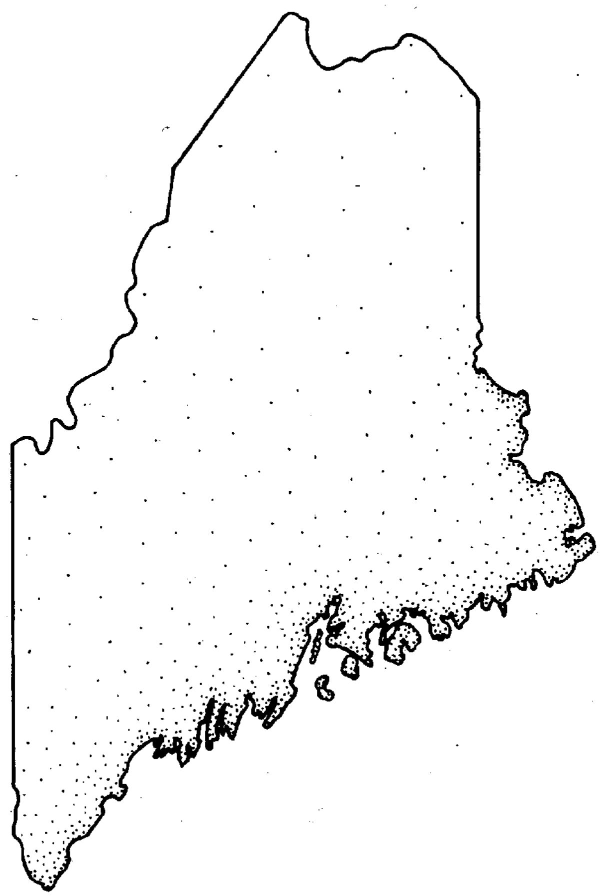
# Aquaculture Monitoring Program

Maine Department of Marine Resources





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# STATE OF MAINE

# AQUACULTURE MONITORING PROGRAM

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## INTRODUCTION

The recent rapid development of the fish farming industry in Maine, as well as in many other parts of the world, has lead to an interest in how this activity may affect the aquatic environment. This report identifies the types of regulatory programs that are being used throughout the world to manage salmon aquaculture, and the environmental monitoring programs that have been developed to ensure that fish farming does not have a significant effect on the environment.

### BACKGROUND ON AQUACULTURE INDUSTRY

Efforts to artificially raise salmon have been undertaken since the late 1800s when hatcheries were developed to increase salmon harvests. Hatcheries raised salmon from eggs and then released them to the wild for the adult phase of their life cycle. As these fish returned to spawn, some of the stock was harvested by the commercial fishing industry and recreational anglers. The remaining fish escaped harvest and spawned to continue the run.

The commercial culture of farmed salmon began in Puget Sound, Washington, in the early 1970s when researchers from the National Marine Fisheries Service (NMFS) and the University of Washington (UW) developed techniques for holding salmon smolts in net cages and feeding them until they reached a marketable size. Two private facilities began shortly thereafter to apply the techniques developed by NMFS and UW in the commercial culture of Pacific salmon.

Later, the Norwegian government saw salmon farming as a means of supplementing the supply of salmon available to its citizens. Factors such as overharvesting by the commercial fishing industry, hydroelectric development, and the effects of acid rain caused "wild" runs of Atlantic salmon to decline severely. Because many of the coastal areas depended on commercial fishing as a viable economic activity, the Norwegian government also saw salmon farming as a means of stimulating the economy of rural, coastal areas. Consequently, a major effort was directed at developing salmon farming as a feasible industry. The success of this effort has been well documented, and Norway is now considered the leader in the field of commercial salmon farming.

This success, combined with growing consumer demand within the United States for salmon, led to an increased interest in commercial salmon farms in the United States, including Maine, in the mid-1980s. There are presently 41 finfish leases, 43 shellfish leases, and 8 combination finfish and shellfish leases in Maine. Fish farming is still conducted at a relatively modest scale in Maine. Of the 41 leases for finfish, the 19 active fish farming sites in Maine produced an estimated 1,990,000 pounds in 1989. These sites have produced an estimated 1,900,000 pounds between January and June of 1990 (Churchill 1990, personal communication). For contrast, in 1989, there were 13 farms in Washington producing roughly 8 million pounds of fish per year.

## NEED FOR ORGANIZED APPROACH TO ENVIRONMENTAL MONITORING

Together with the increased interest in commercial farms, there have been numerous questions raised about the environmental effects from floating fish farms. While the industry itself is still evolving and research in this field is relatively recent, there have been four prominent reviews of the potential effects of floating fish farms: Weston (1986), Rosenthal et al (1988), Nature Conservancy Council (1989), and Parametrix (1989). These studies suggest that, in general, the environmental impacts of fish farming are known, although our knowledge is incomplete. The consensus of international opinion is that these effects are usually highly localized and limited in scope for all well-sited farms. To ensure that farms are sited in appropriate locations and that their effects on the environment are known, a system of permitting and monitoring fish farms is necessary.

## THE COAST OF MAINE

Physical parameters that are important to evaluate when siting aquaculture operations include: (1) current velocities, (2) depth, and (3) stratification of the water column. Although each farm should be evaluated on a case-by-case basis using site-specific conditions, this section discusses some of the parameters that should be considered.

The coast of Maine has an exceptionally complex current regime. The interaction of the world's strongest tides, upwelling, winds, and fresh-water runoffs that are large enough to be a significant factor on the local continental shelf, combined with a convoluted bathymetry make Maine's coastal environment one of the nation's most distinctive.

A detailed knowledge of the inshore currents is necessary to accurately assess the potential impact of aquaculture on the coastal marine environment. The coast of Maine has one of the most complex physical environments of the nation. The coastline is rugged with many estuaries having large river inputs. The nearshore coast is relatively shallow, with many areas having depths less than 20 m up to two-to-three miles offshore and the bathymetry less than 100 m is very uneven. The northern coast has many islands while the southern end of the state does not have any islands. Therefore, a concise classification of the inshore currents by geographic regions is a difficult task.

Maine is one of the few eastern states whose continental shelf is not exposed to the deep Atlantic. Its coast constitutes much of the western boundary of the Gulf of Maine. The Gulf is virtually an inland sea because the 40 m deep George's Bank to the east effectively isolates the Gulf from the Atlantic. Counterclockwise gyres have been identified over the major basins within the gulf. For example, the eastern Maine coastal current is part of the Jordan Basin gyre. Tidally-mixed waters from the mouth of the Bay of Fundy flow southward along the coast to recirculate over the Jordan Basin. A westward resultant drift exists along the coast west of Mt. Desert Island.

The range of the tide in Maine is unusually large. It varies between 3 m in the south to 6 m at the approaches to the St. Croix river in the north. Along the coast east of Portland the flood tide is much stronger than ebb. Tidal-current speeds generally decrease as one moves southward. This means that the average tidal current at Portland is about 10 cm/s, but can exceed 125 cm/s through the Grand Manan Channel (U.S. Coastal Pilot 1988).

Freshwater runoff is an important factor in the northern part of the Gulf. The spring freshet, which occurs in April or May, has a pronounced effect on salinity along the Maine coast. The freshwater inflow is sufficient to intensify the southward flowing current along the coast by adding to the baroclinic pressure gradient of the coastal limb of the Jordan Basin gyre. Fisherman refer to the intensification as the "Spring Current".

Later, during the summer, upwelling-favorable southwesterlies tend to prevail. In simple terms, the winds drive surface waters offshore and draw deep nutrient-rich waters inshore.

The upwelling circulation contributes to the formation of a temperature front (occasionally multiple fronts). Increasing solar heat flux helps to strengthen the front, as does freshwater runoff.

## TIDES AND CURRENTS

### Tides

Tidal driven currents are generally the greatest force that disperse wastes for fish farms. The tide along the Maine coast is a mixed, mainly semi-diurnal type. Direction of flow changes continuously in a clockwise rotation with very little slack water. The strength of tidal currents off the coast of Maine can vary considerably from site to site. In general, the tidal currents are greater in the northern parts of the state than in the southern parts due to the larger tidal range.

However, in areas with a moderate tidal range there can still be a large tidal current where small channels connect large embayments to the open Gulf of Maine. This strong tidal current is the effect of trying to move a large amount of water through a narrow opening. The tidal current through a channel connecting a basin with the open ocean is easy to approximately calculate. One multiplies the area of the basin by the range to obtain the volume of water that must pass through the channel. Dividing by the cross-sectional area of the channel then gives the average speed of the current over the flood or ebb portion of the tidal cycle.

Despite large speeds, there are two reasons why it is difficult to predict whether tidal currents will be effective in the dispersion of fish farm wastes. First, tidal flushing may not be as effective as the steady current of similar speed that sweeps away material. The second reason is related to the interaction of tides and bathymetry. The flow patterns that are set up within the bays and among the islands of central and northern Maine are extremely intricate. Because of bathymetric effects, deflection of the tide depends on the direction it is going; which in turn depends on the phase of the tide and the influence of any non-tidal currents. In addition, a pattern of small interconnecting gyres appears to be a normal consequence (Parker 1982).

### Non-tidal Currents

Non-tidal currents will vary by season. Winds are generally westerly, but often take on a northerly component in winter and a southerly component in summer. Strongest winds are generated by lows and cold fronts in fall and winter, and by fronts and thunderstorms during spring and summer. Extratropical cyclones can bring 30-foot waves and hurricane-force winds to the Gulf of Maine. Forty-or-so extratropical systems move across or close to the Gulf each year. There are an average of 2-to-4 such storms per month, and a maximum of 10 per month. The most intense storms happen September through April. River runoff is at a maximum in April or May every year.

