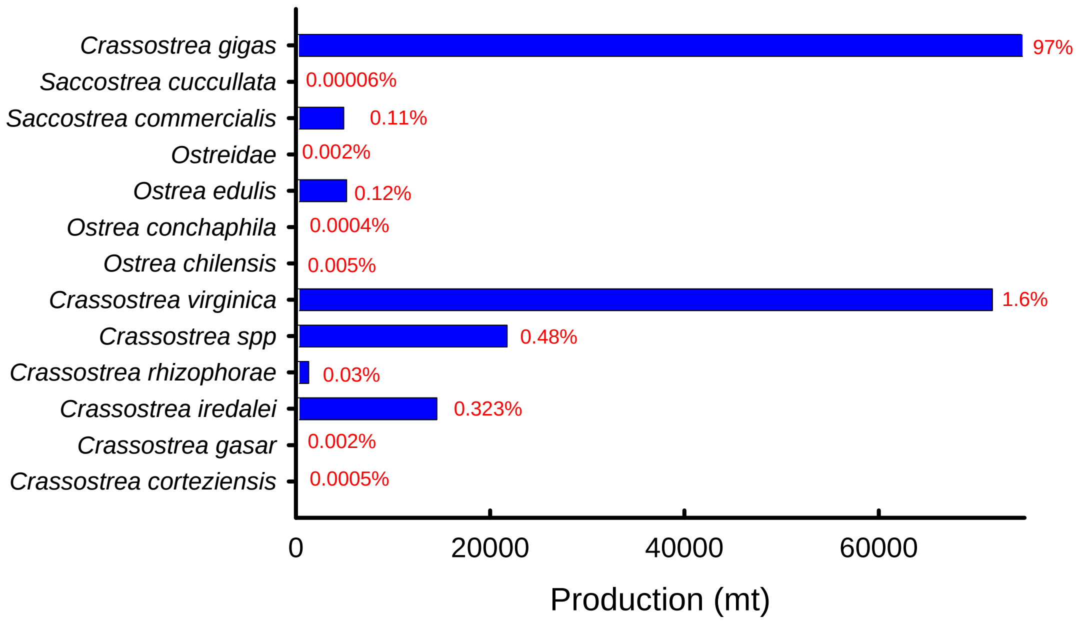

Figure 4. Oyster species and production quantities globally (note: *C. gigas* data are outside of the scale of this graph). Percentages are given as fraction of total oyster aquaculture production in 2003. Source: FAO 2005.

According to FAO, 46 countries produced oysters in 2003. The major production areas are in the Pacific Ocean along the coasts of China, Japan, and Korea (Figure 5). China is the world leader in oyster aquaculture production. Oyster culture in China is based mainly on wild caught spat harvested with collecting devices. The species cultured in China are *C. gigas*, *C. rivularis*, and *S. cucullata*, which are all native to the region. Bottom culture methods are used for *C. gigas* and *S. cucullata*, while rafts are employed for *C. rivularis* aquaculture. A third method of culture using rock substrate also is popular where the seabed is excessively muddy. The culture of *C. rivularis* is conducted in southern China around the Pearl River in Guangdong Province. Culture of *S. cucullata* occurs along a large portion of China's coast from the northern province of Liaoning to the southern province of Guangxi. The species *C. gigas* is cultured mainly along the coasts of the Bohai and Yellow Seas in northern China.

China produced 3.7 million mt of oysters or approximately 82% of world aquaculture production in 2003. It also reported a six-fold increase in oyster production over the past 10 years, while the output of other major oyster-producing countries has remained relatively stable or decreased (Figure 5.).

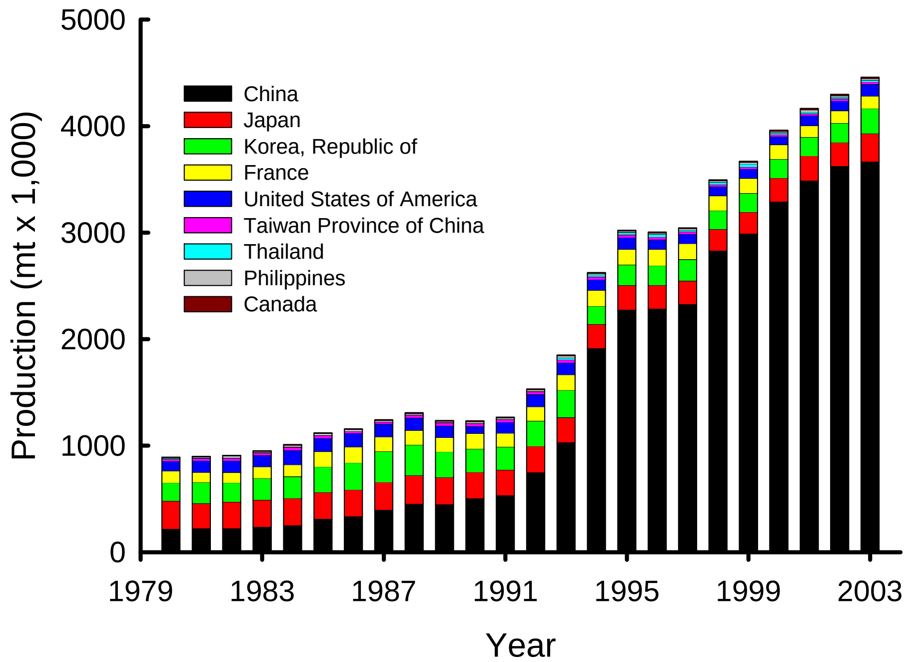

Figure 5. Oyster aquaculture production trends of selected countries. Source: FAO 2005.

The two main production areas in Japan are the Hiroshima and Miyagi Prefectures. The main species produced in Japan is *C. gigas*, which is native to the country. Spat are obtained from the wild with aid of collecting devices. There are two primary methods for grow-out in Japanese culture: raft culture in the Hiroshima Prefecture; and longlines in the Miyagi Prefecture. Longline culture in the Miyagi Prefecture accounts for over 60% of the cultured oysters produced in Japan.

Oyster production in Japan reached 270,000 mt in 1988, but production declined to a low of 199,000 mt in 1998. Since 1998, Japanese oyster production has increased slightly, and in 2003, 221,000 mt of oysters were produced.

Oyster aquaculture in Korea is practiced mainly along the southern coast with more than 80% of the country's production originating in Kyongnam Province. Oyster production on the west coast of Korea is most intensive in Kyonggi Province. There is little oyster aquaculture on the east coast of Korea. The most economically significant culture species in Korea is *C. gigas*, the culture of which has developed rapidly since 1969. Spat are captured from the wild on collecting devices, and oysters are grown out using either racks or longlines.

The peak oyster production in Korea was 288,000 mt in 1987. Since 1993, production has declined, but in 2003 production was up, at 238,000 mt. The cause of the overall decline is not well understood; however, in 1996, 126 incidences of red tide were reported, with losses to oyster culture estimated at $10 million. This suggests that environmental limitations could be the cause of the decline in Korea's oyster industry.

The French molluscan aquaculture industry is well developed because of the great demand for shellfish in France; although production of shellfish in France is large, the country still imports shellfish (FAO 2005) because of the large demand. The native oyster species of France, *O. edulis*, was once cultivated intensely, but disease outbreaks caused a decline in this species. Disease also decimated populations of *C. angulata*, a species introduced in the early 1860s. Today, the major oyster species produced in France is *C. gigas*. This species was introduced to France from Japan in the early 1970s to replenish oyster stocks depleted by disease and is now a well established species. It has proven more resistant to disease than *O. edulis* and *C. angulata*. The Gironde Estuary and Arcachon and Marennes-Oléron Bays are the primary grounds for spatfalls in France. Spat are captured and shipped to sites in Normandy and Brittany to be grown out using either bottom culture, rack, or hanging rope culture.

