ABSTRACT

Title of thesis: THE PURSUIT OF A SUSTAINABLE COASTAL FISHERY: COMPARISONS OF THE OYSTER FISHERY IN CHESAPEAKE BAY AND ARIAKE SEA

Momoko Ishikawa, Master of Science, 2012

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Marine Estuarine Environmental Sciences

A coastal fishery brings high productivity and economic profit while supporting cultural norms. However, it also causes environmental degradation and political conflicts, which sometimes collapse a fishery. With the current global shift from capture fisheries to aquaculture, appropriate management is required for social and environmental sustainability. To identify essential factors in coastal fishery management, I compared the oyster industries in Chesapeake Bay (USA) and in Ariake Sea (Japan) from political, environmental, and cultural perspectives, by field observations, interviews, and literature research. Despite their different historical backgrounds, the two regions have lost most of the oyster resource due mainly to 1) failure of environmental management, 2) environmental degradation and 3) resistance of the fishing communities to necessary changes in fishing methods and aquaculture. Based on these lessons, I propose that a coastal fishery management plan should include environmental management, development of government-initiated aquaculture, understanding cultural backgrounds, and cooperation among science, industry and politics as essential factors.

THE PURSUIT OF A SUSTAINABLE COASTAL FISHERY: COMPARISONS OF THE OYSTER FISHERY IN CHESAPEAKE BAY AND ARIAKE SEA

by

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Master of Science
2012

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ACKNOWLEDGEMENT

I would like to acknowledge people who supported my study by interviewing, discussing, and suggesting pathways.

Thank you to people in the Ariake Sea region: **Dr. Tetsuya Kusuda** at the University of Kitakyushu for introducing me to a number of great scientists in the Ariake Sea region; **Dr. Yoshio Kawamura** at Ariake Fisheries Experimental Station (AFES) for talking about his experiences in coastal fishery management in the Saga Ariake sea area; **Dr. Hiroshi Aramaki** at AFES for telling me about Saga Prefecture's financial support for fishermen; **Dr. Yasuhisa Furukawa** at AFES for taking me to the oyster aquaculture field and talking about technical support for fishermen; **Dr. Keiko Tsujo** at AFES for showing me a seafood auction at Yanagawa fish market; **Mr. Minematsu** at Saga Ariake Fishermen's Cooperative Association Ooura Branch for talking about his experiences of transitioning from traditional capture fishery to oyster aquaculture; **Dr. Yuichi Kotani** at Seikai National Fisheries Research Institute for describing a great picture of oyster industry in Japan; **Mr. Yasushi Utsunomiya and Mr. Takashi Shimizu** at Mikimoto Hakata Pearl Culturing Co., Ltd. for showing me a large-scale bivalve aquaculture for a big business; **Mr. Yukifumi Yoshida** at Department of Fishery, Saga Prefecture for talking about administrative supports for fishermen and associated laws; **Mr. Hiroki Iyooka** at Kyushu University for talking about his study of reviving oyster bars in the Ariake Sea.

Thank you to people in the Chesapeake Bay region: **Dr. Don Meritt, Ms. Stephanie Alexander, and the oyster crew** at Horn Point Oyster Hatchery for letting me join the team for a week and showing hatchery's roles in oyster restoration in Maryland; **Mr. Eddie Walters** at Oyster Recovery Partnership for talking about cooperation between watermen and scientists in the oyster restoration; **Mr. Kevin McClaren** at Choptank Oyster Company for talking about his experiences in running oyster aquaculture business in Maryland; **Dr. Elizabeth North** at University of Maryland Center for Environmental Science for showing her study that is applied in the special fishery management; **Mr. Mike Naylor** at Maryland Department of Natural Resource (MDNR) for talking about Maryland's oyster management plan and its challenge; **Mr. Donald Webster** at Maryland Sea Grant Extension Agency for talking about historical view of oyster management in Maryland and his experiences; **Mr. Chris Dungan** at MDNR Cooperative Oxford Laboratory for talking about his challenge in combating oyster diseases; **Maryland watermen** from the eastern shore of Chesapeake Bay for their opinions and feelings against the oyster management plan.

I thank **Drs. Noritaka Mochioka, Koji Takada, and Akinobu Nakazono** for helping me start my master's course at University of Maryland.

I appreciate **Drs. Vic Kennedy, Michael Paolisso, and Ken Paynter** for their continuous support to my academic life.

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Chapter 1 Purpose of the Study

Fishing and aquaculture in estuaries bring high productivity and economic contributions to coastal areas while they support a traditional culture and society. Estuaries are among the most productive water bodies - while numerous tributaries bring a constant input of nutrients from the land, the shallowness of the basin and tidal action increases sunlight exposure, which brings high primary productivity (Schelske and Odum 1962). A variety of fisheries have developed in estuarine regions around the world probably because, in addition to high productivity, coastal estuaries provide relatively safe and accessible environments for fishing. In most cases, fishing, processing, and shipping are done in an area that is part of or close to residential areas, which helps form fishing communities along the coast. Thus, an estuarine fishery plays an important role in the local economy as well as in developing cultural norms.

At the same time, it is difficult to sustain estuarine fisheries because coastal waters are utilized for human activities in many ways and the environment is vulnerable to such intensive use. The variety of fisheries and aquaculture sometimes conflict with each other. In addition to the intensive fishing activities, coastal areas are used for residence, transportation, industry, leisure (Smodlaka et al. 1999), and sometimes land reclamation. Such activities can pollute the water with chemicals and change water flows, actions that disrupt the normal balance of biological and physical cycles (Odum 1970).

In recent decades, there has been a large change in coastal fisheries: aquaculture has developed rapidly and begun to replace capture fisheries around the world. While capture fisheries' production stopped growing around mid-1980, the aquaculture sector maintained an average annual growth rate of 8.7 % worldwide since 1970, with 51.7 million tons of fish and shellfish produced in 2006, or 47 % of the world's food fish supply (FAO 2008, The state of world fishery and aquaculture. http://www.fao.org/docrep/011/i0250e/i0250e00.htm). Subsequently, the number of people engaged in aquaculture and its ancillary activities has increased, while the number of those engaged in capture fisheries is decreasing due to higher operational efficiencies of fishing boats and thus less need of seagoing personnel. Aquaculture may overtake capture fisheries in the next few years as a key source of animal protein, thus becoming a major industry for the growing global population. Data on the contribution of mollusks to this expansion are more limited, but as an example, molluskan aquaculture in China had overtaken the wild fishery by the mid-1990s (Figure 1).

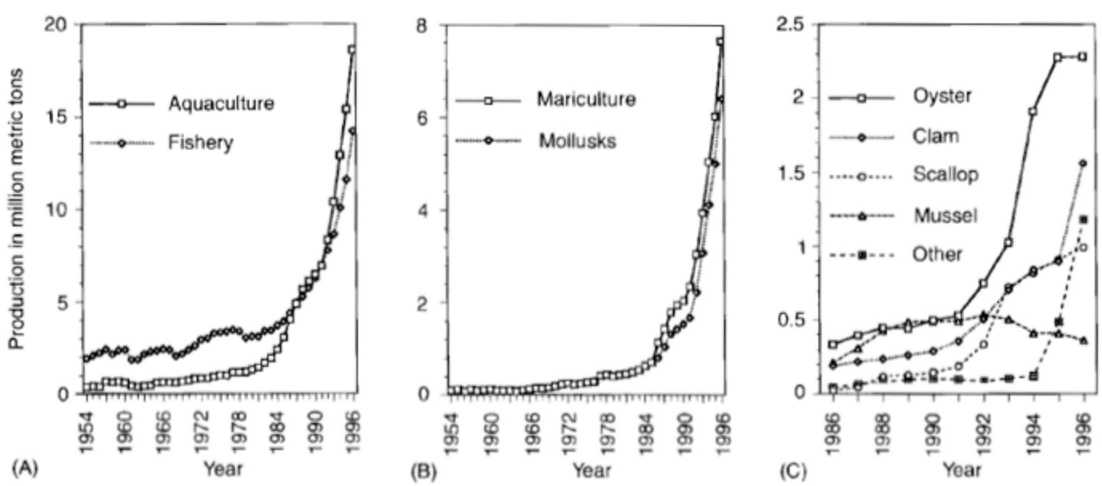

Figure 1. A. Chinese production of mollusks in the wild fishery and in aquaculture. B. The component of mollusks in Chinese mariculture. C. Production among molluskan groups in China. Figure 6 in Kennedy (2001), adapted with permission from Guo et al. (1999).

With such a rapid change, appropriate fishery management is required for social and environmental sustainability. In particular, the development of inshore aquaculture may conflict with other fisheries and other users such as the marine transportation and leisure industries. (An Ocean Blueprint for the 21st Century Final Report of the U.S. Commission on Ocean Policy. Setting a Course for Sustainable Marine Aquaculture. http://www.oceancommission.gov/documents/full_color_rpt/22_chapter22.pdf) Overuse of coastal water may also cause serious environmental degradation (Odum 1970). I propose that coastal fisheries and aquaculture should be managed at the local level with some flexibility because they can conflict with coastal development and other human activities that are regionally specific. Understanding cultural, political, and environmental backgrounds is necessary to establish effective fishery management in a region.

The purpose of my study is to identify a fishery management scheme that can sustain a coastal fishery and aquaculture. I assume that there are common problems that a coastal fishery tends to face although there is variety of fishing practices and their history, cultural backgrounds, and legal structures around the world. To identify essential factors in coastal fishery management, I compared two oyster industries with very different backgrounds to draw out general lessons from social, environmental, and political aspects: Chesapeake Bay, where the idea of private aquaculture is recently being accepted by some (but not all) residents after a long history of resistance, and Ariake Sea, a historically competitive fishing region in western Japan with a long history of government-encouraged aquaculture.

I focused on oyster fisheries in this study because oyster species are fished or cultivated as high-valued seafood production in diverse areas of the world while they draw a scientific attention as keystone species in the ecosystem and their commercial importance has led to much study and discussion of appropriate management practices. Furthermore, oyster industries today have to consider various social and ecological issues such as transition from wild capture to aquaculture, farming non-native species and genetically-modified organisms, epidemic of oyster diseases, and conflict with other resource users in coastal waters (An Ocean Blueprint for the 21st Century Final Report of the U.S. Commission on Ocean Policy. Setting a Course for Sustainable Marine Aquaculture. http://www.oceancommission.gov/documents/full_color_rpt/22_chapter22.pdf).

In the summers of 2009 and 2010, I visited the Maryland part of Chesapeake Bay and the Saga part of Ariake Sea to study the history and present conditions of the oyster industries by field observations, interviews of key persons, and literature research. In Chapter 2 and 3, I will describe environmental features, fishing practices, management issues, and recent conditions of the oyster industry in each region. In Chapter 4, I will compare the two industries and analyze common problems from social and environmental aspects. I then conclude in Chapter 5 with essential factors that coastal fishery management should include.

Chapter 2 Chesapeake Bay

Physical Features, Fisheries, and Human Impacts

Chesapeake Bay, one of the world's largest estuaries, is located on the eastern coast of the United States (Figure 2). It is a long and narrow estuary with an extensive watershed that covers ~166, 000 km^2 of six states – Maryland, Virginia, Pennsylvania, Delaware, New York, and West Virginia (Smodlaka et al. 1999). Its main basin is ~330 km long and extends roughly from north to south.

Many tributaries feed into the bay. Most are relatively small, but three, the Susquehanna, Potomac, and James Rivers, provide about 80% of the bay's freshwater input (Boicourt et al. 1999). In total, tributaries deliver a large amount of nutrient-rich freshwater to the bay. Together with the bay's shallowness (average depth of 14 m), these nutrients support high productivity in the Bay. The constantly changing mixing of freshwater from the tributaries and oceanic water from offshore makes the bay a complex and sensitive environment for a diverse community of organisms. Many aquatic species with commercial value, such as eastern oyster *Crassostrea virginica*, blue crab *Callinectes sapidus*, striped bass *Morone saxatilis*, and Atlantic menhaden *Brevoortia tyrannus* reside in the bay during a part or all of their life.

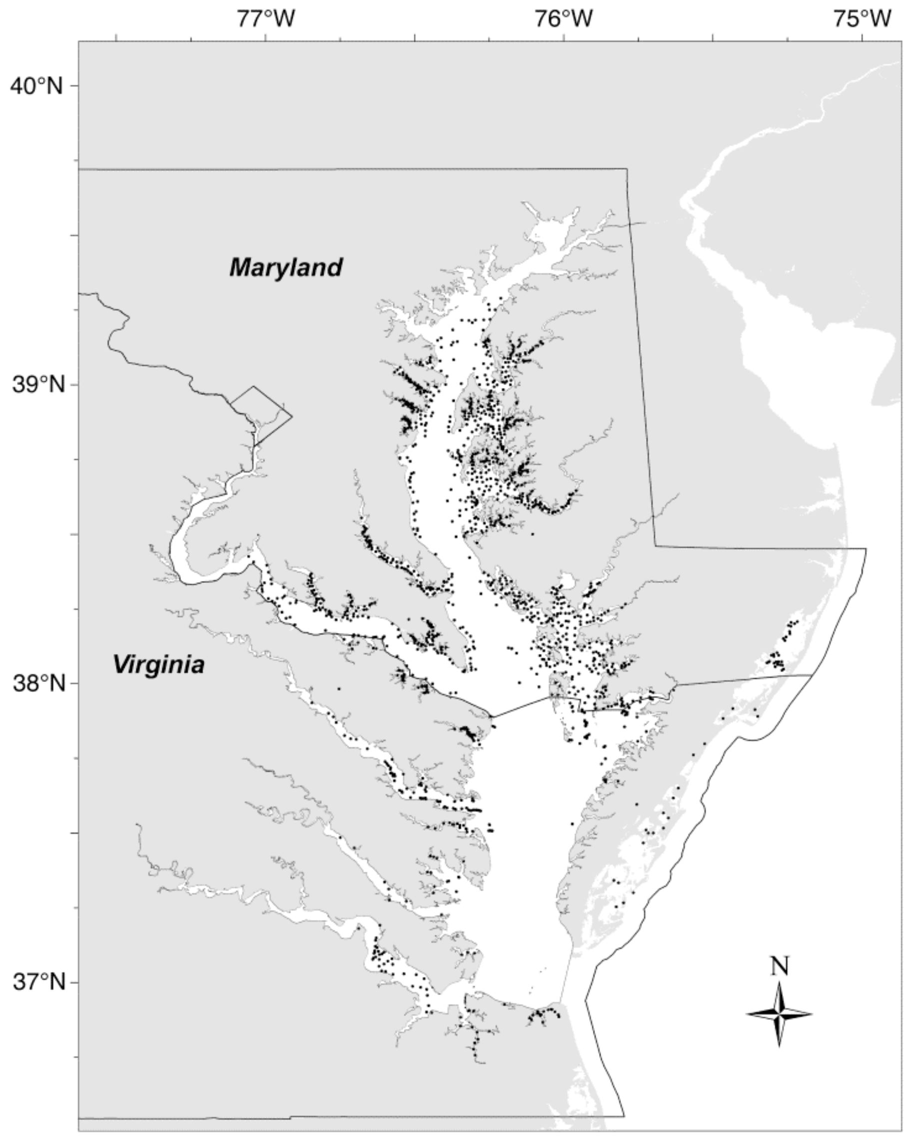

Figure 2. Chesapeake Bay, with charted oyster bars shown as dots. Courtesy of Maryland Sea Grant.