Non-tidal mean currents of 2-to-6 cm/s have been estimated for Penobscot Bay (Humphreys and Pearce 1981). A value of 10 cm/s for the typical mean current was used by Parker (1982) in his work in the Casco Bay area. A mean current of order 10 cm/s probably represents a good general approximation, because the nearshore coastal current is about of this magnitude (Townsend et al. 1985). A gross estimate for the nonsheltered maximum wind driven currents to be used by mariners in coastal Maine (U.S. Coastal Pilot 1988) is 50 cm/s (1 knot).

## STRATIFICATION

Stratification can alter the potential impact of aquaculture because current shear can result and suppress vertical mixing of the water column. Seasonal evolution of the hydrographic structure is determined by tidal stirring, seasonal heating, river runoff, and wind forcing (including the creation of fronts by upwelling).

The impact of aquaculture on the levels of dissolved nitrogen in the surface layer will be most pronounced in the summer when stratification is the strongest. River runoff will be sufficient to help intensify stratification, but in many cases, will not be enough to cause a significant mean current. The bays in Maine are complex so that sheltering from wind and bathymetric steering of the tides will lead to some areas of weak currents. These areas will be especially sensitive to impacts.

There is little stratification during the winter, which means that materials deposited on the bottom can be stirred upward. In the present context this is very important because the bays of Maine typically are very shallow with many depressions that are often isolated from channels. These depressions could collect the deposition from aquaculture facilities. In the winter, tidal stirring and storm-induced flows could then generate strong enough flows to flush out the catchments.

The effectiveness of tide in vertical mixing can be described by what is termed the destratification depth. A certain amount of friction is generated when the tide moves water over the bottom. If the tidal current is swift, the amount of energy generated by friction can cause sufficient turbulent mixing to overcome the potential energy of stratification provided that the depth is not so great that the frictional energy is dissipated.

## AQUACULTURE REGULATIONS IN OTHER AREAS

The aquaculture industry world-wide has shown a dramatic increase in activity over the last 10 years. Governments have developed a wide range of techniques to manage the potential environmental effects of aquaculture. Some environmental programs were in place before the aquaculture industry existed, while other programs have been established specifically for aquaculture. The salmon aquaculture industry is in the relatively early stages of development and these regulations continue to change as more information becomes available. This chapter describes regulatory approaches used in four major salmon aquaculture areas: (1) Maine, (2) Washington, (3) British Columbia, and (4) Norway.

### MAINE

The State of Maine regulates fish farms through two primary mechanisms: (1) the Water Quality Certificate from the Department of Environmental Protection (DEP), and (2) the lease for the use of State aquatic lands for aquaculture from the Department of Marine Resources (DMR).

In addition to State requirements, fish farmers in Maine must also obtain a Section 10 permit from the U.S. Army Corps of Engineers (COE), and a National Pollution Discharge Elimination System permit (NPDES) from the Environmental Protection Agency (EPA). The Region I (New England) office of EPA is presently determining what will be required of fish farmers in Maine for the NPDES permit.

#### Water Quality Certificate

A water quality certificate is required by the Department of Environmental Protection to ensure that discharges to State waters do not have a significant adverse effect on water quality. Estuarine and marine waters in Maine have been classified into three categories (SA, SB, and SC) based on their existing quality (38 M.S.R.A. § 465-B). Included in this categorization are standards that define suitable uses for the water, acceptable levels of dissolved oxygen and bacteria, and acceptable levels of discharge to State waters. Presently, fish farms are prohibited in Class SA waters and allowed in waters classified as SB or SC.

To receive a lease from DMR, the DEP must certify that the farm will not have a significant adverse effect on water quality or violate the water quality standards of the receiving water. Farms that do not choose to seek a lease from DMR, are still required to obtain a Water Quality Certificate from DEP.

The certification process includes a number of criteria that the farmer must meet for issuance of the Water Quality Certificate. These criteria include:

- lease area is in SB and/or SC waters
- minimum current velocities midway between the bottom of the nets and the sea floor are 0.1 knots (5 cm/sec)
- anti-foulant agents are registered for use by the Pesticide Control Board
- fish feed is in pellet form
- dead fish and viscera are not disposed in State waters
- the facility can be inspected by DEP staff during working hours.

In addition to the criteria above, the farm must also maintain a minimum separation distance between the bottom of the nets and the sea floor. The DEP has developed the following formula based on Dr. Donald Weston's depth-current curves (SAIC 1986) to determine the minimum separation distance based on the annual production of the farm.

$$Zmin = 0.0003 (P) - 0.425 (V) + 31$$

where:

P = production capacity in pounds per year
V = mean current velocity in cm/sec at mid-point between the bottom of the nets and the sea floor (measured through one tidal cycle).

Regardless of the farm's annual production, the minimum distance required between the bottom of the nets and the sea floor is 10 ft and the maximum is 60 ft.

In addition to meeting the criteria discussed above, existing farms are completing semi-environmental monitoring of their farms in the spring and late summer. The types of data being collected in these monitoring plans is described in Chapter 4.

<u>Aquaculture Leases</u>

The Department of Marine Resources has an established process whereby aquaculture operations can lease State aquatic lands for their facilities (12 M.R.S.A § 6072). Leases are not presently required for the use of State aquatic lands for aquaculture, however, fish farmers benefit by obtaining a lease in gaining a vested interest in the site.

The regulations prescribing the procedures and substantive criteria governing the consideration of aquaculture leases contain five major elements:

- information supplied with the application
- notice of lease and public hearing
- site review
- procedures for the lease hearing
- decision by the Commissioner.

Information supplied with the application. Applicants for an aquaculture lease must supply a variety of information to DMR as part of the application process. Some of the information required includes:

- what species will be cultured at the site and the source of those organisms
- the environmental evaluation of the site that lead to the decision to seek a lease
- a description of the navigational uses at the site
- the degree of exclusive use required by the project
- a description of commercial and recreational fishing occurring at and near the site
- written permission from every riparian owner whose land will be used and a description of riparian owner's use of the lease site for access to riparian owned land
- the financial and technical capabilities of the applicant to successfully accomplish the proposed project.

The application is submitted to DMR with a non-refundable fee based upon the size of the proposed lease area.

Notice of lease and public hearing. The lease regulations also include provisions for notifying relevant state and federal agencies, riparian owners, and the general public of the lease application and upcoming public hearing. At least 30 days prior to the date of the hearing, DMR must mail a copy of the hearing notice, lease application, and a chart describing the lease area to the groups listed above. In addition, DMR must publish information about the proposed aquaculture operation and the lease hearing at least twice in a newspaper that serves the area affected by the lease. The lease regulations also include provisions for individuals or groups who wish to apply for intervenor status in the adjudicatory process.

Site review. Prior to the lease hearing, DMR undertakes an inspection of the lease site and nearby area. A variety of information is collected and documented in a Site Review report for submittal to the Hearing Officer. A further discussion of the types of information collected in this pre-lease site review is included in Chapter 4.

Lease hearing procedures. The aquaculture lease regulations also include procedures for conducting the lease hearing. These procedures include regulations for the presiding officer's authority, general conduct of the hearing, the nature of admissible evidence, and public participation in the hearing process.

Decision by the Commissioner. After the lease hearing is completed, the Hearing Officer prepares a report to the Commissioner which includes proposed findings of fact, conclusions of law, and recommendations. Within 120 days after the hearing, the Commissioner reviews the record and renders a written decision. In making a decision, the Commissioner considers a number of issues in relation to the statutory criteria. These issues include:

- riparian owner ingress/egress
- navigation
- commercial/recreational fishing
- other aquaculture uses
- ability of the marine area to accommodate aquaculture without adverse effects
- source of cultured organisms
- interference with public facilities.

The aquaculture lease regulations also require a 2,000 ft separation between farms unless, by mutual consent, both farms agree to have their leases closer than the 2,000 ft minimum.

Conditions that govern the use of the lease area and place limitations on the aquaculture operation can be included with the lease, and the Commissioner may require that environmental monitoring be conducted at the lease site. The types of monitoring that are presently being completed at fish farms is discussed in Chapter 4. The Commissioner conducts an annual review of each aquaculture lease and can revoke the lease if lease conditions, terms of the lease, or any applicable law has been violated.

<u>Section 10 permit</u>

Under Section 10 of the Rivers and Harbors Act of 1899, the Army Corps of Engineers (COE) requires fish farmers in Maine to apply for a permit to install and maintain floating fish pens. The Section 10 permit establishes a federal permitting process whereby public interests are considered. Factors that are considered include: fish and wildlife values, recreation, navigation, economics, aesthetics, and general environmental concerns. Through the Section 10 permitting process, the COE receives input from other relevant federal agencies such as the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USF&WS), and the U.S. Coast Guard (USCG).

Federal agencies have drafted guidelines for obtaining Section 10 permits. If a proposed farm is within the guidelines, then the application will be approved without a requirement for baseline or monitoring studies. Farms that do not meet the guidelines may still be approved. However, these applications will be conditioned to require the applicant to provide adequate information and assessments to assure federal agencies that the farm will not endanger the public interest. These farms would also be monitored to assess the environmental effects of their operation and the need for remedial action. The present draft guidelines (March 1990) include four primary elements:

- application and general information
- siting and operational guidelines
- environmental description and impact assessment
- monitoring

**Application and general information**. The application guidelines provide the applicant with the proper format for the application. Included in this section are guidelines for what has to be shown on the drawings, drawing scale, confirmation that the reporting requirements for incidental take of marine mammals have been met, and confirmation that adequate information is available to determine the use of the area by threatened and endangered species.

General information that should be supplied with the application include:

- estimated annual production
- estimate of employment opportunities created by the proposal
- any local and state approvals secured by the applicant
- a statement of technical ability in the field of aquaculture
- a description of the anchoring system and how individual components will be secured to prevent loss during accidental breakup
- confirmation that the farm will be marked and lighted in accordance with USCG regulations
- the amount and composition of fish wastes and how the wastes will be disposed
- how effluents from bathrooms, showers, sinks, and medication tanks will be disposed
- a detailed description of day-to-day operations
- information on any upland facilities associated with the floating farm
- the navigational use in the area
- a description of structures within 2,000 ft
- the present upland uses in the area

**Siting and operational guidelines**. If a proposal meets the following siting and operational requirements, no baseline or monitoring of the site will be required:

- No structure may extend into any area normally used for navigation, federal anchorage, or as a turning basin. Structures should not be closer to these navigational routes than 3 times the channel depth.

