Seafood Watch

Seafood Report

MONTEREY BAY AQUARIUM®

Farmed Scallops

(Illustration © Monterey Bay Aquarium Foundation)

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.

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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

Scallop culture of 1.2 million metric tons (mt) was 10% of the total bivalve production by world aquaculture in 2003. Scallops have a broad, worldwide distribution and can be cultured in many countries. Approximately 96% of the scallops consumed in the United States are captured from the wild and most of these are from domestic U.S. fisheries; the rest are wild-caught product imported from Canada. Although only about 4% of scallops consumed domestically are farmed, nearly all of these are imported from China and Japan.

Scallop spat for aquaculture are captured from the wild with spat collectors or produced in hatcheries and transplanted to sites in coastal waters for grow-out. Culture is by either off-bottom or on-bottom methods where scallops are suspended in the water column or laid on the seabed, respectively. Scallops produced by on-bottom techniques usually are harvested by dredging, while scallops produced by off-bottom techniques scallops are harvested by hand. Dredging of scallops from on-bottom culture plots can have negative impacts on the seabed and cause benthic diversity to decline.

Fertilizers and feeds are not applied at grow-out sites for scallops, 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 scallop grow-out activities.

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

The capture of wild scallop spat for use in aquaculture does not appear harmful to natural scallop populations because spat are transplanted to sites that are generally superior to those where spat would settle naturally. However, caution is raised for cultured scallops in China when wild spat are collected, because of the generally low abundance of scallops in the wild.

Due to the lower impacts of farmed scallops produced by off-bottom techniques, off-bottom scallops are ranked Best Choice, while on-bottom scallops, which are dredged, are a Good Alternative when suspended culture scallops are not available.

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√	√ China, using wild-caught spat		
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√ off-bottom	√ dredged		
Management Effectiveness		√ China and Japan		

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 scallops:

Best Choice 🟩 Good Alternative 🟨 Avoid 🟥

On-bottom (dredged) scallops:

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 scallops are a popular seafood item and the harvest of scallops from the sea cannot meet the demand. The culture of these organisms increased from 975,000 metric tons (mt) in 1993 to nearly 1.2 million mt in 2003, to account for about 59% of world scallop 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. Scallops are an expensive and increasingly-popular member of the bivalve group. There is rapid expansion of the scallop aquaculture industry and as demand grows, production practices in countries from which the United States imports need to be better understood.

Basic biology

Scallops are of the class Bivalvia, order Pterioida, and family Pectinidae. There are more than 360 species of scallops worldwide, and approximately 15 of these are used for aquaculture (Spencer 2002). Proportions of cultured scallop species produced globally are presented in Figure 1.

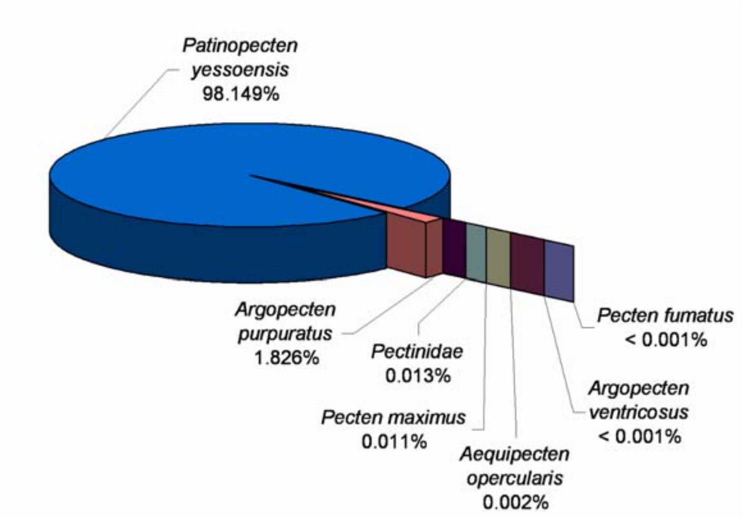

Figure 1. Global proportions of the main scallop species produced by aquaculture. Source: FAO 2005.

In the bay scallop (*Argopecten irradians*) (Figure 2), the labeum is situated at the end of the gill and is composed of a pair of labial palps on each side. The mouth appears to be split in the center of two labial palps and is connected to the esophagus. The flat oval-shaped stomach is connected to the esophagus at its upper end and to the intestine and rectum at its lower end. The rectum passes through the ventricle and goes downward along the back of the adductor muscle and turns to form the anus. The crescent-shaped gonad usually is located between the posterio-ventral part of the foot and the front side of the adductor muscle.

Figure 2. The bay scallop (*Argopectens irradians*). Image credited to Tampa Bay Watch.

Food is filtered by the gills and then sent to the mouth by movement of the labial palps. Food ingested by scallops is composed of phytoplankton, zooplankton, bacteria, and detritus. Under normal living conditions, the two shells of a feeding scallop are slightly open and the tentacles on the edge of the mantle are extended.

If environmental conditions become unsuitable, the young scallop is capable of cutting off its byssus and swimming to a better location by means of a water-jet generated by the closing and opening of its shells. Scallops can swim faster than any other species of bivalves. When it finds a suitable place, it secretes a new byssus and attaches to the substratum again. The ability to secrete the byssus is determined by the size of the scallop and the water temperature. After it has grown up, the bay scallop discards its byssus.

Scallops usually discharge sperm before releasing eggs. Mature sperm are smaller than eggs and swim actively in seawater where fertilization takes place. The embryo gradually develops into a free-swimming, ciliated larva called a veliger. During this stage the shell is secreted and the larva becomes a D-shaped pediveliger. At this stage, the larvae (often called crawlers) have both a functional velum and a foot, and alternately swim about and crawl on the bottom or other substratum. After a few days of crawling, the swimming ability of larvae gradually is reduced until the velum is completely reabsorbed and they must settle. Once settled, organs such as foot, velum and eye spot degenerate, and the gill and adductor muscles develop quickly. The early developmental stages of scallops are depicted in Figure 3.

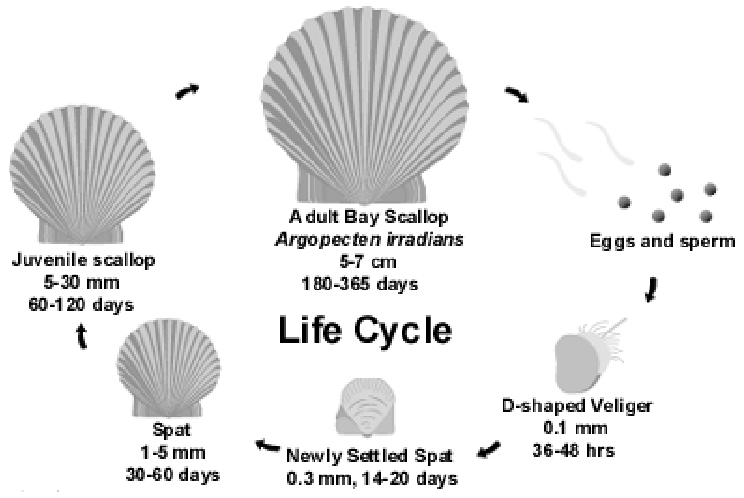

Figure 3. Developmental stages of the bay scallop (*Argopecten irradians*). Image credited to the Florida Fish and Wildlife Conservation Commission.