The Bay's watershed extends from New York to Virginia and from West Virginia to Delaware, making it very large in relation to the Bay itself. There are 16.6 million people currently residing in the watershed and the population is increasing every year (Chesapeake Bay Program. http://www.chesapeakebay.net). In addition to harvesting a large amount of aquatic organisms, Chesapeake residents have historically impacted the bay's environment in many ways. With two major ports – Baltimore and Hampton Roads – the Chesapeake Bay is an important area for transportation and industry. Dredging of shipping channels and pollution from ships and factories along the shore have stressed the sensitive estuarine environment. In the upper bay region, there are many farms, both in the state of Pennsylvania as well as in Maryland, releasing a large amount of manure and fertilizer that cause eutrophication (Kennedy and Mountford 2001). In addition, sedimentation is one of a number of major threats on habitats for aquatic organisms including oysters – sediments from developed and farmed areas have smothered three-dimensional oyster bars and hindered the ability of oysters to feed and reproduce **(**Kennedy and Mountford 2001**).** These impacts from human activities have damaged the bay's environmental health, perhaps irreversibly.

Brief History of the Oyster Industry

The Chesapeake Bay oyster industry has received broad attention -- once, as the greatest oyster-producing region in the world that contributed to the economics of the developing United States (Brooks 1891; Kennedy and Breisch 1983; Keiner 2009) and lately, as a leading example of natural resource management where policy makers, industry, scientific communities, and other stakeholders are working together in developing restoration plans for the devastated population (Kennedy et al. 2011). The rise and fall of the industry (Figure 3) has drawn attention from a broad range of academic disciplines including American history, economics, ecology, politics, and environmental anthropology.

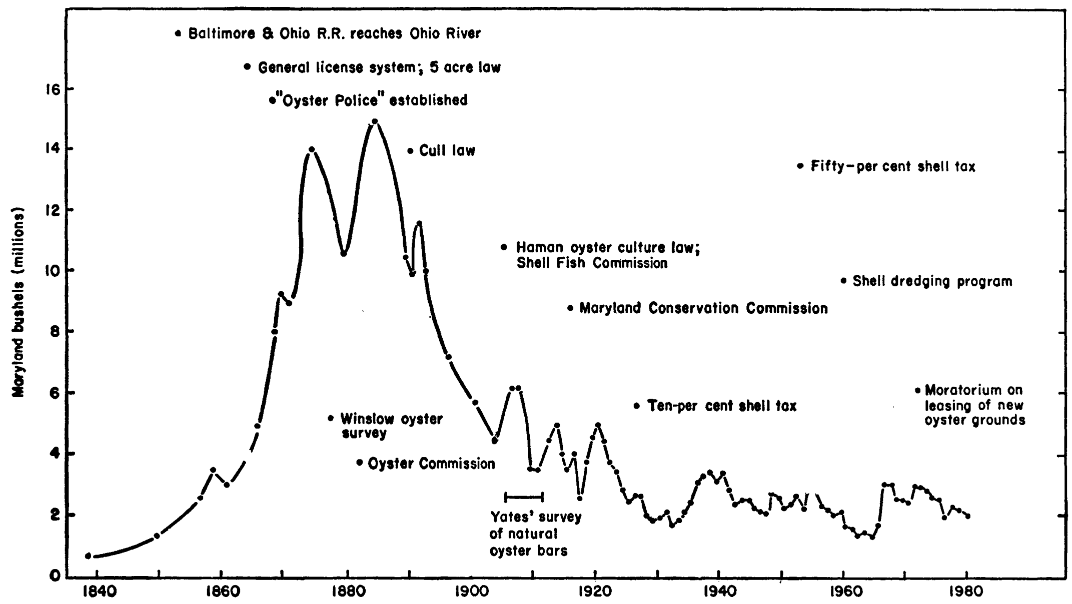

Figure 3. Reported landings of oysters in Maryland during peak harvests and subsequent declines. Important events in the history of management in Maryland are noted. (After Grave 1912, modified and published in Kennedy and Breisch, 1983)

The pre-Colonial Chesapeake Bay environment was a very favorable habitat for the eastern oyster (Brooks 1891). The tremendous tributaries that bring freshwater maintain a suitable salinity for oysters and provide nutrients to support the phytoplankton that oysters feed on. The Chesapeake Bay was called an “immense protein factory” in the developing United States by Mencken (1996).

The eastern oyster is considered to be a keystone species in the bay ecosystem because of its various ecological roles (e.g., Kennedy 1996). There are three major roles that it plays. First, its filter feeding controls phytoplankton abundance and water quality. Newell

(1988) estimated that the oyster populations before the peak of oyster harvest in the late 1800s could filter an amount equivalent to the entire water column of Chesapeake Bay in less than a week whereas the current populations may take over 46 weeks to filter the same amount of water. He also proposed that the recent algal blooms and summer hypoxic conditions are due largely to the drastic depletion of oyster populations. Second, the oyster couples pelagic and benthic processes in the bay, and contributes to nitrogen and phosphorus regeneration (Newell et al. 2005). After filtering pelagic phytoplankton, an oyster discharges feces and pseudofeces that are nutritious food for benthic organisms. Consequently, oysters facilitate nitrification by microbes in the sediment. Since oysters feed on particulate organic matter as well, they provide inorganic nitrogen and phosphorus to phytoplankton to utilize for photosynthesis. Third, oyster reefs in the bay provide habitat for small benthic organisms (e.g., Kennedy 1996; Rodney and Paynter 2006). The three-dimensional structure with many nooks and crannies can be a good refuge for crabs and small fish species, with the hard surface being essential substrate for epifauna like sponges and sea squirts. In addition, such an active oyster bar attracts large predator species hunting prey. Putting it all together, the eastern oyster strongly affects both biological and chemical processes in Chesapeake Bay.

Even with today's depressed status of the industry, many people residing on the shores of the bay earn their livelihood by oystering, processing, and marketing. The eastern oyster has brought not only enormous economic profits (Lipton 2008) but also helped develop a rich cultural heritage in the region. The traditional way of dredging oysters with sailboats (skipjacks) has been maintained to limit daily harvest and has been recognized as a symbol of the Bay's fishing culture. Moreover, Paolisso (2005) believes that the core of the waterman heritage is their own cultural value about work and providing for their families. In the Chesapeake Bay region, 'watermen' refers to fishers who do various kinds of small fishery including oystering. They usually come from traditional fishing families residing in the coastal community. They believe that working on the Bay is a right reserved for them, the only way of living they can rely on, and a way they are proud of and responsible to keep (Paolisso 2005). This shared value among watermen has conflicted with management regulations that fishery agencies have set (described below). Watermen share an underlying assumption that living resources in the Bay should not be managed by humans because they can sustain their way of life so long as God allows them and they work hard on the water (Paolisso 2002).

The development of Maryland's seafood industry has been strongly linked with the eastern oyster. Since the European colonists reached the Chesapeake Bay region, the oyster has been an essential resource of protein for bay residents (Brooks 1891). With a high commercial value, the oyster fishery and ancillary industries also provided many employment opportunities to immigrants and minorities. As the industry grew larger, transportation around the area developed to export the oyster products further throughout the US (Figure 3). Many shipping routes, railways, canals, and highways were established that enabled the oyster industry to expand beyond Maryland and Virginia.

Until the late 19^{th} century, when the Bay experienced a major decline in oyster population (Figure 3), the wild oyster bars were abundant both in the Virginia and Maryland portions so that the states enjoyed the seemingly inexhaustible source for food supply, employment, and economic driver (Kennedy and Breisch 1983; Keiner 2009). Maryland's harvests exceeded 15 million bushels at the peak in the late1800's (Figure 3; Kennedy and Breisch 1983). Dredging was initially beneficial to the unexploited reefs by breaking up oyster clumps and spreading oysters beyond the confines of the bed (Winslow 1881). However, intensive dredging without returning shell to the bottom coupled with sedimentation that smothered the diminished reefs resulted in large barren bottom where recruitment does not occur (Smith et al. 2005).

Furthermore, diversified interests surrounding Chesapeake oysters have caused political conflicts and resulted in failure of appropriate resource management (Kennedy and Breisch 1983). Keiner (2009) described Maryland's longstanding debate on private leasing of oyster grounds from scientists' and watermen's perspective: scientists like Brooks urged the State to lease oyster bottoms, believing it the best solution for the overharvesting. On the other hand, watermen opposed it feeling that private leasing would put control of the resource in the hands of seafood processors who already influenced the industry by owning facilities essential for oystering (Green et al. 1916). As a result of miscommunication between scientists and watermen, the State has often failed in applying scientific knowledge into the resource management.

As a result of habitat destruction, as well as overharvesting, oyster abundances have drastically decreased (Figure 3). Presently the standing stock is estimated to be less than 1% of that of the 19th century (Wilberg et al. 2011), due to a combination of factors, including poor water quality, habitat loss, disease, long-term intensive harvesting, and ineffective fishery management policies. Although Maryland has made great effort with vast amount of funding to restore the wild population and fisheries industry, many previous attempts failed or made only little progress (e.g., Kennedy et al. 2011).

Management Issues

This and the next section focus on significant features related to the Maryland oyster management: 1) historical resistance against leasing grounds for private culture, 2) epizootic diseases controlling oyster populations, and 3) conflict and cooperation between industry and science. Factors 1) and 3) have been always at the center of the discussion of management issues since the very beginning of the oyster industry. Factor 2) has been a major concern in population management since the pathogens were first found (Ford and Tripp 1996). Here I describe historical insights as well as current situations of the industry and rehabilitation efforts. To obtain various opinions from different stakeholder groups, I interviewed people working in the oyster industry and in rehabilitation programs while also attending public hearings for the oyster restoration plan in the summer of 2010.

Historic Disregard for Private Aquaculture

Kennedy and Breisch (1983) point that oyster management in Maryland is an example of a failure of application of science in resource management. Although Maryland was one of the first States to be aware that one solution to the decline in wild populations is promoting private oystering on leased grounds (Brooks 1891), and although many scientific surveys and recommendations were made, these failed to shift the industry from harvesting from public beds to private culture (Kennedy and Breisch 1983; Keiner 2009). In Maryland, oysters have been fished mainly in public beds while Virginia has encouraged production from private grounds. Around the peak of oyster catch in the 1880s, many surveys examined the status of oyster beds and recruitment or population status. After surveying the extent of Maryland's oyster grounds for six years, Yates (1906) recommended that Maryland should promote private culture to mitigate harvest pressure. In fact, data from Chesapeake Bay show that private culture out-produces public beds, perhaps because of better management by lease-holders who must tend to their oysters to protect their monetary investment (Kennedy 1989).

The regulations on oyster fishery have evolved as improved methods have raised harvesting efficiency. Traditional methods include dredging and tonging. The main purpose of the Maryland management has been to reduce efficiency of harvesting by limiting hours, seasons, and catch. For example, most dredging is to be carried out by sailing boats (skipjacks), with the use of motorized power being limited in time. Some restrictions are at the request of watermen who think it unfair to let others get oysters by more efficient means. However, the recommendations that private leasing should be encouraged were not reflected in laws because of pressure from watermen who opposed private cultivation (below). Although working watermen were not a large majority of Maryland residents, their opinions were well listened to because of over-representation by legislators from counties where oystermen lived (Kennedy and Breisch 1983; Keiner 2009).

Why were the watermen against private leasing of the bay bottom for aquaculture purpose? Kennedy and Breisch (1983) proposed that they were afraid of losing their valued independence if corporations leased oyster beds, thereby shutting the watermen out or forcing them to work for an employer rather than independently (see also Brooks 1891, Green et al. 1916, Keiner 2009). The watermen typically thought that harvesting bay oysters was a privilege for Maryland residents and there should be no control on it. Another point of the opposition was that they doubted the possibilities of oyster cultivation on formerly non-productive ground. While such recommendations were intended to make use of habitat where oyster bars did not exist anymore, most watermen did not believe that spat settlement and formation of renewed oyster bars would occur on such barren bottoms (Green et al. 1916).

As a result of the strong resistance, Maryland failed to establish an oyster aquaculture industry and the wild populations were harvested with little restrictions until recent political efforts (described below). At the same time, Maryland has kept the traditional way of living on the water while much of the rest of the world encouraged the growth of aquaculture.

Epizootiology of Haplosporidium nelsoni (MSX) and Perkinsus marinus (Dermo)

Epidemics of oyster diseases *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (Dermo) are one of the biggest concerns in today's oyster management in Chesapeake Bay. The two diseases have changed the structure of the industry by bringing mass mortality and limiting cultivable grounds (Andrews 1979). The two pathogens are considered non-native to Chesapeake Bay (Andrews 1979). The origin of Dermo is unknown (Andrews 1979) but Dermo may have been introduced in the mid-20th Century by scientists or oyster growers (Andrews 1996, Burreson et al. 2000).

The most critical disease, MSX was first discovered in Delaware Bay in 1958 and spread rapidly throughout lower Chesapeake Bay (Andrews 1979). It was a sudden tragedy: MSX killed the Chesapeake oysters at annual mortality rates of 50-60 % and with peak death rates of 20-25 % monthly (Andrews 1979). The high prevalence of MSX among oysters in lower Chesapeake Bay has diminished Virginia's traditional oyster planting because young oysters grown in the upper bay died shortly after they were planted in the lower bay (Andrews 1979). Researchers have made a great effort to understand the disease mechanisms since the first appearance but there still are missing parts in its transmitting process; MSX is considered to have multiple hosts in its life history but the alternate host other than eastern oyster is still unknown. This missing link makes disease management even more difficult.

The other disease, Dermo, has also largely controlled oyster abundance in Chesapeake Bay since the first discovery in 1950 (Andrews 1979). The pathogen is observed throughout a wide range of the east coast including one of the largest oyster-producing grounds in the Gulf of Mexico (Burreson and Ragone Calvo 1996). However, it is in Chesapeake Bay where the species has had the most severe impacts on oyster population, presumably because of geographical and environmental conditions.

Temperature is considered to be one of the major factors that control prevalence, intensity, and disease-progression of *P. marinus,* as well as mortality of oysters (Andrews 1996). In Chesapeake Bay, oyster mortalities are highest from August to October because the pathogen actively proliferates above the temperature of 25 C (Andrews 1996). *Perkinsus marinus* intensity and prevalence clearly follow seasonal fluctuations in water temperature in the James River tributary (Burreson and Ragone Calvo 1996). Crosby and Roberts (1990) actually identified a strong and significant correlation between water temperature and disease pressure when the temperature was lagged three months. This may be because Dermo disease progresses slowly until it finally kills the host much later than during the initial infection (Andrews 1996).

Salinity is another major factor of the disease pressure, which has historically changed the geographical distribution of *P. marinus* in Chesapeake Bay. *Perkinsus marinus* prefers salinity above 9 although it can persist in lower salinity areas. When *P. marinus* was first discovered in Chesapeake Bay, it was already widely distributed in the bay but only below the mouth of the Rappahannock River (Andrews 1996). However, four consecutive drought years in the 1980s kept the salinities in the upper bay at historically high levels, which allowed *P. marinus* to expand its distribution into much of the Maryland portion of the bay. The pathogen persisted there tenaciously with low mortalities (Andrews 1996).

Natural Disease-Resistance of the Eastern Oyster

Dermo disease prevalence and intensity have remained at low levels since 2003, below the average of twenty years (Tarnowski 2010). Although fluctuation of disease pressure has been considered largely controlled by environmental factors in Chesapeake Bay, many field observations imply differences of disease-resistance among eastern oysters that can change their survivorship under the influence of *P. marinus*. Some scientists advocate that individuals that have survived more than two seasons of exposure to *P. marinus* have some resistance against the pathogen, although most oysters experience high mortalities during the first two seasons before they get market size (Encomio et al. 2005). This hypothesis coincides with a discovery of substantial numbers of large oysters by fishermen in Tangier Sound where Dermo disease pressure is generally high (Encomio et al. 2005). Such large, long-lived individuals in an enzootic area might possess some natural disease-resistance to the pathogen.

