Marine Aquaculture Regulation in the United States: Environmental Policy and Management Issues

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ABSTRACT

The U.S. marine aquaculture industry is extremely young. While catfish and trout culture have existed for many decades, the cultivation of species in marine and coastal environments has only emerged within the last 30 yr. Only 15% of total domestic aquaculture production in 1991 consisted of marine species, with oysters representing 80% of marine aquaculture production. The U.S. marine aquaculture industry has not kept pace with the growth of the world industry. One major reason for this slow growth is the absence of a unified federal and state policy and regulatory framework for U.S. marine aquaculture. According to a 1983 study commission by the Joint Subcommittee on Aquaculture, as many as 11 federal agencies are directly involved in regulating aquaculture, and another 10 are indirectly involved. However, only a limited number of direct permitting and licensing requirements are imposed by federal agencies. Thirty-two state regulatory programs were examined and it was discovered that over 1,200 state laws were found to have some significant bearing on aquaculture operations. The majority of laws and regulations that specifically authorize, permit or control aquaculture are usually found at the state level. A review of the current literature suggests that neither the federal nor state regulatory situation has improved since 1983. An examination of South Carolina policy and regulatory actions was undertaken to assess the regulatory and institutional status of marine aquaculture. The state has adopted a strategic plan for aquaculture development, published an interim guidebook to aquaculture permitting, established a state aquaculture permit, and amended and passed legislation on specific industry needs. While South Carolina is viewed by many as having made significant strides in minimizing regulatory and institutional constraints, the growth of marine aquaculture in the state remains slow, and reflects the situation across the country. A number of strategies to remove the barriers marine aquaculture faces have been offered; however, without the development of an overall policy framework at the federal and state level, the potential of marine aquaculture to fulfill the country’s seafood needs will remain unrealized.

INTRODUCTION

Aquaculture in the United States has the potential to become a major growth industry in the 21st century. Global seafood demand is projected to increase 70% by the year 2025 (Joint Subcommittee on Aquaculture, JSA 1993). With harvests from captive fisheries stable or in decline, aquaculture would have to increase production by 700% to a total of 77 million metric tonnes annually to meet the projected demand (JSA 1993). If there is the same type of growth in aquaculture production over the next seven yr as there has been in the last seven, by the end of the 20th century aquaculture could be supplying upwards of 25% of all the seafood consumed in the United States (Harvey 1994).

The United States currently imports more than 60% of its fish and shellfish, representing a total of $9 billion annually (JSA 1993). Seafood products are the nation’s largest agricultural import, second overall to petroleum (JSA 1993). Each year, Americans consume more than $800 million of foreign-grown aquaculture products. Obviously, domestic aquaculture production has not grown at a rate necessary to offset the consumer demand for seafood.

Nevertheless, the development of the U.S. aquaculture industry is felt to be vital to the future of the nation because it promises to produce: (1) high quality seafood to replace that supplied through the harvests of wild stock in decline or at maximum sustainable yields; (2) products for export to help reduce the country’s foreign trade deficit; (3) stock enhancement of important commercial and recreational fisheries species; (4) economic development opportunities for rural and suburban communities; and (5) new employment opportunities for skilled workers (National Research Council, NRC 1992).

During 1990-1991, the U.S. aquaculture industry and
its supporting services accounted for 300,000 full-time jobs with a direct and indirect economic impact of $8 billion (ISA 1993). For every additional 5 million kg of domestic aquaculture production, 1,300 additional jobs could be created on the farms and in related industries (NRC 1992).

MARINE AQUACULTURE IN THE UNITED STATES

The U.S. marine aquaculture industry is extremely young. While catfish and trout culture have existed for many decades, the cultivation of marine species has emerged only over the last 30 yr. In 1991, total domestic aquaculture production was 398 x 10^6 kg with a value of $727 million; only 15% (47 x 10^6 kg at $119 million) was produced by the marine aquaculture industry (Sandifer 1994). Eighty percent of the nation’s marine aquaculture yield was represented by oyster production and 12% by salmon production. Forty-eight species made up the remaining 8% (NRC 1992). The U.S. marine aquaculture industry is relatively small, but it remains vital since most of the huge seafood deficit in fishery products comes from the importation of marine, not freshwater, seafood (Sandifer 1994). Marine aquaculture is now practiced in more than 80% of the states and territories of the United States. Nevertheless, cultivation of all marine species, except oysters, is in the early stages of commercial development in the United States, and most operations have yet to achieve economic stability (NBC 1992). It goes without saying that the U.S. marine aquaculture industry has not kept pace with the growth of the world industry during the East 25 yr (NBC 1992).

The future for marine aquaculture in the United States is much less certain than that of its freshwater counterpart. One serious problem is that most marine aquaculture is conducted in shallow coastal and estuarine waters, which are affected by increasing population pressures and industrial and residential pollution and development. By the year 2010, 70% of the total population of the United States will live within 120 km of the coast (Culliton et al. 1990). In addition, whereas the transition from fishing to aquaculture in freshwater systems is analogous to that of hunting to farming, marine aquaculturists face an additional hurdle: the fact that they have no property interest in the “lands” they need (Nixon 1994). Because the ocean has traditionally been viewed as a common property resource, there are also conflicts with other commercial and recreational users which may slow or prevent the development of marine aquaculture (Harvey 1994).

Growth of the domestic marine aquaculture industry is dependent upon the attainment of five basic requirements (DeVoe and Mount 1989):

1. High Water Quality Locations: The availability and maintenance of a high water quality environment is a primary need for aquaculture. The industry must be assured that current and future uses of the surrounding aquatic environment will not reduce the quality of the waters where the species are being cultured.

2. Access to the Aquaculture Site: In choosing sites, the industry must consider an array of environmental and operational factors. Marine aquaculture typically requires both an aquatic environment and an adjacent on-land base of operation. In choosing sites, the industry may have to obtain permission, rent, lease or purchase outright the adjacent land to assure access to the site.

3. Assertion of Exclusive Fishing and Culturing Bights: Laws in most states provide the public with the right to use state waters for navigation, recreation and fishing. However, various methods of aquaculture used now and proposed for the future may require exclusive use of coastal or ocean waters. Such exclusive use could consequently deny to some degree the use of the area by traditional users.

4. Financial Investment: Establishment of aquaculture operations may require a significant financial commitment; however, aquaculture as an industry is viewed by investors as a high risk activity for many reasons. The availability of funding through venture capital, public and private sector loans, or other sources will depend on a large extent on the anticipated stability of and the level of property rights to be vested with the proposed operation.

5. Government Commitment: In the case of marine aquaculture, this requirement may be the most critical. Government must demonstrate its support by clearly defining the term aquaculture, providing supporting policy statements, offering incentives (which do not necessarily have to be solely financial) to underscore its commitment, and defining and streamlining its regulatory and legal requirements.

Further complicating the future of marine aquaculture is the complexity that stems from unique factors that distinguish it from other forms of agricultural activity, including: (1) the interaction of marine aquaculture with other marine and coastal activities and interests—interactions that are often characterized by conflict; (2) the fact that marine aquaculture is ocean-based, it depends on the use of land and freshwater resources as well; and (3) the numerous environmental and regulatory considerations involved in the development and use of coastal zone land and water resources, usually held in the public trust (NRC 1992).

The purpose of this paper is to review the key institutional and regulatory issues related to marine aquaculture development in the United States, critically examine these issues in more detail through a case study analysis of the situation in the state of South Carolina, and to explore possible remedies that may alleviate constraints on and provide for a more orderly development of the marine aquaculture industry.
REGULATION OF THE MARINE AQUACULTURE INDUSTRY

CHARACTERISTICS OF THE INDUSTRY

To understand the problems that confront U.S. marine aquaculture, the basic nature of the industry must first be reviewed. Marine aquaculture represents a relatively new use of the nation’s coastal resources, and it must compete for access to those resources (Nixon 1994). Newcomers to the industry, as well as local authorities, suffer from a lack of experience, inappropriate advice on site selection, inadequate evaluation of market opportunities and product diversification, and a lack of understanding of marine aquaculture development in relation to other forms of competition (Chamberlain and Rosenthal 1995). Much of this confusion stems from its uniqueness and complexity.

Marine aquaculture requires a site of operation, including upland and water-based locations. Issues of land use and zoning, exclusive use of public lands and waters, and navigation and use conflicts must be addressed. Species cultured in a marine environment continue to raise concerns regarding the protection of native wild stocks, importation and use of non-indigenous species, aquatic animal health, use of drugs and chemicals, and ownership of the cultured organisms. Additionally, the effects marine aquaculture may have on the aquatic environment must also be addressed.