Aquaculture production

Aquaculture has become a more important source of scallops than wild catch in many countries (Figure 4). According to FAO (2005), scallops are currently produced in 20 countries, the leading producer of which is China, followed by Japan, Chile, and Peru (Figure 5). China has in the past been the major producer of all types of bivalves, but Japan has provided most of the major advances in scallop aquaculture technology. Chile and Peru have been diversifying their aquaculture production since the late 1970s, and scallops have proven to be a profitable export.

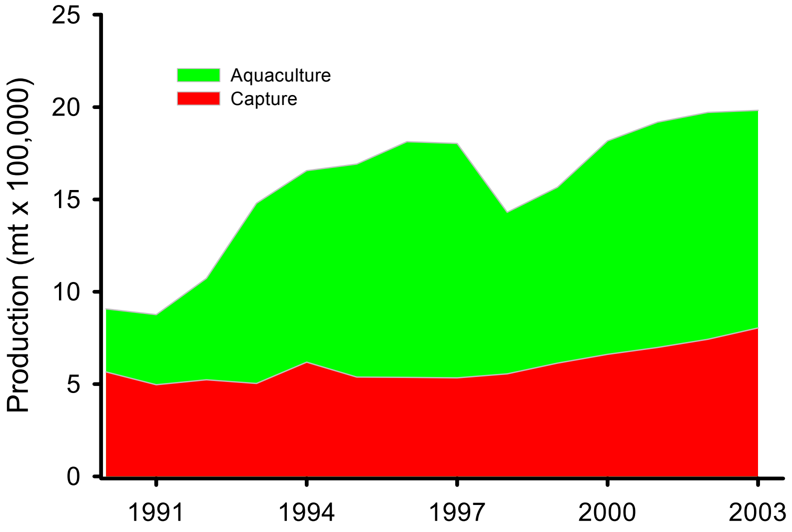

Figure 4. Comparison of scallop aquaculture and wild capture of scallops. Source: FAO 2005.

The two most valuable species of scallops produced in China are the Zhikong scallop (*Chlamys farreri*), which is native, and the Yesso scallop (*Patinopectin yessoensis*). The Zhikong and Yesso scallops are cultured in cool waters of the Bohai and Yellow Seas in northern China, while to a lesser degree the bay scallop is cultured in warmer waters along the mid section of China's coastline. The Yesso scallop was transplanted from Japan to China and the bay scallop is native to North America. Culture of these species using wild-caught seed and Japanese technology began in the 1960s (Spencer 2002). Scallop culture increased and hatcheries were introduced to enhance the spat supply.

From 1993 to 2003, scallop production in China increased five-fold, though during that time period there were dramatic fluctuations in production. For example, production decreased from 1,000,000 mt in 1997 to 629,000 mt in 1998 as the result of mass mortalities during the summer. Gosling (2003) attributed these die-offs to over-crowding, high water temperatures, and deteriorating water quality.

In Japan, the central government has provided significant funding for the advancement of scallop aquaculture. Japanese scallop farming dates back to 1936 in North Hokkaido; however, scallop farming was not successful until the late 1960s. The main species cultured in Japan is the Yesso scallop. Initially, only bottom culture was conducted along the coast of Hokkaido, and presently bottom culture still accounts for over half of the production in this area. Suspended culture of scallops is common in Mustso Bay in northern Aomori. Ear-hanging of scallops was very popular in the 1980s, but production by this technique has declined because of excessive fouling. Scallop production in Japan also fluctuated during the period 1993 to 2003. Production peaked at 265,000 mt in 1996 and then decreased annually until it reached 210,000 mt in 2000. Production increased in 2003 to 258,000 mt.

The main culture species in Chile is the Chilean/Peruvian scallop (*Argopecten purpuratus*). The scallop industry in Chile was established in the late 1970s, and it has become a profitable component of the nation's aquaculture industry. Much of the production in Chile has been aided by Japanese overseers. The main areas of production are the Mejillones, Tongoy, and Herradura Bays in northern Chile. Spatfalls are irregular and the country is reliant on hatcheries for spat. Grow-out of spat to market size is conducted using Japanese lantern nets and ear-hanging techniques. The Chilean scallop industry produced a high of 21,000 mt in 1999, but production declined to 15,000 mt in 2003. Production in Chile has been hindered by insufficient spatfalls and excessive fouling.

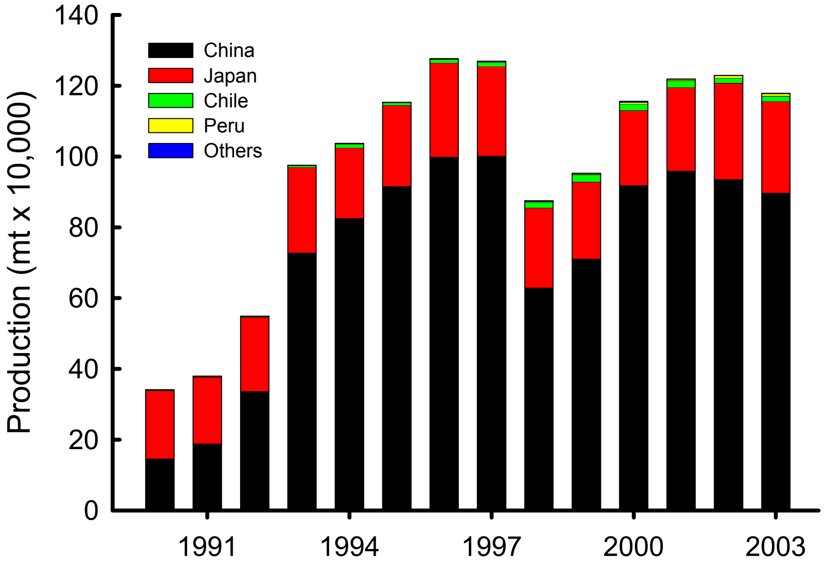

Figure 5. The major countries producing scallops by aquaculture. Source: FAO 2005.

Peru's scallop industry developed from the natural fishery. Divers retrieving scallops for sale sold undersized scallops to farmers for further grow-out. This progressed to the adoption of traditional scallop culture in Peru. The main species produced in Peru is *Argopecten purpuratus*. Seed is obtained from the wild using spat collectors, and grow-out is performed using hanging culture techniques. Peruvian scallop farming is centered on the Bay of Paracas where the seabed is leased from the Department of Fisheries and the Department of Navy.

The Peruvian industry has grown more slowly than that of other major scallop-producing countries. Production in Peru was between 100 and 500 mt during the period 1993-1997. Production has increased, and in 2003, about 6,700 mt of scallops were produced. The increase in production can be attributed to refinement in culture techniques. Moreover, a higher price can be obtained for Peruvian scallops when there is low capture of the Calico scallop (*Argopecten gibbus*) in Florida.

The global value of scallops reached $1.8 billion in 1997 (Figure 6), but declined drastically in 1998 as a result of the decreased production in China. Since 1998, the value of scallops from aquaculture has continued to increase each year and was $1.7 billion in 2003.

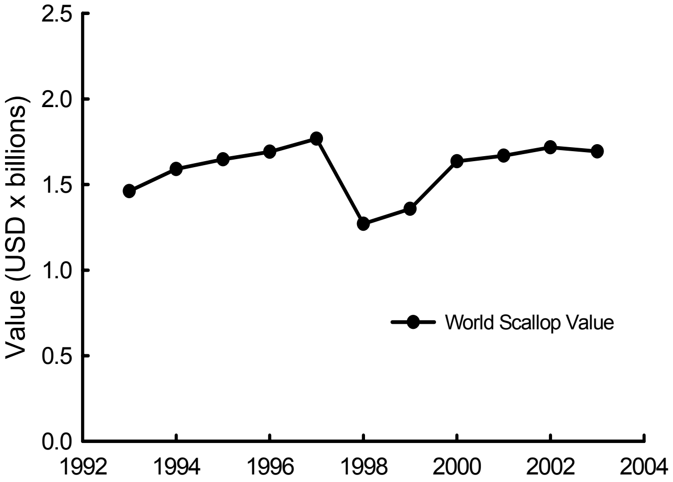

Figure 6. The economic value in billions of U.S. dollars (USD) of world scallop production. Source: FAO 2005.