With an assumption that natural disease resistance varies among oyster population from different regional stocks, Encomio et al. (2005) compared Dermo infection and mortalities among six natural stocks from the Chesapeake Bay and Gulf of Mexico as well as one hatchery disease-resistant strain. They identified a natural disease-resistant stock from Tangier Sound that had lower mortalities than any other stock throughout the two-year study, despite the presence of relatively high intensities of *P. marinus*. The delayed mortality among the stock implies their ability to resist infections for longer periods, which is also reported in a study of another oyster species *Ostrea edulis* against a pathogen *Bonamia ostreae* (Naciri-Graven et al. 1998). Encomio et al. (2005) conclude that different disease resistance between stocks of Tangier Sound and the Rappahannock River implies that there is genetically-based intra-regional variability in Dermo resistance even among Chesapeake Bay stocks.

A comparative study of bivalve sera by Anderson and Beaven (2001) gives better understanding of the basis for the difference in susceptibility to *P. marinus*. Noting that 1) *P. marinus* infection is very active among eastern oysters but not among other bivalve species in Chesapeake Bay and 2) the Pacific oyster that is proposed as a pathway of *P. marinus* into the bay seems to have some resistance to the pathogen, Anderson and Beaven (2001) compared the activities of anti-*P. marinus* serum proteins and peptides in several bivalve species: *Crassostrea virginica* (from Chesapeake and Maine), *Crassostrea gigas*, *Mytilus edulis*, and *Geukensia demissa*. They found that the serum and cells of the mussel species *G. demissa* and *M. edulis* had high levels of anti-*P. marinus* activity, which seems dependent on cytotoxic molecules other than lysozome and antimicrobial peptides. On the other hand, anti-*P. marinus* activities were detected at very low levels among both oyster species *C. virginica* and *C. gigas.* This result may explain the difference in susceptibility to *P. marinus* in bivalve species in the bay. Interestingly, however, differences in the recorded anti-*P. marinus* activities between the two oyster species were insignificant and cannot be used to explain reported differences in resistance to *P. marinus* disease. This suggests that *C. gigas* has another strategy to resist the pathogen, other than the ways mussel species have. Further studies are expected.

Do Selective Strains Have Better Resistance?

With the high possibility that oysters have variability in disease-resistance among different regional stocks, and even among the same population stock, can we produce a strain with a high disease-resistance against *P. marinus* infection? Selective breeding to produce strains with enhanced disease-resistant to mitigate the effects of disease has achieved the most success with MSX (*Haplosporidium nelsoni*), the other major pathogen among eastern oysters, but selection for Dermo has been more difficult to achieve (Encomio et al. 2005).

The selected strains, DEBY and CROSSBreed, were originally established to have high disease-tolerance against MSX. However, Abbe et al. (2010) tested if DEBY and CROSSBreed have better survivorship even against Dermo disease. Their assumption was that performances of oyster strains under natural Dermo disease pressures are influenced by different phenotypic resistance to acquisition of initial infection. In addition, pathogenesis of established infections may be modulated by variable capabilities of infected oysters to inhibit proliferation of infecting *P. marinus* cells or to neutralize pathological effects. To test the assumption, Abbe et al. (2010) compared dynamics of *P. marinus* infection among DEBY, CROSSBreed, and Standard which is also a hatchery-produced disease-free seed but has no specific disease tolerance.
The DEBY stain had significantly better survivorship and growth among the three strains. Its tolerance that delayed initial infection acquisition as well as the enhanced growth of DEBY lowered the mortalities even with high *P. marinus* body burdens. These results imply disease-resistance mechanisms as well as a possibility to establish a resistance-

enhanced strain particularly against *P. marinus* by selective breeding. The findings also suggest that genetic variation affects differences in disease-resistance among eastern oysters.

Management Applications

In addition to the impact from pathogens *P. marinus* (Dermo) and *H. nelsoni* (MSX), there are many anthropogenic factors that have degraded wild oyster population and habitat as well as the oyster industry in Chesapeake Bay. Many previous attempts to manage oyster population have failed or made limited progress because historically those regulations have been established based on politic concerns, not on scientific findings, despite numerous scientific suggestions that were available (Kennedy and Breisch 1983). Restoration efforts may keep failing unless very specific goals and strategies are set based on scientific perspectives (Kennedy et al. 2011).

In the summer of 2010, the State of Maryland proposed the Oyster Restoration and Aquaculture Development Plan as a result of active discussion among politicians, scientists, social scientists, environmentalists, and fishermen. The plan contains two principals in setting regulations. First, the state established sanctuary networks where oyster harvest is prohibited in order to allow wild populations to reproduce themselves over generations. Second, the state promotes private oyster aquaculture by removing previous limits on bottom leasing and by establishing aquaculture enterprise zones (Maryland Department of Natural Resources. Oyster Restoration and Aquaculture Development Proposed Regulations.

http://www.dnr.maryland.gov/fisheries/oysters/oysterrestoration&aquaculturedevelopmentproposedregulationsfactsheet.pdf).

How can the scientific findings of the disease-resistance studies be applied in the proposed plan? First, a selected strain with enhanced disease resistance will bring better yields when used in aquaculture, which a number of entrepreneurs are starting under the new policy. Minimizing disease impacts is crucial for oyster farming in Chesapeake Bay. However, the effectiveness of planting those disease-tolerant strains among wild oyster population to enhance abundance is questionable. Abbe et al. (2010) commented that any genetic advantage will be rapidly diluted by interbreeding with local wild oysters.

Second, the sanctuary policy will give a chance to wild oyster populations to develop natural disease-tolerant strains with genetic variations before they succumb to the fishery. As mentioned, several field observations suggest that large, long-lived oysters in the bay seem to have disease-resistance but these individuals have often been removed during commercial harvest, thus preventing long term establishment of native resistant populations (Encomio et al. 2005).

Recent Restoration Efforts and Aquaculture Development

Is the oyster fishery in Maryland still bringing a reliable livelihood to the watermen in spite of the heavily depleted oyster population? In the 2006 oyster season, there were only 628 oystermen reporting a harvest in Maryland compared with 2,520 oystermen in the 1999 season (DNR Shellfish Program 2006, Maryland Oyster Harvest Bushels, Value, Effort 1975 – 2006. http://www.dnr.state.md.us/dnrnews/infocus/032706hvalue.pdf). Mr. Donald Webster, who has been working in oyster fishery management as a Maryland Sea Grant Regional Aquaculture Specialist and past chair of the Aquaculture Coordinating Council, says many oystermen retired in the 1970s and became builders, carpenters, operators of tugboats, prison guards, etc. (Webster, personal communication). It seems that people cannot live only on oystering in Maryland anymore; still, harvesting oysters provides watermen with a timely income during the fall and winter months while they operate small fisheries in other months such as fishing for blue crabs, harvesting soft shell clams, and netting eels (Webster, personal communication). Fishing for oysters also helps maintain the watermen's self-identity as workers in the sea who can provide a valuable product (Paolisso and Dery 2010). A wide range of the stakeholder group value watermen and the oyster industry as part of the Bay's cultural heritage; it has been argued that harvesting and use of oysters connects people to the Bay (Paolisso et al. 2006).

However, Webster points that the oyster industry in Maryland is sustainable only because it is heavily supported by taxpayers. Although a fee that goes towards oyster rehabilitation is paid on each bushel of harvested oysters, restoration of "natural" or public oyster bars is largely paid for by government agencies in order to maintain a traditional way of life (Webster 2003a). A major change in the industrial structure is needed. Based on the experience of restoring the Chesapeake striped bass population, Webster thinks maintaining the oyster population is more complicated than the case of striped bass because managers have to handle two things at the same time – restoring wild population to the level where oysters serve ecological roles and allowing watermen to catch oysters to keep the industry alive. Oyster population management in Maryland should have long-term perspectives and requires patience (Webster, personal communication).

What goal should be set in the Chesapeake oyster management, and what strategies can achieve it? This question came up for active debate in 2004 when Maryland and Virginia proposed to introduce the Suminoe oyster *Crassostrea ariakensis*, a native of the China Sea, into Chesapeake Bay to compensate for the depleted ecological and economic functions of the native oysters - improving water quality by filtration, providing habitats for the benthic community, and sustaining the oyster industry. The supporters of the proposal emphasized studies that the Suminoe oyster has environmental requirements and tolerances similar to those of the eastern oyster but is resistant to the diseases MSX and Dermo. On the other hand, the opponents warned of risks that non-native oysters might invade the ecological niche of the native oysters and even carry unknown pathogens. The idea of using non-native oysters stimulated discussions to determine a direction of the oyster management in the Bay by which Maryland and Virginia should agree and work together.

In June 2009, the Norfolk District of the U.S. Army Corps of Engineers, cooperating with Maryland's Department of Natural Resources and the Virginia Marine Resources Commission, published a Programmatic Environmental Impact Statement (PEIS) for Oyster Restoration in Chesapeake Bay
(http://www.nao.usace.army.mil/Portals/31/docs/civilworks/oysters/FinalPEISOysterRest

oration.pdf). The PEIS evaluated the potential risks and benefits of introduction of a non-native oyster and alternative restoration actions on ecological, environmental, and cultural aspects. These alternatives include: 1) continuing existing oyster restoration strategies, 2) expanding native oyster restoration, 3) imposing an oyster harvest moratorium, 4) expanding the use of native oysters in aquaculture, 5) expanding the use of non-native oysters in aquaculture, 6) introducing and propagating an alternative oyster species other than *C. ariakensis*, 7) introducing the Suminoe oyster and discontinuing efforts to restore the native oyster, and 8) a combination of previous alternatives. The PEIS also evaluated the feasibility of each strategy for the ultimate management goal the Corps set; that is, to establish an oyster population that would reach a level of abundance in the Bay adequate to support harvests comparable to those seen from 1920s to 1970s (Figure 3).

The PEIS is a comprehensive review of the Chesapeake Bay oysters and is probably one of the leading examples of ecosystem-based management in the world, having synthesized results and discussions from five-year multidisciplinary research projects. Particularly, it contains a significant amount of socio-cultural evaluation on how the proposed and alternative actions would impact the individuals and communities surrounding the Bay (Paolisso et al. 2006). The study even revealed that the Chesapeake oyster is the basis for a cultural model – a shared implicit and tacit understanding about how the world works - among a variety of stakeholders (Paolisso and Dery 2010). Understanding cultural perspectives in resource management can help mitigate conflicts among stakeholders while such shared values link to human emotion and motivation (D'Andrade 1995).

As a result of the efforts put into the consideration of restoring the deteriorated oyster fishery in the Bay, Maryland and Virginia were moved closer to agreeing on a single management policy. This is important because inconsistencies between the two states have been a management obstacle in the past (Kennedy 1989). In the final PEIS (2009), the leading agencies concluded that Alternative 8a, a combination of alternatives that involves only the native Eastern oyster, is the preferred approach for restoring the Chesapeake Bay oyster population; the framers of the PEIS attached greater importance to the ecological risks than to the interests in the use of a non-native oysters. Even though Virginia has "seen certain promise in *ariakensis* aquaculture from the Virginia Seafood Council trials over the past seven years, we agree – based on the recommendations of our Virginia Institute of Marine Science – that moving forward we should focus primarily on restoring the Bay's native oyster," said Virginia Governor Timothy M. Kaine (MDNR press release 2009, http://www.dnr.state.md.us/dnrnews/pressrelease2009/040709.html)

For Virginia, whose watermen and shellfish processors had called for the introduction of *C. ariakensis* (Washington Post 2009), the decision was a difficult one to accept. Maryland, on the other hand, seemed agreeable to the recommendations of the PEIS (MDNR, Maryland position on a preferred alternative for the Final PEIS for restoring oysters to Chesapeake Bay. http://www.dnr.state.md.us/fisheries/oysters/EIS_VA_Corps_Ltr.pdf). Together with the recommendations from Maryland's Oyster Advisory Commission and Aquaculture Coordinating Council, Maryland proposed a Lease Law in 2009 and an Oyster Restoration & Aquaculture Development Plan in 2010 under the leadership of Governor O'Malley. The Plan contains two primary goals: "1) to establish an expanding and sustainable population of native oysters in significant portions of Chesapeake Bay and its tributaries and 2) to establish a private aquaculture industry that emerges as a major economic contributor to the State of Maryland while maintaining a more targeted and scientifically managed oyster fishery (MDNR, Maryland's vision for oysters. http://www.dnr.state.md.us/fisheries/oysters/pdfs/GovernorsOfficeSlidesFinal.pdf)".

To achieve these goals, Maryland set two primary regulations. First, the state established sanctuary networks where oyster harvest is prohibited in order to allow wild populations to reproduce unfished over generations. This allows for oysters to grow as old as possible and perhaps develop disease resistance. The hope is that older, disease-resistant animals will spawn and pass on their resistant genes to their larval offspring, some of which may end up outside the sanctuary on a public oyster bed. The sanctuaries will be expanded from the current 9% of Maryland's portion of the bay to 25%. Second, thousands of acres of bay bottom previously off-limits are opened for private leasing and an aquaculture enterprise zone is established where oyster farmers can lease the bottom in simplified processes.

To explore how people in the industry and science are working towards the goals, I visited related organizations and individuals in the summer of 2010.

Maryland's Plan 1. Rehabilitating the Wild Population

Planting oyster seeds to enhance the existing oyster bar or to make a new population on the barren bottom is an historical activity in the oyster restoration effort in Maryland (Kennedy et al. 2011). In the Oyster Restoration and Aquaculture Development Plan of 2010, planting and preserving the planted site is the major strategy as well. However, planting has been sometimes the focus of criticism, costing enormous money and labor yet having shown limited success. How have planting techniques been improved through history in order to improve the present situation? I found that 1) increasing hatchery production for disease-free oyster seed, 2) promoting cooperation among government, industry, and academia, and 3) selecting appropriate sites for good survival and growth represent the major progress seen in the present effort.

First, a constant supply of oyster seed is essential in large-scale planting. Especially under the current intensive disease pressure, obtaining disease-free seed is crucial. In July 2010, I visited the Horn Point Oyster Hatchery, a facility of the University of Maryland Center for Environmental Science (UMCES) located on the eastern shore of the Bay that produces billions of eyed larvae every year for oyster research, restoration, and educational programs. In the oyster planting program, the hatchery is undertaking all the processes to prepare ready-to-ship spat on shell -- conditioning broodstock, controlling spawning, rearing larvae, and settling them on oyster shell. The hatchery productivity has increased to as much as 756 million spat on shell in 2009 as a result of biological research on temperature-controlling gonadal development, spawning behavior, maximum fertilization, and ideal larvae nutrition as well as experienced handling of the animal (http://www.hpl.umces.edu/hatchery/).

The hatchery looks like a factory, with huge culture tanks that are filled with brackish water pumped from the Choptank River. Swimming-stage oyster larvae are reared in the tanks under the best condition at their age. Salinity, temperature, trace elements, and food supply of lab-cultured phytoplankton are automatically controlled by computer and periodically checked by biologists. When larvae reach >200 µm, a good size for final metamorphosis before settlement, their competency to settle is checked using a microscope to tell if they are 'hot' (competent to settle), or using a foot to crawl and search on substrates to attach. If this is so, the tank is drained and the competent larvae are poured into outdoor setting tanks that hold containers of shell where the eyed larvae are induced to become spat.