Much has been published over the last 10 yr on the environmental impacts of marine aquaculture (see, e.g., Ackefors and Sodergren 1985, Weston 1986, Rosenthal et al. 1988, DeVoe 1992). However, ecological concerns had been raised by a number of authors a decade earlier (see Odum 1974, Ackefors and Rosen 1979). For instance, three major impacts were identified by Odum (1974): aquaculture as a pollution source, the introduction of exotics and physical alteration of the environment. The latter has not emerged as a critical issue, although these alterations could involve changes in circulation patterns within estuaries, increased sedimentation from poorly designed dredging and filling, interference with freshwater input to the estuary, destruction of productive land peripheral to the estuary, and permanent removal of productive estuarine areas (Odum 1974). One of the challenges to the marine aquaculture industry in the United States will be the success (or failure) of addressing environmental sustainability issues (Chamberlain and Rosenthal 1995).

COASTAL ZONE CONFLICTS

While cultists, scientists and resource managers face the task of resolving these issues through research studies, monitoring programs and technical assistance support, the marine aquaculture industry continues to deal with its “growing pains.” In a recent survey of state aquaculture coordinators, industry representatives and extension specialists, Sandifer (1994) found that only nine out of the country’s 24 coastal states and five territories reported moderate growth of marine aquaculture, while 12 reported very slow growth and eight no growth. Asked to identify the major factors responsible for this situation, the respondents indicated that of 12 limiting factors, the top three were use conflicts (92%), permitting (92%) and the regulatory environment (88%) (Sandifer 1994).

Regulations and permitting have often been identified as the principal impediment to the growth of marine aquaculture (McCoy 1989, JLSA 1989, Ziemann et al. 1990, Hopkins 1991, NRC 1992). But it is the underlying issues that underscore the problem. The NRC (1992) identified eight issues that have contributed to the current situation: (1) difficulties and costs of using coastal and ocean space; (2) public concerns about environmental effects of wastes on water quality; (3) conflicts with other users of the coastal zone; (4) increasing population with concomitant increases in pressures on coastal areas; (5) limited number of sites with suitable water quality; (6) objections from coastal property owners to marine aquaculture installations on aesthetic grounds; (7) broad ecological issues, including concerns about genetic dilution of wild stocks and transfer of diseases through the transport and escape of cultured animals; and (8) limited understanding of the biological criteria needed for the design of viable systems.

Use conflicts represent one of the primary issues marine aquaculturists in the United States must face and are likely to become more pronounced and frequent in the future (Chamberlain and Rosenthal 1995). DeVoe et al. (1992) found through a survey of the marine aquaculture industry and state regulatory agencies that the competing use of the coastal zone by recreational users, commercial fishermen and developers was frequently encountered. The escalating costs of acquiring access to coastal lands and waters in the country exacerbate the problem. While Japan continues to focus use of its coastal and marine resources on food production, the United States has not made this commitment. As a result, marine aquaculture’s place among the many uses of the coastal zone in this country is as yet undefined.

THE LEGAL AND REGULATORY STRUCTURE

The current regulatory environment for marine aquaculture in the United States is a major constraint to its development (NRC 1978, 1992; JSA 1993). No formal federal framework exists to govern the leasing and development of private commercial aquaculture activities in public waters (NRC 1992). For instance, because commercial aquaculture is in the early stages of development, regulators have tended to classify fish farming as an industrial activity requiring water treatment different from other
forms of agriculture (Ewart et al. 1995). These factors, along with a general unfamiliarity with aquaculture production technologies, waste characteristics and their impact on different categories of receiving waters have precluded the development of uniform standards and policies based on technical data and environmental risk assessment (Ewart et al. 1995).

In a 1981 study commissioned by the U.S. JSA of the Federal Coordinating Council on Science Engineering and Technology, the Aspen Corporation examined the federal and state regulatory framework for aquaculture (Aspen Corp. 1981). As many as 11 federal agencies are directly involved in regulating aquaculture and another 10 are indirectly involved. However, only a limited number of permitting and licensing requirements are directly imposed by federal agencies. More characteristic are federal agency programs that indirectly regulate fish farmers (e.g., restrictions on drug use, federal laws administered by states, etc.).

Some 50 federal statutes (with accompanying regulations) were found to have a direct impact on the aquaculture industry, although the actual number of statutes that affect an individual operation will vary depending on its size, site location, the species being cultured and other factors. In total, over 120 statutory programs of the federal government were found to significantly affect aquaculture development. Slightly one-half require a direct compliance response from the fish farmer.

The majority of laws and regulations that specifically authorize, permit or control aquaculture are usually found at the state level. The study examined 32 state regulatory programs and discovered that over 1,200 state laws have some significant bearing on aquaculture operations. Policies and regulations were found to affect aquaculture in eight major areas: aquaculture species use; water quality; water use; land use; facility and hatchery management; processing; financial assistance; and occupational safety and health.

The complexity that results from the involvement of many federal, state and local agencies responsible for all aspects (including advocacy, promotion, conduct and regulation) of marine aquaculture leads to an array of planning acts, policies and regulations (NRC 1992). Federal laws are applied differently in various geographic regions of the country (NRC 1978), and the industry remains concerned about the lack of coordination among agencies regulating aquaculture (JSA 1993). Unfortunately, the federal government has yet to make any significant headway in reducing regulatory constraints (McCoy 1989).

Federal agencies which establish the “ground rules” that most state agencies must follow have adopted vague, confusing and poorly conceived regulations, or none at all (McCoy 1989). This translates into inconsistencies in the development and application of laws and regulations at the state level (deFur and Radar 1995). Few states have a comprehensive regulatory plan which satisfactorily balances economic development and environmental protection. As a result, regulations governing aquaculture are scattered throughout state statutes and do not necessarily fit aquaculture (Breaux 1992). Complicating matters is the fact that existing permit programs do not have provisions for determining the capacity of the coastal and estuarine system for aquaculture, land-based or in situ (deFur and Radar 1995).

Major aquaculture problems that arise from state laws and regulations are caused by the lack of uniformity of laws among the states, the sheer number of permits, licenses and certifications that must be obtained, and the difficulty in obtaining them (NRC 1978, 1992). Each state has its own unique legal, political and economic climate for aquaculture, and culturists must navigate the regulatory environment differently in each. Only a few states have developed the information management capability to present the applicant with a comprehensive list of all the legal requirements that must be met. State regulatory programs can be and usually more restrictive than federal guidelines and regulations dictate. The result is that state agencies vary greatly as to what standards they apply to aquaculture (McCoy 1989), and some still apply laws designed for other applications such as those for public fisheries management (NRC 1978, 1992).

Another limitation to the current regulatory regime for marine aquaculture in the United States is the lack of long-range and whole system planning (deFur and Radar 1995). Aquaculture policy appears to be made by granting permits on a case-by-case basis (Rubino and Wilson 1993), and the requirements are often determined using regulations and technical standards not originally developed or intended for aquaculture (Ewart et al., 1995). Each permit is considered individually by the issuing agency, usually with no provision for examining cumulative impacts (deFur and Radar 1995).

A final regulatory issue limiting marine aquaculture’s growth is the time and cost involved in obtaining permits and licenses. According to McCoy (1989), it may take some four yr or more to obtain the necessary permits for startup. A prospective aquaculture operation could be required to spend over $100,000 in legal and consultant fees to obtain permits (McCoy 1989). For instance, the first applicant for an NPDES (National Pollutant Discharge Elimination System) permit spent $150,000 for environmental assessments and legal fees relating to the processing of his permit (Zieman et al. 1990).

SOUTH CAROLINA: A CASE STUDY MARINE AQUACULTURE IN SOUTH CAROLINA

South Carolina is well suited for aquaculture development. Along the coast, the state’s 80,000 ha of estuarine
area, 30,000 ha of wetland impoundments and over 4000 km of tidal creeks are potentially available as production sites (JLSA 1989). Its coastal waters are of high quality; 79% are designated as suitable for shellfish harvesting (Knowles 1988). The mild climate makes the culture of warm-water species feasible.