- Farms should have a minimum separation distance between the bottom of the net and the sea floor. The COE guidelines use a formula developed by DEP that is based on annual production and mean current velocity to establish the minimum distance requirements. The absolute minimum distance between the bottom of the nets and the sea floor at mean low tide is 10 ft, and the minimum separation distance increases with increasing water depth to a maximum separation of 60 ft.

- Minimum mean current velocities halfway between the bottom of the pens and the sea floor are 0.1 knots (5 cm/sec).

- Applicants must identify the source of their seed stock or juveniles, and must confirm that the fish or eggs they use will be from North American stocks from west of the

Continental Divide. In addition, applicants must confirm that only eggs from North American stocks will be used after 1995.

- Farms may not be located within ¼ mile of any area named in acts of Congress or Presidential proclamations as national parks, wilderness areas, recreational areas, lakeshores, natural landmarks, or wildlife refuges.

- Farms may not be located within ¼ mile of any area designated as high-use or critical habitat for any threatened or endangered species protected under federal or State law. If protected species are present in the area of the proposed farm, the applicant must document their location within a 1-mile radius of the site. The applicant must also provide a detailed analysis of the potential impacts of the project on these species and propose monitoring measures.

- Farms may not be sited near eelgrass beds, kelp beds, or other subtidal habitats that provide important nursery habitat for fish and shellfish.

- Farms may not be sited in areas supporting significant commercial or recreational fishing or boating activities.

Environmental description and impact assessment. In this section, the applicant is required to provide the COE with the environmental information necessary to evaluate the site. The specific requirements are discussed further in Chapter 4.

Monitoring. If a Section 10 permit is issued to a farm that does not meet the guidelines discussed above, then the applicant will be required to complete environmental monitoring of the site. These specific monitoring requirements are also discussed in Chapter 4.

National Pollution Discharge Elimination System (NPDES) permit

The NPDES permit system was created by Section 402 of the Federal Water Pollution Control Act to ensure that point source discharges would not impair the nation's water quality. In May 1989, EPA determined that floating fish farms should be required to obtain NPDES permits. The first permits for fish farms were issued in the state of Washington in April 1990 (see the Washington section of this chapter and Chapter 4 for a further discussion of the NPDES requirements) and are currently under appeal. The Region I (New England) office of EPA is currently in the process of determining what requirements will be part of NPDES permits for fish farms in Maine.

WASHINGTON

The State of Washington uses a number of existing State and federal environmental programs and regulatory mechanisms to manage the aquaculture industry. The primary programs are the:

- State Environmental Policy Act (SEPA)
- Shoreline Management Act (SMA)
- Interim Guidelines for the Management of Salmon Net-Pen Culture in Puget Sound
- Hydraulic Project Approval (HPA) permit
- Aquatic Lands Act
- Finfish/Import Transfer permit
- National Pollution Discharge Elimination System (NPDES) permit
- U.S. Army Corps of Engineers' Section 10 permit.

**Washington State Environmental Policy Act of 1971**

The State Environmental Policy Act (SEPA) was passed by the Washington State Legislature in 1971 to help everyone in the state make better environmental decisions. SEPA contains substantive policies and goals which apply to actions at all levels of government within the state. When agencies, local governments, or private developers initiate an action, SEPA's provisions mandate that specific procedures be followed to ensure that appropriate consideration be given to environmental factors. Typically, the SEPA process is implemented at the local government level and the local governmental entity acts as the "lead agency" in administering the environmental review. State agencies can also serve as "lead agencies" for overseeing the environmental review.

When someone submits a permit application for a private development such as a shopping center, or when an agency proposes some activity, plan, or policy; SEPA requires them to complete an environmental checklist. The purpose of the checklist is to identify potential impacts of the proposal and to help the lead agency determine if further environmental review is necessary. The checklist requires the applicant to supply basic information about the proposal in areas such as air and water resources, soils, plants and animals, land and shoreline use, aesthetics, environmental health, recreation, historic and cultural preservation, transportation, public services, and utilities. The checklist is distributed to state resource agencies for their comments on the potential environmental impacts. From the information supplied on the checklist and the comments received from agencies with environmental expertise, the lead agency makes a "threshold determination" whether a project may have probable significant adverse impacts on the environment.

There are three possible threshold determinations that can be made under SEPA: (1) a determination of nonsignificance (DNS) (the project will not have a significant adverse impact on the environment), (2) a mitigated determination of nonsignificance (Mitigated DNS) (the project will not have significant adverse impacts if mitigation measures are incorporated into the proposal, and (3) a determination of significance (DS) (a proposal may have significant impacts and an Environmental Impact Statement (EIS) is necessary to discuss the potential impacts and their significance). The threshold determination made by the lead agency is appealable.

If a proposal receives a DNS or the applicant agrees to a Mitigated DNS, the project may proceed with other permitting applications. If a proposal receives a DS, then an EIS must be completed before any further approvals are granted. SEPA regulations include provisions for limiting the scope of the EIS to focus only on those issues that are identified as having a probable significant adverse impact on the environment. The EIS is initially published as a Draft for public and agency review. After considering all comments submitted on the Draft and making any necessary revisions, the EIS is issued as a Final EIS. Adoption of the Final EIS by a lead agency is also appealable. Once a DNS, Mitigated DNS, or a Final EIS is issued and all appeals resolved, the SEPA environmental review process is over.

<u>Shoreline Management Act of 1971</u>

The Washington Shoreline Management Act (SMA) was implemented to assure appropriate and orderly development of the State's shorelines, and provide for State shoreline management by planning for and fostering all reasonable uses in a manner that enhances the public interest, protects against environmental impacts, and preserves the natural character of the shorelines.

The SMA was established as a cooperative management program between local governments and the State. The SMA required cities and counties, with assistance from the State, to complete three tasks: (1) inventory shoreline characteristics and resources, (2) develop a shoreline master program in compliance with the SMA and State guidelines, but tailored to local conditions, and (3) develop a permit system to regulate substantial development in the shoreline area.

Within State guidelines, each local jurisdiction is responsible for developing and administering its own local shoreline master program with goals, policies, and regulations adjusted to fit local conditions. Each local master program includes a categorization of the shoreline into different environmental designations such as urban, rural, conservancy, or natural. This system is designed to provide a uniform basis for applying policies and use regulations within distinctively different shoreline areas. These categories are based on the existing development pattern, the biophysical capabilities and limitations of the shoreline being considered for development, and the goals and aspirations of local citizenry.

In addition to categorizing the shoreline area, the local master program includes regulations for use activities that typically occur in shoreline areas such as piers and marinas, aquaculture, residential development, commercial development, forest management practices, port and water-related uses, bulkheads and breakwaters, recreation, archaeological and historical sites, dredging, and utility development.

The SMA also required local governments to develop a permit system to regulate substantial development in the shoreline area. With some exemptions, most development proposed for the shoreline must receive a shoreline permit before construction. Permit applications receive public review and are evaluated against the existing goals, policies, and regulations contained in the local master program. Potential environmental impacts are reviewed under SEPA and are considered during the shoreline permit decisionmaking process.

Interim Guidelines

The Interim Guidelines were developed by Dr. Donald Weston for the State of Washington to provide a basis for a coordinated approach to the management of salmon farming in Puget Sound. The Guidelines also provide a mechanism for collecting environmental data to ensure that floating fish farms would not have a significant adverse impact on the environment. Included in the Guidelines are three major components: (1) a site characterization survey, (2) a baseline survey, and (3) annual monitoring. The Guidelines categorize farms into three different size classes, and base the amount of necessary environmental data collection on the size of the farm. Because they have less effect on the environment, smaller farms have less requirements for environmental data collection and annual monitoring. The details of the Guidelines are contained in Chapter 4.

Hydraulic Project Approval

The Hydraulic Code of Washington establishes regulations to protect food fish, shellfish, and game fish species and their habitat from impacts of construction projects that use any of the marine or fresh waters of the State. The Hydraulic Project Approval (HPA) permit requires projects to demonstrate that they are designed to provide adequate protection to fish species and habitats. The HPA permit allows State fisheries agencies to review projects on a case-by-case basis to determine the potential impacts on fisheries resources.

State Aquatic Lands Lease

The State of Washington owns 1,300 miles of tidelands and all the submerged land below extreme low tide in the state. The Washington Department of Natural Resources (DNR) acts as the proprietary manager for State-owned public lands. Uses of public aquatic lands such as commercial fish farms, docks, and marinas; require ground leases from DNR. Leases specify location, structural development, operational practices, lease terms, environmental monitoring, rent, and other requirements. In addition, all lessees must obtain all required local, state, and federal permits.

Finfish Import/Transfer Permit

This permit is required by the Washington Department of Fisheries (WDF) for anyone who wishes to import aquatic organisms into State waters for culture purposes; or to transfer these organisms from one area to another within the State. The purpose of this permit is to assure that diseases, pests, or predators are not introduced into State waters. All introductions of new species are assessed for potential environmental impacts during the SEPA review process.

### National Pollution Discharge Elimination System Permit (NPDES)

The NPDES program, under section 402 of the Clean Water Act, was established to control point source discharges. The NPDES program allows the Environmental Protection Agency (EPA) or delegated state agencies the ability to prescribe conditions to ensure that discharges from point sources will comply with the requirements of the Clean Water Act.