FAO (2005) data reveals that there is relatively little production of scallops by aquaculture in the United States, but capture of scallops in U.S. waters is approximately 207,000 mt. Of this quantity roughly 7,000 mt is exported (FAO 2005). Thus, the U.S. consumes 200,000 mt of captured scallops from U.S. waters and 23,580 mt from imports, which include a combination of cultured and wild-caught scallops. Data on the fraction of scallop imports produced by aquaculture internationally is not readily available, but estimates of this fraction can be calculated using a combination of U.S. trade data and FAO aquaculture and capture fisheries statistics (Table 1). From these estimates a rough idea of the quantity of scallops produced by aquaculture and by which country can be tallied. U.S. imports of scallops produced by aquaculture are estimated at 8,304 mt or roughly 35% of all scallops imported. Yet when compared to total scallops consumed in the U.S., scallops imported and produced by aquaculture represent only 3.7%. Thus, over 96% of all scallops consumed in the United States are captured from the wild.

Although these estimates reveal that few farmed scallops are consumed in the United States, there is a fraction of scallop imports which are produced by aquaculture. The overwhelming majority of these imports originate in China and Japan (Table 1).

Table 1. U.S. imports of scallops produced by aquaculture and country of origin for 2003 (USDA FAS 2005; FAO 2005). Percentage of aquaculture production calculated using FAO statistics on aquaculture and capture production of scallops for individual countries. Note: Quantity of scallop aquaculture imports estimated by fraction of individual countries' percentages of scallop aquaculture and does not represent actual value of U.S. imports of scallops produced by aquaculture.

Country	U.S. scallop import quantity (mt)	Percentage of export country aquaculture production of scallops	Estimate of scallop imports by aquaculture (mt)
Australia	1	<1	<1
Indonesia	1	0	0
Belgium	3	0	0
Denmark	3	0	0
Iceland	4	0	0
Ireland	5	4	0
Spain	5	0	0
Chile	13	99	12
New Zealand	47	0	0
Korea	57	42	24
Hong Kong	74	0	0
Russia	313	5	15
Mexico	458	<1	<1
Peru	845	31	262
Philippines	1,544	0	0
Argentina	3,047	0	0
Japan	4,938	43	2,123
China	5,867	100	5,867
Canada	6,353	<1	<1
Total	**23,580**	**35**	**8,304**

Aquaculture systems

As with other bivalve culture, scallop culture can be divided into two main activities: spat production; and grow-out of spat to market size. Wild spat can be collected in areas of natural spatfalls, but where spatfalls are absent or unreliable scallop spat can be produced in hatcheries. Grow-out can be by on-bottom or off-bottom techniques in open coastal systems.

Seed Stock Production

Capture

Collection of wild spat takes place in areas where natural spatfalls are dependable. Ito (1986) and Ito et al. (1988) described procedures for procuring spat. Spat collector design varies according to tradition and materials available for their construction. The most common type of spat collector is a mesh sack with substrate stuffed in the sack to expand the surface area. These sacks are a refinement of the traditional onion bag. The sacks are hung from rafts, or more commonly longlines[1] during spatfall. Scallops fall through the mesh openings of the sack and settle on the internal substrate. Certain species of scallops will detach from initial settlement after they reach 10 mm; therefore, spat collectors should have mesh with 6-mm opening (Hardy 1991). Ito (1991) also described spat collectors made from *Laminariaceae* (kelp) suspended from longlines. Unlike other bivalve species, scallop spat are sensitive to handling and must be transferred to grow-out systems rapidly. Hardy (1991) suggested that no more than 10 to 12 hours should pass between removal of spat collectors and placement of spat in grow-out plots.

Hatcheries

Seed stock production in hatcheries depends on many variables and the environmental tolerance of individual scallop species. Temperature and salinity play an important role in scallop spawning and larval development. Ideally, hatcheries should be located near the shore of a bay or estuary where water is naturally suitable for direct use and expensive temperature and salinity alterations are not needed. 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), and brood stock management requires only small amounts of water exchange. The principles of scallop hatchery operation are similar for all species and locations. A schematic drawing of a modern scallop hatchery is illustrated in Figure 7.

Brood stock management

Brood stock are usually selected from wild stocks for optimal color, desirable morphological traits, rapid growth rates, high fecundity, and good survival. Brood stock are transferred to conditioning tanks that receive raw, unfiltered water supplemented with cultured algae. Sand and gravel substrate typically is added to the conditioning tanks. Water flow rates are established by the amount of brood stock in tanks. Feeding regimes rely on food provided by natural seawater or from algal culture. Most modern molluscan hatcheries use algae produced on-site to reduce input of disease and fouling organisms common in natural water. Algae typically are from commercially-available, pure, uni-algal cultures of marine algae. An initial nutrient solution is made from sterile water and inoculated with the pure algae culture. Following initial inoculation, the algae are incubated in containers of increasing size as the population of algae grows. Air stones provide adequate dissolved oxygen and mixing to stabilize algae blooms. Quantitative allotments of algae for feeding scallops are estimated by sampling the rearing vessels and determining the abundance of algae. Practical experience, availability of algae, and scallop species will dictate the algae feeding regimes employed in a specific hatchery; however, all hatcheries should feed efficiently to prevent discharge of algae during water exchange.

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[1] Longlines for molluscan aquaculture are not the same as longlines for capture fisheries. The term refers to cables or ropes stretched and anchored to the seabed. Bivalves are attached to these longlines and grown to market size (see Figure 7).

Spawning

Spawning is induced in scallops by cycling water temperature. Brood stock are transferred to spawning troughs filled partially with cool water to stimulate scallops to extend their siphons. After 15 to 30 minutes, the water is drained and replaced with warmer water. This process is repeated for 1 to 6 hours. After 6 hours, scallops that have not spawned are returned to the conditioning tank (Spencer 2002). Sperm are released before eggs; thus, once spawning starts each scallop is put in an individual container. Eggs are transferred to containers of sterile water and then finally combined with sperm and fertilization occurs. Alternatively, scallops that have been thermally cycled and spawned can be allowed to mass fertilize in the spawning troughs.

Fertilization of scallops takes place rapidly under optimal water conditions (Spencer 2002). Fertilized eggs are collected and gently washed through mesh screens to separate them. Egg incubation requires high quality water to avoid fungal and bacterial organisms which infect eggs. Water may be filtered, but many modern facilities use ultraviolet filters to sterilize water (Figure 7). Moreover, Utting and Helm (1985) recommended adding 1 mg/L of ethylenediaminetetraacetic acid (EDTA) to water in incubation containers to prevent possible toxicity of heavy metals. This has been a common practice in China (FAO 1991). Un-aerated plastic cylinders can be used to incubate eggs. Hardy (1991) noted that at this stage of incubation, antibiotics are often used. In China, apart from treating the water as much as possible to keep it pure, antibiotics, such as terramycin, chloromycetin, penicillin, etc., are usually used to eliminate fungal infections in the larval culture tanks (FAO 1991). Within 96 hours, eggs develop into D-shaped larvae called D-larvae (Hardy 1991).