The true emergence of aquaculture as a viable industry in South Carolina occurred in the early 1980s with commercial production of cultured species of penaeid shrimp (*Penaeus* spp.), catfish (*Ictalurus punctatus*) and crawfish (*Procambarus* spp.). Since that time, hard clam (*Mercenaria mercenaria*) and striped bass (*Morone saxatilis*) hybrid aquaculture have developed. The state’s Joint Legislative Subcommittee on Aquaculture (JSLA) (1989) identified spotted seatrout (*Cynoscion nebulosus*), redfish (or channel bass, *Sciaenops ocellata*), sturgeon (*Acipenser* spp.), blue crab (*Callinectes sapidus*), bay scallops (*Argopecten irradians*) and the American oyster (*Crassostrea virginica*) as prime marine aquaculture candidates.

Table 1 illustrates annual production (in kg) and ex-pond value (in $U.S.) of selected species by South Carolina commercial producers from 1989 to 1994.

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<tbody>
<tr>
<td>Catfish</td>
<td>15,331</td>
<td>101,650</td>
<td>132,857</td>
<td>54,567</td>
<td>136,078</td>
<td>183,433</td>
</tr>
<tr>
<td>Crawfish</td>
<td>21,545</td>
<td>18,144</td>
<td>18,144</td>
<td>19,278</td>
<td>13,608</td>
<td>11,340</td>
</tr>
<tr>
<td>Hybrid striped bass</td>
<td>N/A</td>
<td>259</td>
<td>5,080</td>
<td>22,680</td>
<td>4,672</td>
<td>11,340</td>
</tr>
<tr>
<td>Marine shrimp</td>
<td>12,424</td>
<td>33,371</td>
<td>26,281</td>
<td>38,038</td>
<td>49,895</td>
<td>45,359</td>
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<tr>
<td>Hard clams</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>DNA</td>
<td>DNA</td>
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<tr>
<th>Value of:</th>
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<tbody>
<tr>
<td>Catfish</td>
<td>236,000</td>
<td>2,569,000</td>
<td>1,788,000</td>
<td>796,000</td>
<td>2,100,000</td>
<td>3,154,000</td>
</tr>
<tr>
<td>Crawfish</td>
<td>589,000</td>
<td>400,000</td>
<td>600,000</td>
<td>595,000</td>
<td>645,000</td>
<td>525,000</td>
</tr>
<tr>
<td>Hybrid striped bass</td>
<td>N/A</td>
<td>18,810</td>
<td>336,000</td>
<td>1,125,000</td>
<td>252,400</td>
<td>662,000</td>
</tr>
<tr>
<td>Marine shrimp</td>
<td>753,600</td>
<td>1,839,300</td>
<td>1,419,500</td>
<td>1,928,800</td>
<td>2,300,000</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Hard clams</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>DNA</td>
<td>900,000</td>
</tr>
</tbody>
</table>

DNA = data not available

South Carolina has demonstrated its commitment to aquaculture development in a number of ways. The S.C. General Assembly stated in 1985 that “aquaculture has the potential for augmenting existing commercial and recreational fisheries and for producing other renewable resources, thereby assisting the state of South Carolina in meeting its food needs and contributing to the reduction of foreign seafood imports into South Carolina and the United States. It is, therefore, in the state’s interest, and it is the state’s policy, to encourage the development of aquaculture in South Carolina” (Title 2, Chapter 22, Amendments, S.C. Code of Laws).

In addition, a major financial contribution was made by the state to fund the construction and operation of the $4 million James M. Waddell, Jr. Mariculture Research and Development Center. The Center, which includes a 929 m² research building, a 242 m² maturation building, a 2,323 m² outdoor tank pad and 25 experimental ponds ranging in size from 0.13 ha to 2.5 ha serves as a major focal point for mariculture research and technology transfer programs in the state and region.

In the 10 yr since the state formalized its position in support of aquaculture, a number of efforts have been undertaken to enhance the growth of the industry. Nevertheless, aquaculture development, particularly in the marine and coastal regions of the state, continues to be limited by the complex regulatory structure, user conflicts and the frequent emergence of unanticipated issues. The regulatory structure and permitting process for marine aquaculture in South Carolina are briefly reviewed below to illustrate these issues.
REGULATION OF MARINE AQUACULTURE IN SOUTH CAROLINA

Marine aquaculture represents a fairly new use of the coastal resources in South Carolina. Its success is predicated on the use of a variety of natural resources. Local, state and federal regulatory agencies seek to allocate these natural resource needs through a permitting system. In theory, by incorporating both agency and public comment in the permitting process, the interests of the aquaculturist, other resource users and the general public can be considered in decision-making (JLSA 1989).

LOCAL LEVEL

As previously mentioned, many of the regulations that affect aquaculture are found at the state level. This is not to say that local, municipal and federal laws and policies are significant; however, towns, cities and counties have responsibilities to their citizens to provide orderly development and police power protection. However, most do not formally recognize aquaculture per se and, in many cases, have a difficult time determining where it falls within their master plans and zoning regulations. Indeed, some local governments consider aquaculture an agricultural activity, while others may classify it as a commercial or even industrial enterprise. Even after attempts to educate local governing boards and citizens, aquaculturists may still face major obstacles in some communities due to concerns about water quality, aesthetics and overall quality of life issues.

FEDERAL LEVEL

At the other end of the spectrum, seven federal agencies have regulatory programs that directly affect the marine aquaculture industry: the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the U.S. Food and Drug Administration, the U.S. Department of Agriculture, the U.S. National Marine Fisheries Service, and the U.S. Coast Guard (Table 2). Federal oversight of the marine aquaculture industry is fragmented; there is no overall federal framework to address aquaculture development in the coastal zone. Further, while recent evaluations of marine aquaculture suggest that offshore locations may represent a viable alternative (NRC 1992), no formal policies have been developed to manage aquaculture development in the U.S. Exclusive Economic Zone. As a result, existing federal policies vary from one agency to another (and may even differ among divisions within the same agency) and the permitting process can be time-consuming and quite confusing.

STATE LEVEL

The complexity of the permitting process in South Carolina for marine aquaculture lies in the diversity of agencies involved and their general lack of knowledge of the industry. Twelve agencies and divisions of state government are involved in the regulation of marine aquaculture, concerned with the use of state lands and navigable waters, protection of water quality and quantity, use of aquatic organisms, including exotic species, and other issues (Table 3). Prior to state government restructuring in 1993, the S.C. coastal Council and the S.C. Water Resources Commission were responsible for managing all state lands and waters in the public trust, and regulating the nature and location of water-dependent structures. The S.C. Department of Health and Environmental Control (S.C.DHEC) implements the provisions of the National Pollutant Discharge Elimination System and the Section 401 Water Quality Certification Program, as established by the U.S. Environmental Protection Agency under the Clean Water Act of 1977 and its amendments, and is also responsible for maintaining shellfish sanitation standards. The S.C. Wildlife and Marine Resources Department (now the S.C. Department of Natural Resources; see below) regulates the use of the state’s tidal mud flats and bottoms for the placement of aquaculture structures, and is responsible for all finfish and shellfish permits (for red drum, spotted seatrout, flounder, marine shrimp, hard clams and oysters), boat and equipment permits, and dealer/processor licenses. Other state agencies are involved as well (see Table 3).

Another factor that has added to the complexity of the state’s aquaculture regulatory process is the division of agency responsibilities over permitted activities in public waters. The state is divided into three permitting zones: Zone A represents the inland portion of the state excluding the eight coastal counties; Zone B represents areas within the eight coastal counties excluding the “critical area;” and Zone C represents the “critical area” (Fig. 1). The “critical area” is defined by the S.C. Coastal Management Act of 1977 to include all coastal waters, tidelands, beaches and primary oceanfront sand dunes seaward of a boundary line as determined by the state’s coastal zone management agency (Section 48-39-10 et seq., S.C. Code). Prior to 1994, the S.C. Water Resources Commission had sole responsibility for permitting in Zone A and the S.C. Coastal Council was solely responsible in Zone C. Proposed activities in Zone B required an applicant to obtain a permit from the S.C. Water Resources Commission and a certification from the S.C. Coastal Council that the activities were consistent with the policies of the state’s Coastal Zone Management Plan. If certification was denied, the permit could not be issued. Therefore, the location where an aquaculture operation was proposed dictated the regulatory process to be followed and the agencies to be involved.