France's oyster industry has declined gradually over the past 10 years. In 1994, the French oyster industry produced 150,000 mt, but production declined to 115,000 mt in 2003. The decrease in production generally has been a result of disease problems affecting native oysters, which currently represent only a small component of the industry. Additionally, in 2002, the Prestige oil spill caused a decline in oyster production. In January of 2003, the French government banned the sale of oysters originating in the Arcachon Bay because of encroaching oil slicks.

Oyster culture in the United States involves a variety of species, including *C. gigas* (non-native), *O. edulis* (non-native), and *O. conchaphila* (native) on the Pacific coast, and *C. virginica* (native) in the Gulf of Mexico and mid-Atlantic. Species are typically raised by rack or bottom culture in intertidal waters.

The United States is a relatively large producer of oysters, but production has been declining, from 101,777 mt in 1991 to 93,820 mt in 2002. In 2003, production rose to 108,000 mt. During the first half of 2003, the United States imported 9,640 mt of oysters but exported only 2,275 mt (Aquaculture Magazine 2004). Thus, the United States produces the majority of oysters consumed in the country.

Oysters are a delicacy served raw, cooked, canned, or smoked, and typically obtain a high price. According to FAO, the world farm gate value of oysters in 2003 was 3.8 billion dollars (Figure 6). The trend in oyster value has been quite stable considering the reported six-fold increase in production by the Chinese.

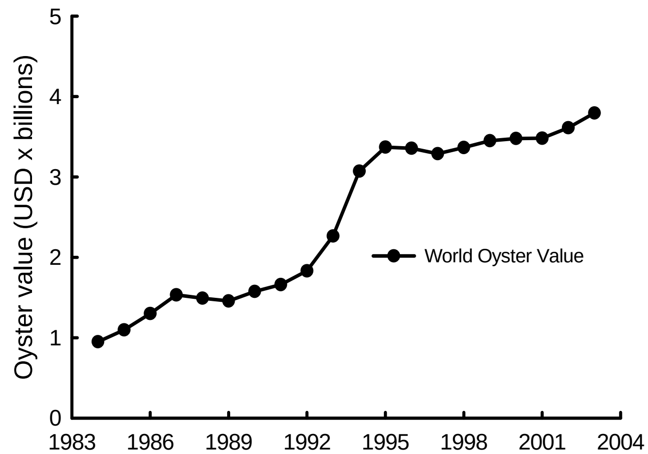

Figure 6. The economic value of world oyster production. Source: FAO 2005

Aquaculture systems

Oyster culture can be divided into two activities: production of spat; and grow-out of spat to market size. Seed production can be accomplished in hatcheries, or spat can be captured from the wild on collecting devices. In many places, especially in Asia, wild spat are used; however, hatcheries are used widely in the western world and are becoming more important in Asia. Grow-out of oysters to market size is performed by either bottom or off-bottom practices, but both methods involve stocking juvenile oysters into coastal waters where they feed on natural organisms. There are minor differences in environmental tolerances of the different oyster species, but in general, the culture practices rely on the same principles. In the following discussion on oyster culture, the emphasis will be placed on the Pacific oyster (*C. gigas*), because it is the most widely-cultivated oyster species in the world.

Seed stock production

Capture

France, China, and Japan rely heavily on natural spatfalls for seed stock (Spencer 2002; Gosling 2003). Numerous types of spat collectors are utilized depending on tradition and practical experience. In France and Japan, spat-collectors are often made from the shells of scallops, oysters, or other bivalves, and called cultch. The cultch can be laid out in trays, but a more common method is to drill holes in the pieces of cultch and suspend them from ropes or wires. This allows for three-dimensional use of the water column for collection of spat, thus increasing efficiency. It is also common to use PVC tubes or PVC trays that have been pre-soaked and sun-dried to remove any hazardous chemicals that reduce success of spat collection (Gosling 2003). After collection, spat are transferred on the PVC to a grow-out facility.

Hatcheries

In many countries, other than France, China, and Japan, where oysters are produced by aquaculture, hatcheries are important sources of spat. For example, according to Ward et al. (2000), the Pacific oyster industry in Australia was derived from importation of this species from Japan to Tasmania in the 1940s and 1950s and is almost entirely hatchery based. Hatcheries are typically located near the shore of a bay or estuary where sufficient quantities of good quality water can be pumped into the facility. Temperature and salinity play an important role in spawning and larval development, thus hatcheries are typically situated where these two variables remain within an acceptable range so that expensive modifications to temperature and salinity are not necessary. Broodstock and larvae are fed algal cultures, and care must be exercised to avoid water quality deterioration in culture vessels as a result of feeding. Continuously flowing seawater is not necessary in a bivalve hatchery because both larval and algal food are cultured in standing water (Castagna and Manzi 1989; Castagna et al. 1996), but broodstock 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, however, to a more controlled hatchery environment consisting of artificial light sources, insulation, and heat exchangers for water temperature regulation (Figure 7). In newer hatcheries, pipes and tanks are constructed almost solely from fiberglass and plastic. These structures allow easy manipulation of hatchery organization, and they are typically 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.

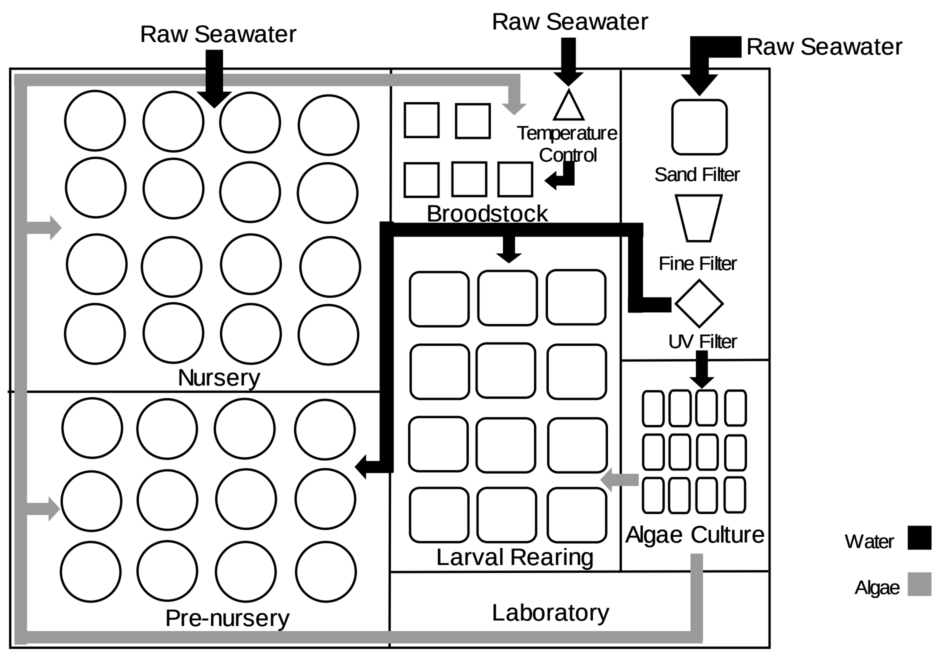

Figure 7. Schematic drawing of a modern oyster hatchery. Image credited to Boyd and McNevin (2003).