Summer is the season everything happens at the hatchery (Stephanie Alexander, hatchery manager, personal communication). Starting in March, the hatchery begins an expanded spawning season by sensitively controlled water temperature to condition oysters for spawning. That is, the water is gradually warmed more rapidly than in nature and the oysters are well fed. This stimulates them to undergo early gametogenesis. When they are found to be ripe, they are stimulated to spawn by sharply raising the water temperature and perhaps adding gonad material. Spawned eggs and sperm are mixed in appropriate proportions to produce fertilization and the fertilized zygotes are subsequently reared in the culture tanks, being fed nutritious algal food and having their culture water changed regularly. The process of spawning, rearing, and setting larvae, and shipping them for planting is continuously repeated until the end of the season. During the busy operation, the crew also provides hatchery tours for interested citizens and receives media coverage - the hatchery also works as a place for education. The crew and summer students work relentlessly.

Early one morning during my visits, there was a group of people working cheerfully at the dock by the hatchery. They operated a crane to hoist stainless steel containers of spat one after another onto the “Oyster Recovery Partnership” ship. These people were watermen who were heading to Chester River to deploy the oyster spat as a part of Oyster Recovery Partnership activities. They ship the spat the hatchery produces to the targeted planting sites across the Bay twice a week during summer; this intensive planting activity could not be achieved without the experienced watermen.

Promoting such close cooperation among government, industry, and academia is the second point I found important in the current restoration effort. The Oyster Recovery Partnership (ORP) was founded to effectively implement oyster stock management objectives in Maryland that was addressed by the Oyster Roundtable in 1993. The ORP works with management agencies such as National Oceanic and Atmospheric Administration, the U.S. Army Corps of Engineers, and the Maryland Department of Natural Resources to assist with tasks and adaptive management. They collaborate with experts from UMCES to provide hatchery production and monitor the planted oysters, with environmental organizations such as the Chesapeake Bay Foundation, and with

Maryland watermen who have the necessary equipment and knowledge to operate in the local environments of the Bay.

Mr. Eddie Walters, who is responsible in field operations for the ORP planting project, is from a traditional fishing family on Kent Island that has fished in the Bay for five generations, and is an experienced waterman of 40 years. His goal is to leave children the nature that he has enjoyed (personal communication). He believes that we cannot just go back to the way things were, and that there are roles for scientists and watermen in improving the resource. He feels that the difficulty in the oyster restoration of the Bay is that there are too many people and groups who have different attitudes and powers being involved. However, watching a part of the ORP activities where his crew operate the vessel to plant laboratory-produced spats, I saw a good start of a cooperative relationship between the Maryland watermen and the scientific community.

How were the planting areas that Eddie's crew headed to determined? My third point, selecting appropriate planting sites for the optimized efficiency was done based on the latest scientific findings. An oyster larvae dispersion study conducted by Dr. Elizabeth North, an oceanographer from UMCES, is one such project that contributes to spatial fishery management. Funded by DNR as a part of the PEIS research, her group determined the spatial dispersal of oyster larvae in Chesapeake Bay using coupled hydrodynamic and larval transport models and transferred the dispersal findings to a juvenile/adult demographic model. The results suggest optimum bar locations for the purpose of restoring spawning stock.

As a scientist from UMCES, an organization that society expects to assist the oyster restoration effort, Dr. North sometimes provides consultants from several agencies with her research findings. Her concern is that some of them do not let her know how they use her findings in making political decisions. She believes that each agency has different goals and that what they want may be different among agencies. Although she did not clearly mention it, her concern might be the point that the scientific data can be used for a tool to justify a certain policy.

Influence of the oyster diseases is also a major concern in determining planting sites. The DNR Shellfish Program has conducted annual fall surveys of oyster populations in Maryland's Chesapeake Bay since 1990 that includes extensive analyses for stream flow, spat fall, mortalities, and commercial harvest as well as disease prevalence and infection intensity among oysters from broadly distributed natural oyster bars. Mr. Chris Dungan, a pathologist from the Cooperative Oxford Laboratory, has performed oyster parasite diagnostic tests in the program. His group has also succeeded in *in vitro* propagation of *Perkinsus marinus*, the pathogen of Dermo disease, which enabled them to determine the entire life cycle of the parasite.

He believes that there is no ability to wipe out the diseases completely from the Bay, but that understanding disease mechanisms and trends is necessary for proper fishery management. He appreciates that it was a brave decision of Maryland to expand the sanctuary network, which he believes allows wild oysters to reproduce over generations and perhaps to develop genetic disease resistance. As a result of the 2009 fall survey, he proposes that oyster disease levels remained below average for the sixth consecutive year because of an increase in oyster genotypes conferring increased disease resistances among oysters and their progeny that survived the severe disease pressures of the 1999-2002 drought years. However, he feels that the decision to expand the sanctuary network should have been done two decades ago, when the wild population still had resilience.

Maryland's Plan 2. Promoting Private Aquaculture

The other component of the Maryland's new plan is to promote private aquaculture. As described earlier, Maryland has been struggling with irregular efforts to develop an aquaculture industry for more than a hundred years. What were the obstacles for prospective oyster farmers in starting their business in Maryland, and how are the new regulations designed to overcome them?

First I visited Marinetics, Inc., an oyster aquaculture company in Cambridge, Maryland. The company was established in 1999, 10 years before Maryland's Aquaculture Development Plan was addressed. When I visited their office located in the green countryside outside Cambridge, one of the co-owners Mr. Robert Maze showed me their hatchery facility that was assembled by recycled parts from everywhere in an effort to save money in the start-up cost. After 5 minutes ride in their old van on the bumpy road, passing corn fields and the forest, a beautiful cove came into view. In it were hundreds of thousands of floats that support bagged oysters along the pier. The company now grows10 million oysters on the water surface and sells about 1 million oysters each year

(Bay Journal 2010). Their "Choptank Sweets" brand oysters are appreciated by local restaurants and grocery stores for the flavorful taste, beautiful shell shape, and year-round availability (http://www.marineticsinc.com).

The company's manager Mr. Kevin McClaren told me of the difficulties they experienced in starting their aquaculture business in Maryland's Chesapeake Bay. First, the process of permitting was complicated and time-consuming. They had to apply for five different permissions and licenses from five different state and federal agencies: an aquaculture license from DNR, boat registration from DNR, a permit from Army Corps of Engineers, a water quality certificate from Department of Environment, and a permit from the Health Department. It took the company about two years to put their first oysters in the water after obtaining all the required permits. The second difficulty involved developing markets for cultured oysters, which Mr. McClaren felt was a bigger challenge than combating disease, predators, the weather, and winds. The third involved convincing neighbors who did not want to have the aquaculture business in their backyard. Mr. McClaren noted that most of the local landowners were suspicious of Marinetics because people are afraid of something new. The company repeatedly explained to seaside residents that their oyster aquaculture will not harm human health and the environment.

The difficulties the company experienced are not surprising since Maryland has never had an industrial base for oyster aquaculture. In 2009, the Governor of Maryland put forward an Aquaculture Lease Law to remove obstacles on developing aquaculture industry and to establish a regulatory framework. It made thousands of acres of bottom that were previously off-limits available for leasing, including 95,000 acres of natural oyster bars that are no longer utilized by the commercial oyster fishery. In addition, the leases can be held by corporations and non-residents, which was previously restricted. The Oyster Restoration and Aquaculture Development Plan in 2010 reinforced the lease laws by designing Aquaculture Enterprise Zones where leases are already established by the state and in which individuals can begin farming without obtaining their own permit. The permitting process should go more smoothly under the new plan.

How feasible would it be for watermen to start aquaculture under the new Maryland plan? As mentioned, a major concern involves marketing (K. McClaren, personal communication). Watermen should be able to raise oysters after some trial-and-error because they are familiar with oyster biology and the working environment. However, if they attempt to produce millions of oysters like Marinetics does, they need to find someplace to sell all the products to pay off the cost. If the business scale is small, it can be feasible because there are many successful husband-and-wife oyster businesses in northeastern states (K. McClaren, personal communication).

Shifting to aquaculture will change a commercial watermen's working life a lot. Watermen are dissatisfied with the new plan (Mike Naylor, Shellfish Program Assistant Director at Maryland DNR, personal communication). They strongly criticized the oyster restoration and aquaculture development plan at a public hearing that was held in August 2010 at Wye Mills, Maryland (personal observation). The complaints focused on their doubt on the validity of the past and proposed restoration efforts, including the expanded sanctuary program, and their fear of the changing livelihood. Some comments detailed in a watermen's brief handed out to the visitors in the public hearing included "watermen across the state will be competing for oysters on fewer public bars, but we have not been given ample time or resources to transition to aquaculture," "I would be competing with the current shucking market. A bottom cultivated oyster market would not be competitive during the regular oyster season," "obtaining shell is an obstacle for any watermen transitioning to aquaculture," "to undertake top-water aquaculture I would need to develop a new market," "the DNR is ill equipped to provide access to loans". These claims are certainly important to the watermen. Whether their concerns will be borne out will take time to determine.

Indeed, aquaculture is an uncertain business that requires some initial investment yet takes two to three years of growing period between oyster planting and growth to market size. The state of Maryland is trying to lower the barriers for aquaculture enterprise by establishing not only the regulatory framework, but also an affordable loan program. DNR has formed a partnership with the Maryland Agricultural and Resource-Based Industry Development Corporation to make $2.2 million available for those who want to start shellfish aquaculture at this time, and two thirds of the funding is reserved for commercial watermen. The requested loan proceeds would be used to purchase substrate, seed, or capital equipment. In addition, the University of Maryland Extension and the Maryland Department of Agriculture also provide training and business planning assistance (Application for Maryland Shellfish Aquaculture Financing, http://www.dnr.maryland.gov/fisheries/oysters/industry/funding/ShellfishAquacultureFin ancingApplicationFinal.pdf). The Aquaculture Enterprise Zones are open to anybody but will hopefully be utilized by commercial watermen. Mr. Naylor wants watermen to take a first step and find some advantages of aquaculture, believing that if they feel that aquaculture can make money, things will change.

Webster (2003b) declares: "It is not easy for an industry as entrenched as the Maryland seafood industry to move in new directions. While most venerable institutions tend to resist change, change is inevitable… Today we face a situation where we have nothing to lose and everything to gain by making major changes to the way Maryland manages aquaculture. Nothing in business remains static and those who resist change are usually left behind by those who embrace it."

Chapter 3 Ariake Sea

Physical Features, Fisheries, and Human Impacts

The Ariake Sea is a semi-closed bay located in the west of Kyushu, the southern island of Japan (Figure 4). It is one of the most productive water bodies in Japan with a surface area of 1,700 km^{2,} which is about one-seventh that of Chesapeake Bay (Table 1). The Sea has diverse aquatic environments, as well as diverse fisheries; while the inner bay forms a broad muddy flat that is suitable for bivalve fishery and *nori* seaweed cultivation, the bay mouth is a rather pelagic environment that allows fishers to deploy set nets for finfish fishery. The tributaries are also good grounds for traditional freshwater fisheries of various endemic species (Sasaki 2005a).

	Ariake Sea	Chesapeake Bay
Surface area (km^2)	1700	11600
Average depth (m)	20	6.4
Volume (km^3)	34	57
Freshwater inflow (km^3/year)	8.2	-
Population in the region (million)	3.2	16.6

Table 1. Comparisons of Ariake Sea and Chesapeake Bay in some environmental factors.

Ariake Sea has a stomach-like shape with a long and narrow body and a small entrance. In spite of this constricted shape and high nutrient loads from tributaries, Ariake Sea has until recently maintained biological and physical cycle as well as high productivity in a good balance. Sasaki (2005a) attributes this to three significant functions of Ariake Sea. First, a large tidal range that can reach up to 6 m makes pump-like water movements and brings fresh oceanic water into the bay. This water flow helps the bottom water mix, thus avoiding oxygen deficiency. Second, the wide tidal flats and shallow water provide the best photosynthetic condition for phytoplankton to consume excess nutrient salts. Third, suspended particles from the turbulent bottom circulation become available to feed shellfish and fish juveniles (Sasaki 2005a).

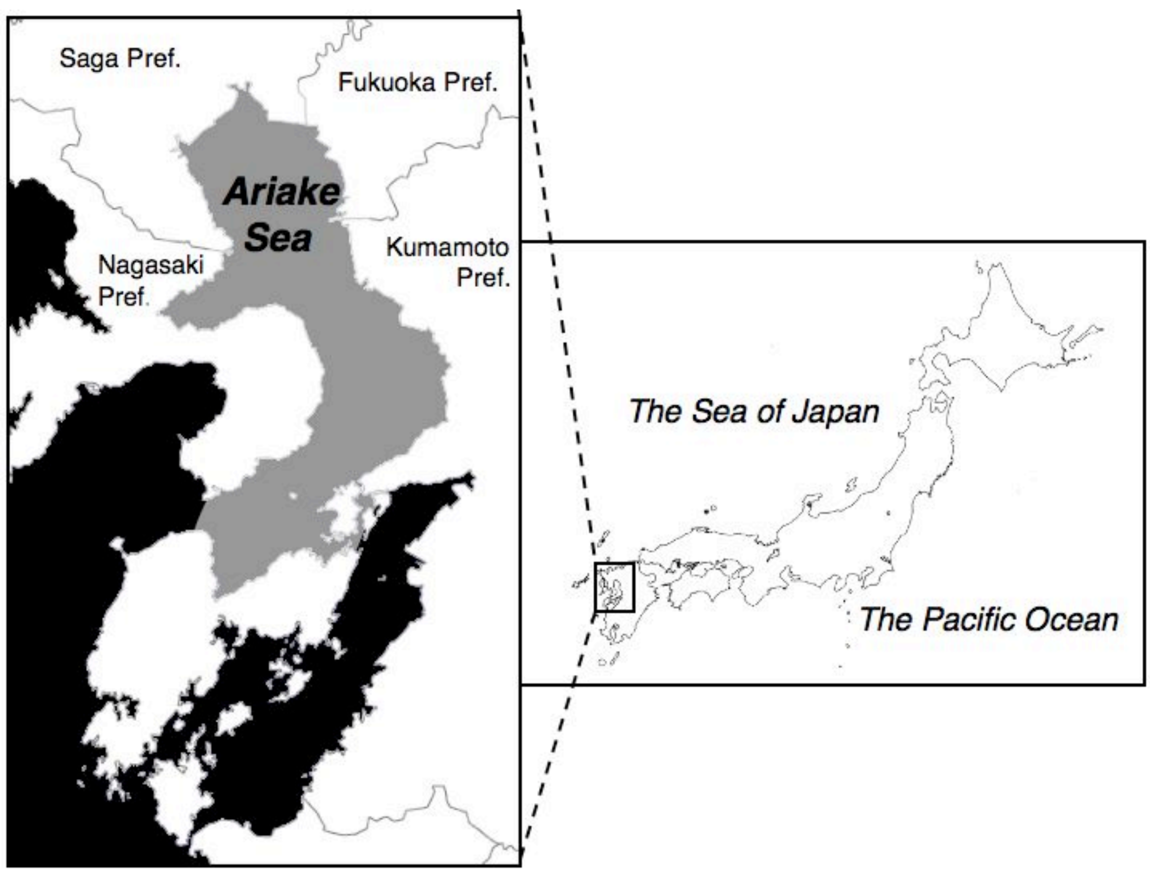

Figure 4. The Ariake Sea and the surrounding four prefectures.