In May 1989, EPA determined that some salmon farms in the state of Washington constitute "concentrated aquatic animal production facilities" under 40 C.F.R. §122.24. Presently, it appears that all fish farms are likely to be considered as concentrated aquatic animal production facilities in the future. EPA and the Washington Department of Ecology (WDOE) issued draft NPDES permits for three salmon farms in late December 1989. The Draft permit included conditions and monitoring requirements based on the Interim Guidelines. After public review and comment, WDOE issued Final NPDES permits for the three farms in April 1990. These permits have been appealed to the state Pollution Control Hearings Board. This appeal board will determine if the permit conditions and monitoring requirements in the NPDES permits are adequate to protect the environment. See Chapter 4 for a detailed discussion of the requirements of the NPDES permit.

### U.S. Army Corps of Engineers Section 10 Permit

The Army Corps of Engineers (ACOE) reviews projects in State waters for their probable impact on the public interest. Factors that are considered during their review include such areas as: fish and wildlife values, general environmental concerns, economics, conservation, aesthetics, navigation, historic values, safety, and in general, the needs and welfare of the people. During the Section 10 permit review process, other federal agencies such as the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USF&WS), the U.S. Coast Guard (USCG), and EPA also review the permit proposal for potential environmental impacts.

In Washington, all farms must obtain a Section 10 permit. Because the substantive environmental issues involving salmon farms have been identified and resolved through the Shoreline permit and the SEPA review processes, the Section 10 permit is primarily a formality. If federal issues such as navigation and endangered species are not adequately covered through the State and local processes, then federal agencies can use the Section 10 permitting process to ensure their concerns are addressed.

## BRITISH COLUMBIA

The provincial government of British Columbia is the primary entity responsible for siting and regulating salmon farms in British Columbia. Although local governments have some input over aesthetic issues along their shorelines, they do not have a framework such as the Washington Shoreline Management Act for regulating activities off their shorelines. All aquaculture activities in British Columbia must obtain a variety of provincial and federal permits and authorizations similar to those required in Washington. Examples of these permits include:

- a lease from the provincial government to use provincial lands for aquaculture
- an approval from the Coast Guard related to navigation issues
- an approval from the Canadian Department of Fisheries and Oceans that sensitive fish habitats, wild stocks, and commercial, recreational, and Native food fisheries will not be affected
- demonstration of compliance with Municipal zoning requirements
- an approved Fish Farm Development Plan
- an insurance and performance bond
- a Transplant Permit for moving eggs, smolts, or fish
- an Import Permit for bringing Atlantic salmon into the province, if applicable
- an annual production report detailing the amount of fish purchased and sold during the year.

The government of British Columbia has established locational guidelines for siting farms, undertaken Coastal Resource Identification Studies (CRIS) in specific areas to identify and resolve use conflicts between farms and existing aquatic users, and has implemented an environmental monitoring program that is described in Chapter 4.

<u>Locational Guidelines</u>

The provincial government has established locational guidelines for siting farms. These siting guidelines include requirements that fish farms may not be located:

- within 3 km of an existing fish farm
- within 1 km of a Park or Ecological Reserve
- within 125 m of a commercial or recreational shellfish bed
- near sensitive fish habitats
- within 1 km of the mouth of a salmon-bearing stream

Coastal Resource Identification Study (CRIS)

In 1986, the government of British Columbia identified several areas of their coast that had an expanding aquaculture industry and increasing conflicts with existing users of the marine environment. The Ministry of Forests and Lands undertook studies in these areas to evaluate the extent of the conflicts. The intent of the Coastal Resource Identification Studies (CRIS) was to identify coastal waters of high value for a wide range of resource interests, and use this information to direct aquaculture applications away from areas where competing interests were high.

The Ministry of Forests and Lands consulted local, federal, and provincial agencies; commercial fishing groups; environmental organizations; commercial and recreational boating associations; and aquaculture groups. Each group was invited to participate by identifying areas that were "critical" or "important" to its specific activities. Using this information from all groups, the Ministry of Forests and Lands categorized the coastal waters in the study area into one of three groups based on the anticipated level of conflicts: (1) Conditional Opportunity Areas, (2) Limited Opportunity Areas, and (3) No Opportunity Areas. Guidelines for each area are summarized below.

Conditional Opportunity Areas. Applications in these areas follow the normal application procedures, but include a minimum spacing between farms of 3 km and a requirement for public notice. Proponents must notify adjacent landowners (within 1 km of site and 300 m inland), publish a notice of application in a specified newspaper, place a notice of application at the site, and provide their development plans to key federal and provincial agencies and local governments for comment. In addition, the farmer may be requested to supply selected interest groups with a copy of the development plans for their comments.

Limited Opportunity Areas. This classification is slightly more restrictive than the Conditional Opportunity Area described above. The Ministry of Forests and Lands will consider aquaculture applications in these areas where relevant user group interests identified by the CRIS can be reconciled or accommodated by the farmer. In addition to the normal application procedures, farmers will be required to contact relevant public groups with an interest in the area. Written evidence of the interest groups position on the proposal must be submitted to the Ministry before a lease application is processed. Any special siting requirements necessary to accommodate interest group concerns will be incorporated into the lease document. Also, the public review time is expanded to 60 days to provide extra time for interest group review.

No Opportunity Areas. As the name implies, these areas are off-limits to any aquaculture development because of the intensity of existing uses of the area.

This process provides a mechanism for groups who are currently using marine waters to have a voice in siting aquaculture facilities. However, the system is weakened by the fact that groups with a vested interest in identifying the maximum amount of coastal area as "important" or "critical" were involved in helping determine which areas should be restricted to further aquaculture development. Some of the interest groups completed detailed, thoughtful maps of the areas that were important to them; while other groups identified all coastal waters as important. A significant amount of interpretation was required on the part of the Ministry. Only four areas have had CRIS studies completed. Aquaculture operations proposed in coastal waters outside of these four areas follow standard application procedures.

## NORWAY

Detailed information on aquaculture management programs in Norway has been limited due to distance and language barriers. However, one program that has received considerable attention is the LENKA program.

### LENKA

LENKA was an intensive three-year coastal zone management program started in Norway in 1987 to establish an efficient and standardized tool for coastal zone planning. The intent of the Norwegian government was to have a planning tool to aid in the development of the aquaculture industry in such a way as to maintain high productivity while minimizing environmental effects and conflicts with fisheries, environmental groups, and recreational activities. The program cost approximately 6.5 million dollars (U.S.).

The LENKA program has three primary components: (1) partitioning of the coast into manageable sections, (2) characterizing each geographic section, and (3) developing a model for assessing the capacity of each area for aquaculture development. More information on these three components are given below.

Partitioning. Norway's 57,000 km coastline was divided into numerous sub-areas (called LENKA zones) of manageable size such that each major water body could be addressed independently. Thus, the LENKA zones consist of archipelagos, fjords, large bays, and open-fjord basins.

Characterizing. Each LENKA zone was characterized for four different groups of parameters: (1) marine environment, (2) existing exploitation, (3) infrastructure, and (4) special areas. The primary parameters evaluated in each category are:

*Marine Environment*

**Pollution.** Contamination of the environment effects the health or marketability of fish raised in the water. This parameter included evaluating toxins and organic loadings as pollutants. Massive outlets from industry and agriculture were considered most important.

**Temperature.** Temperatures that are too low or too high can hinder aquaculture development. Areas with regular long periods (greater than 6 weeks) of temperatures below zero degrees centigrade were determined to be unsuitable for aquaculture. Of special interest was the extreme temperatures occurring within a time span of 5 to 6 years which LENKA authorities defined as frequent.

**Ice cover.** Areas covered with ice at least every five years were of special interest.

**Exposure.** The parameter evaluated was wave height. Areas determined to be suitable for aquaculture were those areas where wave heights did not exceed 2 m.

**Depth.** The general rule used in LENKA is that cages must be sited in waters at least 20 m deep. They also leave open the possibility of adjustments to this depth criterion based upon local current velocities.

*Existing exploitation*

This category evaluates the effect of potential aquaculture operations on existing or potential activities in the area. The following parameters were evaluated in this category:

- effects on settlement patterns
- recreational activities
- port development
- fisheries
- shipping traffic.

*Infrastructure*

This category deals with particular requirements which are necessary for an aquaculture operation to succeed. In this category, the following parameters were evaluated:

- road development
- distribution of manufactured feed
- processing facilities
- health service
- waste disposal systems.

*Special areas*

This group of parameters details the potential conflicts that aquaculture facilities may have on important biological habitats. Examples of the parameters include:

- spawning habitat for important fisheries species
- reserves for coastal birds and marine mammals.

Assessing LENKA zone capacity. The assessment of the capacity of each LENKA zone for aquaculture has two major aspects: (1) the evaluation of the capacity for organic loadings, and (2) the evaluation of available space in the water body. In addition, this component of the LENKA process takes into account the parameters described above.

*Capacity for organic loading*

Each LENKA zone is classified by topography. This reflects the water exchange regime in the area and identifies areas that have significant water mixing problems such as fjords with high sills. Areas are classified into one of three categories: A, B, or C. Areas classified in the "A" category have the highest potential for aquaculture production. Though exact values have not yet been established, maximum annual production will be limited to 1,000 metric tonnes (2.2 million pounds) within 16 $km^2$ areas. Annual production at individual sites (defined as 1 $km^2$ areas) will also be limited in size. Class "B" sites have slightly lower capacity for aquaculture development. Class "C" sites comprise areas such as basins and silled fjords where special attention should be focused on oxygen depletion concerns. Aquaculture development in Class "C" areas is not recommended unless sufficient data is presented to ensure that impacts to the environment can be avoided.

*Available space*

A number of environmental parameters restrict the space available for aquaculture development. Examples of these parameters include ice cover, exposed areas, cold water, and shallow areas. In addition to environmental parameters, other uses of the water restrict the available space. Examples of these include existing aquaculture facilities, security zones for salmonids, areas for navigation, nature reserves, and animal protection areas around bird and marine mammal habitat.