Broodstock management

Broodstock are usually selected from wild stocks for optimal color and morphological traits, as well as rapid growth rates, high fecundity, and good survival. In some cases, however, as in the United States and Europe, domesticated strains of oysters have been developed and used. The characteristics of broodstock vary depending on the market for the oysters. For example, in

France, shell morphology is an important characteristic because much of the market is for oysters served in the shell.

Oysters chosen for broodstock can be harvested from existing farm stocks and transferred to hatcheries or they can be held and reared in hatcheries. Broodstock are transferred to conditioning tanks that receive raw, unfiltered water supplemented with cultured algae. Pacific oyster broodstock require a salinity >25 ppt and temperature of 20 – 24°C (Spencer 2002). Water flow rates are adjusted for the amount of broodstock in tanks, but rates typically are 0.25 L/min for a tank of 100 adults (Spencer 2002).

Feeding regimes rely on plankton provided by natural seawater or by algae from laboratory cultures (Matthiesson 2001). Use of algal cultures for food avoids introduction of disease and fouling organisms common in natural waters. Algae are typically cultured from pure, commercially-available strains. An initial nutrient solution is made in sterile water and inoculated with the pure algal culture. Following initial inoculation, algae are incubated in containers of increasing size as the population grows. Air stones provide adequate dissolved oxygen and mixing. Quantitative allotments of algae for feeding oysters are estimated by sampling the rearing vessels and determining the abundance of algae. Appropriate volumes of algal solution to provide the desired amount of algae cells to be fed can then be determined.

Broodstock are typically fed cultured, unicellular, marine algae each day. Practical experience, availability of algae, and oyster species being produced dictates the algae feeding regime employed in a specific hatchery (Silapajarn personal communication). Feed should be provided conservatively to encourage efficient removal of the algae by oysters and minimize discharge of algae during water exchange (Spencer 2002).

Spawning

There are two spawning techniques in the production of Pacific oyster seed: thermal cycling; and surgical removal of the gametes. In thermal cycling, two separate water supplies, one of 18 – 20°C and the other 28 – 30°C, are alternated (Spencer 2002). Broodstock are transferred to spawning troughs typically made of fiberglass. Troughs are filled partially with cooler water to stimulate the extension of the oyster's siphon. After 15 – 30 minutes, water is drained and replaced with warmer water. This process is repeated for 1 – 6 hours. After six hours, if some oysters have not spawned, they are returned to the conditioning tank. Eggs and sperm may be collected and quantitatively allotted to containers, or both sexes may be left to mass fertilize. The other method of obtaining gametes is to sacrifice the oyster and surgically remove the gametes from the adults (Helm and Millican 1977). This method allows for closer examination of egg quality. Pipettes can be inserted into the gonads and gametes siphoned out. Eggs and sperm are transferred to separate containers of sterile water. Fertilization takes place in controlled containers where eggs and sperm are added proportionally. Eggs are incubated in hatching jars until hatching.

Polyploid induction
Sometimes, chromosome alteration of oyster eggs is practiced to produce faster growing oysters. After fertilization but before hatching, egg chromosome numbers can be manipulated to produce what is known as triploid oysters, sterile oysters that have three sets of chromosomes; the oysters grow faster than normal oysters because they do not spend energy on reproduction.

Triploid oysters are produced by blocking the release of the polar body II in newly fertilized eggs. There are several chemicals which induce triploidy, but the most successful one is cytochalasin B (Allen et al. 1989; Scarpa et al. 1994). This compound has been approved for use in oyster hatcheries in the United States by the Food and Drug Administration (FDA). Cytochalasin B inhibits microtubule development and also induces cellular DNA fragmentation. Dose rates of cytochalasin B for eggs range from 0.5 – 1.5 mg/L cytochalasin B (Nell et al. 1996). Eggs are held for several minutes in the solution (Nell et al. 1996). Other chemicals that have also been used to induce triploid production include caffeine and 6-dimethylaminopurine (Nell et al. 1996), but these chemicals, which are not approved for use on oysters in the United States, are not as effective as cytochalasin B.

Tetraploid oysters are fertile and produce 100% pure triploids when mated with normal diploids (Que et al. 2003). The development of tetraploid oysters has revolutionized triploid production for the oyster culture industry as no chemicals are used on edible oysters. Guo and Allen (1994) developed and patented the tetraploid procedure for Pacific oysters, which involves blocking polar body I in eggs from triploids (although triploids are sterile, there are rare instances when triploids can produce eggs) fertilized with normal sperm.

There are several countries either experimenting with polyploid commercial production or already commercially producing polyploid oysters. Chew (1994) reported, for example, that triploid Pacific oyster culture in the United States accounts for one third to one half of total worldwide polyploid oyster production, and Wang et al. (2000) described the intense culture of various polyploidy shellfish in China. Triploidy was also successfully induced in the mangrove oyster (*C. lugubris*) in Thailand and production of these organisms is being explored (Roongratri and Youngvanichset 1988). Additionally, there is some interest in producing polyploid Sydney rock oysters in Australia, but there have been some coloration issues in the oyster, which has hindered its commercialization (Nell 2002).

Although the desired end result of polyploidy is to produce a sterile oyster, there is evidence to suggest that it is not 100% effective (Calvo et al. 2001; Zhou 2002), suggesting the possibility of introduction of non-native oysters assumed to be sterile.

Larval development
In larval culture, the density of organisms from fertilization tanks is reduced to ensure adequate growth of straight-hinge stage (see Figure 2 earlier in this section) or D-larvae oysters. Aeration to keep larvae in suspension is provided by oil-free pumps (Helm and Spencer 1972). At this stage, feeding with prepared algae cultures is initiated. Spencer (2002) recommended a mixture of *Chaetoceros calcitrans*, *Isochrysis galbana*, and *Tetraselmis suecica* for Pacific oyster larvae greater than 120 µm. Water is exchanged 3 or 4 times per week in the larval rearing tanks. After about 10 days, larvae reach the pediveliger stage, and the feeding rate is lowered.

The most common system for rearing pediveligers is a downwelling system in which continuous downward water movement is induced with an airlift pump (Spencer 2002). This action suspends healthy pediveligers away from dead or sick larvae, which collect on the bottom of the tanks. Pediveligers are fed algae by the same method used for D-larvae. When pediveligers reach the eyed stage, usually at 10 – 12 days, settlement substrate is added. This may be cultch or, more commonly, PVC dishes. Once 70 – 80% of the pediveligers have reached the eyed stage, the tank is illuminated; pediveligers swim away from the light and settle quickly (Spencer 2002). After metamorphosis, oysters can no longer swim, and they attach themselves to the settlement substrate. Onset of metamorphosis can be accelerated by the addition of L-dopa and/or epinephrine (Coon et al. 1986).

Nursery

Oyster spat are removed from settlement substrate by scraping with a sharp edge. The spat are then transferred to the nursery system. There are two common types of nursery systems for Pacific oysters: upflow; and raceway. The upflow method suspends the spat on mesh screens in the water column while water is forced up from the bottom of the rearing unit. This method allows constant water flow to bring food organisms to the juvenile oysters. Spencer (2002) recommends stocking densities of 200 mg/liter of culture volume, a water flow rate of 20 – 50 mL/min per gram of live spat, and weekly water exchange. Weekly water exchange in nursery units flushes out wastes into the environment and allows spat to be cleaned. A less common nursery system uses wooden trays lined with plastic and a thin layer of sand on the bottom. Spat are placed in the trays, which are then transferred to a fiberglass raceway. Flow rates and densities in the raceways are similar to those in the upflow method. Spat are kept in the nursery until they are large enough for transfer to the grow-out system.