Triploid shellfish are sterile and therefore do not exert energy for reproduction. This allows for more energy to be diverted to growth. Chromosome modification to produce sterile oysters is a common practice (Chew 1994); however, attempts to induce triploidy by treatment of scallops with caffeine and 6-dimethylaminopurine have been unsuccessful (Nell et al. 1996). Yang et al. (2000) were able to produce triploid scallops by cytochalasin B treatment, but only a small percentage of triploids resulted and survival was low. Thus, chromosome modification is not yet a common practice in commercial scallop culture.

Larval development

Scallop densities in the incubation containers are reduced to ensure adequate growth of D-larvae. Aeration to hold the larvae in suspension is provided with oil-free air pumps (Helm and Spencer 1972). Water quality requirements for D-larvae are similar to those of the eggs in the incubation vessels. At this stage, feeding of prepared algal culture is begun. Water is exchanged 2 or 3 times per week in the larval rearing tanks (Hardy 1991; Spencer 2002). The exchange typically is performed at one time to conserve algae added for food.

During cleaning, larval cultures can be graded and deformed larvae discarded. To reduce water use, minimize disease risks, and efficiently utilize algae, recirculating systems are often used at this stage. Water usually is allowed to fall through successive trays containing the pediveligers. Metamorphosis is reached within 3 to 4 weeks after fertilization (Hardy 1991). Metamorphosis occurs over a 2-day period, and at completion of metamorphosis, scallop larvae are ready for transfer to the nursery.

Nursery

There are several nursery methods for rearing scallop spat. Most involve flow-through units, but recirculation units are also used. In flow-through systems, seawater that has passed through a 45 µm filter is supplemented with algae (Spencer 2002). As spat reach suitable size for survival in open waters they are transferred to the grow-out site.

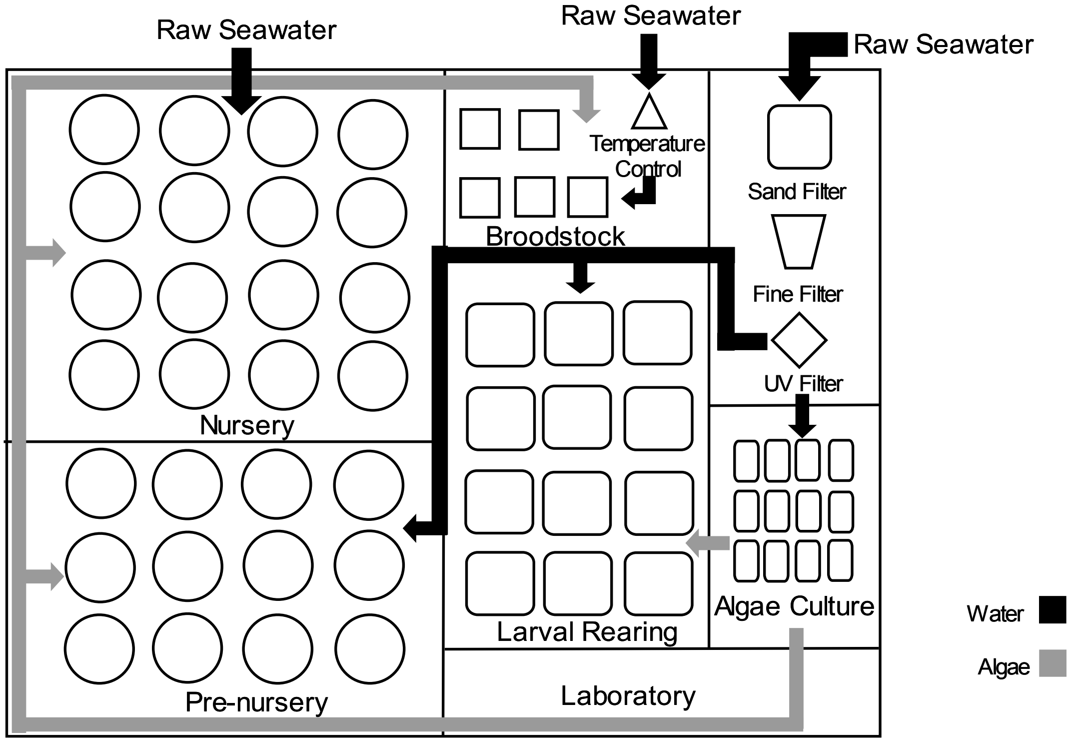

Figure 7. Schematic drawing of a modern scallop hatchery.

Grow-out

Grow-out of scallop spat to market size is either conducted through bottom or off-bottom culture practices at sites where waters are productive and contain an abundance of organic particles. Suspended (off-bottom) culture of scallops is the more productive of the two methods, as suspended scallops have access to the greater abundance of plankton in the mid-level water column (Hardy 1991); however, there are conditions that favor the production of scallops on the sea floor. For example, strong storms can dislodge rafts and longlines used in suspended culture, so bottom culture of scallops is more practical in areas where heavy waves are common. Culture of scallops on the seabed also requires less expensive equipment than suspended culture and is easier to maintain.

Bottom culture of scallops is most prevalent in Japan and is known as “sowing culture.” Before grow-out begins, the seabed is dredged to remove predators such as starfish and sea urchins (Gosling 2003). Scallop spats are placed on the sea floor at a rate of 5 to 6 individuals/m^2 (Ito 1991). In further efforts to control predators, some smaller farmers construct barriers of netting or stone, 15 cm or more in height around culture plots (Hardy 1991). This procedure is feasible only when scallops are harvested by divers because dredging destroys the barriers. In larger, more industrialized plots, barriers are not used and harvest is by dredging. In Japan, dredging of culture plots is alternated and monitored by local cooperatives in order to minimize impacts on the seabed (Gosling 2003). The culture period is 2.5 to 3.5 years, with survival up to 30%, and shell size of 100 mm at harvest. When harvest is by dredging, about 80% of scallops are recovered (Spencer 2002).

Off-bottom culture of scallops is far more widespread than bottom culture. There are several methods in which scallops are suspended off the bottom of the sea floor. In China, the common off-bottom method is confinement in lantern nets. Lantern nets are a staple of the fishing industry in which nets are placed at different depths to catch or hold fish (Hardy 1991) as depicted in Figure 8. The mesh typically has 30-mm openings and galvanized steel rings are inserted to separate each layer of the container. The entire lantern net is attached to a rope, openings for stocking and harvesting the scallops are sewed shut, and the unit is suspended in the water column by aid of ropes attached to longlines or rafts. Depending on the size and stocking rates of the lantern nets, cranes may be necessary to lift the scallops out of the water. Longlines are sited in relatively calm and productive waters and maintained between anchored plastic drums or other floats. Floats can be weighted down so as not to be visible on the water surface. Mooring devices may be concrete blocks or boat anchors. Rafts are a simple variation of the longline method in which multiple lines or steel rods are extended between floats and ropes to which lantern nets are attached. Rafts are moored to the seabed with anchors or concrete blocks. In China, stocking rates for lantern nets are 50 to 80 *C. farreri* per layer, which amounts to 2,000 to 3,000 individuals per lantern net (Gosling 2003). In Chile, small lantern nets are stocked with 16 to 18 *Argopecten purpuratus* per layer (Piquimil et al. 1991). The lantern nets are hung on longlines up to 100-m in length. Harvest timing at the grow-out stage is dependant on species, but can range from 6 to 18 months. Survival is usually about 85% if conditions are optimal.