Subtracting all the areas that are restricted from the total area within a LENKA zone gives a net areal capacity for aquaculture development. This area can then be compared against the capacity of the LENKA zone for organic loading and the smallest value will set the limit on future aquaculture development.

## MONITORING PROGRAMS

Countries around the world with a salmon aquaculture industry have established a variety of programs for monitoring the effects of fish farms on the environment. Some countries such as Chile do very little monitoring of environmental effects, while other areas such as the State of Washington have extensive monitoring programs. The goal of all of the monitoring programs is to assess the effect of the farm on water quality and benthic communities. This chapter describes the monitoring programs established in Maine, Washington, British Columbia, Scotland, and Ireland. Appendix A presents an estimation of the costs related to analyzing typical parameters common to many monitoring programs.

### MAINE

The primary mechanisms for environmental monitoring of fish farms in Maine are through the DMR's leasing program, and the requirements related to obtaining a Water Quality Certificate from the DEP. In addition to the DMR and DEP requirements, monitoring may also be required as part of the COE's Section 10 permit and EPA's NPDES permit.

#### Leasing program

The State of Maine does not currently require a lease for the use of state aquatic lands for aquaculture. However, if a fish farmer obtains a lease, they secure a vested interest in the aquatic area of their farm. As part of the leasing process, DMR staff conduct a preliminary survey of the proposed site. This preliminary survey contains four elements: (1) a diver survey, (2) biological and water quality data collection, (3) water circulation data collection, and (4) other associated information.

After the site of the proposed farm is located and marked, DMR staff examine the site by SCUBA diving under where the pens will be. Qualitative observations are made of the relative abundance of fauna at the site. The relative number of different species observed on the dive are characterized as abundant, common, or occasional. In addition, the diver notes the general bottom topography and substrate type.

While at the site, DMR staff collect a variety of biological and water quality data. Included in the series of data collected are:

- Water samples (5 L) are taken at the surface, midwater depth, and near the bottom to collect phytoplankton, zooplankton, and larval fish data. Samples are passed through a 38$\mu$ sieve and resuspended in 50 ml of seawater. Species in these screened samples are then identified and enumerated.

- Water quality data is collected throughout the water column as a profile. Parameters that are measured during the preliminary survey include: temperature, dissolved oxygen, pH, and conductivity.

Surface current velocity and direction are measured throughout a complete tidal cycle by an electronic meter placed at the center of the site. Subsurface currents are measured using a "window shade" drogue. The drogue is set so that the center of the window shade is 20 ft below the surface of the water. The drogue is released from the center of the site and the direction and time required to travel a specific distance from the center of the site is recorded.

In addition to the data collected at the site, DMR staff also collect other information relevant to the site. This information includes:

- commercial fishing activity observed near the site
- any available long-term current and temperature data relevant for the lease site
- records of ice build-up in the area
- the location of shellfish beds near the lease site
- historical fishing areas near the site
- location of moorings and areas used for navigation
- location of critical habitats and any threatened and endangered species in the area
- distances to other nearby aquaculture leases.

This information is presented to the Hearing Officer as part of the lease hearing process described in Chapter 3. As a condition of obtaining a lease from DMR, fish farms must also obtain a water quality certification from DEP.

Water quality certificate

Some existing farms are submitting environmental monitoring reports in the spring and late summer to support their Water Quality Certificate. These reports consist of four elements: (1) establishing a set of sampling stations, (2) completing a diver survey, (3) collecting sediment samples for benthic analysis, and (4) discussing the results of the analyses.

**Establishing sampling stations**. The placement and number of stations established for a particular farm varies from site to site. Factors that affect station placement include the type of pen (square or circular), configuration of the pens (rectangular or square), the distance between the pens, and the direction of the prevailing currents. Sampling stations are usually established below the perimeter of the pens, and at distances of 50 to 150 ft away from the pens.

Diver survey. The diver survey includes observations of any organic accumulation under the pens, *Beggiatoa* bacteria mats, feed pellets, epifauna near the pens, and the consistency and composition of bottom sediments.

**Benthic sampling**. During the dive under the pens, divers use a 6 in diameter, 10 in long piece of thin-walled PVC pipe to collect sediment samples at each station for the benthic analysis. Sediment samples are washed through a 860 $\mu$m sieve and all material retained on the screen is preserved in Formalin. The samples are sorted to separate organisms from sediment and detritus, and then enumerated to the species level.

**Results**. The monitoring report discusses the qualitative observations made while diving under the pens and the results of the benthic sampling. For each sampling station, the benthic results are reported as the total number of species, number of capitellids (opportunistic polychaete worm indicative of organic enrichment), and a value indicating the relative ecological diversity.

The monitoring reports also compare the present results to information from previous monitoring reports. The difference between past and current data are discussed in a qualitative manner and are not statistically evaluated. Nevertheless, the reports identify whether the layer of organic material at each station below the pens is decreasing or increasing over time.

**Section 10 permit**

The Army Corps of Engineers, in conjunction with other federal agencies, have drafted guidelines for what is required as part of the Section 10 permit application. The following baseline information is presently required as part of the fish farm application:

- **Sensitive habitats.** The applicant must identify any known locations of sensitive habitats such as protected species, shellfish beds, eelgrass beds, kelp beds, and known spawning or nursery areas.

- **Bottom characteristics.** Required information includes bathymetry and seafloor topography; and sediment type, composition, chemistry, and grain size. Using these characteristics, farmers are required to identify the depositional character of the area, the sediment deposition rate, and the degree to which the sediments are oxygenated.

- **Water currents.** The required information includes current velocity and direction, direction of the ebb and flood tides, direction of the prevailing current, depositional or dispersive nature of the currents, flushing rate of nearshore or embayment areas, and site wave characteristics and their prevailing direction. Applicants are further required to use this information to hypothesize about the fate of wastes discharged from the pens. The potential effects of storms on the pens are also to be evaluated.

- **Water chemistry.** Information required for the Section 10 permit includes: dissolved oxygen, salinity, total suspended solids, biochemical oxygen demand, total organic carbon, sulfide, nitrate/nitrite, urea and ammonium, salinity and temperature profiles, and turbidity levels.

- **Biota.** The current COE guidelines for Section 10 permits require the applicant to provide information on species composition, distribution and relative abundance, and community structure of benthic invertebrates; occurrence of shellfish habitats; and occurrence and relative abundance of submerged aquatic vegetation, fish, mammals, and birds.

- **Socio-economic factors.** Section 10 permit applicants must provide information on the type, duration, and frequency of all other existing activities and uses of the site and surrounding area. The application must discuss participation, employment, and socio-economic value of these uses and activities. This discussion must also evaluate the degree to which the proposed project would exclude or otherwise affect these activities or uses.

If a Section 10 permit is granted for a site that does not meet the COE guidelines discussed in Chapter 3, then the applicant may be required to provide monitoring data. The monitoring program includes 3 major elements: (1) a benthic survey, (2) collection of water quality data, and (3) a hydrographic survey.

**Benthic survey.** This survey should document benthic habitat quality, invertebrate community structure, abundance, and species diversity, and the accumulation of any solids on the sea floor, their depth and lateral extent, and the nature of the accumulation. Divers should use cameras to record benthic habitat conditions under and near the pens in the control area.

Benthic samples should be taken under the pens and in the surrounding area within 1,000 ft from the farm perimeter. Transects for sampling stations should be selected based upon prevailing currents, and the anticipated net drift of waste material. Additional stations should be established in: (1) previously identified depositional areas of fine-grained sediments where farm waste are expected to accumulate, (2) sensitive habitat areas, and (3) appropriate reference areas.

Samples should be taken monthly between July and September, and in alternate months during the rest of the year. Sediment samples should be analyzed for the following factors:

- grain size
- pH
- redox potential
- sediment BOD
- total organic carbon
- seabed oxygen consumption
- sedimentation rate.

Water quality data. The water quality variables required to be measured for the COE monitoring plan include:

- pH
- dissolved oxygen
- salinity
- temperature
- sulfide
- nutrients
- turbidity.

Water samples should be taken at 0.1 and 1.0 m above the sediment and at the bottom of the nets. Five stations are required:

- one up-current of the pens
- one directly within the pens
- three down-current of the pens in the direction of the prevailing current.

The frequency of sampling should be the same as that for the benthic survey. The time and tide conditions should be standardized, preferably at low tide and early in the morning.

Hydrography survey. The applicant must provide monitoring information to document current velocity and direction both up- and down-current of the farm, the maximum and minimum currents, and the prevailing current direction.

## WASHINGTON

Presently, the State of Washington uses two different monitoring programs for the salmon farming industry. The existing salmon farms in Washington (13 farms) are monitoring the environment near the pens using the *Interim Guidelines*, and three new farms that are not yet developed will be required to follow the new NPDES monitoring requirements.

### Interim Guidelines

The monitoring program contained in the *Interim Guidelines* was developed by Dr. Donald Weston for the State of Washington to provide a mechanism for collecting environmental data to ensure that floating fish farms would not have a significant adverse impact on the environment. The monitoring program uses a three-tiered approach based on the amount of fish produced over one year. Class I farms produce less than 20,000 lbs per year, Class II farms produce between 20,000 and 100,000 lbs per year, and Class III farms raise more than 100,000 lbs in a year. This classification system recognizes that smaller farms will have less effect on the environment than large farms (over 100,000 lbs annual production) and should be subject to less extensive monitoring requirements. A summary of monitoring requirements for each size category is listed in Table 1.