Grow-out

Grow-out of oysters is usually done in the intertidal zone of a bay or estuary. Formulated feed is not used in grow-out of oysters, thus oysters rely on the natural ecosystem to provide the nutritional requirements for growth.

Spat of about 20 mm in length, collected from the wild or raised in hatcheries, are transferred to grow-out sites. Two culture techniques are employed in grow-out: bottom culture; and off-bottom culture. The two methods are practiced widely, and in the United States a combination of bottom and off-bottom culture is employed. In China, where spatfalls are regular, oysters traditionally have been collected on artificial rock piles. The rocks are typically natural marble or flagstone and are sometimes cleaned with a liming material and set out to dry before placement in areas with natural spatfalls (Spencer 2002). After spatfall, rocks are moved to more productive and protected locations to grow to market size. The production process in China takes approximately 4 years, and meat yields can be up to 15 mt/hectare (Cai and Li 1990).

Another method of bottom culture used in France relies on mesh screens placed over spat laid on sediment in the intertidal zone. Alternatively, spat may be combined in mesh socks, which are laid on the bottom. The oysters are allowed to grow for 12 – 24 months then removed, graded, and re-laid for an additional 12 – 24 months. Densities are usually 5 – 7 kg/m^2 during the early stage of growth, and 0.7 – 0.9 kg/m^2 for the final stage of grow-out (Gosling 2003). Spencer

(2002) found that a stocking rate of 200, 20-g oysters per square meter gave a 60 g increase in growth over 2 years with a survival of 50%. In all bottom culture techniques, there is a need for predator protection. To keep crabs from entering culture areas, fences about 40 cm high are often built of plastic mesh or other readily-available material (Gosling 2003).

Off-bottom grow-out

Off-bottom culture of oysters is a more common practice than bottom culture in some Asian countries, and it employs a number of different structures for oyster attachment. The benefits of off-bottom culture include: avoidance of benthic predators; site selection independent of sediment type; and three-dimensional use of the water column (Brett et al. 1972). Raft culture typically requires a site with deeper water to prevent the trays or lines from "bottoming out" during low tide.

Japan's oyster industry is primarily based on capture of wild spat on suspended cultch and grow-out using rafts or longlines (Spencer 2002). Oysters are collected on scallop or oyster cultch, attached at 1 – 2-cm intervals along wires, and separated by bamboo spacers. These devices, called rens, are about 2 m long. Spat are transferred to intertidal zones to be "hardened." In the hardening process, newly settled spat are exposed to strenuous conditions of frequent dryness to select stronger juveniles for grow-out. The hardening process takes approximately 6 months. After the hardening period, oysters are spaced along a longer wire. These rens (often 9 or 10 m long) are attached to grow-out rafts or longlines. Longlines are lines of wire suspended by floats from which the oysters are suspended on rens. Typical rafts measure 20 m by 10 m, and are constructed with bamboo poles on supporting beams and plastic floats. Rafts can be connected in groups, and groups of five typically linked by chain are moored to the seabed with two or three, several-ton concrete blocks. Initial stocking densities are approximate, but rens with 60 – 70 shells attached are placed on the rafts at 20-cm intervals. Quantities of Pacific oysters harvested from rafts range from 7 – 20 kg/ren (Quayle 1988).

In Korea and China, racks, stakes, and longlines are used in the grow-out phase of oyster culture. Stake culture is most common in China, where bundles of 6 – 10 stakes are arranged in a tent structure. Stakes are driven into the seafloor by hand and spat settle on the stakes. After settlement, the stakes are relocated to more productive or sheltered waters. From this stage, the grow-out cycle is approximately 18 months and yields can be up to 6 tons of meat per hectare (Nie 1991). Rack culture is common in both Korea and China. Racks are simple wooden structures that suspend the oysters 0.5 – 1.0 m above the ocean bottom. Oyster or scallop cultch are drilled and attached to steel or wooden rods, which are placed on the racks. The culture process takes 18 – 24 months and yields from rack culture are similar to those of stake culture. The most prevalent method of grow-out in Korea is longline culture. Oyster spat are collected on cultch at locations that have natural spatfalls, and transferred to longlines that are sited in relatively calm and productive waters. Floats at the top of the longlines can be weighted down so as not to be visible on the water surface. Mooring devices are concrete blocks, boat anchors, or other suitable weights. Oyster cultch with attached spat are drilled and inserted on wire that has been crimped at approximately 20-cm intervals to separate cultch. Oyster production and yields on longlines are similar to those of raft culture.

On-bottom grow-out
The other common grow-out method is the culture of oysters on seabeds. In this discussion, "oyster ranching" will refer to the collection of oysters from the wild, replanting in another ocean region, and dredging at harvest. Oyster ranching is practiced in numerous countries (Burton et al. 2001), including the United States, the United Kingdom, Mexico, France, Germany, and others. This typically entails distributing oysters on cultch or spat directly into the sea to grow-out on the seafloor and harvesting by dredging or manually with tongs. This culture method is cheap but less controllable than off-bottom culture and is more destructive to the seabed.

In the United States, production techniques vary by location. In the Pacific Northwest and Northern California, the majority of oysters farmed are produced by on-bottom techniques (Mathiessen 2001). The main species produced is *C. gigas*; however, there is some culture of *O. lurida*. The seed stock can be obtained from hatcheries or from the wild. Hatchery techniques used to produce triploid oysters, however, make wild-capture of spat relatively inefficient for producers. Seed, whether collected from the wild or produced in hatcheries, settle on oyster cultch and are laid in protective bays and inlets. In areas where the sea bed is not suitable for grow-out, suspended oyster culture can be practiced or oyster shells or gravel can be applied to the sea bed to produce a more rigid surface (Matthiessen 2001). Most of the grow-out is practiced in the inter-tidal region, and harvest is achieved by manual harvest or dredging (Matthiessen 2001).

In the Gulf of Mexico, U.S. producers typically culture *C. virginica* by extensive bottom culture techniques, and harvest is achieved by dredging from oyster boats. Dredges are metal baskets with a row of spike-like teeth. When dragged over oyster beds, dredges uproot the oysters from the bed and force loose oysters into the basket. Suction dredges are also used and are efficient in clearing bottoms of 10,000 bushels per day. Some oyster producers on the U.S. East Coast and in the Gulf of Mexico use racks or sacs suspended on stakes as a grow-out method.

In Louisiana coastal waters, the Delaware River, and the Chesapeake Bay, respective state agencies spread cultch in the coastal waters, and private growers harvest the cultch with attached seed (*C. virginica*), which is transferred to private culture plots. The culture technique typically is bottom culture. Dredging and manual harvest are common in these regions. In the Chesapeake Bay, there is a concerted effort to replenish the declining oyster populations, starting with production trials of triploid non-native Suminoe oysters (*C. ariakensis*).

Availability of Science

There is considerable scientific and grey literature on oyster aquaculture. The United Nations Food and Agriculture Organization (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 oyster culture.

Aside from FAO and NACA (Network of Aquaculture Centers in Asia-Pacific) documents, information on oyster culture in Asian countries is not readily available to the public.

Market Availability

Common and market names:
Farmed oysters are sold as "oysters." When used for sushi or sashimi, oysters are commonly sold as *kaki*.