Pearl nets sometimes are used instead of lantern nets. A typical pearl net is constructed with 4- to 9-mm mesh netting and arranged as illustrated in Figure 8. The base of the net is usually between 30 to 50 m^2. The vertical spacing between separate nets is usually 0.5 m. Strings of 7 to 10 pearl nets are hung on rafts or longlines with a horizontal spacing of approximately 4 m (Spencer 2002).

Ear-hanging is another off-bottom method of grow-out. Ito (1991) recommended a 1.3 to 1.5-mm hole be drilled at the front-eared beak of the left valve of the scallop, above the right notch or through front ears near a byssal notch. Scallops are tied to polyethylene rope in pairs at 15-cm intervals. Each string of scallops can contain up to 130 individuals. The ear-hung scallops can be suspended from rafts or longlines.

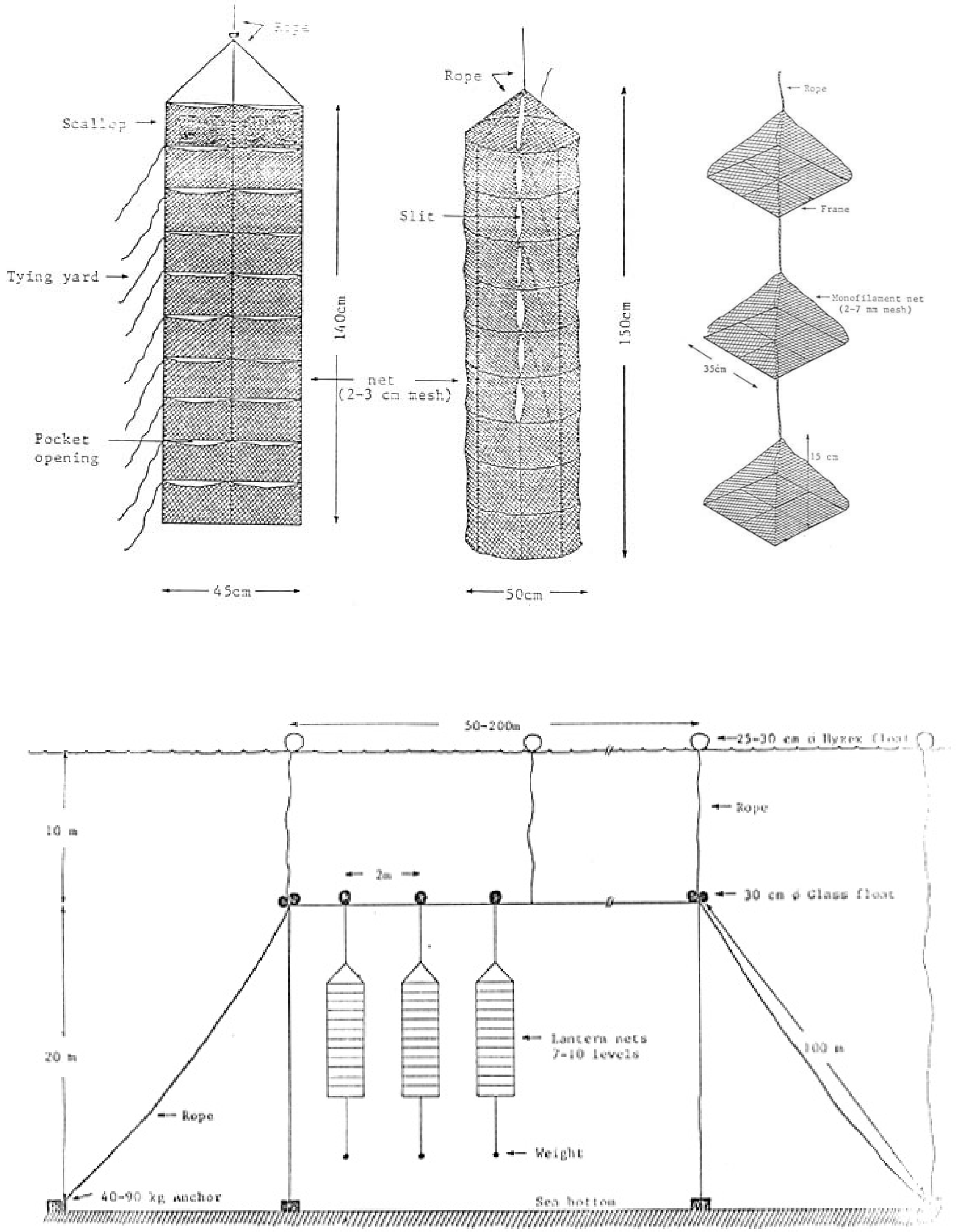

Figure 8. Top – from left to right, pocket net, lantern net, and pearl nets used for suspended culture of scallops. Bottom – schematic drawing of submerged longline used to hang scallop nets. Image credited to Network of Aquaculture Centers Asia-Pacific (NACA 1987).

Availability of Science

There is considerable scientific and grey literature on scallop 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 scallop culture. However, information on actual culture techniques in China and Japan were difficult to locate for this report. Japan's scientific community does not readily share research findings openly, and reports of China's current practices for scallop aquaculture are sometimes contradictory. Aside from FAO and NACA (Network of Aquaculture Centers in Asia-Pacific) documents, information on scallop culture in Asian countries is not readily available to the public.

Market Availability

Common and market names:
Scallops.

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

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

Import and export sources and statistics:
Scallop imports are from a variety of countries. However, the main countries that produce scallops by aquaculture are China and Japan. These countries account for the largest fraction of aquacultured scallops imported to the United States. There is trade of scallops with Chile and Peru, but not near the magnitude of that of China and Japan. The United States consumes mostly wild-caught scallops and the fraction of total consumption that is from aquaculture is estimated to be 3.7%. However, with an increasing global reliance on aquaculture this figure could change and will likely change as demand increases.

Analysis of Seafood Watch® Sustainability Criteria for Farmed Species

Criterion 1: Use of Marine Resources

Scallops 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 this aquaculture activity. Because scallops 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 with spat collectors, there is no bycatch of fish and shrimp. Spat for some scallop culture may be dredged; thus, this method of spat collection 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; however, considering the virtually non-existent scallop fishery in China, it is questionable whether this type of seed procurement is a good practice. In areas where there is a capture fishery and stocks can be evaluated, capture of wild spat may be a justifiable practice. Nevertheless, hatchery production of scallop spat is becoming a more common practice and reliance on wild spat may become less of a controversy. Quantifying the amount of spat produced in hatcheries is difficult in Asia 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 scallops, thus fishmeal and fish oil are not used. In some cases scallops are produced in hatcheries, and cultured algae are used as food for scallops. Scallops rely on natural organisms and other non-living organic matter in the grow-out stage, thus removing nutrients from the water column.

The overwhelming majority of scallop spat collected from the wild do not pose a significant risk to wild scallop stocks, but in China it is difficult to determine the effect of this practice, thus the use of marine resources ranks moderate for China while Japan and the other scallop producing nations pose a low risk.

Use of Marine Resources Rank:

All nations except China:

Low 🟩 Moderate 🟨 High 🟥 Critical ⬛

Chinese farms not using hatcheries to procure seed:

Low 🟩 **Moderate 🟨** High 🟥 Critical ⬛

Criterion 2: Risk of Escapes to Wild Stocks and Ecosystems

Scallops 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. The Yesso scallop and bay scallop were introduced to China and culture of the Yesso scallop in China is the highest in the world. Information on stock status of native scallops in China is not available and thus the effects of this introduction are not well known. Furthermore, FAO reports no capture landings of scallops in China. Japanese scallop aquaculture relies on native species and capture of the native Yesso scallop appears to be stable.