Table 1. Summary of monitoring requirements for farms sited under the Washington State Interim Guidelines.

| | Site Characterization Survey | Baseline Survey | Annual Monitoring |
|---|---|---|---|
| CLASS I FACILITIES | Prior consultation with agencies<br><br>Bathymetric survey<br><br>Hydrographic survey<br>Current velocity and direction<br><br>Diver survey | None | None |
| CLASS II FACILITIES | Same as Class I | None | Benthic survey<br>Diver survey |
| CLASS III FACILITIES | Same as Class I and II with the addition of<br><br>Drogue tracking and vertical profiles | Sediment chemistry sampling<br><br>Benthic infauna sampling | Benthic survey<br>Diver survey<br>Sediment chemistry<br>Benthic infauna<br><br>Water Quality sampling<br><br>Current velocity & direction |

The monitoring program in the *Interim Guidelines* comprises three different environmental surveys: (1) site characterization, (2) baseline survey, and (3) annual monitoring. As can be seen in Table 1, all farms are not required to complete all three surveys.

**Site Characterization**. This survey provides initial information to enable regulatory agencies to determine the potential extent of environmental effects at a particular site. It also provides valuable information to the prospective fish farmer on the suitability of the site. The four elements of the site characterization survey are: (1) consultation with resource agencies, (2) a bathymetric survey, (3) a hydrographic survey, and (4) a diver survey.

*Consultation with resource agencies.* Prior to initiating any field work, the fish farmer is encouraged to contact resource agencies and local government. This initial contact allows the agencies to identify any specific problems with a particular site such as nearby bald eagle nests, chronic poor water quality, marine mammal haulout areas, or important fisheries spawning areas. Local government can identify any potential conflicts with existing user groups.

*Bathymetric survey.* The bathymetric survey should identify water depths where the pens will be located out to a point 300 ft away from the farm perimeter. This survey should be done along two perpendicular transects at a density and spacing to adequately characterize bottom features such as depressions.

*Hydrographic survey.* The hydrographic survey comprises three components: (1) current velocity and direction, (2) drogue tracking, and (3) vertical profiles of temperature, salinity, and dissolved oxygen. Farms with annual production amounts of less than 100,000 lbs (Class I and II) are not required to perform the drogue tracking and vertical hydrographic profiles.

**Current velocity and direction.** At the center of the potential farm site, current velocity and direction should be monitored at a depth of 6 ft and mid-way between the bottom of the pens and the sea floor. Current velocity and direction should be monitored throughout one tidal cycle with a minimum of 10 measurements evenly spaced throughout the cycle. Measurements should be made during "average" tides, and should not be representative of either extreme neap or extreme spring tides.

**Drogue tracking.** To estimate the potential fate of particulate material, drogue tracking should be performed. This allows the identification of any potential eddies that would recirculate suspended material back into the same area. Two drogues should be released from the center of the potential farm and tracked for a minimum of 8 hours. The drogues should be set at depths of 6 ft and mid-way between the bottom of the proposed pens and the sea floor.

**Temperature, salinity, and dissolved oxygen profiles.** Vertical profiles may be used to evaluate the intensity of water column stratification. Measurements should be taken at depths of 1, 10, 20, 30 ft, and at 30 ft intervals thereafter. the deepest measurement should be made 3 ft above the sea floor.

*Diver survey.* The primary purpose of the diver survey is to identify any habitats of special significance. The survey should cover the area below the proposed pens out to a point 300 ft from the farm perimeter. In waters greater than 75 ft in depth, the diver survey is not required. Diver observations should include:

- substrate type
- presence/absence of *Beggiatoa* mats
- density of important flora and fauna such as crabs, shellfish, eelgrass, geoducks, demersal fish, and other large invertebrates
- geoduck and hardshell clam density should be estimated by counts along the transects, and the abundance of other invertebrates and fishes should be described in general terms such as "rare" or "common."

**Baseline Survey**. The baseline survey is only required of Class III farms (greater than 100,000 lbs annual production) and is intended to characterize the sediment chemistry and benthic community below the pens. This survey should be completed after the pens are in the water (to ensure their precise location), but before the pens are stocked with fish.

Stations should be established along a transect on the "downcurrent" side of the pens beginning at the perimeter of the pens and extending away from the pens at distances of 20, 50, 100, and 200 ft in the direction of prevailing currents. Each station should sampled by three replicate diver cores, or three grab or box corer samples. Each replicate should be analyzed for the following parameters:

- total organic carbon
- total Kjeldahl nitrogen
- grain size distribution (median phi, percent gravel, sand, silt/clay)

Transparent cores should be used so that the redox potential discontinuity (RPD) can be recorded.

Benthic samples should be collected by either a diver using a core sampler (minimum area of 0.01 $m^2$), or by a grab or box corer (minimum area of 0.1 $m^2$). The same grab/box corer samples used for sediment chemistry should be used for benthic analysis provided no more than one-quarter of the surface of each sample has been removed for sediment chemistry. The same stations used for sediment chemistry should be used for the benthic samples. Three replicates should be collected at each sampling station. Each benthic sample should be sieved on a 0.5 mm screen or nested 1.0 and 0.5 mm screens. All macrofauna retained on the screen should be identified to the lowest practical taxonomic level, generally species.

**Annual Monitoring**. The annual monitoring recommended under the *Interim Guidelines* comprises four elements: (1) a benthic survey, (2) water quality sampling, (3) a hydrographic survey, and (4) operational practices. Class I facilities (less than 20,000 lbs annual production) are not required to complete annual monitoring, and Class II farms (between 20,000 and 100,000 lbs) are only required to conduct a diver survey.

*Benthic survey*. The annual benthic monitoring survey consists of diver observations and sampling of sediment chemistry and benthic infauna. Transects (minimum of 200 ft in length) should extend out from the perimeter of the farm on both axes. The transects should be extended if sedimentation is visible beyond 200 ft from the pens. The same 75 ft depth limitation for diver safety is also in effect for annual monitoring.

The diver should estimate the depth of accumulation at 20 ft intervals along each transect and note the greatest distance from the pens that the accumulation is present. In addition, the diver should estimate the densities of demersal fish, crabs, and other invertebrates, and should note the presence/absence of Beggiatoa mats.

Class III operations should collect sediment chemistry and benthic infauna samples. The station location and sampling protocol should be exactly as described in the baseline benthic survey.

*Water quality survey*. This survey should be conducted between July and September. Within one hour of slack tide, three stations should be sampled: (1) 100 ft upcurrent of the pens, (2) 20 ft downcurrent, and (3) 100 ft downcurrent. The precise location of the stations should be located to monitor the water passing through the greatest possible number of pens. Three replicates should be taken at each station at a depth mid-way between the water surface and the bottom of the pens. Samples should be analyzed for the parameters listed below.

- dissolved oxygen
- temperature
- pH
- ammonia
- nitrite/nitrate (separate or combined)
- concentration of un-ionized ammonia should be calculated.

*Hydrographic survey*. Current velocity and direction should be measured at the depth at which the water quality samples are taken. A single measurement should be made 20 ft downcurrent of the pens concurrently with collection of the water quality sample taken at this station. Loading estimates (g/kg fish/day) should be calculated for ammonia and nitrite/nitrate based on:

- the net increase in concentration between the upcurrent station and the 20 ft downcurrent station

- the current velocity 20 ft downcurrent

- the cross-sectional area of the farm

- the weight of fish on hand at the time of the water quality survey.

*Operational practices*. In addition to the raw data collected for the annual monitoring report and a description of the methods of data analysis and interpretation, the annual report should include the following information.

- General description of the facility (species cultured, size fish will be marketed)
- Size, number, and configuration of pens at time of sampling
- Annual production (lbs)
- Estimated weight of fish in pens during survey (lbs)
- Stocking density (average and range) (lbs/$ft^3$)
- Type of feed used and method of feeding
- Type of antibiotics used and frequency of usage over the past year
- Interactions with birds and marine mammals and summary of types and frequency of predator control measures used
- Types of antifoulants employed and frequency of net treatment.

National Pollution Discharge Elimination Permit (NPDES)

In May 1989, EPA determined that some salmon farms in the state of Washington may constitute "concentrated aquatic animal production facilities" under 40 C.F.R. §122.24. EPA delegates their authority for implementing the Clean Water Act to the Washington Department of Ecology (Ecology). After numerous public hearings, Ecology issued NPDES permits in late April 1990, to three new farms. These three permits represent the first NPDES permits ever issued for salmon farming facilities in the United States. Presently, the provisions of these NPDES permits are under appeal to a Washington State appeal board. The requirements included in the permit may change in the future based upon the outcome of the appeal process.

The NPDES permit in its current form contains three major elements: (1) water quality limitations and monitoring requirements, (2) an operations plan and best management practices, and (3) an environmental monitoring program.

Water Quality Limitations and Monitoring Requirements. This section of the NPDES permit allows fish farmers to discharge wastes provided they monitor certain parameters and do not exceed established water quality standards. Table 2 identifies the parameter, standard, and frequency of monitoring.

In addition to the water quality requirements, the NPDES permit includes a number of conditions related to protecting water quality. These conditions require the permittee not to discharge waste such as floating solids, soaps or detergents, or oily wastes. The permit also does not allow the use or discharge of toxic chemicals to control the fouling of nets. Other effluent conditions require the farmer to retrieve any floating debris that originates from the farm, and requires the farmer to recover any large debris which enters the water and sinks to a depth of less than 100 ft.

Table 2. Water quality standards and monitoring frequency required in fish farming NPDES permit.

| Water Quality Parameter | Standard | Monitoring Frequency |
|---|---|---|
| Dissolved Oxygen | Minimum of 7.0 mg/L; if less than 7.0 mg/L, no decrease below ambient of more than 0.2 mg/L. | Three times per week |
| Turbidity | No increase of more than 5 Nephelometric Turbidity Units (NTU) | Once a week in February, May, August, and November during net cleaning |
| Settleable Solids | Annual accumulation limited to amounts which do not result in the establishment of anoxic zones | Monthly |

<u>Operating Conditions and Best Management Practices</u>. This section of the NPDES permit requires the farmer to develop a plan of operations and best management practices (BMPs) that minimizes the release of pollutants. Each of these elements has conditions that the farmer must comply with; although many of these measures are already implemented by the fish farming industry in general as techniques of good animal husbandry. Elements of a plan of operations and best management practices include:

- feeding operations
- application of disease control medication
- handling of fish mortalities
- control and cleaning of net foulants
- sanitary and solid wastes
- spill control plan.