Seasonal availability:
Farmed oysters are available year-round, but fresh oyster availability may be limited in specific regions for food safety reasons (See Appendix).

Product forms:
Oysters can be served raw (shucked or unshucked), smoked and canned, or frozen.

Import and export sources and statistics:
The majority of oyster exports are in their shell; fresh or chilled (Figure 8). Frozen oyster meat accounts for 18% of global exports, while approximately 13% are European flat oysters (shucked or unshucked, fresh or chilled).

Analysis of FAO data revealed that although China is the world leader in oyster production (accounting for some 82% of global production) it contributes only a small proportion of the country's production to the global market. Some 0.4% of China's oysters produced by both aquaculture and capture are exported compared to 2.4%, 4.1%, and 5.4% for the United States, the Republic of Korea, and France, respectively (FAO 2005). According to the United States Department of Commerce, the U.S. imported roughly 3.1 metric tons (mt) of oysters in 2003, of which 1.8 mt was from Canada, 0.6 mt was from Korea, and 0.7 mt was divided among other countries.

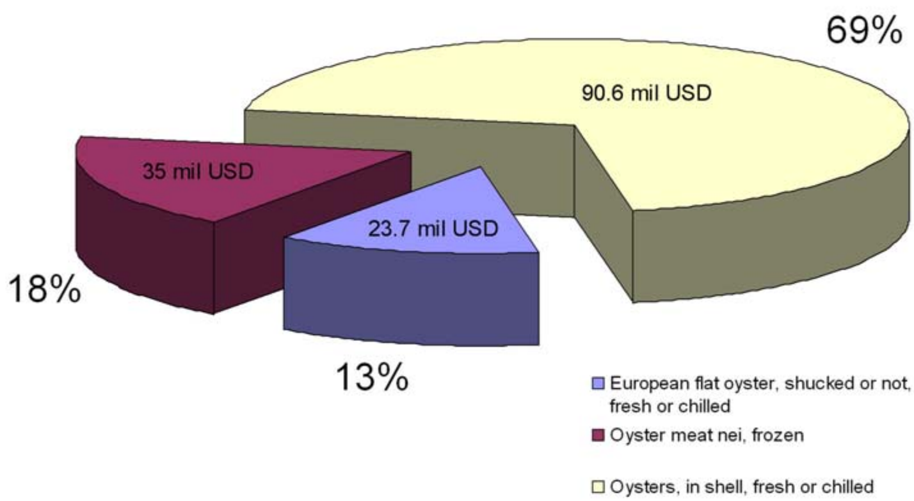

Figure 8. Global oyster export market. Percentage of total quantity of oysters exported globally and respective values in millions of U.S. dollars (mil USD). Source: FAO 2005.

Oyster aquaculture has appeared to have saturated the market for oysters as import and export values per metric ton of oysters are exhibiting a downward trend (Figure 9). As this continues, producers will continue to make less money for their product without market differentiation. A positive of this market trend is there is less need to harvest wild oysters from the oceans.

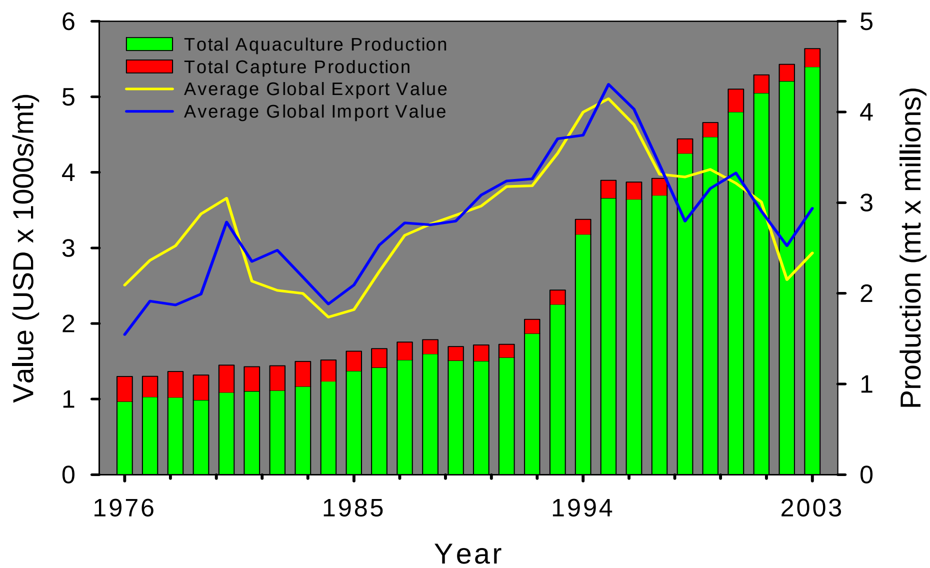

Figure 9. Global oyster trade as compared to oyster aquaculture and capture production. Import and export values are thousands of U.S. dollars per metric ton (USD x 1000s/mt), and aquaculture and capture production units are millions of metric tons (mt x millions). Source: FAO 2005.

III. Analysis of Seafood Watch® Sustainability Criteria for Farmed Species

Criterion 1: Use of Marine Resources

Oysters require no wild fish in the form of fish meal or fish oil in aquaculture production or natural production, thus there is no direct effect on wild fish populations from this aquaculture activity. Because oysters 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 limits primary productivity as most coastal ecosystems tend to be more eutrophic than nutrient limited.

There is also little evidence to suggest that capture of wild oyster spat and broodstock for aquaculture lessens the abundance of oysters in coastal ecosystems. Spat captured for aquaculture usually are transplanted back into the same ecosystem where they would have settled naturally. Oyster farms are sited where conditions are good for growth, and oyster survival and growth no doubt are better than at many other sites where the spat would have otherwise settled naturally. When spat are collected with spat collectors, there is no bycatch of fish and shrimp. Spat for some oyster culture may be dredged, although hatcheries are more common (Matthiessen 2001). Dredging of spat could cause benthic damage in areas with sensitive habitat (see Criterion 4), but considering the increasing reliance on hatcheries there is little evidence to suggest this would be a growing concern.

The combination of no reliance on ocean resources for feed inputs as well as little impact of broodstock capture on wild populations results in a low conservation concern for this criterion.

Use of Marine Resources Rank:

Low	Moderate	High	Critical

Criterion 2: Risk of Escapes to Wild Stocks and Ecosystems

Oysters 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).

Although biosecurity has increased in much of the world, there are still areas where laws are not in place to control the importation of non-established or non-native species. Presently, there is an interest in restoring wild oyster production in the Chesapeake Bay, and pilot studies in aquaculture production of *C. ariakensis* already are underway. The species is non-native and not established in the Chesapeake, but the oysters that are being studied are triploid and not able to reproduce under culture conditions.[1]

The use of tetraploid and triploid oysters appears to have little environmental impact at present. However, there is evidence that triploid oysters can revert to heteroploids in which case some of there gametes could be functional (National Research Council 2004). Tetraploids, although used only as broodstock, are reared to maturity in the wild. This may present concern regarding the release of tetraploids gametes in the wild because tetraploid oysters are fertile. At present, these oysters are not in production but caution is warranted whenever a non-native species is intentionally released into a novel habitat.