Synthesis

Scallops produced by aquaculture and consumed in the United States are primarily from China and Japan. There is little information to suggest that escapes of cultured scallops in either country have a negative effect on wild stocks. There is also a lack of information on the condition of wild scallop stocks in China. In Japan, the planting of scallop seed in the wild for recapture has proven a successful way of maintaining wild stock recruitment. This could be the case in China, but release of non-native scallops may present a conservation concern for wild stocks. Nevertheless, there is no evidence that has suggested that farming of the Yesso and bay scallops in China has adversely affected wild populations since the introduction of the culture species. Furthermore, these species have been under culture for several decades in China and these introductions, like the introduction of the Pacific oyster to North America, have not proven to cause irrevocable harm to the environment. Thus, as with all other forms of bivalve culture the risk of wild stock detriment by escape of culture species ranks low.

Risk of Escapes to Wild Stocks Rank:

[✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

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

The available knowledge of diseases and parasites affecting scallops is quite limited in comparison to other bivalves. Sindermann (1970) and Getchell (1991) reviewed the diseases of scallops and stated that only a few diseases and parasites are known and their effects on the hosts are slight. Getchell (1991) also stated that no virus or virus-like disease had been identified in scallops, and little literature was found to dispute this observation. Tubiash et al. (1965), on the other hand, described a bacillary necrosis of *Argopecten irradians* larvae. Early signs of the disease were evident 4 to 5 hours after inoculation with the bacterial pathogen, and included a reduction in motility and the swimming of many larvae on the bottom of the container with their rudimentary foot or velum extended. At 8 hours, mortalities began to occur, and at 18 hours, complete mortality was observed. Sherburne and Bean (1986) described another disease affecting larger scallops in Maine, but identification of the pathogen was not possible. Prokaryotic infections appear to be prevalent in scallops (Gulka et al. 1983; Blackbourn et al. 1998; Morrison and Shum 1982), but these diseases do not seem to cause mass mortalities.

Many invasive species such as nematodes, fungi, algae, crustaceans, gastropods, polychaetes, and others, are found in scallops. It is quite difficult to attribute scallop mortalities directly to these invasive species; however, under extenuating environmental conditions, they may favor the onset of disease or parasitism.

The effects of disease organisms can be greatly reduced if precautionary measures are taken to reduce stress, and proper care is given to keep hatcheries clean and disease free.

Synthesis

There are few incidences of disease outbreaks among scallops (Sindermann 1970; Getchell 1991), and little evidence of cultured scallops threatening native stocks when disease organisms exist. Thus, the risk of disease transfer from cultured scallops to wild scallops ranks low.

Risk of Disease and Parasite Transfer to Wild Stocks Rank:

[✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

Criterion 4: Risk of Pollution and Habitat Effects

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

Scallops 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 scallop 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 scallop culture is highly intensive in an embayment with restricted water circulation, scallop 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 scallops can be a positive factor. Scallop aquaculture sites can remove excess nutrients from the ecosystem, improving water quality in coastal areas.

Sediment effects

Scallops 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.

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

Fouling control

Fouling is a major impediment in scallop aquaculture. Suspended culture is quite prone to the fouling and clogging of mesh netting, 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; 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. Although the use of these chemicals is reduced or non-existent in shellfish culture in some parts of the world, some Asian countries have been slow to adopt these better practices. Zhang and Donghui (1997) described a “JH net” antifoulant that did not contain heavy metals. Hao et al. (1990) showed that the use of a copper/ tin paint could decrease the quantity of fouling agents on scallop nets while the content of copper and tin in scallop biomass remained below the Chinese Standards for Food and Health. There is little information on current practices in China, but recent seafood industry reports of seafood being rejected from China and other Asian countries for high levels of contaminants should raise consumer concern on how shellfish and other aquatic species are farmed.

Dredging

Spat for seed stock in on-bottom culture are dredged and transferred to culture areas. Harvest of scallop on-bottom culture plots is also done 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. Kefalas et al. (2003) reported that scallop dredging causes long-term changes in the structure and biodiversity of sponge assemblages in the Gulf of Kalloni, Aegean Sea. Jenkins et al. (2001) concluded that the majority of damage to large benthic invertebrates during scallop dredging occurs unobserved on the seabed, rather than in the by-catch.

The area dredged per unit weight of scallops harvested is typically less for aquacultural production than for scallop fishing; however, this is dependant on natural spatfalls and varies seasonally. If there is good recruitment, less area is dredged for collection of wild seed, yet if recruitment is low, large tracks of seabed may be dredged. Another dredging practice is the use of dredges to clear culture plots of predators where 25% of predators could be removed (Nadeau et al. 1999).

Water quality

Scallops 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[2], and ammonium, phosphate, silicate, and other nutrients back into the water (Dame et al. 1991; Gosling 1992). The growth rate of scallops 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 scallops would contain 14 kg nitrogen and 1.4 kg phosphorus. The volume of water filtered by scallops 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 scallop culture is superimposed.

Synthesis

The grow-out of scallops is accomplished in the natural environment, thus there is a beneficial effect on water quality, though dredging of scallop plots may cause moderate harm to benthic organisms and habitat. There are few reports of disease outbreaks at scallop grow-out sites, thus there is little need for antimicrobials, though they are used in hatcheries (Hardy 1991).

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 scallops because harvest is restricted to relatively small plots. This contrasts with dredging of long expansive scallop beds for spat collection or capture fishery harvests. Presently, the risk of pollution and habitat effects thus ranks low for off-bottom cultured scallops, while it ranks of moderate concern for scallops grown on-bottom and harvested by dredging.

Risk of Pollution and Habitat Effects Rank:

Off-bottom culture:	**Low** 🟩	Moderate 🟨	High 🟥	Critical ⬛
Dredged scallops:	Low 🟩	**Moderate** 🟨	High 🟥	Critical ⬛

Criterion 5: Effectiveness of the Management Regime

The health of cultured bivalves 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 the United States, Canada, and in other developed nations, strict rules are enforced on what sites can be used for shellfish aquaculture. This has helped promote the notion that shellfish are a “clean” and “green” seafood, and this is true in these countries. This is not the case in China, however. The Chinese have been struggling with coastal water quality problems for decades now and discard of industrial pollutants and human and agricultural wastes

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

have severely impacted the coastal environment. Some sites therefore are not suitable for the culture of bivalves. Lee and Qu (2004) described a massive red tide that developed off the coast of Hong Kong in 1998. This was also the year scallop production in China dropped dramatically. Lee and Qu (2004) went on to note that red tides are a common occurrence in these coastal waters. Xue et al. (2004) studied contaminants in cultured shellfish in Fujian coastal areas and found shellfish samples were polluted mostly with organophosphorous pesticides, dichlorvos and methamidophos, as well as organochlorine pesticides (e.g., DDT, DDE). Furthermore, Len et al. (2004) found high fecal coliform concentrations in shellfish in Liaodong Bay. Shellfish farmers are not the cause of this pollution, however, nor is there much they can do about it, so management protocols for these types of issues are not common.

In China, the Export-Oriented System (EOS) is a strict regulatory system that monitors food products from exporting companies at every step, from the pesticides and chemicals used on farms to food processing facilities to packaging plants. Companies wishing to export food products must obtain special licenses from the EOS administration. This aids in food safety and to some degree chemical use at aquaculture sites, but shellfish culture practices could be improved. NACA (Network of Aquaculture Centers in Asia-Pacific) and FAO (United Nations Food and Agriculture Organization) are playing a large role in implementing Best Management Practices (BMPs) in cage culture and mariculture operations in China (Michael Phillips, personal communication). Workshops are put on to try to teach farmers the better ways to produce their crop. These workshops provide critical information to small farmers not purveyed to the large industrial scale aquaculture producer’s knowledge base.