**Environmental Monitoring Program**. The format of the NPDES annual monitoring program is similar to the Interim Guidelines. This program has three major components: (1) water quality monitoring, (2) benthic monitoring, and (3) underwater photographic survey.

*Water Quality Monitoring.* The sampling stations are required in the NPDES permit are the same as those required in the Interim Guidelines:

- 100 ft upcurrent of the pens
- 100 ft downcurrent of the pens
- 20 ft downcurrent of the pens.

The NPDES permit requires the following parameters to be measured:

- temperature
- salinity
- pH
- dissolved oxygen
- turbidity
- total dissolved nitrogen (ammonia and nitrite/nitrates)
  (replicate samples for dissolved nitrogen must be collected from 20 ft downcurrent station).

Monitoring must be performed prior to the introduction of fish during the summer months if possible. Subsequent monitoring must be performed annually when the fish poundage exceeds 100,000 lbs.

Sampling shall be taken at each station at three depths:

- at the surface
- mid-way between the surface and the bottom of the nets
- mid-way between the bottom of the nets and the sea floor

Samples should be taken within three hours of slack tide. Directional current flow should be established and quantified during the time of sampling.

*Benthic monitoring.* During the first year of the permit, the farmer must undertake benthic and sediment chemistry monitoring prior to the introduction of fish. In subsequent years, monitoring must be completed whenever the amount of fish in the farm exceeds 100,000 lbs. In addition, monitoring for antibiotic resistance must be performed during annual monitoring when feed containing antibiotics exceed 2 percent of the total feed administered, or when the quantity of antibiotics exceeds 200 lbs total active ingredient in the previous 12 months.

Transects must be established along the medial line of the long axis at stations of 0, 50, 100, and 300 ft distance from the perimeter of the pens in the direction of the dominant current. Stations at 0 and 100 ft distance in the opposite direction must be monitored. In addition, a reference station with similar physical and chemical characteristics as the farm area must me sampled and characterized with each sampling effort.

At each station, three replicate Van Veen grab (0.1 $m^2$) samples must be taken. Sediment depth must be at least 5 cm, and the redox discontinuity depth must be recorded. As with the Interim Guidelines, replicate samples must be analyzed for total organic carbon, total nitrogen, and grain size distribution.

The monitoring of benthic macroinvertebrates takes place at the same stations as specified for sediment chemistry analysis. At each station, five replicate Van Veen grab samples must be collected and sieved on a 1.0 mm screen. Two of the replicates are archived and the remaining three replicates are analyzed for the following information:

- number of species and individuals
- distributional information on the numerically dominant species (mean, standard deviation, and range of numerical density)
- similarity in groupings
- species diversity.

Species diversity shall be calculated according to the Shannon-Weiner index or other appropriate method.

*Underwater photographic survey.* This final section of the monitoring program requires the farmer to conduct a photographic survey of the established benthic monitoring stations in years when benthic monitoring is required. Using SCUBA divers or remotely controlled underwater cameras, the farmer must photograph the benthos at each station from a distance of 3 to 6 ft. The format can be either 4 to 5 still photos, or 15 to 30 seconds of motion photography at each station. Photographic documentation shall clearly portray the appearance of the seafloor within a circle of 30 ft diameter centered on each station. These photographs must be taken within two weeks following the collection of the benthic samples.

## BRITISH COLUMBIA

The environmental monitoring program established in British Columbia is a three-tiered program based on the weight of feed used in the farming operation over a year converted to a dry weight (i.e. if a farm uses 100 tonnes of feed with 10% moisture content, then the amount of dry feed would 100 - 10%, or 90 tonnes). The three size categories are:

- Schedule C, greater than 630 metric tonnes (1,386,000 lbs)

- Schedule B, between 120 and 630 metric tonnes (between 264,000 and 1,386,000 lbs)

- Schedule A, less than 120 metric tonnes (264,000 lbs).

All sizes of farms are required to submit information on a quarterly basis on materials accounting, fish production, and waste handling. These requirements are discussed below.

All farms are required to provide information such as longitude and latitude, and average depth of pens. Once a year, on the third quarter report, farms must project their feed usage for the upcoming year to determine the appropriate monitoring requirements. Farms are also required to provide quarterly information on all materials used in the operation that could directly or indirectly enter the water such as feed types and amounts, percent moisture in the feed and their corresponding dry weights, pigments, anesthetics, antifoulants, disinfectants, or cleansers. The information required includes the name of the material, the amount used during the quarter, a description of how the material was applied, and the methods of disposal.

In addition to the information on materials used at the farm, all farms must estimate the total weight ("biomass") of all live fish on the farm site at the end of each quarter. Farms must also estimate the total weight of all fish that died during the quarter.

In remote areas of British Columbia, disposal of wastes is a significant concern. All farms must indicate the method used for disposing of dead fish and human waste, and if fish are bled on the farm site, what method was used to dispose of the effluent.

The specific monitoring requirements for each of the three classes are described below.

Schedule C farms (over 630 metric tonnes)

In addition to the information discussed above, Schedule C farms must monitor environmental conditions in the following areas: (1) water quality, (2) current speed and direction, and (3) sediment accumulation and benthos. Each area varies in the frequency of data collection and the specific requirements are discussed below in greater detail.

Water quality. Once a month all Schedule C farms must undertake monitoring of temperature, salinity, and dissolved oxygen, and Secchi disk readings. These profiles are taken once a month and submitted to Ministry of Environment on a quarterly basis. Profiles of temperature, salinity, and dissolved oxygen are to be taken within two hours of sunrise. In addition, about 12 hours after the morning profiles a profile of dissolved oxygen should be taken. During both sampling times, profiles should be taken at a site on the upstream side of the netcage array, and on the downstream side of the array. Water temperature, salinity, and dissolved oxygen must be measured at both sites at depths of 1, 5, 10, 20, and 30 m (if possible), and 1 m above the bottom.

Schedule C farms must also conduct regular monitoring of ammonia and nitrite plus nitrate concentrations. These profiles are to be taken on the same day as the temperature, salinity, and dissolved oxygen profiles. However, these profiles are only required for one sampling site and at only one time during each monthly sampling session. Collection of these samples should be timed to coincide with slack water. Sample depths are the same as for temperature, salinity, and dissolved oxygen.

Current speed and direction. Schedule C farms must characterize the current regime at the farm site for a period of one month only. Current speed and direction have to be recorded at a minimum frequency of once per hour during the 30 day period. The current meter should be placed so that nets do not dampen the current velocity. Typically, the meter is moored about 30 m from the offshore side of the cages and suspended from a surface float at a depth of 15 m.

Sediment accumulation and benthos. All Schedule C farms are required to conduct an annual underwater survey to determine organic sediment accumulation and impact on the benthic community. The survey should be conducted during a period of good visibility in September or October.

To monitor sediment accumulation under the cages, Schedule C farms must establish two transect lines. Two transects, marked every 10 m, are established under the farm. The transects are positioned at right angles to each other and cross under the center of the cage array. The length of each transect line should extend 30 m beyond the outside perimeter of the cages. In the interest of diver safety, transect lines do not need to extend into depths greater than 30 m. Once the transect lines have been arranged, reference marks are established at 10 m intervals along the transect line. These reference marks can be sections of "rebar", metal bars in concrete anchors, or marks on the transect line itself. If the farm is in waters greater than 30 m in depth, sediment traps may be used for sediment accumulation information.

During the annual survey, divers proceed along each transect measuring the following parameters at each 10 m marker.

- Depth of sediment accumulation relative to the reference mark
- Five most dominant macrophytes and their corresponding density
- Five most dominant invertebrates and their corresponding density.

The following information is also required as part of the annual survey:

- A map showing existing cages, walkways, and buildings
- Depths at the farm site using 10 m contours
- Approximate areas of silt, sand, gravel, or rock substrate within lease area
- Presence or absence of sediment accumulation with depth estimate
- Distribution of bacterial "mats" of Beggiatoa sp. if present.

In addition to reporting results from the transect survey, a qualitative summary should be included to provide a characterization and comparison of the following three habitats:

- The benthic community directly effected by farm deposition
- The benthic community adjacent to the deposition area within the lease area
- A control area beyond the influence of the farm.

Schedule B farms (between 120 and 630 metric tonnes)

Schedule B farms are required to supply information on materials accounting, fish production, and waste handling as previously described.

Water quality. All Schedule B farms are required to provide monthly temperature and salinity profiles for a period of one year. On an annual basis, Schedule B farms must monitor temperature and dissolved oxygen during the summer months (April to September). The number and location of sampling stations for Schedule B farms is the same as discussed for Schedule C farms. Water quality samples should be taken once during the day within two hours of sunrise. Sampling depths for Schedule B farms are the same as for Schedule C sites.

Current speed and direction. The Schedule B requirements are the same as for Schedule C.

Sediment accumulation and benthic survey. Schedule B farms are required to conduct an annual underwater survey to provide an assessment of the extent of farm derived organic sedimentation and the effect on the benthic community. This survey can be done by diver, or by remotely operated vehicle if the water depth is greater than 30 m. The following information is required as part of the annual survey:

- A map showing existing cages, walkways, and buildings
- Depths at the farm site using 10 m contours
- Approximate areas of silt, sand, gravel, or rock substrate within lease area
- Presence or absence of sediment accumulation with depth estimate
- Distribution of bacterial "mats" of Beggiatoa sp. if present.

The benthic survey requires a brief assessment which qualitatively describes the major organisms and plants of the benthic community. The survey should characterize and compare the following three habitats:

- Benthic community directly impacted by farm deposition
- Benthic community adjacent to the deposition area within the lease area
- A control area beyond the influence of the farm with similar substrate, depth, and exposure to currents.