Frequency and impact of escapes

Ayres (1991) and Dinamani (1991) described several of the impacts and modes of introductions of the Pacific oyster in Australia and New Zealand, respectively. One of the greatest impacts of Pacific oyster introductions over the years has been its displacement of native oysters. The spread of this introduced species has been to the detriment of some long-standing and valuable fisheries based on local rock oysters (Medcof and Wolf 1975). The Pacific oyster competes with native oyster species for space and food and may even smother them. This potential change in the species balance also has the potential to impact species other than oysters through a modification of their habitat.

In the U.S. Pacific Northwest and in British Columbia, the native oyster species is *O. lurida*. This species has been declining in numbers for the past century, and this decline was the major factor which led to the introduction of *C. gigas*. This introduction took place in several stages throughout the first half of the 20th century before there was a regulatory structure for the introduction of non-native species. As for competition, it has been postulated that there is a lack of adequate food to sustain native oysters, or there may be some physiological effect, namely metabolic competition taking place that reduces the success of *O. lurida* (Chew 1991). In any case, *C. gigas* is competing with *O. lurida* for resources, but it is unknown whether the native oyster population has been suppressed by the success of the Pacific oyster or whether there are other factors at play.

There is interest in developing genetically-improved oysters that grow faster and that are more resistant to diseases and other adverse conditions that may develop during culture. One major effort has been on the development of polyploids (Nell et al. 1996). There also are efforts to improve oysters through selective breeding and other genetics-based techniques (Ward et al. 2000). Specific negative effects of culture of these hatchery-reared oysters on wild oyster populations have not been identified, but there are concerns that genetically-altered culture animals can negatively impact biodiversity.

Presently, there is no containment system in aquaculture that is 100 % effective and almost all oyster culture is conducted in open systems where there is some risk of escape, especially for non-native species of oysters; however, because oysters are non-motile, this risk is less than that posed by finfish or shrimp culture during the grow-out stage. In areas where non-native oysters

[1] Culture conditions refers to the time period oysters are contained in grow-out plots. There would be a risk if triploids were not collected at the time of harvest and left to grow in the wild.

have been introduced, negative interactions with wild stocks, especially through competition for food and space, have been well documented. Plans to use non-native species (albeit with imperfect plans for sterility) for restoration of native oyster beds is also cause for concern.

The history of use of non-native oysters, the inherent open systems required for the grow-out phase of oyster culture, and future restoration plans using non-native oysters, result in a moderate conservation concern for the risk of escaped fish to wild stocks criterion for farmed oysters.

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 numerous incidences of viral diseases in shellfish culture; however, identification and isolation of these diseases is quite difficult (Gosling 2003). Bacterial diseases, on the other hand, are more easily identified. Among bivalves, oysters are the most susceptible to disease. A brief synopsis of the pathogens that affect oyster culture is presented in Table 2. Oyster diseases, as with many shellfish diseases, can severely limit hatchery production because of the static water environment and elevated water temperatures (Gosling 2003). Proper sterilization of water and use of disease-free broodstock are thus of critical importance in oyster culture.

The most damaging oyster diseases are MSX, juvenile oyster disease (JOD), bonamiasis, nocardiosis, and Dermo. MSX disease first appeared in 1957 in Delaware Bay where it caused massive mortalities of eastern oysters (*C. virginica*) both wild and cultured (Barber undated). Juvenile Oyster Disease was first noted in 1988 in hatchery-produced eastern oyster seed held at nursery sites in Maine, New York, and Massachusetts (Elston 1990). It has been responsible for mortalities of over 90% in certain locations. First noticed in oysters brought into the United States from Europe, *Bonamia ostreae* became a prominent protozoan disease of oysters in California. This disease was subsequently transported with seed to Brittany, France where it led to the demise of the flat oyster industry throughout Europe.

Pacific oyster nocardiosis is a syndrome that kills oysters during periods of relatively high water temperatures, and thus is sometimes associated with Pacific oyster summer mortality. Dermo disease was first documented in the 1940s in the Gulf of the Mexico where it caused extensive oyster mortalities. The disease was found in the Chesapeake Bay in 1949, and since it has been consistently present there. Dermo disease has spread in the United States and can be found in other places, including Delaware Bay, Cape Cod, New Jersey, and Maine. The range extension was attributed to introductions by many means over many years in conjunction with recent increases in sea-surface temperatures during the winter (Ford 1996; Cook et al. 1998; Ford et al. 2000).

Dermo disease, MSX disease, and Bonamiasis can cause serious problems in grow-out plots and hatcheries, thus it is critical that care is taken to maintain hygiene and traceability of transplanted oysters. Most of the management protocols for controlling these diseases focus on preventing their transmission (Elston 1990).

In addition to disease, farmed oysters also fall prey to introduced predators. Two major predators were introduced with Japanese oyster seed over the years: the Japanese oyster drill (*Ocenebra japonica*); and the turbellarian flatworm (*Pseudostylochus ostreophagus*). These two species have become well adapted in various oyster growing bays in the State of Washington as well as in Humboldt Bay in California (Chew 1991).

Table 2. Examples of some pathogenic bacterial and protozoan diseases in oysters. Source: Gosling 2003.

Species affected	Pathogenic agent	Disease	Type
Crassostrea gigas	*Nocardia* sp.	Pacific oyster nocardia (PON) or summer disease	Bacterial
C. virginica	*Vibrio* sp.	Vibriosis (bacterial necrosis)	Bacterial
C. virginicia	New species of α-proteobacteria (CVSP)	Juvenile oyster disease (JOD)	Bacterial
C. virginicia	*Haplosporidium nelsoni*	MSX	Protozoan
C. virginicia	*H. costale*	Seaside disease	Protozoan
C. virginicia	*Perkinsus marinus*	Dermo disease	Protozoan
Ostrea edulis	*Pseudomonas sp.*	Bacterial disease	Bacterial
O. edulis	*Bonamia ostreae*	Bonamiasis	Protozoan
O. edulis	*Marteilia refringens*	Digestive gland or Aber disease	Protozoan
Saccostrea glomerata	*M. sydneyi*	QX disease	Protozoan

Instances have occurred where introduced oyster species have spread parasites and disease to native oysters and caused severe mortalities. Andrews (1996), for example, described the spread of MSX in the eastern U.S. Over 2 million bushels of seed oysters from the James River public beds were transplanted annually to private beds in 4 major growing areas: Hampton Roads, lower Bay proper, Mobjack Bay at mouth of York River, and the Rappahannock River. The introduction of *Haplosporidium nelsoni* (the causative agent of MSX disease) in 1959 resulted in killing most oysters throughout the Bay, and private planting was abandoned.

Early in the 1940s, oysters in Gulf Coast waters began falling to a protozoan parasite, *Perkinsus marinus* (the causative agent of Dermo). In the mid 1980s, Dermo began killing oysters in the Chesapeake Bay. Over the next decade, the parasite spread throughout the Chesapeake, sometimes inadvertently transported by replenishment programs and commercial operations that moved oysters from reproductively rich bottom grounds to areas more favorable for grow-out (Ewart and Ford 1993). By the early 1990s, Dermo had infested virtually every major oyster bottom in the Chesapeake Bay. In the mid 1950s, *P. marinus* was introduced into Delaware Bay when infected seed oysters were transplanted from the lower Chesapeake Bay. Dermo has continued to move up the Atlantic coast, and has been recorded as far north as Maine.