These functions (which resemble the important functions in Chesapeake Bay) make Ariake Sea highly productive and one of the most important fishery grounds in Japan. The Bay is divided into four fishery-jurisdictions based on borders between the prefectures of Saga, Fukuoka, Kumamoto, and Nagasaki. The main products from the bay are farmed *nori* seaweed and various bivalves. In particular, the inner part of the bay provides nutrient-rich shallow water and the best condition for *nori* farming, producing 40% of the total annual production in Japan in recent decades (Sasaki 2005b). The Bay is also famous for various traditional fisheries in the muddy flat, providing tourists and residents with local delicacies.

Although the Bay could be called a "treasure sea" for its high productivity, the yield in all the four prefectures has decreased since the period of 1973-1980 (Figure 5). This decline in fishery production is considered the result of habitat deterioration in the Bay. Development activities such as land reclamation, river improvement work, sand extraction, and port construction have caused crucial environmental degradation by changing water flow and bottom sediment input (Sasaki 2005c).

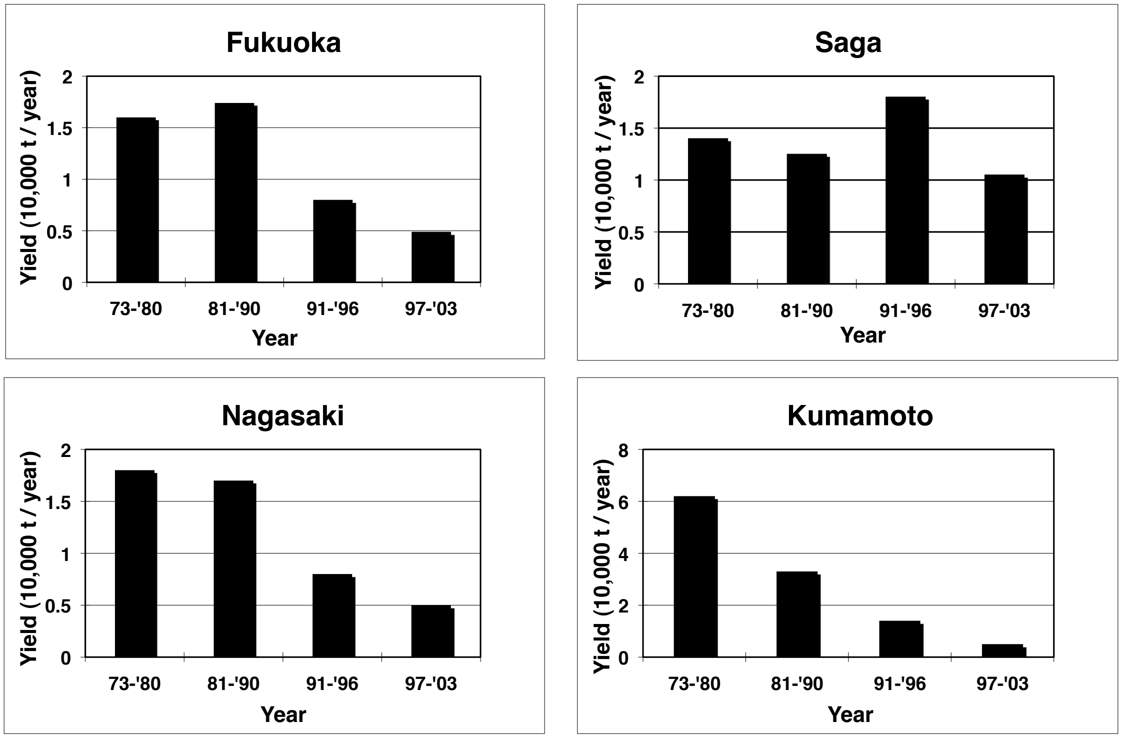

Figure 5. Changes of total yields from capture fishery and aquaculture combined from 1973 to 2003 in the four prefectures surrounding the Ariake Sea (Sasaki 2005b).

Especially the Isahaya Bay Reclamation Project in the inner part of Ariake Sea is considered the main reason for unstable conditions facing *nori* farming as well as rapid decreases of populations of the Tairagi clam, *Atrina pectinata*. Red tides and oxygen deficiencies have also been observed often since 1998 (Sasaki 2005c). The controversy and environmental changes due to the reclamation are described below.

Brief History of the Oyster Industry

The Ariake Sea was once the largest oyster producing area in Japan during the 1920s. According to "Historical Achievement of Oyster Farming (Kaki Youshoku Jiseki)" written by a local fisherman Rakutaro Murata, Murata began farming Suminoe oyster *Crassostrea ariakensis* in the region of today's Saga Prefecture in 1884 (Saga Fishery Adjustment Committee 1998). He collected natural oyster spats on bunches of bamboo stems he set in the muddy flat. The collected spats were transplanted offshore to a higher salinity where Suminoe oysters grow faster and were subsequently harvested in 10 to 12 months. This method became popular among fishermen in the region and made enormous profits. The production steadily increased since the late 1900s and peaked in 1919 with approximately 60 % of the total production in Japan that year (Saga Fishery Adjustment Committee 1998; see also Figure 6).

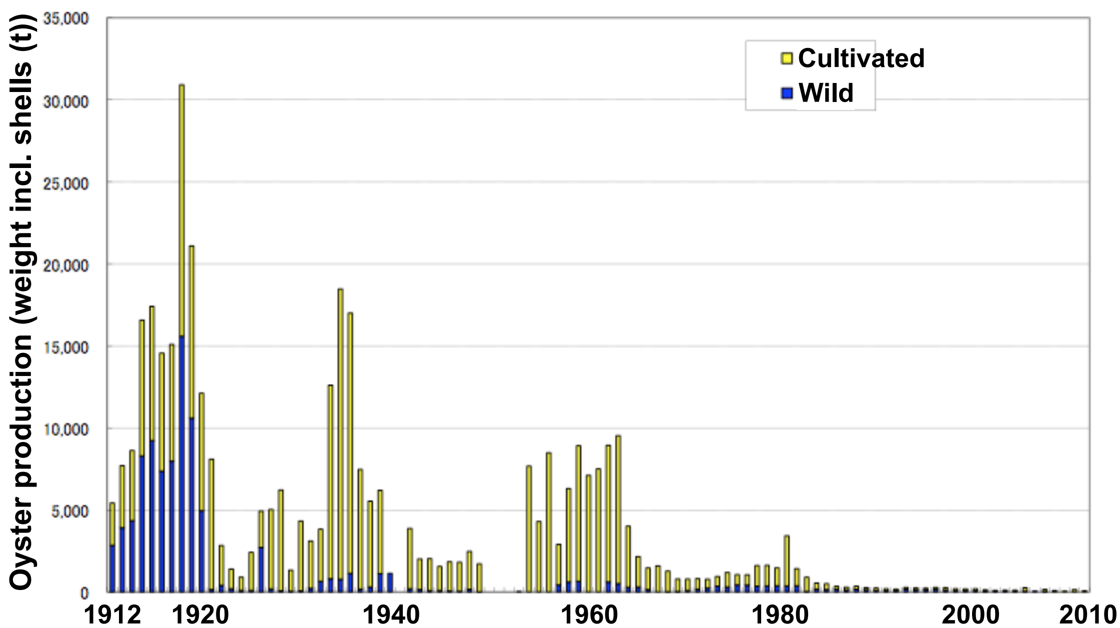

Figure 6. Reported landings of wild and cultivated oysters in the Saga part of Ariake Sea from 1912 to 2010. Courtesy of Saga Prefectural Ariake Fisheries Research and Development Center.

Unfortunately, a historical flood event in 1953 stopped the progress by causing a large volume of freshwater runoff that contained the pesticide parathion from agricultural lands. This pollution wiped out the farmed oysters and other shellfish in the Bay. To rescue the local fishermen from financial crisis, Saga Prefecture promoted *nori* seaweed farming as an alternative source of income (Saga Fishery Adjustment Committee 1998). *Nori* seaweed *Porphyra yezoensis* was introduced to the Saga part of Ariake Sea (inner bay) in 1904 from Kumamoto Prefecture, where fishermen had succeeded in profitable *nori* farming. Later, Japan experienced a breakthrough in the *nori* production after a discovery of the conchocelis-phase of the plant (Drew 1949), which enabled farmers to understand the entire life history of *nori* and store seeds in farming practice. Given the situation, it was reasonable for Saga Prefecture to encourage the fishermen to shift from oyster farming to *nori* farming by supporting economic and technical needs (Kawamura 2002).

Regrettably, the prefecture wiped out wild oyster bars and oyster shells on the bay bottom (Figure 7) with a bulldozer to prepare a flat bottom for *nori* farming because the current farming method requires planting a number of posts that support meshes to which *nori* attaches (Figure 8). The constructions have been occasionally repeated since 1976 until the oyster bars were severely damaged (Saga Fishery Adjustment Committee 1998). It was unfortunate that people in fishery management pursued an immediate economic measure from *nori* farming and did not foresee outcomes of the destruction of oyster bars that play important ecological roles in the estuarine environment. Iyooka et al. (2008) estimated that oyster's filtration capacity in the inner Ariake Bay has decreased to 10 % of that in 1978.

Figure 7. Oyster beds at low tide in the Ariake Sea. The posts are designed to keep out rays. Photo by V. Kennedy in 2007.

Figure 8. Nets used in culture of *nori* in the Ariake Sea. Photo by V. Kennedy in 2007.

Management Issues

Japan maintains an intensive fishery and aquaculture industry in its coastal waters through a fishery adjustment system in which a local government plans a comprehensive use of coastal waters and grants exclusive fishery rights to qualified fishermen. Japanese coastal fisheries comply with a Fishery Adjustment system made under the national Fishery Act of 1948. The law establishes Sea-Area Fisheries Adjustment Commissions and allows local Fishermen's Cooperative Associations to be administrative bodies in each jurisdiction, aiming for a democratic administration where local fishermen's opinions count greatly in decision-making process. The Japanese management scheme is acclaimed for its feasible and effective way to deal with fishing conflicts that is region specific. However, the self-imposed user management has a tendency to focus on productivity and profitability by its nature (e.g., Uchida et al. 2010) and lacks a sense of resource conservation (Sato 1978), which is probably incompatible with sustainable resource use. In this section, I discuss advantages and disadvantages of the Japanese coastal fisheries management system.

Concept of Sea Tenure and Coastal Fishery Management in Japan

Japanese coastal fishery management sometimes draws international attention as a solution to the "tragedy of the commons", a situation where a natural resource is overexploited because of accelerated competition among resource users where access to the resource is open (Hardin, 1968), which often happens in fisheries (Feeny et al. 1990). Important features of Japanese fishery management are its concept of sea tenure, dedicated access to marine resources, and co-management structure by fishermen and local government. The sea tenure concept, namely the ownership of the aquatic environment and natural resource just like in the terrestrial environment, is observed typically in tropical and subtropical island communities in the western Pacific (McCay 2001). The discovery of the sea tenure concept by western scientists is considered one of the greatest contributions of ethnographical study in improving fishery management (Kalland 1990).

Japan has developed the sea tenure concept and fishery management through the history of national construction, economic growth, and fishery development. In the ancient time of Japan, the aquatic environment and organisms used to be considered as common resources and there was no control on access to them in the Taiho Code, the first full-fledged law in the early 8th century. The Code stated that “yields from the mountain, river, bush, and aquatic environment belong to nobody” (Kaneda 2003). In the Middle Ages, however, a feudal system developed across Japan, where local lords governed their territory and people. At the same time, fishery regulations developed region by region because there were emerging fishing conflicts as a result of fishery development. The sea tenure concept has developed for the purposes of conflict avoidance and feudalistic governance of aquatic yields. The customary sea tenure concept was stipulated as a set of standard fishery regulations in Urahou or fleet law (1743) by the feudal government, which stated that coastal waters were considered to be extensions of the land and thus a part of the feudal domain (Makino and Matsuda 2004).

The customary fishery management by local government became radically converted into central management during the modernization process of the nation. In the middle of the 19th century, the feudalistic government of the Tokugawa lord family was overthrown and replaced by the Meiji government, the first modern government in Japan. The new government replaced many customary laws and systems by European-style ones in a radical modernization of the national institutional work (Ruddle 1992). In this process, Japan's sea was nationalized and a fishing license system issued by the central government was introduced instead of the traditional local management. However, this radical transition ended in failure due to fishing conflicts increasing because of too many newcomers entering fisheries (Makino and Matsuda 2004). It turned out that the traditional management scheme controlled the number of fishery participants adequately and the Meiji government soon decided to replace the fishery law by Meiji Fishery Act of 1910, which was created based on traditional local management, before the Japanese fishery collapsed.

However, people found another problem in the Meiji Fishery Act when the customary management was written in the modern law. The feudalistic custom remaining in the closed fishing communities did not allow fair fishing opportunities to all the community members. Traditional ruling families enjoyed their privilege to rule their domain that the family fished for generations and the law allowed them to renew their fishery right as long as they claimed. The working class suffered from expensive rents subjected for fishing grounds where the ruling families claimed their virtual ownership. Consequently there were many fishing grounds that were occupied by the ruling families but not utilized for fishery purposes because of the expensive rent (Sato 1978).

Thus a reformed fishing law was established after World War II under occupation of General Headquarters of Allied Forces aimed at democratization of Japanese industries. The priority goal of the current Fishery Act of Japan is democratic management by working fishermen themselves and an optimal use of fishing grounds. To achieve this goal, the law required that a prefectural Governor must make a comprehensive plan for managing fishing grounds and must renew a fishery right every five or ten years. It also prohibits renting fishery rights to others in order to avoid the unused fishery grounds that were observed under the Meiji Fishery Act. In fact a good fishery ground is intensively utilized under the current law.

Administrative Process for Fishery Management

Under the Fishery Act, the coastal water around Japan is divided into 66 sea areas and each area is under the jurisdiction of the littoral prefecture (Kaneda 2003). To practice coastal fishery or aquaculture in Japan, one has to obtain a fishery right granted by the prefectural Governor, which allows one exclusive use of water for a defined fishery with defined equipment in a defined area. However, obtaining a fishery right is never done arbitrarily because the coastal water is distributed to resource users following the comprehensive plan of water use established by the local government every 5 or 10 years. This is called the fishery adjustment system, which is designed to allow exclusive water use in a competitive fishing ground (Figure 9).