In addition to the confusion concerning South Carolina’s permitting process, the costs in money and time to obtain requisite permits, licenses and certificates has constrained
<table>
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<th>Agency</th>
<th>Regulatory Responsibility</th>
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<tr>
<td>U.S. Army Corps of Engineers (COE):</td>
<td>*Section 10 Permit - required for any structure and work in or affecting navigable waters (Rivers and Harbors Act of 1899, 33 U.S.C.403)</td>
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<tr>
<td></td>
<td>*Section 404 Permit - required for the discharge of dredge or fill material into U.S. waters including wetlands (Clean Water Act, 33 U.S.C. 1344, Section 301). Before this permit can be issued, a certification from the responsible state agency is required stating that the proposed activity would not cause a violation of the state’s water quality standards.</td>
</tr>
<tr>
<td>U.S. Environmental Protection Agency (EPA):</td>
<td>*National Pollutant Discharge Elimination System (NPDES) prohibits the discharge of any pollutant from any “point source” into the waters of the U.S. without a permit from the state agency administering the Elimination Act within the state (S.C. Department of Health and Environmental Control, SCDHEC).</td>
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<td>*Use and Application of Pesticides - through the registration and establishment of tolerance levels. Approvals and possibly permits may be required from EPA and SCDHEC.</td>
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<td>*Commenting agency on COE permit applications.</td>
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<tr>
<td>U.S. Fish &amp; Wildlife Service (FWS):</td>
<td>*Fish and Wildlife Import and Export License - required for anyone who imports or exports animals or fish for the purposes of propagation or sale with a value of more than $25,000 a year.</td>
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<td>*Commenting agency on COE permit applications.</td>
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<tr>
<td>U.S. Food &amp; Drug Administration (FDA):</td>
<td>*Drug regulations - affect the use of chemicals as additives to feed as well as chemicals used for the treatment of disease and parasite infections. Separate approval for drug or chemical use for each species cultured is required.</td>
</tr>
<tr>
<td>U.S. Department of Agriculture (USDA):</td>
<td>*Vaccine regulations - approval of all vaccines used in an aquaculture operation must be obtained. Very few vaccines are registered for use in this manner, due to the time-consuming and costly process. Again, each vaccine must be separately certified for each species.</td>
</tr>
<tr>
<td>U.S. National Marine Fisheries Service (NMFS):</td>
<td>*Fisheries regulations - can affect the potential of marine aquaculture in the nation’s exclusive economic zone.</td>
</tr>
<tr>
<td></td>
<td>*Commenting agency on COE permit applications.</td>
</tr>
<tr>
<td>U.S. Coast Guard (USCG):</td>
<td>*Protection of Navigation - including the marking of any structure located in navigable waters of the United States.</td>
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Table 3. South Carolina natural resources agencies involved in regulating aquaculture development (prior to agency reorganization in 1994).

<table>
<thead>
<tr>
<th>Function</th>
<th>Agencies</th>
</tr>
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| **State lands and navigable waters:** | 1. S.C. coastal Council  
   - “Critical Area” Permit (Zone C)  
   - Coastal Zone Certification (Zone B)  
  2. S.C. Water Resources Commission  
   - Navigable Water Permit (Zone A)  
  3. S.C. Land Resources Conservation Commission  
   - Stormwater Management Permit  
| Protection of water resources: | 1. S.C. Dept. of Health & Environmental Control (Water Pollution Control)  
   - Construction Permit  
   - National Pollution Discharge Elimination System Permit  
   - Section 401 Water Quality Certification  
  2. S.C. Water Resources Commission  
   - Groundwater Use Permit  
| Use of aquatic organisms: | 1. S.C. Wildlife & Marine Resources Dept. (Marine Resources)  
   - Shellfish/Mariculture Permit  
   - Mariculture Finfish Permits  
   - Mariculture Shellfish Permits  
   - Shellfish Harvesting Permit  
   - Harvesting Equipment Permits  
   - Dealer/Processor Licenses  
  2. S.C. Wildlife & Marine Resources Dept. (Freshwater Fisheries & Wildlife)  
   - Gamefish Breeder’s License  
  3. S.C. Wildlife & Marine Resources Dept. (Executive Office)  
   - Importation of Exotic Species Permit  
   - Hybrid Striped Bass Aquaculture Certificate and Permits  
  4. S.C. Dept. of Health & Environmental Control (Water Pollution Control)  
   - Shellfish Sanitation Certificates and Permits  
| **Other:** | 1. S.C. Department of Archives and History  
   - Protection of Archeological Sites and Artifacts  
  2. State Attorney General’s Office  
   - Determination of Clear Title to “Private” Submerged Lands (e.g., coastal wetland impoundments)  
  3. S.C. Dept. of Agriculture  
   - Inspections of Processing Facilities to Ensure Compliance with Good Manufacturing Practices |

the industry as well. An applicant can spend over $2,800 in one-time application fees and $5,300 in additional fees and rents annually. If water quality monitoring, legal assistance and consultants are necessary, these costs can be 10 to 20 times more expensive (Table 4). Just as consuming is the time it can take for permit applications to be processed and agency decisions to be made.

The NPDES permitting process in South Carolina is a case in point. Administered by the SCDHEC, an NPDES permit is required from any “person discharging or proposing to discharge wastes into the waters of the state...” under the state’s Pollution Control Act (Act No. 1157, Chapter 1, Title 48, S.C. Code). The normal processing time for an NPDES permit is stated to be approximately two months; however, if a public hearing is necessary or the permit is adjudicated, the processing time could be extended (Fig. 2). Nevertheless, NPDES permitting for aquaculture facilities in South Carolina continues to be a source of contention between the SCDHEC and the aquaculture industry (DeVoe 1994). The S.C. Farm Bureau continues to identify it as one of its top policy concerns [and has each year since 1986 (DeVoe 1994, J. Whetstone, pers.].
Table 4. Terms and costs of permits for aquaculture in South Carolina.

<table>
<thead>
<tr>
<th>Permit Type</th>
<th>Term</th>
<th>Fee</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local permits</td>
<td>One time/annual</td>
<td>$200-500</td>
<td>Fees, licenses</td>
</tr>
<tr>
<td>Federal permits</td>
<td>One time</td>
<td>$100</td>
<td>Application fee</td>
</tr>
<tr>
<td>State permits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Navigable waters permit</td>
<td>One time</td>
<td>$500</td>
<td>Application fee</td>
</tr>
<tr>
<td>Critical area permit (in CZ)</td>
<td>One time</td>
<td>$200</td>
<td>Application fee</td>
</tr>
<tr>
<td>Section 401 certification</td>
<td>One time</td>
<td>$500</td>
<td></td>
</tr>
<tr>
<td>NPDES permit (discharge)</td>
<td>Annual</td>
<td>$400-2400</td>
<td></td>
</tr>
<tr>
<td>Stormwater management permit</td>
<td>One time</td>
<td>$≤$1000</td>
<td></td>
</tr>
<tr>
<td>Shellfish/mariculture permit</td>
<td>One time</td>
<td>$25</td>
<td>Application fee</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>$5/ac</td>
<td>Up to 500 acres</td>
</tr>
<tr>
<td>Shellfish harvesting license</td>
<td>Annual</td>
<td>$100</td>
<td>First year plus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$25</td>
<td>annually thereafter</td>
</tr>
<tr>
<td>Boat license</td>
<td>Annual</td>
<td>$20</td>
<td>Boats ≤18 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$25</td>
<td>Boats &gt;18 feet</td>
</tr>
<tr>
<td>Equipment license</td>
<td>Annual</td>
<td>$10</td>
<td>Each piece</td>
</tr>
<tr>
<td>Wholesale seafood dealer license</td>
<td>Annual</td>
<td>$50</td>
<td></td>
</tr>
<tr>
<td>Land and sell license</td>
<td>Annual</td>
<td>$25</td>
<td></td>
</tr>
<tr>
<td>Other costs:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water quality monitoring</td>
<td>Annual</td>
<td>$\text{varies}$</td>
<td>Required under</td>
</tr>
<tr>
<td>NPDES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legal fees</td>
<td>One time</td>
<td>$\text{varies}$</td>
<td>Hourly fee</td>
</tr>
<tr>
<td>Consultants</td>
<td>One time</td>
<td>$\text{varies}$</td>
<td>Hourly fee</td>
</tr>
</tbody>
</table>

Due to two primary issues: (1) the time it has actually taken SCDHEC to review and render decisions on NPDES permits for aquaculture has averaged four months or more; and (2) the annual fees for an NPDES permit have increased from a range of $200 to $800 in 1992 (depending on the discharge volume and number of "pipes"), to $400 to $1,600 or higher in 1995.