The eastern oyster populations in the Chesapeake Bay have fallen to approximately 1% of the original stock status, and part of this reduction is a result of the spread of Dermo and MSX (National Research Council 2004). Presently, the introduction of the Suminoe oyster (*C. ariakensis*) is being explored to restore the oyster industry in the Chesapeake. As of July 2004, approximately 860,000 triploid Suminoe oysters have been tested in the Bay. The Virginia

Seafood Council has received permits to conduct industry trials with triploid Suminoe oysters. Caution is warranted, however, as the importation of *C. ariakensis* to the Chesapeake Bay may be yet another carrier of oyster parasites or diseases. Although there have been no identifiable pathogens yet, introductions of non-native species can pose a viable risk of disease transfer. This concern, combined with the documented cases of disease and parasite transfer as a consequence of oyster farming, result in a moderate conservation concern for this criterion.

Risk of Disease and Parasite Transfer to Wild Stocks Rank:

Low | **Moderate** | High | Critical

Criterion 4: Risk of Pollution and Habitat Effects

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, 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. Also, monitoring of oyster growth and survival is necessary, and physical cleaning to prevent fouling can be incorporated into a monitoring program.

Pelagic effects

A study of the Thau Lagoon of the Mediterranean Sea along the coast of France (Chapelle et al. 2000) provided specific details of pelagic effects of oyster culture. Oyster plots occupied about 10% of the water surface area of the lagoon and yielded about 30,000 mt of C. gigas per year. The study found that these oysters had a major influence on the ecology of the lagoon. The watershed of the lagoon was the main source of nutrients, and the input of nutrients coincided with periods of rainfall. During dry periods nitrogen was recycled through the activity of the oysters and the system remained highly productive even though there was no input of nitrogen from the watershed. Oysters also had an important impact through filtration of plankton and other particulate matter and biodeposition. Filtration lowered plankton abundance, and suspended solids concentration and biodeposition caused enrichment of sediment with organic matter in culture areas. Local hypoxia in the water column resulted from oyster respiration and other benthic respiration in the oyster-farming areas, and oxygen fluxes in these areas were about three hundred fold more than in the rest of the lagoon.

The results of the study on Thau Lagoon confirmed that oyster culture makes water less eutrophic by removing plankton. However, the presence of oysters did not prevent hypoxia common in eutrophic waters. Oyster beds increased respiration rates and caused local hypoxia even though plankton abundance was diminished through filtration by oysters. It should be noted that this is an extreme instance where hypoxia occurred as a result of cultured oyster respiration and is likely not a common consequence of oyster farming.

Sediment effects
Crawford et al. (2003) observed that farming of oysters and mussels in Tasmania had little effect on benthic communities when compared to the effects of salmon culture (Crawford et al. 2001 and 2002). There were no extensive mats of Beggiatea bacteria, no spontaneous outgassing from sediment, no major shifts in benthic infauna to species tolerant of high organic loading, no redox (a measure of the oxidation potential of the benthos) values of 0 millivolts or less, and no elevated concentrations of sulfide as is often observed beneath salmon culture operations. Thorne (1998) made similar observations on shellfish culture in Tasmania. As a result, Crawford et al. (2002) did not recommend monitoring of shellfish areas in Tasmania other than for annual video records.

Shellfish stocking densities are low in Tasmania, however, and more severe effects have been observed in other regions. Extensive bacterial mats have been observed under longlines, for example (Dahlbäck and Gunnarsson 1981), and changes in benthic community composition in an area of intensive oyster culture were observed in Spain (Tenore et al. 1982). Additionally, Hayakawa et al. (2001) studied biosedimentation by Japanese oysters (*C. gigas*) in Ofunato estuary in Japan, and found that there was a seasonal trend in sedimentation increasing through spring and summer, to a maximum of 23 g/m^2 per day in September (2200 mg Carbon, 290 mg Nitrogen, and 28 mg Phosphorus/m^2 per day). There also was dissolved oxygen depletion in deeper water in the vicinity of the oyster beds. Large increases in sediment organic matter accumulation were not observed during the Hayakawa et al. (2001) study, however, suggesting that decomposition was roughly equal to biodeposition.

Small increases in organic matter concentrations in sediment have been observed in mussel culture (Tenore et al. 1982), and this effect can be expected in areas with large amounts of oyster culture as well.

It is obvious that there is no uniform impact of oyster culture on the habitats they are raised in, and site selection is of primary interest, as the negative effects of an oyster grow-out facility will be determined by this factor.

Fouling control
Quayle (1988) discussed the use of a 1 – 2% copper sulfate dip of 1 hour or more to remove fouling organisms from oysters. Quayle (1998) alludes to the use of other compounds for fouling control and specifically mentions the use of xanthatin. Sevin® (Bayer CropScience, Research Triangle Park, NC USA) brand 4F carbaryl insecticide has also been used to control burrowing shrimp in culture plots (Brooks 1993), but it appears as though this is not very effective, and thus is becoming a less common practice.

Other impacts of oyster beds include the cutting of eelgrass—which is an important species in some shallow water marine areas—to clear the ocean bottom for oyster culture, as well as the clearing of the ocean bottom to remove oyster predators. The oyster drill is particularly destructive to oysters, and in attempts to control the oyster drill, in highly infected areas, the ocean bottom is often cleaned and plowed after each oyster harvest.

Dredging
Although the on-growing of oysters on racks, trestles or stakes in the intertidal zone will have an impact on the littoral habitat, dredging of oyster spat or adult oysters in particular can have negative impacts on the harvest grounds. Mechanical harvesting of oysters using dredges and hydraulic-powered tongs extracts both living and attached shell matrix and has been blamed for a significant proportion of the removal and degradation of oyster reef habitat (Reise 1982; Hargis and Haven 1988; Northridge 1991; Rothschild et al. 1994; Dayton et al. 1995). Dolmer et al. (2001) found that impacts of bivalve dredging include changes in seabed topography and sediment structure, resuspension of sediment, and reduction in biodiversity of macrofauna. The habitat impacted by dredging serves many aquatic species as a refuge, and dredging could indirectly cause the decline of aquatic life other than oysters.

On the other hand, Powell et al. (2001) examined the effects of dredging on oyster beds in Delaware Bay, and determined that over a long time period dredging may significantly influence oyster bed physiography and community structure; however, once the bed has become a fished bed, moderate dredging that results in a yearly-swept area of no more than four times the area of the bed is unlikely to result in significant further impact on the oyster populations living there. Moreover, while wild oysters and other bivalves often are harvested by dredging with the same effects that have been noted in bivalve aquaculture plots (Shumway et al. 2003), the density of oysters and other bivalves is greater in aquaculture plots than in natural bivalve beds; thus, the relative effects of dredging are much less per unit of capture for bivalve aquaculture than for wild capture of bivalves. If dredging is conducted on a large scale for seed stock harvest, however, impacts of dredging will be of a similar magnitude as that of wild fishery harvests.

Water quality
Data were unavailable on specific references about antibiotic use in hatcheries; however, the use of antibiotics is prevalent in finfish and shrimp aquaculture in Asia and likely used in hatchery production and possibly grow-out of oysters in that region. In the United States, the Minor Use and Minor Species Animal Health Act of 2004 (MUMS) was signed into law on August 2, 2004, and is intended to encourage development of new animal drugs for minor species and for minor uses in major species. Policies are still being formed, but concern may be raised about the use of antibiotics in U.S. shellfish culture once permits begin to be issued. Additionally, cytochalasin B, 6-dimethylaminopurine, and other compounds are used for polyploid induction in oysters, and these compounds can possibly be inadvertently discharged from hatcheries into coastal waters.