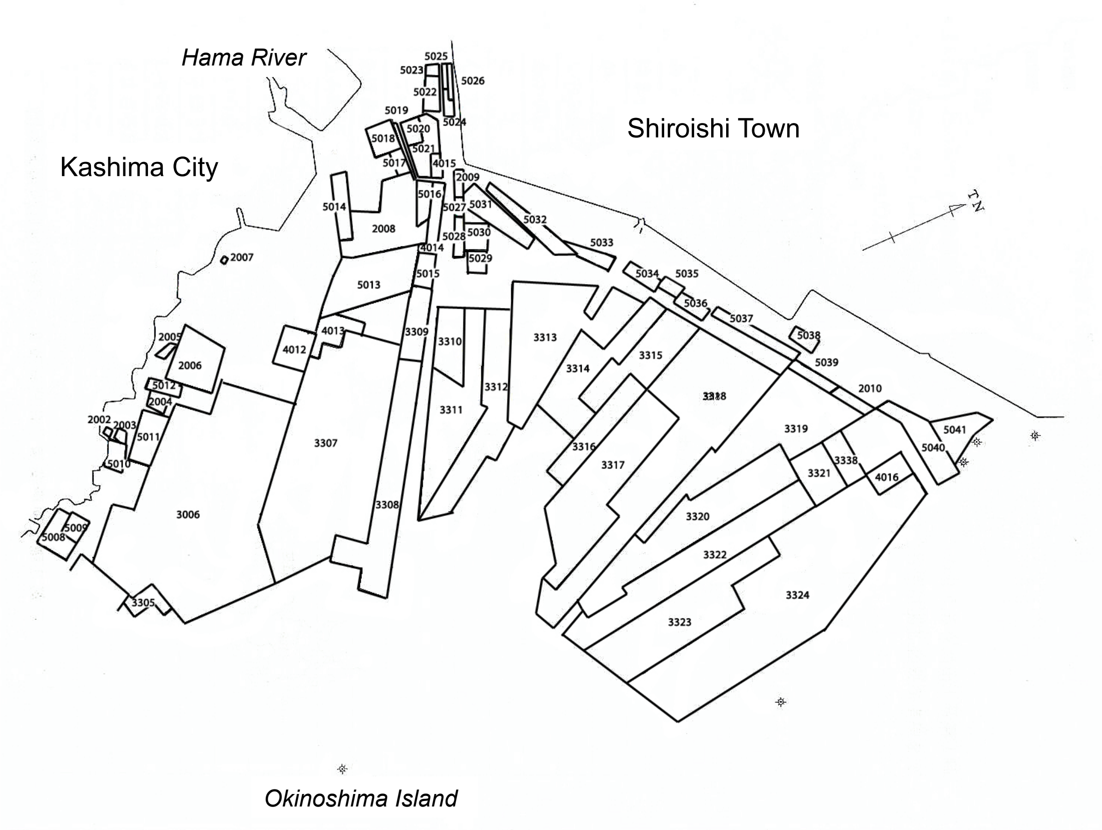

Figure 9. An example of five-year fisheries plan from the Central District of Saga jurisdictional sea area. Four-digit numbers indicate each Demarcated Fishery Right that defines the practitioner, fishing gear, and fishing period. Modified from Saga Prefecture 2009. The coastal water around Japan is systematically allocated to fishers, which helps avoid fishing conflicts. Modified after Saga Prefecture Fishery Department 2009.

Another purpose of the fishery adjustment system is to protect rights of working fishermen, who have been socially vulnerable over time, by reflecting their opinion in decision-making and by controlling the influence of the ruling class and Governor's own authority. For this purpose, the Fishery Act requires that each prefecture has a Sea-area Fisheries Adjustment Commission to play substantial roles in the fisheries adjustment process. A Commission is an organization independent of the prefectural government established in each sea area to advise and check the Governor's decision and to reflect fishermen's intentions in fisheries adjustment. The Governor cannot make any decision without hearing the Commission's opinion. The Commission consists of 15 members: nine members are elected fishermen, four are academic experts appointed by the Governor, and two are representatives of the public interest appointed by the Governor.

Here is how the administrative process works (Figure 10): First, under the name of the Governor, a five-year plan of how to use his/her jurisdictional sea area is made based on fishermen's requests. Types, areas, periods, and districts for aquaculture are exactly defined in this plan. Second, fishermen apply for a fishery right[1] for a certain type of aquaculture, based on the Governor's plan. Third, if more than one fisherman applies for a certain aquaculture sector, the Governor qualifies and prioritizes the applicants according to the priority order that the Fishery Act defines (Table 2). Basically, experienced fishermen living in the district and belonging to the local Fishermen's Cooperative Association are given priority.

[1] There are three types of fishery rights depending on types of fishery: "fixed gear fishery right" for large-scale set net fisheries, "demarcated fishery right" for aquaculture, and "common fishery right" for seine fisheries, small-scale set net fisheries, and capturing stationary aquatic animals. Here, I focus on the administrative process of obtaining demarcated fishery rights dealing with aquaculture.

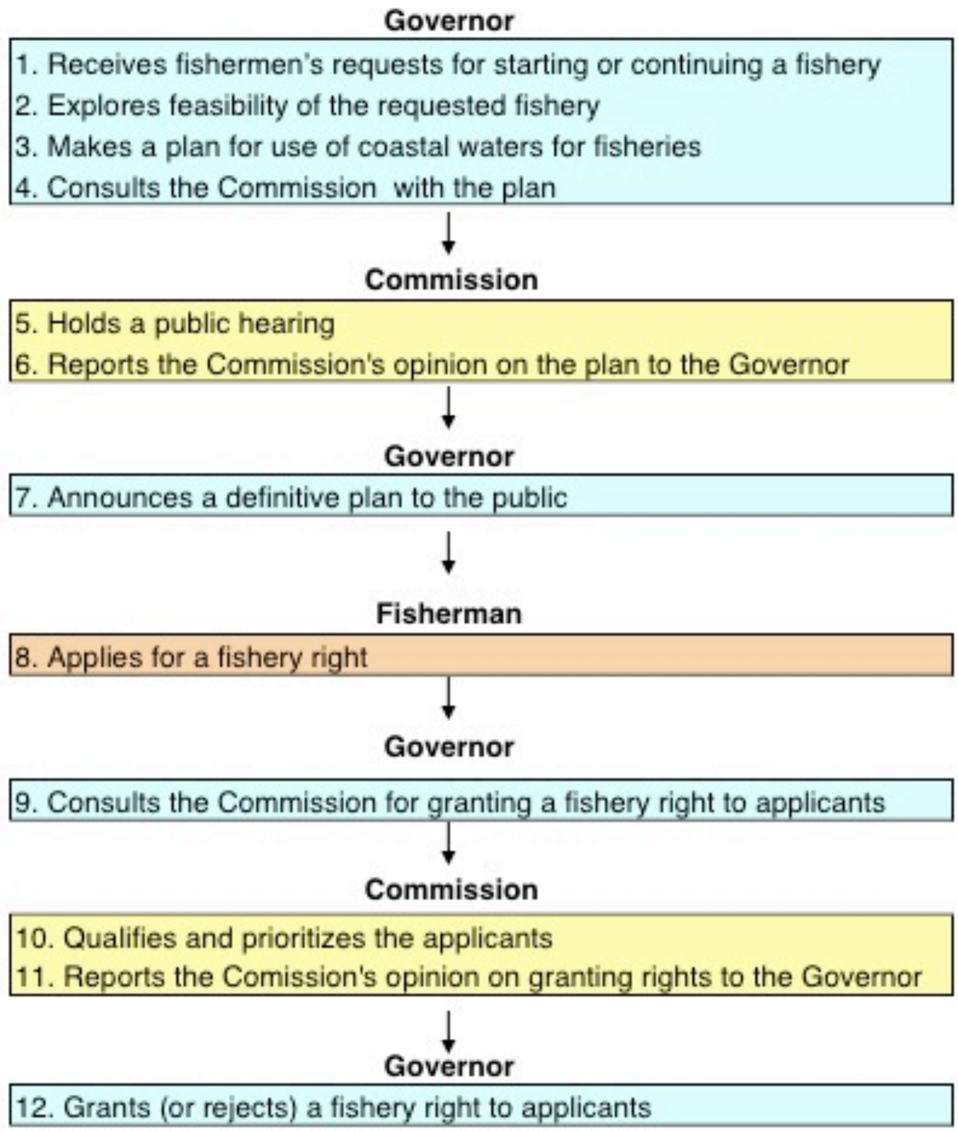

Figure 10. A process of Fishery Adjustment System in which the Governor, the Sea-area Fishery Adjustment Commission, and local fishermen participate in the process. Created after Kaneda 2003.

Priority order	Organization
1	Local Fishermen's Cooperative Association (FCA)
2	Local Productive Association
3	Other
	a. Fisherman > Other
	b. Individual > Company
	c. Resident in the district > Other
	d. Person with experience in the same sort of fishery > Other
	e. in d, Experience in the same sea area > Experience in the other sea area

Table 2. Priority order that the Fishery Act of Japan defines for a demarcated fishery right. The highest priority is given to local Fishermen's Cooperative Associations. Table was created after Kaneda 2003.

Supports for Fishery

In addition to the protective fishery right system, a fishery in Japan is supported by the government in technical and financial aspects. In my opinion, this is not only because fishing is an uncertain industry that depends on a natural resource that fluctuates according to environmental conditions that individuals cannot overcome but also because fishing is an important industry related to Japan's national interest. While Japan's food self-sufficiency was as low as 39% in 2010, fishery production remains at 60%, a relatively high figure (Changes in food self-efficiency, Ministry of Agriculture, Forestry, and Fisheries of Japan. http://www.maff.go.jp/j/zyukyu/zikyu_ritu/pdf/22sankou4.pdf) and is even an important exporting product (The white paper on Japanese fishery, Fisheries Agency of Japan 2008). Also, the Japanese fishery industry has attained the world's highest standards in the field of science and technology that can create new businesses. Like other primary industries, the fishery industry developed a cultural norm that has become a foundation of national identity.

As to technological support, a Fisheries Experiment Station, a research agency run by the prefectural government, helps local fishermen with technical issues as well as by serving as a bridge between government and fishermen (Short 1989). The Station periodically investigates local yield, environmental conditions, and particular problems such as disease prevalence to advise fishermen with their scientific expertise. Fishermen consult them even on legal issues that are not easy to understand. When a group of fishermen hopes to start a new aquaculture project, the Station would arrange an experiment to determine the feasibility and establish a protocol. These technical supports encourage fishermen to try a new business and avoid fruitless failure. Also, the Station holds workshops to offer local fishermen opportunities to learn new technologies and other issues.

Prefectural governments financially support local fishermen when they find it beneficial for the community. For example, Saga Prefecture prepared budgets in 2007 for removing harmful rays, raising prawn stock, advertising local products, constructing a port, and supporting fishermen's mutual aid, etc. (Saga Prefecture 2007). Prefectures also support initial investments of newly starting aquaculture business under certain conditions.

Advantages and Disadvantages of Japanese Management System

The Japanese coastal fishery management is based on the close relationship between a prefectural government and practitioners. By exchanging information and opinions frequently, government and practitioners can work together to deal with changing circumstances flexibly. The financial and technical support of a prefectural government and research institutes encourages fishermen to develop a new aquaculture and to improve their practice for better livelihood. I believe that such a strong cooperation has overcome technical and financial problems and upgraded Japan's fishery to the highest level in the world. The fisheries adjustment system also seems to be working well in systematic use of coastal waters as well as protecting fishermen's rights in decision-making process.

On the other hand, the exclusive fishery-right system may prevent newcomers from entering the fishing community. The process of qualification and prioritization for fishery-right applicants is too protective and favorable to the local fishermen so that it is almost impossible for one to get a demarcation without belonging to the local FCA. In fact, many of the fishing communities across Japan commonly face the problem of aging and shrinking populations (Lim and Matsuda 1995). Also, the Fishery Act prohibits a governor from renewing a fishery sector that has not been productive for years (Kaneda 2003), which may prevent innovative enterprise that takes time to maintain constant yields. Fishery-right and fishery-adjustment system may be reinforcing the conservativeness of Japanese fishing communities.

In terms of conservativeness, some fishery sociologists in Japan point out that feudalistic customs among fishing communities still exist even though the Fishery Act of 1949 mainly aimed to wipe them away. For example, positions as fisherman representatives for Sea-area Fisheries Adjustment Commission are usually occupied by the "boss" of the community, that is, someone from the previous ruling class (Iwakiri 1969), although the commission system was established to protect the working class. Bosses tend to enjoy the "honorary post" instead of pursuing public benefit for the community and optimum use of the fishery ground. It may take some more years for the fishing community to become aware of the sense of public welfare because the traditional way of thinking has passed on for generations (Sato 1978).

Another problem is that the current management structure lacks a sense of environmental protection. Although the exclusive use of water column controls the excess competition among resource users that causes overexploitation, there are no strict regulations for catch and dense aquaculture; it is up to the rules a local FCA makes (Sato 1978). Top-down control may be necessary to some extent since the user's self-management tends to focus on profit by its nature. As to decisions about coastal water use, there should be a third party to assess environmental impact because opinions by a Fishery Adjustment Commission can be overly favorable to fishermen since 9 of the 15 commission members are local fishermen. We can see an example of management failure in the episode of destruction of oyster bars earlier.

I conclude that the Japanese management system is feasible in conflict management and systematic water use in a way that suits the tradition of the fishing community since it has developed through the history of the fishery. The commitment of the government to the development of fishing and aquaculture has also contributed to achievement of the Japanese fishery industry to the highest level of the world. However, the circumstance of the fishing community has been changing as a result of the emerging problems of aging of the community and environmental degradation. The management system should be reformed from the closed way among the fishing community to being open to the whole society in order to deal with more complicated situation surrounding the Japanese fishery.

Environmental Issues: Isahaya Bay Reclamation

As in any estuarine environment, the ecosystem of the Ariake Sea is vulnerable where the water movement and the biological and physical cycle maintain purification-function in a sensitive balance. The large tidal flat particularly plays an important role in the Ariake system (described earlier). On the other hand, the tidal flat is also an important land resource in Japan, where 70 % of the country is mountainous and not arable. Many tidal flats across Japan have been reclaimed to increase agricultural land and residential area since the early modern period (Sasaki 2005c). In fact, the Ariake Sea has lost 3,000 ha of its tidal flat for reclamation and other development construction since 1979, which is 56% of the total loss of Japan's tidal flats (Sasaki 2005c).

Here I explore the National Isahaya Bay Reclamation Project (1989) that greatly impacted the Ariake fishing industry and caused national controversy about environment and development. It will shed light on the importance of maintaining a healthy environment for a coastal fishery as well as its difficulty because of various stakeholders existing in the aquatic environment.

The National Isahaya Bay Reclamation Project is a large-scale public works program to reclaim tidal flats of Isahaya Bay, the west side of Ariake Sea, by a double-dike approach where the outer dike closes off the whole Isahaya Bay, 3,550 ha in total, and the inner one encloses the reclaimed land of 1,635 ha (Figure 11). The objectives are 1) to prevent typhoon-fed flooding that frequently hits the coastal area and 2) to create agricultural land with a balancing reservoir for irrigation (Sasaki 2005c). The government completed construction work by closing the outer dike in 1997 although there were arguments concerning environmental impact to the Bay (Sasaki 2005c).

The problem was revealed in the public in 2000 when the harvest of cultured *nori* seaweed was devastatingly low, apparently as a result of a large scale harmful algal bloom that hit the inner Ariake Sea, culturists assume. For the recent decades the Ariake region had produced 4 billion sheets of *nori* per year, which is about 40% of total production in Japan and had contributed to local economies as a main resource of income. However, the production in 2000 was as low as half of the average for the decade (Sasaki 2005b). It is also reported that some shellfish species such as Manila clam, *Ruditapes philippinarum*, and Tairagi clam have decreased or even disappeared since 1993 (Sasaki 2005b). Local fishermen and aquaculturists argued that the reclamation work has changed the environment and consequently diminished this production. Some of them stated that the water flow has weakened since the outer dike was closed (Sasaki 2005d).