STATE RESPONSE TO ADDRESS MARINE AQUACULTURE REGULATORY ISSUES

Prior to 1985, when marine aquaculture was beginning to emerge, there were no state policies or programs in place to ease the burdens facing the industry. Since that time, several policy actions have been initiated by the General Assembly and state agencies to address the regulatory complexity, and limiting nature of the administrative and bureaucratic structure of the state. As noted above, the S.C. General Assembly did pass legislation in 1985 which for the first time acknowledged the existence and potential of the fledging aquaculture industry (Chapter 22, Title 2, S.C. Code). A Joint Legislative Committee on Aquaculture was formed to foster needed legislation through the S.C. General Assembly and an Interagency Advisory Staff Group was established to offer advice and information to the Joint Committee. Also called for was the development of a statewide aquaculture plan. Thus the process by which the state began to respond to the needs of the aquaculture industry was underway; the critical analysis presented below of these actions and their impact on the industry suggests to this author that the state of South Carolina, while being acknowledged as having made “significant progress in streamlining the regulatory and permitting constraints affecting aquaculture” (Breaux 1992), still has much to accomplish.

DEVELOPMENT OF AN AQUACULTURE PERMITTING GUIDEBOOK

The regulatory and permitting maze that faced prospective aquaculturists in South Carolina during the early 1980s was overbearing for three reasons. First, no regulatory framework existed for the aquaculture industry. Second, the permitting agencies did not understand the industry or the regulatory requirements necessary to balance the needs of the industry with other users. Third, there was no single, consolidated source of information available on the regulatory process. As a result, the industry had no guidance in
Area "A" - Permits issued by S. C. Budget & Control Board
Area "B" - Permits issued by S. C. Budget & Control Board, but must be certified by S. C. Coastal Council
Area "C" - Permits issued by S. C. Coastal Council
navigating the regulatory seas, and the agencies had no basis upon which to guide the industry through the process.

In 1983, an ad hoc Committee on Aquaculture Permitting, consisting of state agency officials, extension specialists and industry representatives, was convened to address these issues. It took the committee almost two yr to unravel the permitting process for aquaculture and, in late 1984, an Interim Guide to Aquaculture Permitting in South Carolina was published (DeVoe and Whetstone 1984). The purpose of the guide, which has been updated twice, is to provide prospective applicants assistance in meeting regulatory requirements. More than 300 copies of the guide have been distributed upon request and has served as a model for guidebooks developed by several other states.

However, there are several limitations to the utility of such a publication. In South Carolina’s case, the guide was published for use by the aquaculture community only until a formal state permitting mechanism was established; this has yet to occur. Another problem relates to the regulatory and permitting environment itself—it is in a dynamic state of evolution. Laws and regulations continue to be passed and amended. As a result, the guide is in continuous need of revision. This can be a costly process, and a decision as to who pays must also be made.

DESIGNATION OF AQUACULTURE AS AGRICULTURE

The S.C. General Assembly passed legislation in 1986 which declared that the terms “agriculture, agricultural purposes, agricultural uses, farm crops, cultivated crops or words of similar impact shall include...aquaculture” (Sec. 46-140, 1976 Code). The aquaculture industry in South Carolina, as well as throughout the United States, strongly supports this designation as it gives state departments of agriculture more of a role over private aquacultural activities. Since 1986, aquaculturists have benefitted from a number of USDA and state agriculture department programs, including numerous sales tax exemptions, access to farm loan programs and additional technical assistance provided through the Agricultural Stabilization and Conservation Service and other USDA agencies.

However, it appears that many in the aquaculture industry are looking to the federal and state departments of agriculture as “shields” from excessive environmental regulation. As long as aquacultural practices involve the use of public resources (tidelands, waters, wetlands, etc.), the industry will most likely continue to be subject to the laws and regulations of federal and state agencies that seek to protect these public resources.

CREATION OF AN AQUACULTURE PERMIT ASSISTANCE OFFICE

The S.C. General Assembly emphasized the importance of providing permitting assistance to the aquaculture industry through the creation, in 1988, of the Aquaculture Permit Assistance Office (Title 46, Chapter 51, S.C. Code). This legislation established the position of Permit Facilitator within the S.C. Department of Agriculture to assist culturists in: (1) obtaining permits; (2) obtaining technical assistance from state, private, and academic institutions; (3) understanding new changes in state or federal regulations that may affect the outcome of a permit application; and (4) obtaining application forms.

In addition, the legislation required that the executive directors of all state agencies involved in regulating aquaculture convene to develop a single application form which “must be used by all the permitting agencies” (Title 46, Chapter 51, S.C. Code). It requires the agencies to refer any individual seeking permits for aquaculture to the Aquaculture Permit Assistance Office to complete an application and provide all information required by the permitting agencies to process the application and render a decision.

The creation of the Aquaculture Permit Assistance Office has greatly enhanced the ability of small-scale culturists to traverse the regulatory process. The permit facilitator has essentially eliminated the time it had taken for culturists to identify the process to be followed and the agencies with jurisdiction. While the application process has been streamlined, the fact remains that a myriad of permits, certifications and licenses are still required. Improving the “front end” of the process has not affected the time, cost and complexity of the regulatory structure for aquaculture. In addition, the permit facilitator has no direct permitting authority, so while (s)he can assist the culturist administratively, (s)he cannot affect permitting decisions. Finally, the time savings that accrue to prospective culturists are solely front-end; once the application is received by the permit facilitator and sent for processing, it follows the normal permitting timetable regularly used by the agencies.

PLANNING FOR AQUACULTURE DEVELOPMENT

The S.C. General Assembly, in creating the Joint Legislative Committee on Aquaculture, required its staff to prepare and periodically update a state aquaculture development plan to include an assessment of resources, opportunities and constraints to foster interagency and institutional cooperation in the development of aquaculture (Title 2, Chapter 22. S.C. Code). The Strategic Plan for Aquaculture Development in South Carolina (1989) was prepared to: (1) identify existing private and public sector aquaculture activities in South Carolina; (2) outline a development program for commercial aquaculture and its required public sector assistance; and (3) identify factors limiting aquaculture development in South Carolina.
formulate a plan to remove constraints and stimulate commercial development.

The strategic plan identified five major factors that require attention (regulatory constraints, environmental concerns, financial needs, marketing restrictions, and knowledge and information) and offered 41 recommendations to enhance aquaculture’s development. It represented the first major comprehensive evaluation of the aquaculture industry performed in the state. The plan also identified specific action steps needed to address the recommendations and assigned responsibilities for carrying them out.

As with any plan, implementation is the key. While specific action items and strategies for implementation were included in the plan, no incentives (or disincentives) were offered to ensure the recommendations were addressed. The Joint Legislative Committee on Aquaculture and its Interagency Advisory Staff rarely called for up dates on the status of implementation, and the joint committee itself was dissolved as part of state government reorganization in 1993. So while the aquaculture industry continues to call for plan implementation, it is having more difficulty effecting necessary changes in law and regulations. As a result, only 17 of the 41 recommendations have been addressed in the six yr since the plan was adopted by the S.C. General Assembly.

SOUTH CAROLINA STATE GOVERNMENT REORGANIZATION

Throughout its history, South Carolina has had a strong legislative form of government. Each of the state’s 127 agencies reported directly to their respective standing committees in the Senate and House of Representatives, which controlled their programmatic activities and budgets, while the role of the Governor’s office had essentially been advisory in nature. By the early 1990s, however, this system was challenged as one that represented “run-away” government, with no centralized authority being held accountable for agency actions and spending.

In 1993, the S.C. General Assembly passed sweeping state government restructuring and reform legislation. Seventy-five of the state’s 127 agencies were consolidated into 17, 12 of which were made part of the newly created Governor’s Cabinet. The nine natural resources-related agencies in existence prior to 1993 were combined into two: The S.C. Department of Natural Resources and the SCDHEC (Table 5).

Table 5. South Carolina state government reorganization of the natural resources agencies.

<table>
<thead>
<tr>
<th>Major department</th>
<th>Offices and departments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b. S.C. Land Resources Conservation Commission (NR)</td>
</tr>
<tr>
<td></td>
<td>c. S.C. Water Resources Commission (NR)</td>
</tr>
<tr>
<td></td>
<td>d. Migratory Waterfowl Commission</td>
</tr>
<tr>
<td></td>
<td>e. Geological Mapping (from Budget &amp; Control Board)</td>
</tr>
<tr>
<td></td>
<td>f. State Geologist</td>
</tr>
<tr>
<td></td>
<td>g. Natural Resources Police (law enforcement)</td>
</tr>
<tr>
<td>2. S.C. Dept. of Health &amp; Environmental Control</td>
<td>a. S.C. Dept. of Health &amp; Environmental Control</td>
</tr>
<tr>
<td></td>
<td>b. S.C. Land Resources Conservation Commission (R)</td>
</tr>
<tr>
<td></td>
<td>c. S.C. Water Resources Commission</td>
</tr>
<tr>
<td></td>
<td>d. S.C. Coastal Council (coastal zone management)</td>
</tr>
<tr>
<td></td>
<td>e. S.C. Mining Council</td>
</tr>
</tbody>
</table>

NR = non-regulatory; R = regulatory

One intention of the General Assembly was to ease the burden of the regulatory process on permit applicants by reducing the number of agencies with which they had to deal. Further, the state was seeking to achieve “one-stop” permitting; state government reorganization has provided a regulatory setting where this goal may soon be realized. But as the move toward centralization continues, several issues remain. While “one-stop” permitting may be desirable, it essentially internalizes the permitting process. All permits required prior to government reorganization must still be obtained by the culturist; however, agency decisions on each are now made internally. Opportunities to negotiate permit terms and stipulations are minimized as a result.