Effluents discharged from hatcheries also contain unconsumed algae and pseudo-feces from culture units; however, hatcheries must maintain high quality water, and they do not discharge large volumes of effluent. Oyster hatchery effluents are also not expected to cause organic pollution or nutrient enrichment of coastal waters (Silapajarn, pers. comm.).

Oysters obtain their nutrition by filtering particulate organic matter (e.g., phytoplankton, zooplankton, bacteria, and suspended soil particles) from the water, and like other bivalves they digest particulate organic matter and expel feces, pseudofeces, and ammonium, phosphate, silicate, and other nutrients. A major factor determining the suitability of a site for oyster culture is the amount of particulate organic matter in the water, as a site with abundant particulate matter can support a high abundance of oysters. Nutrients removed from water by oysters and other bivalves are converted to biomass and ultimately harvested. Therefore, culture of oysters and other bivalves should lessen concentrations of particulate matter and nutrients and make waters less eutrophic.

Synthesis
Effluent is of little concern in oyster hatcheries because little water is discharged. Moreover, because the grow-out of oysters is accomplished in the natural environment, there is a beneficial effect on water quality in the culture area, though some localized effects have been observed at very high densities. Chemicals used in hatchery production of polyploid oysters are also minute and do not appear to cause a contamination concern. The construction and operation of trestles or racks for oyster culture in the intertidal zone will have an impact on the littoral habitat, but harvesting by dredging is highlighted in this analysis as a 'moderate' risk of disturbing the habitat and causing temporary declines in biodiversity. Harvesting of culture plots is less destructive than wild-harvest of oysters because harvesting is restricted to relatively small plots. The exception is if long expanses of oyster reefs are dredged for spat collection. Despite the 'moderate' risk of habitat damage from dredging, overall,, the risk of pollution and habitat effects for oyster farming is low.

Risk of Pollution and Habitat Effects Rank:

Off-bottom:	**Low**	Moderate	High	Critical
On-bottom/dredged:	**Low**	Moderate	High	Critical

Criterion 5: Effectiveness of the Management Regime

Analysis of grey and scientific literature suggests that great care is taken to preserve the environment surrounding oyster farms. The health of cultured oysters depends on habitat quality more so than other species produced by aquaculture because they can quickly bioaccumulate contaminants in their tissues (see Appendix 2). Thus, in developed countries and in some developing ones there are strict regulations governing water quality and habitat change as it pertains to oyster culture. 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 within the industry that the farming practices of oysters are of lower impact than other forms of aquaculture has also 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 has developed BMPs for shellfish production on the West Coast. Additionally, the East Coast Shellfish Growers Association (ECSGA) submitted a pre-proposal to the Northeast Regional Aquaculture Center (within the USDA) for funding the development of shellfish BMPs, but has yet to get funding approved. BMPs have also been developed for the state of Massachusetts. The use of therapeutics in U.S. aquaculture is overseen by the FDA and regulations are quite stringent regarding use of unapproved chemicals. The U.S. Environmental Protection Agency (EPA) regulates the use of non-pharmaceutical chemicals used in shellfish culture as well. Laws are strict and shellfish producers typically do not use unapproved chemicals. This comprehensive suite of management measures is deemed to be highly effective and thus of low conservation concern.

Effectiveness of Management Rank:

Highly Effective	Moderately Effective	Ineffective	Critical

IV. Overall Evaluation and Seafood Recommendation

Like clams, mussels, and scallops, oysters are filter-feeding bivalves that inhabit much of the world's oceans. Farming of oysters accounts for over 95% of total global production of this bivalve. Oyster seed can be reared in hatcheries or collected from the wild, and grow-out is accomplished in natural, inter-tidal, or sub-tidal waters, using off-bottom suspended culture or on-bottom techniques. When oysters are farmed on the seafloor they are ultimately harvested using dredges, mechanical tongs, or less often manually with tongs. Dredging of oysters to collect spat or to harvest market size oysters after grow-out can have negative environmental effects, but dredging of cultured oysters results in less impact per unit production than dredging of wild oysters, due to greater densities on smaller plots.

Because oysters are filter feeders, oyster aquaculture facilities generally improve coastal water conditions by converting nutrients and organic matter to biomass. In addition, they don't rely on wild-caught fish in the form of fish meal or fish oil. Oysters have, however, been introduced to non-native areas, and aquaculture has played a role in some of these introductions and consequential disease transfers and competitive interactions with wild stocks. There are also ongoing attempts to restore coastal areas with non-native oysters and stimulate aquaculture production of these species in those areas, which could increase the risk of new disease transfers to wild oysters. Additionally, there are growing concerns regarding impacts of genetically altered oysters being raised in the wild. Oysters are non-motile at the adult stage and thus there is no true "escape" of these organisms from culture plots, but there can be instances where oysters are overlooked by producers and left to grow and reproduce in the wild.

Management regimes and codes of conduct have been formed by the shellfish industry and generally these codes and practices go above and beyond laws governing the culture activity. Overall, at present, oysters pose substantially less risk to the environment than do other cultured finfish or crustacean species.

For oysters grown in both off- or on-bottom culture, three out of the five criteria are of low conservation concern, with the two criteria of moderate concern being the Risk of Escapes and Risk of Disease Transfer. This results in an overall recommendation of Best Choice for farmed oysters.

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√			
Risk of Escapes to Wild Stocks		√		
Risk of Disease and Parasite Transfer to Wild Stocks		√		
Risk of Pollution and Habitat Effects	√			
Management Effectiveness	√			

Overall Seafood Recommendation

Off-bottom cultured oysters:

Best Choice	Good Alternative	Avoid

On-bottom/dredged oysters:

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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VII. Appendices

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)	■
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	■
Criterion 1: Use of marine Resources	■

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	■
Criterion 2: 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	■
Criterion 3: Risk of Disease Transfer to Wild Stocks	■

Factor		Ranking
Effluent water treatment		
Evidence of substantial local effluent effects		
Evidence of regional effluent effects		
Extent of local or regional effluent effects		
Potential to impact habitats: Location	off-bottom	
Potential to impact habitats: Location	dredged	
Potential to impact habitats: Extent of Operations	off-bottom	
Potential to impact habitats: Extent of Operations	dredged	
Criterion 4: Risk of Pollution and Habitat Effects		

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	
Criterion 5: Effectiveness of the Management Regime	

Appendix 2: Public Health

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

Improved detection methods, 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) emphasizes that outbreaks of shellfish-borne illnesses still occur. More outbreaks of shellfish illnesses result from private collection and consumption of shellfish than from commercial suppliers of shellfish, however, and 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 of consuming cooked shellfish; nevertheless, Shumway (1992) stresses that cooking will not always deactivate infectious particles in shellfish.

"Shellfish watch" programs are common throughout the developed world, and 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) provides 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 oysters and other shellfish concentrate the pathogens to much greater concentrations than found in the water.

Because oysters and other shellfish can cause public health concerns, most developed nations have imposed standards for microbial quality of oysters. 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 $\leq$ 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 90th 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 (90th 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) are 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 that 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, including amnesic shellfish poisoning (ASP), paralytic shellfish poisoning (PSP), and diarrhetic shellfish poisoning (DSP). These intoxications can be quite serious or lethal. The symptoms for each of these are listed below:

> 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 – 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 in-coordination 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, 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 poisoning 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. 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, polycyclic aromatic hydrocarbons, and butyltin). Shumway (1992) provides a list of action levels for concentrations of several undesirable substances in seafood in Table A1, below.

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	Fish and shellfish
	0.40 ppm	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