Japan also suffers from water quality deterioration and red tides, but not to the extent of China. There are specific monitoring programs in place by local Prefectures as these are the main source of regulatory enforcement in Japan. Japan’s Law of Fisheries states that only groups of fishermen organized into fisheries cooperative associations can apply for aquaculture rights, otherwise a fisherman may apply for an individual right, called a license. The application for an aquaculture right includes all the details of the proposed facility. After being advised by the Prefecture Fisheries Coordination Committee, the governor determines the area that will be assigned and the conditions and limitations that will be in place.

Synthesis

Little information on existing BMPs can be found for either China or Japan. The Japanese aquaculture research community does not readily share much of its research with the rest of the world, and in China there are efforts to develop BMPs, but none could be located for this report. As a result of the absence of knowledge on management structure, management of cultured scallops imported into the U.S. from China and Japan ranks only moderately effective.

Effectiveness of Management Rank:

Highly Effective 🟩 **Moderately Effective** 🟨 Ineffective 🟥 Critical ⬛

Overall Evaluation and Seafood Recommendation

Scallops are a delicacy and obtain a high price in a growing U.S. market. Scallops can be raised through a variety of methods, which, in regards to environmental impacts, fit into two categories: on-bottom, and off-bottom. On-bottom practices involve dredging and physical disturbance of the benthos; whereas off-bottom practices generally have milder impacts. At present, disease transfer is not a major risk. Scallops do not consume marine fish in the form of fishmeal or fish oil, and they typically make waters less eutrophic by filtering out nutrients. Capture of wild scallop spat typically does not affect the wild populations, but in China where there is little information on the status of wild stocks this practice is cause for concern. In this case scallop seed raised in hatcheries appears to be an optimal alternative. The impact of the introduction of the Yesso and bay scallops to Chinese waters will likely not be a cause of native scallop collapse. In general, farmed scallops present relatively few threats to biodiversity and ecological integrity. Those grown using off-bottom (suspended culture) techniques are considered a Best Choice, while those harvested using dredges are considered Good Alternatives when off-bottom scallops are not available.

Table of Sustainability Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources	√	√ China, using wild-caught spat		
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√ off-bottom	√ dredged		
Management Effectiveness		√ China and Japan		

Overall Seafood Recommendation

Off-bottom scallops:

Best Choice 🟩 Good Alternative 🟨 Avoid 🟥

On-bottom (dredged) scallops:

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

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References

Blackbourn, J., S. M. Bower, and G. R. Meyer. 1998. *Perkinsus qugwadi* sp.nov. incertae sedis, a pathogenic protozoan parasite of Japanese scallops, *Patinopecten yessoensis*, cultured in British Columbia, Canada. Canadian Journal of Zoology 76:942–953.

Boesch, D.F. and R.B. Brinsfield. 2000. Coastal eutrophication and agriculture: contributions and solutions, p. 93-115. In: E. Balázs, E. Galante, J.M. Lynch, J.S. Schepers, J.P. Toutant, E. Werner, and P.A.Th.J. Werry (eds.) Biological Resource Management: Connecting Science and Policy. Springer, Berlin.

Brooks, K.M. 1993. Impacts on benthic invertebrate communities caused by aerial application of carbonyl to control burrowing shrimp in Willapa Bay, WA IN: Abstracts of technical papers presented at the 85th annual meeting of the National Shellfisheries Association, Portland, Oregon, May 31-June 3 1993, Journal of Shellfish Research 12(1), 146.

Carlton, J.T. 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia, 28p.

Castagna, M. and J. J. Manzi. 1989. Clam culture in North America: hatchery production of nursery stock clams, pages 111-126. In: J. J. Manzi and M. Castagna (eds.), Clam Culture in North America. Elsevier, Amsterdam, The Netherlands.

Chew, K. K. 1994. Tetraploid Pacific oysters offer promise to future production of triploids. Aquaculture Magazine 20(6):69-74.

FAO (United Nations Food and Agriculture Organization) 2005. Yearbook of Fisheries Statistics extracted with FishStat Version 2.30 (Copyright 2000). Fisheries database: Aquaculture production quantities 1950-2003; aquaculture production values 1984-2003; capture production 1960-2003; Commodities Production and Trade 1976-2002. www.fao.org/fi/statist/FISOFT/FISHPLUS/asp.

FAO. 1991. Training Manual on Breeding and Culture of Scallop and Sea Cucumber in China. Prepared for the Scallop and Sea Cucumber Breeding and Culture Training Course conducted by the Yellow Sea Fisheries Research Institute in Qingdao People's Republic of China and organized by the Regional Seafarming Development and Demonstration Project (RAS/90/002). United Nations Food and Agriculture Organization, Rome Italy. http://www.fao.org/docrep/field/003/ab729e/AB729E00.htm#TOC

Florida Fish and Wildlife Conservation Commission. Bay scallop life cycle schematic http://www.floridamarine.org/features/view_article.asp?id=6287

Getchell, R.G. 1991. Diseases and parasites of scallops, pages 1017-1055. In: S. E. Shumway (ed.), Developments in Aquaculture and Fisheries Science, Volume 21, Scallops: Biology, Ecology and Culture. Elsevier, Amsterdam, The Netherlands.

Goldburg, R. and T. Triplett. 1997. Murky waters: Environmental effects of aquaculture in the United States. Environmental Defense Fund, Washington, D.C., USA.

Gosling, E. 2003. Bivalve Molluscs: Biology, Ecology and Culture. Fishing News Books, Oxford, United Kingdom.

Gulka, G., P. W. Chang, and K. A. Marti. 1983. Prokaryotic infection associated with a mortality of the sea scallop, *Placopecten magellanicus*. Journal of Fish Diseases 6:355-364.

Hao, Y., B. Sun, and C. Zho. 1990. Water Conserv., Off. Yantai, Shandong Prov., People's Rep. China. Journal of oceanography of Huanghai and Bohai Seas/Huangbohai Haiyang. Qingdao. Vol. 8, no. 1, pp. 57-62.

Hardy, D. 1991. Scallop Farming. Fishing News Books, Oxford, United Kingdom.

Helm, M. M. and B. E. Spencer. 1972. The importance of the rate of aeration in hatchery cultures of the larvae *Ostrea edulis*. Journal du Conseil International pour l'Exploration de la Mer. 34:244-255.

Ito, H. 1991. Japan, pages 1017-1056. In: S. E. Shumway (ed.), Developments in Aquaculture and Fisheries Science, Volume 21, Scallops: Biology, Ecology and Culture. p 1017-1055. Elsevier, Amsterdam, The Netherlands.

Ito, H. 1986. "Hotate-gai ten-nen saibyo nikansuru flowchart nitsuite" [A flowchart for natural spat collection of the Japanese scallop]. [in Japanese] Hokusuiken News 34:1-5.

Ito, H., H. Moriya, and T. Sasaki. 1988. "Hokkaido enganiki niokeru hotate-gai fuyuyosei no bunpu to gaikai-saibyo gijutsu" [Larval distribution and offshore spat collection technology of Japanese scallop in Hokkaido's coasts]. [in Japanese]. Proceedings of Spring Meeting of the Japanese Scientific Society of Fisheries (1988).