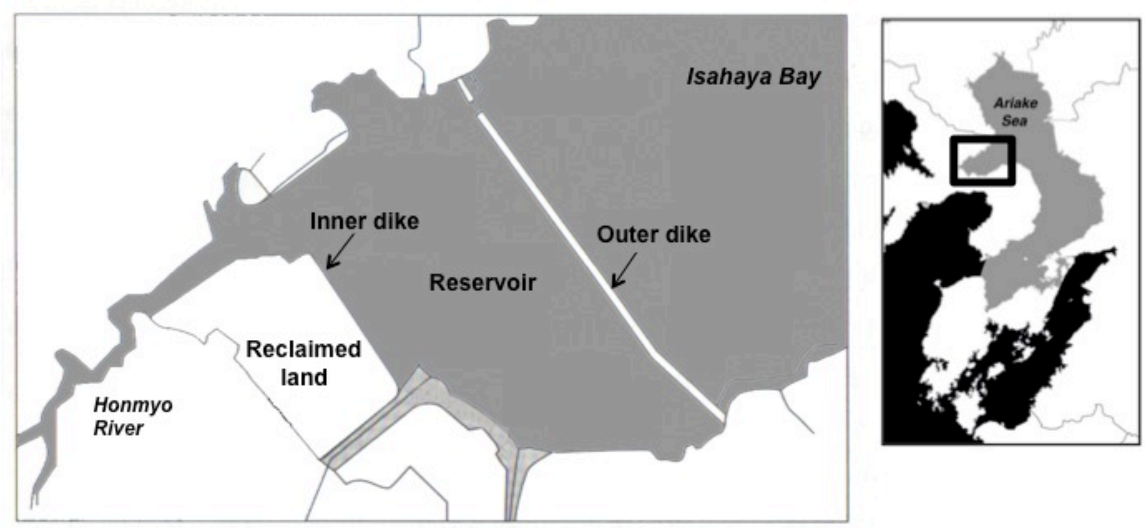

Figure 11. A summary of National Isahaya Bay Reclamation Project (left). Isahaya Bay, the west side of Ariake Sea (right), is closed off by the outer dike. The inner dike encloses the reclaimed land (modified after Sasaki 2005c).

However, there was a group of people who did not agree with the correlation between reclamation work and poor fishery production because there are also many natural factors influencing water flow and tide that determine condition of the Ariake environment. For example, the tidal gap of the Ariake Sea is largely influenced by the degree of earth rotation and moon rotation, producing differences in the velocity of tidal flow in 18.6-year period (Matsukawa 2005). There are also data that the catch in the Ariake Sea had decreased since 1980 before the construction work started.

To determine if the reclamation work is a major causative factor in recent environmental degradation and decline in aquatic production, a group of scientists explored the change of the Ariake ecosystem in various aspects and synthesized each individual study (Sasaki et al. 2005). They noted that harmful algal blooms had not occurred in the Ariake region before the work but were frequently observed after construction work.

Here is a scenario of what happened in the Ariake Sea, they concluded: First, the velocity and direction of the water flow has altered since the shape of Ariake Sea changed after Isahaya Bay was closed by the dike. Thus the water column is stratified because water flow is not strong enough to mix it, causing oxygen deficiency in the bottom. Freshwater with nutrient loads from tributaries flows on the surface (density flow) north along the coast by the force of earth rotation. Nutrient-rich water on the surface thus frequently triggers algal blooms that consume nutrients and make rather nutrient-poor water, which prevents healthy growth of cultured *nori.*

Another point involves the loss of tidal flat itself. A tidal flat is known as a productive environment that provides phytoplankton with a best condition for photosynthesis with shallow water that allows penetration of sunlight coupled with nutrient input from tributaries. The Isahaya tidal flat originally contributed to the physical cycle by removing excess nutrients through consumption by the food web. Closing the dike eventually disrupted the cycle, killing organisms that participate. Foul water is also discharged from the reservoir into the Ariake Sea causing another anoxic environment. The group of scientists concluded that the reclamation work has impacted the entire Ariake Sea environment and caused the decline in some fishery production.

Supported by the scientific insights, a group of Ariake fishermen requested discontinuation of the construction to protect their livelihood. However, the government did not accept the claim but rather completed the construction rapidly, illustrating the saying "once public work starts, it never stops (Kunishima and Miura, Failure Knowledge Database. http://www.sozogaku.com/fkd/en/hfen/HD1000139.pdf)", prioritizing economic stimulation by the public work. The suit by fishermen was finally legally accepted by the Fukuoka High Court who ordered the government to prepare to open the floodgates of the dike and keep them open for five years in December 2010, 10 years after the group initially prosecuted (The Asahi Shimbun 2010). The turning point might have been the change of government in August 2009 to the Democratic Party of Japan which has a policy to open the floodgates. However, now a number of farmers oppose opening the floodgate; they are afraid that the reservoir inside the dike on which they depend to irrigate their farmland will receive saltwater inflow (The Asahi Shimbun 2010).

The National Isahaya Bay Reclamation Project is a good example of problematic development of aquatic environment which tells us several important lessons: 1) the estuarine environment is vulnerable to change, 2) a coastal fishery largely depends on production capacity of the environment, 3) a radical construction work without sufficient environmental assessment and monitoring can cause an irreversible degradation in environmental quality, and 4) there are many stakes in terms of estuary use. In the Isahaya Bay, the government wants to distribute money and create jobs by public work, residents want to prevent flooding, fishermen want to keep their livelihood, farmers want to increase their agricultural land, biologists want to preserve the unique fauna in the Ariake Sea, and environmentalists want to protect the environment.

Recent Restoration Efforts and Aquaculture Development

The Recent Restoration Efforts

As described in the earlier section, the Japanese fishery adjustment system under the Fishery Act focuses on conflict avoidance but lacks an environmental perspective. However, as several coastal fisheries have collapsed in the recent decades, academic experts in Japan have been making an effort to include conservation perspectives in fishery management. Particularly, the Ariake Sea draws scientific attention as a leading example of ecosystem-based management, the concept of reflecting the relationships among all ecosystem components including the environment, which is now being recognized in Japanese natural resource management.

The Japanese Government established “Act on Special Measures Concerning Rejuvenation of Ariake Sea and Yatsushiro Sea” in 2002 to rehabilitate the degraded environment and diminished fishery catch after the Isahaya Bay Reclamation Project. This is a rare example that the national government made a legal action in a restoration effort not for a certain aquatic species but for an entire water body. It also seems the opposite management approach to the Maryland’s Oyster Restoration and Aquaculture Development Plan (Chapter 2) which is focused on the single species, eastern oysters. Under the rejuvenation act, related agencies and prefectural governments have implemented restoration activities such as surveys, improvement of fishery areas, and public education.

However, a problem was that each action or research project was aimed just for a particular aspect of rehabilitation because the governmental agencies act within their jurisdiction while the scientists study within their subject. To synthesize the scattered information and restoration efforts into a consistent rehabilitation goal, a five-year interdisciplinary project “Rehabilitation of Ariake Bay and Demonstration of Rehabilitation Technologies” was launched in 2005, being supported by Ministry of Education, Culture, Sports, Science and Technology of Japan. During this attempt, Ariake Method, an integrated rehabilitation method for Ariake Sea, was established.

Meanwhile, “Ariake Bay Rehabilitation Organization” was established in 2005 to network between universities, environmental businesses, and non-profit environmental organizations. The Organization aims to integrate best scientific knowledge and suggest a strategic rehabilitation policy based on it. The Organization particularly focuses on the ecological roles that oyster bars play. It arranged a survey to map the oyster bars with public participants and a public seminar on oyster bars.

As mentioned earlier, Iyooka et al. (2008) estimated that the oyster’s filtration capacity in the inner Ariake Bay has decreased to 10 % of that in 1978 since oyster bars were removed for *nori* farming grounds. They suggested that re-developing wild oyster bars and reviving traditional oyster cultivation can improve water quality of the bay by removing particulate organic matter that cannot be removed by *nori* farming.

Redevelopment of Oyster Aquaculture

Another movement towards oyster farming involves a group of Ariake fishermen who started oyster aquaculture in 2001 using a hanging method. With financial and technical support by Saga Prefecture, the group has gained profits from oyster aquaculture, although there are still some technical problems. The group is now trying to establish a new tourism attraction "Takezaki Oyster Road" where visitors devour local-grown oysters in small restaurants (Figure 12) (or obtained from vendors) built along the coast, contributing to the local economy.

Figure 12. Roadside restaurant serving locally grown oysters. Photo by V. Kennedy in 2007.

I visited the Saga part of Ariake Bay in the summer of 2009 to explore how fishery adjustment and prefecture's support worked in an emerging aquaculture sector. I interviewed a leader of an aquaculturist group, officers in the Fishery Department of the Saga Prefectural Government, and scientists at the Ariake Fisheries Experimental Station. Here is what I found.

Hanging oyster aquaculture in Ooura district of Saga Prefecture (Figure 13) was started by a group of fishermen who used to harvest the infaunal bivalve tairagi by a traditional method with diving helmets. They came to think of starting oyster aquaculture because the tairagi population had drastically declined since the Isahaya Bay Reclamation Work began. In addition, the diving method using heavy equipment became physically hard for them. They got interested in rafting oyster aquaculture, which is making a good profit with relatively less labor in various regions across Japan (Imai 1971). They thought that the environment of the Ariake Bay with the nutrition-rich and warm water might provide good conditions for high growth of oysters. Actually, the Ariake region once made a huge profit from oyster farming by transplanting method in 1910s before *nori* farming occupied the region (described above).

Figure 13. Hanging oyster aquaculture in Ooura district of Saga Prefecture. The raft made of timber supports about 1,000 ropes and each rope holds 13 clusters of Pacific oyster. Photo taken in 2009 by Y. Furukawa, a scientist of Ariake Fisheries Experimental Station.

Hearing the fishermen's intention, the Ariake Fisheries Experimental Station planned and supervised a one-year experimental aquaculture program in 2001 with a collaborator Mr. Minematsu, a leader of the fisherman group. They adopted hanging culture method where oysters are suspended off the bottom from a raft. This method has led to a rapid increase in production in the Japanese oyster industry since it was first initiated in 1920s, having the advantages of 1) improved growth rate, since oysters are submerged and able to feed throughout the tidal cycle, 2) reduced mortality, for bottom-crawling predators cannot reach suspended oysters, and 3) flexibility and expansion in the use of growing areas, for the nature of the bottom does not matter (Matthiessen 2001). They also selected the Pacific oyster *Crassostrea gigas* as the cultured species. This species is grown across

Japan because of its high growth rate and tolerance of a wide range of water temperature, salinity, and pathogens (Imai 1971).

The yield from the experiment was quite profitable. The experiment produced 8.4 tons of oysters from three rafts, which produced an estimated yield of ¥4,210,000. With the successful result, the Ariake Sea-area Fishery Adjustment Commission advised the Saga Governor to add a demarcated fishery right in the Ooura district for rafting oyster aquaculture in his fishery ground plan of 2003. Then, Ooura FCA applied for it so that FCA members including Mr. Minematsu can practice hanging aquaculture in the demarcation. The fishery right, Ariake District no. 2101, describes its validation as following: "Demarcated fishery right for rafting oyster aquaculture; applicant: Saga prefecture Ariake FCA Ooura branch; valid from September 1, 2003 to August 31, 2008; fishery period from January 1 to December 31; applied area: 400,000 square meters in the Ooura district."

In the beginning of the rafting aquaculture initiative, there were supports for the fisherman group in technical problems as well as administrative processes by several public agencies. First, Tara municipal government (that covers Ooura district) helped the group cut initial cost by providing timber to make rafts from thinning of municipally-owned forest. The Ariake Fisheries Experimental Station also helped Ooura FCA purchase natural-collected oyster spats from Miyagi prefecture that accounts for the majority of seed oysters distributed to oyster growers across Japan for its constant production (Imai 1971; Matthiessen 2001). The scientists from the Station have periodically visited the aquaculture site to estimate the yield and growth rate of oysters and to advise the fishermen how to deal with mortality issues during summer. They also helped fishermen calculate the benefit-cost ratio that is required in application for prefectural financial support as following.

The Fishery Department of the Saga Prefectural Government financially supported Minematsu's group. The Department funded the initial experiment of 2001 by purchasing the yields. They also shared one third of the costs of the following: 5.75 million ¥ for oyster rafts in 2004, 4.79 million ¥ for an oyster washer machine in 2005, and 1.88 million ¥ for ultraviolet sterilizers in 2007. The Department also invited an academic expert for a workshop they held in 2006 to solve a technical problem the group faced. The Distribution Department of Saga advertised the local oyster products to local supermarkets as well as to restaurants in Tokyo and other Asian cities. They also helped establish a local oyster brand "Takezaki Oyster" with additional value as a tourism attraction.

The Seikai National Fisheries Research Institute (SNFRI), one of several national fisheries research institutes run by the central government to improve Japan's fishery and aquaculture from scientific aspects, is another organization supporting oyster aquaculture from the technical aspect. When I visited the region in 2009, scientists from SNFRI were putting a set of scallop shells on shore, aiming to collect spats from local-growing oyster bar as an alternative source of oyster seeds. Because Miyagi seeds seemed less tolerant against high temperature during summer, perhaps because their origin is in the northern part of Japan, SNFRI were trying to find a method to constantly provide the farmers high quality seeds that suit the Ariake environment. In November 2011, they announced their success in the attempts (SNFRI in Japanese. http://www.fra.affrc.go.jp/pressrelease/pr23/231121/paper.pdf).

Chapter 4 Comparisons and Analysis

What lessons can be learned from the two oyster industries with very different backgrounds? In this chapter I compare the two regions from four perspectives: history and production, environmental issues, management practices, and cultural features. Although the two regions have very different histories, I found two common problems that might be instructive in coastal fishery management in general.

Comparisons

History and Production

Rises and falls of the oyster industry in the Maryland part of Chesapeake Bay and the Saga part of Ariake Sea seem somewhat similar (Figure 3 and 6). In the past, both regions had the largest oyster production respectively in the United States and Japan and the industry played important roles in society. In the Chesapeake Bay region, production of eastern oysters peaked in the late 1800s with 15 million bushels in Maryland (Kennedy and Breisch 1983). Oystering and ancillary industries provided employment opportunities to Maryland residents as well as emerging populations of immigrants. Packed oysters were exported to other areas in the US by ships and along railways, canals, and roads and brought an enormous profit. In the Ariake region, Suminoe oyster production peaked in the 1900s at 18,000 tons (Saga Fishery Adjustment Committee 1998). The fisher families developed oyster communities where entire processes - from collecting natural seeds to selling shucked production – were done. The oyster production was sufficient to be shipped to other countries in Asia as well as other part of Japan.

An important difference between the two industries seems to be fishing methods. Most of the oyster production in Maryland's Chesapeake Bay is harvested from public oyster beds by tonging, dredging, and sometimes diving. On the other hand, fishers in the Ariake region historically collected oyster seeds on bamboo sticks and planted them offshore for faster growth, then exclusively harvested as oysters reached market size. Also, in the present, a group of fishermen in the Ariake region is trying to establish hanging oyster aquaculture that brings efficient production. The difference in methods - harvesting wild animals in Maryland and farming naturally collected spats in the Ariake region – leads to further differences in management practice as well as cultural features as described later in this section.

The oyster production in the two regions has drastically decreased up to now, to the point that oyster production is no longer a main resource for the local economy. Production in the Chesapeake region has declined for over a hundred years due to overharvesting, degraded water quality, sedimentation, prevalence of oyster diseases, and low oyster recruitment (Kennedy and Breisch 1983; Rothschild et al. 1994). On the other hand, the historical Ariake oyster industry suddenly vanished due to a flood event accompanied with pesticide pollution from agricultural lands as well as government-initiated construction in preparing *nori*-farming grounds (Saga Fishery Adjustment Committee 1998). However, with the diminished yields, oyster species in the two regions are still drawing political attention as keystone organisms to improve the degraded aquatic environments as well as a possible economic driver.

Environmental Issues

Both Chesapeake Bay and Ariake Sea have physical features that are typically seen in temperate estuaries. Continuous nutrient loads from tributaries, the semi-closed shape of the basin, and shallow water that allows penetration of sunlight maintain high productivity as well as protective environments for aquatic organisms. Tidal exchange produces a changing influence of fresh and oceanic water, resulting in a complex environment with variable salinity and temperature. The two regions have historically maintained productive fishery grounds for various shellfish and finfish species.