Another issue is emerging as well. While the SCDHEC is now the state’s primary natural resource regulatory agency, the S.C. Department of Natural Resources has retained all regulatory responsibilities over the state’s wildlife and fisheries and, in the case of aquaculture, the state’s public tidelands and coastal waters. There appears to be
Possible NPDES and No Discharge System Permit Processing Paths with Estimated Time Frames Shown

- **Public Notice of Intent to Issue or Deny**: 30 days
- **Significant Public Comment**: 10 to 15 days
- **Notice of Public Hearing**: 30 days
- **Hold Public Hearing**: 30 to 180 days
- **Issue Notice of Determination and Permit or Deny**: 30 to 180 days
- **Issue or Deny Permit**: 2 to 5 days
- **Deny Permit**:
  - **NO**: 10 to 15 Days No public hearing necessary
  - **YES**: Request for Adjudicatory Hearing received with 15 days of issuance
    - **NO** (hearing): Answer request within 10 days
    - **YES** (hearing) 30 to 90 days

- **Appeal to State Supreme Court – 2 to 3 Years More**
- **125 to 650 DAYS + 6 to 12 MONTHS appeal of Adjudicatory Hearing denial, or decision of Board after Adjudicatory Hearing**
- **125 to 280 DAYS Public Hearing, request for Adjudicatory Hearing denied, no appeal to Circuit Court**
- **225 to 650 DAYS Adjudicatory Hearing held, no appeal of the final decision of the Board**

- **Appeal to Circuit Court**
- **Court Dictates Hearing**
- **Pre-hearing negotiations may lead to resolution of differences**

- **Final Decision by Board to Issue or Deny**: 30 to 90 days
- **Hearing Officer’s Report to Board**: 30 to 190 days
- **Hold Adjudicatory Hearing**: 10 days
- **Public Notice of Adjudicatory Hearing**
an emerging friction between the two agencies over their respective roles regarding aquaculture development in the state. The legislated responsibilities of the S.C. Department of Agriculture’s Aquaculture Permit Assistance Office have come into question as well.

**CHANGES IN STATE LEGISLATION AND REGULATION**

Much of the marine aquaculture activity occurring in South Carolina would not now exist if the S.C. General Assembly had not passed new or amended existing laws. Overall, the state has responded when necessary to facilitate the development of marine aquaculture operations. For instance, the SC. General Assembly: (1) provided exemptions from seasonal and minimum size regulations to the hard clam aquaculture industry (1986 and 1989); (2) legalized the culture of hybrid striped bass in 1988, after very difficult negotiations that took place over a four Yr period; (3) declared that all fish, shellfish, crustaceans and plants grown in bonafide aquaculture operations remain the private property of the culturist until sold or traded (1989); (4) provided for significant penalties (including fines and imprisonment) for anyone convicted of causing damage to aquaculture facilities or stealing cultured fish and shellfish (1989); (5) developed an importation policy for the use of non-native penaeid shrimp species in culture operations (1990); and (6) is considering coastal zone regulations that allow for the use of the state’s waters and tidal bottoms for aquaculture near population centers (proposed for 1996).

In addition, the state’s aquaculture industry and agencies are working to develop a General Permit for qualified aquaculture operations under the National Pollutant Discharge Elimination System program and, together with the universities, are beginning to develop the criteria necessary to prepare best management practices (BMPs) for certain forms of marine aquaculture.

South Carolina has obviously demonstrated a willingness to deal with constraints to aquaculture development through legislative and regulatory reform, but it has done so in a reactive, crisis-management mode. This becomes extremely clear when examining the State Code Of Laws—statutes directly affecting aquaculture are spread throughout the Code Book. As a result, there is no overall state frameWork for aquaculture in South Carolina.

**THE FUTURE FOR MARINE AQUACULTURE IN THE UNITED STATES**

South Carolina is viewed by many as having made significant strides in minimizing regulatory and institutional constraints to marine aquaculture. Nevertheless, the situation in South Carolina is representative of the complexity of the issues that face many coastal states throughout the United States. Progress is occurring throughout the country, albeit at a fairly slow pace. The potential of marine aquaculture remains high as research information and technologies continue to be generated for cultivating a diversity of marine species, ameliorating the environmental effects of the industry and developing cost-effective sustainable culture techniques. Realization of that potential is being severely limited by the institutional and legal constraints presented above.

These issues are not new to the industry. Note the key conclusions of the NRC panels that, in 1978 and 1992, met to review the potential and growth of the U.S. aquaculture industry. In 1978, an NRC panel concluded that constraints on the development of the U.S. aquaculture industry “tend to be political and administrative, rather than scientific and technological” (NRC 1978). Fourteen years later, the NRC stated that “solutions to the environmental problems constraining marine aquaculture will involve approaches that combine technological ‘fixes’ with improved regulatory and management structures, as well as public education...” (NRC 1992). It is certainly unfortunate that while these issues were fully explored in the late 1970s, many still remained in 1992 and do so today.

A number of proposals have been offered over the last four yr to remove these constraints and move the industry forward. The NRC (1992) suggested that, among other things, the U.S. Congress should: (1) designate marine aquaculture as a recognized use of the coastal zone; (2) create a legal framework to address constraints; (3) modify federal regulations that now limit development of marine aquaculture, and (4) create a congressional committee on aquaculture; and (5) explore opportunities offered byshore and offshore aquaculture.

At the state level, Rubino and Wilson (1993) recommended that: (1) aquaculture be defined as agriculture in law; (2) a lead agency be identified in each state to coordinate regulatory programs; (3) the permitting process be streamlined; (4) conflict resolution measures be adopted; (5) aquaculture be included in government planning; (6) regulations be formulated in consultation with the industry; (7) adoption of best management plans be encouraged; and (8) research, education and extension efforts be supported and expanded.

The key, however, to the future of marine aquaculture in the United States is the creation of technological and political systems that will provide for sustainable marine aquaculture. Sustainable aquaculture will only be achieved if all facets of the industry-production and technology, economics and marketing, business and financing, natural resource needs and protections, and administrative and legal institutions—are de& with simultaneously. This is a lofty goal, as the difficulty lies in the details of how exactly to attain it, as those details differ with different modes of aquaculture (Bardach 1995). Nevertheless, education and communication will be the primary tools required to
move toward a viable and sustainable marine aquaculture industry in the United States.

LITERATURE CITED


Harvey, D.J. 1994. Outlook for U.S. aquaculture. Agricul-


Effects of Fish Farming on Macroinvertebrates: Comparison of Three Localities Suffering from Hypoxia

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Nansei, Mie 516-01, Japan

ABSTRACT
To clarify the effects of fish farming on macrofauna, quantitative samples of the macrofauna and sediments were obtained from Gokasho Bay in the spring and summer, and were compared with samples from Osaka Bay and Omura Bay. These three localities suffer from environmental hypoxia as a result of fish farming (Gokasho Bay), sewage and industrial effluent (Osaka Bay), and enclosed topography (Omura Bay). In these localities, density and biomass increases correspond to oxygen recovery in autumn. In Gokasho and Osaka bays, near-azoic conditions were observed in the summer when anaerobic conditions prevailed, but in the winter and spring high population densities (14,700-16,000 ind/m²) were encountered. These high densities are primarily due to the occurrence of an overwhelmingly dominant species, i.e., the spionid polychaete Pseudopolydora paucibranchiata in Gokasho Bay (62.7% of the total number) and the capitellid polychaete Capitella sp. in Osaka Bay (73.7%). The large populations in these localities may be the result of the rich food source derived from gross organic enrichment, but in Omura Bay low organic input seems to restrain the abundance (1,920 ind/m²) even when oxygen levels recover. The dominance of P. paucibranchiata, which is a suspension- and selective-surface deposit feeder in Gokasho Bay, suggests a large amount of food at the water-sediment interface. This food material originates from the leftovers or feces of cultured fish. However, the dominance of the nonselective subsurface deposit feeder, Capitella sp., in Osaka Bay may reflect the accumulation of organic debris within the substratum. Thus, the two distinct dominant species indicate the different state of the bottom environments in Gokasho Bay and in Osaka Bay.