Jory, D. E., M. R. Carriker and E. S. Iverson. 1984. Preventing predation in molluscan mariculture: An overview. Journal of the World Mariculture Society 15:421-432.

Kefalas, E., J. Castritsi-Catharios, and H. Miliou. 2003. The impacts of scallop dredging on sponge assemblages in the Gulf of Kalloni (Aegean Sea, northeastern Mediterranean. ICES Journal of Marine Science Vol. 60, no. 2, pp. 402-410.

Loosanoff, V. L. 1960. Use of chemicals to control shellfish predators. Science 131:1522-1523.

Lee, J.H.W. and B. Qu. 2004. Hydrodynamic Tracking of the Massive Spring 1998 Red Tide in Hong Kong. Journal of Environmental Engineering. Vol. 130, no. 5, pp. 535-550.

Lin, F., Z. Yu, Y. Liang, D. Guan, and J. Feng. 2004. The fecal coliform and total bacteria in shellfish in the coastal environment of Liaodong Bay. Marine environmental science/Haiyang Huanjing Kexue Vol. 23, no. 3, pp. 43-45.

MacKenzie, C. L. 1977. Use of quicklime to increase oyster seed production. Aquaculture 10:45-51.

MacKenzie, C. L. 1979. Management for increasing clam abundance. Marine Fisheries Review 41:10-22.

Morrison, C. and G. Shum. 1982. Chlamydia-like organisms in the digestive diverticula of the bay scallop, *Argopecten irradians* (Lmk). Journal of Fish Diseases 5:173-184.

Naylor, R. L., R. J. Goldburg, J. H. Primavera, N. Kautsky, M. C. M. Beveridge, J. Clay, C. Folks, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature 405:1017-1024.

Nell, J. A., R. E. Hand, L. J. Goard, S. P. McAdam, and G. B Maguire. 1996. Studies on triploid oysters in Australia: Evaluation of cytochalasin B and 6-dimethylaminopurine for triploidy induction in Sydney rock oysters *Saccostrea commercialis* (Iredale and Roughley). Aquaculture Research 27:689-698.

Network of Aquaculture Centres Asia-Pacific (NACA). 1987. Status of scallop farming: A review of techniques. Bangkok Thailand. http://www.fao.org/docrep/field/003/ab714e/AB714E00.htm#TOC

North Carolina Department of Environment and Natural Resources. Cover page scallops image. http://www.ncfisheries.net/ncdmf/FM2.html

Piquimil, R.N., L. S. Figueroa, O. C. Contreras, and M. D. Avendano. 1991. Chile, pages 1001-1016. In: S. E. Shumway (ed.), Developments in Aquaculture and Fisheries Science, Volume 21, Scallops: Biology, Ecology and Culture. Elsevier, Amsterdam, The Netherlands.

Scarpa, J., J. E. Toro, and K. T. Wada. 1994. Direct comparison of six methods to induce triploidy bivalves. Aquaculture 57:271-279.

Sherburne, S. W. and L. L. Bean. 1986. A synopsis of the most serious diseases occurring in Maine shellfish. American Fisheries Society, Fish Health Section Newsletter 14:5.

Shumway, S. E. 1992. Mussels and public health, pages 511-542. In: E. Gosling (ed.), The Mussel *Mytilus*: Ecology, Physiology, Genetics, and Culture, Developments in Aquaculture and Fisheries Science, Vol. 25. Elsevier Scientific Publishers, Amsterdam, The Netherlands.

Shumway, S. E. 1990. A review of the effects of algal blooms on shellfish and aquaculture. Journal of the World Aquaculture Society 21:65-104.

Shumway, S. E. and J. N. Kraeter. 2000. Molluscan shellfish research and management. Proceedings of the Workshop Charting a Course for the Future. United States Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., USA.

Shumway, S. E., C. Davis, R. Downey, R. Karney, J. Kraeuter, J. Parsons, R. Rheault, and G. Wilfors. 2003. Shellfish aquaculture – in praise of sustainable economies and environments. World Aquaculture 34(4):8-10.

Shumway, S. E., D. Card, R. Getchell, and C. Newell. 1988. Effects of calcium oxide (quicklime) on non-target organisms in mussel beds. Bulletin of Environmental Contamination and Toxicology 40:503-509.

Sindermann, C. J. 1970. Principal Diseases of Marine Fish and Shellfish. Academic Press, New York, New York, USA.

Sindermann, C. J. 1971. Disease-caused mortalities in mariculture, status and predictions. Proceedings of the World Mariculture Society 2:69-74.

Souchu, P., A. Vaquer, Y. Collos, S. Landrein, J. Deslous-Paoli, and B. Bibent. 2001. Influence of shellfish farming activities on the biogeochemical composition of the water column in Thau lagoon. Marine Ecology Progress Series 218:141-152.

Spencer, B. E. 2002. Molluscan Shellfish Farming. Fishing News Books, Oxford, United Kingdom.

Tampa Bay Watch. Bay scallop image. http://www.tampabaywatch.org/programscallop.htm

Tubiash, H. S., P. E. Chanley, and E. Leifson. 1965. Bacillary necrosis, a disease of larval and juvenile bivalve mollusks. Journal of Bacteriology 90:1036-1044.

Untied States Department of Agriculture/Foreign Agriculture Service (USDA/FAS). 2005. FAS Trade statistic database. http://www.fas.usda.gov/

Widdows, J. and P. Donkin. 1992. Mussels and environmental contaminants: bioaccumulation and physiological aspects. In (ed. E.M. Gosling), pp. 383-424. The mussel Mytilus: ecology, physiology, genetics and culture. Amsterdam: Elsevier Science Publ. [Developments in Aquaculture and Fisheries Science, no. 25]

Xue, X., D. Yuan, C.L. Wu, X. Li, and D. Luo. 2004. The analysis of contents and sources of pesticides in cultured shellfish of Fujian coastal areas. Marine environmental science/Haiyang Huanjing Kexue Vol. 23, no. 2, pp. 40-42.

Yakily, J. M. 1989. The biology and culture of mussels of the genus Perna. ICLARM Studies and Reviews 17, International Center for Living Aquatic Resources Management, Manila, Philippines.

Yentsch, C. M. and L. S. Incze. 1980. Accumulation of algal biotoxins in mussels, pages 223-246. In: R. A. Lutz (ed.), Mussel Culture and Harvest: A North American Perspective, Developments in Aquaculture and Fisheries Science, Vol. 7. Elsevier Scientific Publishers, Amsterdam, The Netherlands.

Yang, H., F. Zhang, and X. Guo. 2000. Triploid and tetraploid Zhikong scallop, *Chlamys farreri* Jones at Preston, produced by inhibiting polar body I. Marine Biotechnology 2:466-475.

Zhang, J. and Y. Donghui. 1997. Preparation and application of JH antifouling agent for scallop net cages. Shandong fisheries/Qilu Yuye. Yantai Vol. 14, no. 6, pp. 15-17.

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 (Yellow China wild caught spat) 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 (Chinese scallop stocks – yellow)	🟩 🟨
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 (Yellow China)	🟨 🟩
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 (Yellow – China)	🟩 🟨
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

Scallops 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 scallops. Thus, scallops should not be reared in areas where waters receive significant levels of pollution or where potentially toxic dinoflagellates are abundant. Scallops 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 scallops and other shellfish concentrate the pathogens to much greater concentrations than found in the water.

Because scallops and other shellfish can cause public health concerns, most developed nations have imposed standards for microbial quality of scallops. 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 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) 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