Ariake Sea has a more diverse environment than Chesapeake Bay in terms of water depth. Due to the steep slope, Ariake Sea has a depth range from tidal flats in the inner bay to pelagic environment in the bay mouth where the depth reaches 165 m. Chesapeake Bay has shallow water in average with a gentle slope, which is typically seen in estuaries in the North American continent. This difference affects native oyster species and their distributions in each estuary. Oyster bars in Chesapeake Bay consist only of eastern oyster *Crassostrea virginica* whose environmental tolerance allows them to distribute in the bay widely. On the other hand, Ariake Sea has at least three oyster species depending on the salinity and depth; Pacific oyster *Crassostrea gigas* (11-33 salinity), Suminoe oyster *Crassostrea ariakensis* (9-30), and Kumamoto oyster *Crassostrea shikamea* (7-30) (salinity ranges from Amemiya 1928[2]). Thus, oyster bars in the Ariake Sea sometimes consist of multiple species.

[2] The scientific names are corrected to follow updated classification.

The fertile and unique ecosystems in Chesapeake Bay and Ariake Sea are also vulnerable to human activities. The two estuaries have been utilized and impacted by humans in various ways as coastal communities grow. With large ports and shipping routes, Chesapeake Bay has been a center of industry that pollutes the bay with sewage containing chemicals. Excess nutrients and sedimentation from animal and agriculture farms from the upper bay area have been a big concern in Chesapeake Bay (Kemp et al. 2005). In the Ariake Sea, local and national governments have made a great effort in reclamation of tidal flats in order to extend agricultural and residential areas as well as to protect residents from typhoon-induced floods. A series of shore protection works has altered the bay's shape and water flow which has caused oxygen deficiency and harmful algal blooms during warmer months (Sasaki et al. 2005).

Management Practices

There are big differences in fishery management principals between Chesapeake Bay and Ariake Sea, probably because traditional fishing practices and cultural backgrounds in the two regions are very different. In Chesapeake Bay, watermen individually ride on boats and harvest oysters by tonging or dredging from public oyster beds throughout the bay. In Maryland, the Department of Natural Resource has regulated licensed commercial watermen on oyster catch by season, hours, oyster size, and amount caught per day. The purpose of fishery management has more focused on reducing efficiency of harvesting and less on maintaining oyster population.

On the other hand, most fishermen in Japan form local Fishermen's Cooperative Associations and work under certain rules set by the association. Coastal fishery management in Japan has been developed based on this tradition of fisher's self-induced rules. In competitive fishery grounds like Ariake Sea, the purpose of fishery management is to distribute fishery grounds in a fair and democratic way and avoid monopoly by the historical ruling families. The Fishery Adjustment Commission, whose principal members are representatives of local fishermen, assumes a vital role in the administrative process of issuing fishery rights. This system works well in conflict management among resource users but lacks a sense of conservation of the environment and living resource. Overall, management principals in the two regions seem very different but have a common problem - they are focused on mitigating conflicts and complaints from resource users but not on the resource itself.

Another difference in fishery management between Chesapeake Bay and Ariake Sea might be governments' role in aquaculture development. In the Maryland part of Chesapeake Bay, political leaders had historically inhibited expansion of oyster aquaculture by limiting acres for leasing and prohibiting non-Maryland residents and corporations from holding leases. This was an effort to appeal to the influential watermen who strongly opposed development of aquaculture because of being afraid of losing their "privilege" in harvesting oysters (Kennedy and Breisch 1983; Keiner 2009). Although several scientists recommended farming oysters in privately leased grounds as a solution for the intensive harvest (e.g., Brooks 1891), these political conflicts eventually delayed Maryland in development of oyster aquaculture for over a hundred years.

Contrarily, national and local governments in Japan have initiated development of various coastal aquacultures by providing fishing communities with technical and financial support. Fishery research institutes and universities are funded to improve and innovate aquaculture technology that sometimes leads the world. This is because aquaculture is a major industry of the nation that raises its food self-sufficiency and brings high-value exporting products. In the Ariake Sea region, the Saga prefectural government has supported *nori* farming because the seaweed is a highly profitable product in Japan - now the region earns ¥ 40,000,000,000 per year from *nori* farming (Sasaki 2005 b). Oyster hanging aquaculture is also supported by several fishery agencies as a new economic driver in the region.

Cultural Features

Despite the similar estuarine environment, communities surrounding the two bays seem to have different cultural features. First of all, fishermen's character in each area is quite different. The Chesapeake watermen value their independency. Working as freelancers, exploring the bay as they want, and hunting natural animals that bring a high profit – this life style seems to be what they are proud of and want to keep as heritage (Paolisso 2002). On the other hand, fishermen in Ariake Sea - and in Japan generally - value cooperation among community members and obligation for the rules and orders the local community regulates (Lim and Matsuda 1995). This difference reflects a difference in relationship between fishers and management agencies. While Chesapeake watermen often push back against management decisions DNR makes, hating to be controlled, Ariake fishermen are more obliging to fishery management agencies because the agencies are “insiders” of the fishery community. The fishermen even ask fishery agencies for assistant and advice with their scientific expertise.

As to fishery practice, the Ariake fishermen seem flexible in how they keep their livelihood; they relatively easily switch it if a new custom brings larger profit with efficiency. As seen in the history, some Ariake fishermen shifted from oyster farming to *nori* farming and other from capturing tairagi clams to hanging oysters. Chesapeake watermen seem more proud of and wedded to their established life style. They also regard aquaculture as completely different from fishing and as not their business as seen in their resistance against development of aquaculture. This difference may be partly due to the length of history of aquaculture in the two countries.

Another cultural difference is seen in water use. In Japan, the coastal waters have been primarily used for fishery and aquaculture. Thus, there are no complaints from shoreline residents for having aquaculture facilities in their view; rather, those facilities are considered a component of nostalgic scenery of fishing villages. In Chesapeake Bay, the watershed is used in various ways in addition to commercial fishery: boating, hunting birds, recreational fishing, and having vacation. Thus, shoreline property owners sometimes complain that the scenery is marred by fishery and aquaculture facilities as seen in the example of Marinetics.

Common Problems Observed

Failure of Integrative Management of Living Resources and the Environment

Comparisons of the oyster industries in the Maryland part of Chesapeake Bay and the Saga part of Ariake Sea reveal importance and difficulty of integrative management on living resources and the environment. Although the two estuaries were originally capable of producing huge oyster populations, the industries of the two regions have almost collapsed due to lack of a self-sustaining oyster population and a healthy environment. The history of the two regions shows that an imbalanced ecosystem is not able to produce the abundance of aquatic organisms that it originally could.

A coastal fishery depends on environmental capacity while it impacts the surrounding ecosystem in a tremendous way. Oysters are an obvious example; while they feed on phytoplankton whose density fluctuates depending on the environmental factors such as temperature, light penetration, nutrients, dissolved oxygen, pH, water quality, etc., a population of oysters also influences the ecosystem by filtering suspended materials, providing small organisms with nutritious pseudo-feces, and being a habitat for benthic communities. More or less, every aquatic species depends on and plays an indispensable role in the ecosystem. Thus, a living resource cannot be managed apart from the ecosystem - maintaining a healthy environment is vital to sustain coastal fisheries.

However, the history of the two regions I am describing shows that fishery management tends to focus on raising profit as well as conflict avoidance among resource users; the environment and even fished species often gain less recognition in fishery management.

For example, in the Ariake Sea, the Saga prefectural government cleared away oyster beds instead of trying to restore them after a historical flood killed a great number of oysters and oyster farming became no longer profitable. The government then prepared acres of flat grounds so that previous oyster farmers could shift to profitable *nori* farming. However, scientists and *nori* farmers now recognize that oyster bars play a vital role in the biological and physical cycles in the ecosystem, which also helps sustain *nori* farming. The management principal in the past handled only the immediate needs - human factors - and lacked an understanding of the need to maintain the healthy environment that sustains productivity.

An interesting point is that a failure of resource management happened not only because of lack of scientific insights. Rather, political pressures often hampers applying scientific advice in management practice. Because the two estuaries have been used for human activities in many ways and there are many stakes existing, fishery management has not been done in a scientifically ideal way. As described earlier, Maryland was one of the advanced oyster-producing states where scientists surveyed the oyster population, analyzed mechanisms of oyster recruitment, and warned about the decreasing oyster population over one hundred years ago (e.g., Brooks 1891). However, a suggested solution – farming oysters on leased bottom – has not been reflected in oyster management until very recently because of political pressures from fishermen as well as politicians who wanted to appeal to fishermen (Kennedy and Breisch 1983). This episode indicates that conflict between stakeholders is probably one of the largest obstacles in directing resource management.

The Isahaya Bay Reclamation Project in the Ariake region also revealed a conflict of interest that delayed an important decision and eventually degraded the environment irreversibly. Although fishermen and scientists in the Ariake region attempted to stop the project, it took 10 years until the court ordered the national government to discontinue the work and open floodgates. This delay happened because the reclamation project was supported by various stakeholders - the government who wanted to distribute money and create jobs by public work, residents who wanted to prevent flooding, and farmers who wanted to increase their agricultural land. After the work was completed, Ariake fishermen faced historically low yields in their main fishery – *nori* and shellfish farming.

In summary, a decline in oyster production due to the failure of resource management is observed in both regions. Integrative management on target species and the surrounding environment is necessary, but in reality it is less regarded and difficult to carry out because of various human factors. Such failure of environmental management may happen in any estuarine fishery because causative factors seem common – a productive but sensitive environment, lack of foresight in fishery management, intensive human activities in coastal waters, and political conflicts due to various stakeholdings.

Exclusiveness and Conservativeness of the Fishing Community

Another problem commonly observed is that the tradition or culture of the fishing community has sometimes hindered proper management. Although a fishery industry occasionally needs a drastic change in industrial structure as society changes, the exclusiveness and conservativeness of some fishing communities may slow the necessary change.

It is known that a fishing village forms a unique community based on shared interest that is particular in fishing - uncertainty in catch, weather, and sea conditions; dangerous labor; special skills; rituals; and other region-specific issues make fishers feel a sense of community (e.g., Acheson 1981). Observing the fishing communities in Chesapeake Bay and the Ariake Sea, I thought this is true. In the Ariake region, it is more obvious in a practical way - fishers formed a Fishermen's Cooperative Association to share facilities, cost, labor, market, fishing techniques, and protection from poaching. Also, the fishing practices have been passed on through generations among the shore-side families, which makes fishers feel as they are a part of heritage.

This shared sense, which also seems to be true of Chesapeake Bay watermen, sometimes makes the community tend to ignore suggestions from outsiders, probably because fishermen believe themselves to be experts of the sea. In Chesapeake Bay, Maryland watermen have opposed the scientific advice that they should shift to farming oysters in order to avoid the intensive harvest. This strong opposition based on fishermen's beliefs, experience, and specialized knowledge of the environment combined with political conflict, eventually delayed the important change in industrial structure over one hundred years. Even today, some Maryland fishermen assume that regulations that the Department of Natural Resources made based on scientific insights are totally wrong (Mike Naylor, Shellfish Program Assistant Director at Maryland DNR, personal communication).

In Japan, the exclusiveness of the fishing community is reinforced by management schemes. Although the systems of fishery right and fishery adjustment work well in conflict avoidance, the systems give a great advantage to local fishermen in water use. This may prevent newcomers from entering the fishing community and consequently cause a shrinking society. Conservativeness of Japanese fishing community makes a big change difficult – although Japanese society has changed greatly over 65 years, the Fishery Act of Japan has basically been unchanged since it was established after World War 2.

Nowadays resource management includes issues that require a broad outlook and cooperation beyond small communities. For example, to deal with oyster diseases widely spread in Chesapeake Bay, Maryland and Virginia should agree with consistent management policy because the issue needs management beyond jurisdiction; transplanting oyster seeds from an oyster bed to another tributary can spread disease further; introducing a non-native oyster to the Bay can cause ecosystem disruption. Also, the Isahaya Bay reclamation project brought national controversies about development of aquatic environment that includes environmental, social, and economic aspects. A fishing community should listen to and communicate with people from the surrounding society and sometimes needs liberal opinions to deal with more and more complicated issues in coastal water use today.

Chapter 5 Conclusions

Comparing the Maryland part of Chesapeake Bay and Saga part of Ariake Sea, I have uncovered common problems for which I believe the two regions have once failed in sustaining oyster fishery. I also believe that these problems, described in Chapter 4, can be instructive in any coastal fishery management because the problems seem attributed to common characters of estuaries in terms of the environment, water use, and the culture of fishing communities. Having these lessons, I offer the following suggestions that a coastal fishery management should include in order to achieve ecological and social sustainability.

- **Environmental management:** A healthy environment is a foundation for aquatic organisms to grow and reproduce. From the case studies, it is clear that a degraded environment is one of the primary reasons for the decline in oyster populations. In natural resource management in the United States, there is an emerging consensus of ecosystem-based management that management should reflect the relationships among all ecosystem components, including the environments in which target species live. I think that the concept is particularly applicable in an estuarine fishery where fishery production is highly dependent on environmental capacity while an aquatic species plays a vital role in the ecosystem.

- **Government-initiated aquaculture:** Rapid growth of aquaculture is inevitable to meet growing demand for seafood and coastal waters are primary fields for seawater culture. I assume that aquaculture is a kind of industry that requires government intervention because today's aquaculture includes many issues that can affect the public interest, such as exclusive use of the water column; water pollution with wastes, antibiotics and other chemicals; and ecosystem disruption with invasive species and genetically modified organisms. Also, those who are switching from a capture fishery to aquaculture would need financial and technical support. I think that national and local governments should initiate developing legal frameworks and supporting system to anticipate these matters.

- **Management scheme that suits cultural backgrounds:** Although there probably are common characters and tendencies among fishing communities, comparisons of the two oyster industries revealed that they have very different backgrounds in terms of fishing practice, management scheme, water use, character of fishers, and attitude to aquaculture. Understanding these cultural backgrounds is important when developing a particular management scheme in order to get good compliance. For example, the fishery adjustment system works well in Ariake Sea where fishermen's cooperative associations have played a vital role in conflict avoidance but may not work in Chesapeake Bay where fishermen work individually and value their independence.

- **Cooperation among science, industry, and politics:** To achieve the goals outlined above, close communication among science, industry, and politics will be vital because as seen in the two case studies, most management failures in the past were attributed to conflicts between stakeholders. The Oyster Recovery Partnership in Chesapeake Bay may be a leading example in today's natural resource management that requires broad insights from academic experts, resource users, and decision makers and putting them in practice.

Although I believe that the four factors above are all essential in a successful coastal fishery management, the last one is perhaps among the most important because comparisons of the two oyster industries revealed that good scientific, cultural, and political insights will not be reflected in a management practice if there is not a cooperative relationship among stakeholders. I assume that the last factor can not be naturally developed, while the other three can be because there are interested people – scientists can claim the importance of environmental management, politicians can claim the necessity of aquaculture development, and social scientists can claim the importance of understanding cultural backgrounds. However, there may be less interest in developing the fourth factor - unless people in each stakeholder group are aware of its importance, cooperation among them can not be achievable.

Interestingly, the oyster industries in the Maryland's Chesapeake Bay and Saga's Ariake Sea have currently been making a similar effort; while they are trying to enhance the wild oyster populations, they are also developing new aquaculture frameworks. It seems that the two industries with very different cultural backgrounds have long struggled in finding a way of consuming as well as conserving the natural resource and finally came to the same conclusions. I am optimistic about the management success in both regions at this time because managers are now aware of the importance of synthesizing each aspect in fishery management and have started developing a cooperative relationship among science, industry, and politics.

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