INTRODUCTION
As fish farming has developed since the beginning of the 1960s in Japanese coastal waters, there has been a steady rise in levels of water deoxygenation and the occurrence of noxious red tides, which often have caused mortalities of maricultured organisms. It is estimated that 80% of the feed discharges outside of the culture cages, in the form of leftovers (20%) and excretions of fish, i.e., feces (10%) and urine (50%) (Itoh 1994). These organic wastes induce qualitative and quantitative changes in the surrounding macrofauna (Brown et al. 1987, Ritz et al. 1989, Tsutsumi et al. 1991).

In Gokasho Bay, which has a lagoon style coastline with an area of 22.2 km² and a mean depth of 12.7 m (Fig. 1), fish farming has been carried out since the introduction of yellowtail culture in 1962. Thereafter, the culture of red sea bream was incorporated, and since then fish production has progressively increased. In this bay, fish farms are concentrated in a small inlet, where fish cages cover an area of 2.4 ha. In 1993 in this area, 7,800 mt of feed were used for culture and 1,360 mt of fish were produced. This active farming has also unfortunately caused serious problems, such as oxygen deficiencies in the water (Abo and Toda, in press) and blooms of noxious dinoflagellates (Honjo et al. 1991, Toda et al. 1994).

In order to clarify the effects of fish farming on the bottom environment, this study has examined the macrofauna from three localities with hypoxic waters: Gokasho Bay, where there is an abundance of fish farms; Osaka Bay, characterized by heavy sewage pollution; and Omura Bay, where the topography is that of an enclosed bay with restricted water exchange.

MATERIALS AND METHODS
A survey of the macrobenthos was conducted in Gokasho Bay (34°19'N, 136°40'E), the innermost part of Osaka Bay (34°39'N, 136°02' E), and Omura Bay (32°58'N, 129°53'E) (Fig. 1). In each locality, samples were collected on two occasions, i.e., in the deoxygenated season (August-September) and in the oxygen-recovery season (February-April) (Table 1). Sampling procedures were similar throughout the investigations. Two replicate samples were taken at each station with a 0.04-m² Ekman-Birge grab and a 1-mm mesh sieve. The collected animals were identified, the number of individuals of each species counted, and their wet weights determined after blotting.
Fig. 1. Omura Bay (A), the inner part of Osaka Bay (B), and Gokasho Bay (C, C'), showing sampling stations (filled circles), areas suffering from hypoxia (hatched area), and fish farms in an inlet of Gokasho Bay (C', stippled area).
Table 1. Surveys of the macrobenthos in three localities in Japan.

<table>
<thead>
<tr>
<th></th>
<th>Gokasho Bay</th>
<th>Osaka Bay</th>
<th>Omura Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of stations</td>
<td>2</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Reference</td>
<td>Yokoyama et al. 1996</td>
<td>Yokoyama 1986</td>
<td>Yokoyama 1995a, b</td>
</tr>
</tbody>
</table>

“The number of stations under the influence of hypoxic waters.

Table 2. Community parameters of the macrobenthos in three localities in Japan.

<table>
<thead>
<tr>
<th></th>
<th>Gokasho Bay</th>
<th>Osaka Bay</th>
<th>Omura Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (ind/m²)</td>
<td>14700</td>
<td>16000</td>
<td>1920</td>
</tr>
<tr>
<td>Biomass (gm/m²)</td>
<td>57.7</td>
<td>90.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Diversity indices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H'(bit)</td>
<td>2.5</td>
<td>1.4</td>
<td>3.1</td>
</tr>
<tr>
<td>H’max</td>
<td>0.7</td>
<td>-a</td>
<td>2.1</td>
</tr>
<tr>
<td>J’</td>
<td>0.45</td>
<td>0.36</td>
<td>0.72</td>
</tr>
<tr>
<td><strong>a</strong></td>
<td></td>
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</tbody>
</table>

CHARACTERISTICS OF MACROFAUNA IN THE THREE LOCALITIES

Gokasho Bay is divided into five ecological areas on the basis of species composition. Among them, the inlet area around the fish farms (see Fig. 1c') has distinct features in its species composition, community structure, and seasonal fluctuations (Yokoyama 1996). The characteristics of the community parameters (Table 2) and the dominant species (Table 3) in this area are compared with those from the other two localities suffering from environmental hypoxia.

The area around the fish farms in Gokasho Bay is characterized by large concentrations of the spionid polychaete *Pseudopolydora paucibranchiata* which comprised 62.7% of the total number of individuals in April 1993. This species also ranked first in biomass, but the ratio of occupancy was relatively low (21.1%) because of its small size. The dense population of *R. paucibranchiata* and the occurrence of many other species (a total of 67 species), including the polychaetes *Lumbrineris longifolia* and *Prionospio pulchra*, the amphipod *Protomima imitatrix*, and the bivalve *Theora fragilis*, enhanced the density (14,700 ind/m²) and the species richness (H’max, 5.7), showing the highest level in the three localities. In August 1993, however, the fauna was limited to a few individuals...
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Table 3. Dominant and subdominant species (three species ranked highest in density or in biomass) in three localities in Japan during the oxygen-recovery period.

<table>
<thead>
<tr>
<th>Species</th>
<th>Ind/m²-²</th>
<th>Percent²</th>
<th>Species</th>
<th>gm/m²-²</th>
<th>Percent²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudopolydora paucibranchiata</td>
<td>0210</td>
<td>62.7</td>
<td>Pseudopolydora paucibranchiata</td>
<td>12.2</td>
<td>21.1</td>
</tr>
<tr>
<td>Lumbrineris longifolia</td>
<td>950</td>
<td>6.5</td>
<td>Paraprionospio sp.</td>
<td>8.5</td>
<td>14.7</td>
</tr>
<tr>
<td>Prionospio pulchra</td>
<td>619</td>
<td>4.2</td>
<td>Theora fragilis</td>
<td>7.4</td>
<td>12.7</td>
</tr>
<tr>
<td>P. pulchra</td>
<td>1270</td>
<td>8.0</td>
<td>Nectoneanthes latipoda</td>
<td>2.3</td>
<td>25.8</td>
</tr>
<tr>
<td>Nebalia bipes</td>
<td>1110</td>
<td>7.0</td>
<td>Theora fragilis</td>
<td>1.6</td>
<td>19.0</td>
</tr>
<tr>
<td>Sigambra sp.</td>
<td>1'55</td>
<td>8.1</td>
<td>Ophidromus sp.</td>
<td>1.1</td>
<td>12.4</td>
</tr>
</tbody>
</table>

²Percentage in the total density and in the total biomass of the benthos.

Table 4. Environmental factors in three localities in Japan.

<table>
<thead>
<tr>
<th>Bottom water</th>
<th>Gokasho Bay</th>
<th>Osaka Bay</th>
<th>Omura Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen (mg/L⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb/Apr</td>
<td>4.6-5.1</td>
<td>4.3-4.6</td>
<td>4.9-5.4</td>
</tr>
<tr>
<td>Aug/Sep</td>
<td>0.8-1.7</td>
<td>1.3-1.5</td>
<td>1.0-1.3</td>
</tr>
<tr>
<td>Sediment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median diameter (μm)</td>
<td>2.6-7.1</td>
<td>4.9-5.1</td>
<td>5.4-5.9</td>
</tr>
<tr>
<td>Silt-clay fraction (%)</td>
<td>23.3-87.6</td>
<td>158.3-66.7</td>
<td>73-70</td>
</tr>
<tr>
<td>Ignition loss (%)</td>
<td>8.3-18.2</td>
<td>13.3-32.1</td>
<td>14.2-15.5</td>
</tr>
<tr>
<td>COD (mg/gm⁻¹ dry)</td>
<td>5.0-31.9</td>
<td>16.3-25.1</td>
<td>11.0-33.0</td>
</tr>
<tr>
<td>Total sulfide (mg/gm⁻¹ dry)</td>
<td>0.15-0.96</td>
<td>0.58-0.86</td>
<td>0.04-0.33</td>
</tr>
</tbody>
</table>

In the innermost part of Osaka Bay (delta mouth of the Yodo River), where a large amount of sewage and industrial effluent flows into the water from the densely populated Kyoto-Osaka area, near-azoic conditions prevail from early summer through autumn (Yokoyama et al. 1985, Yokoyama 1994). However, intense recruitment of the capitellid polychaete Capitella sp. during a short period in the winter causes high values in density and in biomass. In February 1985, Capitella sp. dominated the density (73.7% of the total number) and the biomass (8.11%) (Yokoyama 1986). Other species characteristic for this area include the polychaete P. pulchra and the crustacean Nebalia bipes, but their ratios of occupancy in the total density or biomass are low, usually less than 8% (Table 3).

Omura Bay, which is a vast, enclosed basin characterized by stagnant water and fine sediments, lacks an overwhelming species dominance, as is the case in the other two localities (Yokoyama 1995a, b). P. pulchra ranked first throughout the sampling period, but it had relatively low abundance percentages, i.e., 38.2% in spring and 30.9% in summer, which is the reason why there are high evenness values (J', 0.72-0.78; Table 2). In Omura Bay, a zoic condition is rarely found in summer, although the values in density and in biomass during the oxygen-recovery season were low (1,920 ind/m², 8.9 gm/m²) compared to the other two localities.

ENVIRONMENTAL FACTORS AFFECTING MACROFAUNA

Physical and chemical factors in the three localities are summarized in Table 4. A characteristic common to these localities is the deoxygenation of the bottom water in the...
summer period. However, it is impossible to determine the differences in the degree of deoxygenation between these localities from the present data. Anoxic conditions have frequently been observed in Gokasho Bay (Abo and Toda, in press), Osaka Bay (Tsuruho et al. 1980), and Omura Bay (Akagi and Hirayama 1991). Such deoxygenation must be a dominant factor in the declining density and biomass levels during the summer.

High values of COD (33.1 mg/g⁻¹) and total sulfide content (7.1 mg/g⁻¹) in the sediment in Osaka Bay indicate the extreme deterioration of the bottom environment. In Gokasho Bay, in spite of a large amount of organic wastes from the fish farms, values of IL loss and COD were not as high as in Osaka Bay. This is probably because of the moderate water movements, which are indicated by the relatively small value of the silt-clay fraction (58.3%). The enclosed topography of Omura Bay induces the deposition of fine particles in the main basin (median diameter, 7.5; silt-clay fraction, 93.7%). Such stagnant conditions cause oxygen deficiency in the overlying water, although eutrophication is not as advanced as it is in the other two localities.

In Omura Bay, oxygen was at saturation levels during the spring. In Gokasho and Osaka bays, however, low oxygen conditions remained after the summer, as shown by the low values of oxygen saturation: 6 1% in Gokasho Bay during the spring, 50.5% in Osaka Bay during the winter. The protracted occurrence of oxygen deficiency in Gokasho and Osaka bays suggests the continuous input of large quantities of organic matter.

Organic enrichment in Gokasho and Osaka bays may be favorable in providing a rich food source for macroinvertebrates, but it also deoxygenates the water and subsequently eliminates the benthos in the summer. Macroinvertebrates which have a physiological ability to withstand low oxygen tensions and high sulfide concentrations increase their populations rapidly by utilizing the accumulated organic resources even when oxygen levels do not recover sufficiently. Under these conditions, predators and competitors will be excluded by their low resistance to oxygen deficiency. P. paucibranchiata and Capitella sp. are good examples of organisms which can exploit nutrient sources in a harsh environment. Tamaki (1985) reported an extreme increase of a P. paucibranchiata population within a caged plot, established experimentally on a tidal flat. The environmental conditions around the fish farms in Gokasho Bay may resemble those of the caged plot in preventing predators and/or competitive organisms.

Finer particles of sediment contain a larger amount of organic matter. However, in general, this organic matter is accumulated over a long period and is highly decomposed, and it probably serves a limited role as a nutrient for macroinvertebrates. Although fine, enriched sediments are deposited on the bottom of Omura Bay, where large values of IL and COD were observed (Table 4), the poor food source seems to restrain the biomass even when oxygen levels recover.

COMPARISON OF THE DOMINANT SPECIES

Distinct dominant species exist in two localities, i.e., P. paucibranchiata in Gokasho Bay and Capitella sp. in Osaka Bay (Table 3), although the two localities have similar trends in their community structure and seasonal fluctuations. It is widely held that many pollution indicators have opportunistic life history characteristics such as small size, short generation times, large reproductive rates, and high mortality levels (Grassle and Grassle 1974, McCall 1977, Pearson and Rosenberg 1978). Such characteristics allow these species to quickly colonize denuded areas at any time of the year when the habitat is improving.

Table 5 summarizes the life history traits of the two dominant species. The Capitella species complex, which is known worldwide as an indicator of heavy pollution, is regarded as a typical opportunist because of its prolonged breeding season, high growth rate, brief maturation period, and high mortality levels after periods of high reproduction (Grassle and Grassle 1976). As for the Japanese species of Capitella, a similar pattern of life history has been reported (Tsutsumi and Kikuchi 1984, Tsutsumi 1987, Kikuchi 1991). A timetable for the development of P. paucibranchiata, which was described by Myohara (1980), indicates that this species is also an opportunist; it has a small adult size (5-10 mm in length) and reproduction begins about one month after oviposition. Blake and Woodwick (1975) suggested that P. paucibranchiata in California reproduces throughout the year. It is, therefore, possible that these two species are dominant in the unstable environment by virtue of their ability to reproduce rapidly at any time of the year.

The two dominant species exhibit dissimilar traits in development (Table 5). A mature female of P. paucibranchiata reproduces every week (iteroparous), and produces small eggs; larvae hatch from the egg capsule 3-4 days after oviposition at the 3-segment stage, then larvae spend a relatively long planktotrophic pelagic period (2-4 wk). Capitella sp. in Japan reproduces once during their lifetime (semelparous), and produces a smaller number of larger eggs and lecithotrophic (not feeding) larvae which have a brief pelagic period (<24 h) (Table 5). Such differences in development were discussed by Levin (1984). She suggested that P. paucibranchiata has an advantage over Capitella spp. in California in colonizing new habitats by enhanced dispersal mechanisms. She also suggested that Capitella spp. has an advantage in its ability to reduce its mortality levels during the short pelagic period and in its ability to exploit nutrient-rich habitats during
the adult stage of the life cycle. In Gokasho Bay, the azoic area created by oxygen deficiency is readily repopulated by *P. paucibranchiata* through dense settlement of available larvae, which hatch from the surrounding habitats.

Another difference between the two species is their distinctive feeding mode (Table 5). *P. paucibranchiata* makes tubes which project into the water, and feeds selectively on subsurface sediments containing decayed organic particles and associated microbes (Tenerore, 1975, Fauchald and Jamars, 1979, Tsutsumi et al. 1990). Such a difference in feeding mode seems to indicate the different state of the bottom environments between Gokasho Bay and Osaka Bay. Active fish farming has been carried out in an inlet of Gokasho Bay, where the input of fish feed is as high as 325 kg/m²-yr⁻¹ over an area of 2.4 ha. Itoh (1994) estimated that 80% of the food input is loaded into the environment and 30% discharges directly as organic particles in the form of leftovers and fish feces. It seems likely that suspended organic wastes are sent to the bottom layer and that these particles drift on or above the seabed depending on the degree of water movement. The dense population of *P. paucibranchiata* must be sustained by these organic wastes that serve as a possible food source at the water-sediment interface. At the innermost part of Osaka Bay, where the bottom currents are weak, a large amount of organic debris seals in the sediment. That organic matter apparently nourishes a large population of Capitella species. Such a difference in the form of organic matter may lead to the success of distinct dominant species in these two localities.

**SUMMARY AND CONCLUSIONS**

Community structure and seasonal fluctuations of the macrobenthos around the fish farms in Gokasho Bay are similar in some respects to those in Osaka Bay, which is polluted by sewage wastes, but are different from those in Omura Bay, which is characterized by an enclosed topography. High organic input from the fish farms in Gokasho Bay eliminates the macrofauna during the summer, but induces an overwhelming dominance by the suspension and surface deposit feeder *P. paucibranchiata* in the oxygen-recovery season. Environmental deterioration around the fish farms is obvious, but is not usually as severe as it is in Osaka Bay, where *Capitella* sp. dominates. Thus, we can monitor the bottom environments around the fish farms by examining the community structure, seasonal fluctuations, and species composition of the macrobenthos.

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