Schedule A farms (less than 120 metric tonnes)

The only monitoring requirements for Schedule A farms is to provide information on materials accounting, fish production, and waste handling as previously described.

## SCOTLAND

In Scotland, similar to British Columbia and Washington State, the amount of environmental monitoring is based on the amount of fish at the farm. There are three size classifications that determine the type and amount of monitoring:

- greater than 500 metric tonnes peak biomass (1.1 million lbs)
- between 250 and 500 metric tonnes peak biomass (550,000 to 1,100,000 lbs)
- less than 250 metric tonnes peak biomass (550,000 lbs).

In addition to the basic monitoring requirements, additional information may be required for specific sites. The Scottish program also allows flexibility to increase or decrease monitoring requirements according to the sensitivity of the site, results of previous monitoring, or changes in the farming operations. Basic monitoring requirements of the three classifications are discussed below.

Farms with a peak biomass greater than 500 metric tonnes

Currents. Current measurements should be taken at three depths: (1) 2 m below the surface, (2) halfway between the surface and the bottom, and (3) 2 m above the bottom. Recordings should be taken at 30 minute intervals over six hour periods covering the neap flood and ebb tides, and the spring flood and neap tides. Comprehensive records of wind speed and direction should be kept during current speed monitoring surveys.

Samples. Sampling sites should be on two axes perpendicular to each other with one of the axes parallel to any prevailing current. One sampling station should be at the center of the farm, one station at the edge of each side of the farm, and one station 25 m away from the farm along the axis formed by the central station and the station at the edge of the farm. In addition, one reference station should be selected at least 500 m away from any development that resembles the farm site in terms of depth, exposure, and current speeds. Where clusters of cages are more than 50 m apart, then each group should be treated separately with its own set of 9 sampling stations.

At each station, the following samples should be collected every year.

*Water samples*. Water samples should be collected twice a year during August/September and January/February at three depths (surface, mid-depth, and 2 m above the bottom) and analyzed for:

- Dissolved oxygen
- Temperature
- Salinity
- Ammonia
- pH

In addition, each station should be assessed for water transparency using a standard Secchi disc.

*Sediment samples*. In August/September, four samples should be collected at each station using a 0.025 $m^2$ grab. Three samples should be analyzed for benthic fauna and the fourth should be used for measuring the redox potential. A small subsample of sediment is used to measure organic carbon. Qualitative notes should be kept describing the appearance of the sediment. Biological data should be reported as a species by station matrix and diversity indices (including Shannon Weiner) and evenness (J) index.

<u>Farms with a peak biomass between 250 and 500 metric tonnes</u>

The number of sampling stations and the amount of current measurements required for this class farm is the same as farms over 500 tonnes. Sampling for water quality is not required for this size farm. Sediment sampling in August/September is required using the same number of replicates as described for farms over 500 metric tonnes.

<u>Farms with a peak biomass less than 250 metric tonnes</u>

There are no existing monitoring requirements for farms below 250 metric tonnes. Environmental samples may be required if there is any evidence of an effect on the environment resulting from the farm's discharge, a major change in the stocking density or farming operations, or if the site is considered very sensitive.

<u>Additional requirements</u>

Besides the basic monitoring requirements, the government may ask for additional information on a case-by-case basis. The types of information that may be requested include actual variation of biomass on a monthly basis and a forecast of biomass into the future, and details of the types and quantities of chemicals used at the farm site.

**IRELAND**

Ireland requires an environmental statement prior to commencing with fish farming activities at a site. This statement includes baseline information in five categories: (1) hydrography, (2) physical characteristics, (3) chemical characteristics, (4) biological characteristics, and (5) other considerations. In addition, a monitoring program has been established. Parameters included in each category of the baseline survey are listed below.

Baseline environmental statement

Hydrography

- Water exchange/flushing characteristics including current speed and direction
- Bathymetry of the area.

Physical characteristics

- Temperature profiles
- Salinity profiles
- Water transparency - secchi disc.

Chemical characteristics

- Oxygen
- Ammonia (total)
- Nitrate
- Nitrite
- Total N
- Total P
- Silicate
- Particulate organic carbon and nitrogen

Biological characteristics

- Phytoplankton
- Chlorophyll
- Zooplankton
- Benthic fauna

Other considerations

- Number and type of cages
- Quantity of fish
- Type of food (wet, moist, or dry pellets)
- Proposed chemical treatment of fish
- Use of anti-fouling paints

Continuous monitoring

After the introduction of fish to a site, monthly monitoring of salmon farms is required during the winter and every two weeks during the summer. The following parameters are included in this monitoring program.

- Temperature/salinity profiles
- secchi disk readings
- oxygen and pH
- ammonia, nitrate, and nitrite
- total N, total P, and silicate
- zooplankton, phytoplankton, and chlorophyll
- particulate organic carbon and nitrogen

In addition to the monitoring parameters listed above, the Irish government also requires that sediment traps and the benthos be examined every three to six months. There is no information available on the details of the monitoring program such as the number and array of sampling stations, whether replicates at each station are required, the protocols for sample collection, or the degree of precision in reporting the data.

## RECOMMENDATIONS

The State of Maine needs an organized framework for managing the aquaculture industry. That framework must include a mechanism to provide State agencies with the environmental information necessary to ensure that this new industry will not have an adverse effect on the environment. This process must also be designed to be efficient for the aquaculturist so they are not unduly burdened with expensive, overlapping, and time-consuming requirements of various resource agencies.

Ideally, the review process should be broad enough at the outset to identify any potential conflicts at a specific site. The monitoring program should be designed to collect an adequate amount of environmental data for impact assessment, yet be sensitive to the size of the aquaculture operation and the relative amount of effect it can have on the environment. Therefore, a "tiered" approach to the monitoring requirements should be established that recognizes that larger farms will have a greater effect on the environment than smaller farms. This "tiered" approach has been implemented in Washington State, British Columbia, and Scotland. We recommend following the classification developed by Dr. Don Weston for the State of Washington's Interim Guidelines:

Class I - annual production of less than 20,000 pounds

Class II - annual production between 20,000 and 100,000 pounds

Class III - annual production of greater than 100,000 pounds

Some of the recommendations made in this chapter are already being done to a certain extent in Maine. To assist the reader where necessary in understanding the difference between what is being proposed versus what is already being done, a short description of what is being done in Maine will follow the major recommendations in italics. More detailed information is available in the sections on Maine in the Aquaculture Regulations and Monitoring Programs chapters.

### LEASE OF AQUATIC LANDS

The State of Maine should revise their existing statutes to require that all aquaculture operations obtain a lease to use State lands. By requiring a lease for all facilities, the State will have a mechanism to implement the collection of monitoring data and ensure that farms are adequately sited.

*The State of Maine currently gives the farmer the option of applying for an aquatic lease.*

## Application information

The information submitted as part of the required aquaculture lease should be sufficient for reviewing agencies to determine the proposal's probability of causing any significant adverse impact to the environment. In addition to the existing lease information requirements, the following information should be included as part of the lease application package for all farming proposals:

- development and maintenance schedule
- size, number, and configuration of pens (during first year of operation and complete level of development)
- size, number, and placement of anchoring system
- annual production in pounds (during first year of operation and complete level of development)
- stocking density (average & maximum) (lbs/ft$^3$)
- proposed method of harvesting
- type and amount of feed to be used and method of feeding
- predator control measures
- method for cleaning nets
- waste management program (how dead fish and human wastes from the farm will be disposed, and if the fish are bled at the site, how will the blood be disposed of)
- use of antibiotics and antifoulants
- location and description of all activities within a 2,000 ft radius of the farm
- site characterization report.

*If a farmer applies for a lease, Maine has an established set of information they require as part of the lease application. In addition, the DEP also requires this type of information for their water quality certificate. Informally, DMR is expanding the amount of information they request from farmers.*

## Site Characterization

Characterizing the site provides reviewing agencies with the background environmental information necessary to determine the potential extent of environmental effects. Different size farms would have different requirements for completing the site characterization. Site characterization comprises three surveys: (1) bathymetry, (2) hydrography, and (3) diver.

**Bathymetry.** A survey of bottom features should be performed to identify any bathymetric features that may affect the accumulation of excess feed and feces. Transects should be established with a density and spacing so as to adequately characterize the bathymetry under the pens and within 300 ft of the farm perimeter. Typical spacing of transects will vary with the configuration of the pens, but transects should be established for each axis and stations along each axis should be no more than 50 ft apart.

*Maine completes a diver survey as part of its lease program. The survey is qualitative and no set transects are used.*

__Hydrography__. Characterizing the current velocities and directions is necessary for applying depth/current siting guidelines and predicting the dilution and dispersion of excess feed and fecal material. At the center of the farm, measurements should be made 6 ft below the surface and 3 ft above the bottom. Ten evenly spaced measurements should be taken throughout one complete tidal cycle during a period of "average" tides (neither neap nor spring).

Class III farms should collect drogue tracking data to estimate the fate of particulate matter and the potential for excess feed and feces to get caught in an eddy. Drogues set at a depth of 6 ft and mid-way between the bottom of the pens and the sea floor should be released from the center of the proposed site. The longer period of time that the trajectory of these drogues are tracked, the better the information on the circulation patterns will be. However, the trajectories of the drogues should be recorded long enough to include at least one complete tidal change. It is recommended that the drogues be tracked for at least 8 hours. If the drogues are transported beyond a practical tracking range, they may be reset at the center of the site during the 8 hour period.

Class III farms should also complete vertical profiles of salinity, temperature, and dissolved oxygen at the site during the summer months to assess the intensity of water column stratification. Measurements should be made at depths of 1, 10, 20, 30 ft, and at 30 ft intervals thereafter. In addition, the lease applicant should provide any available site-specific information collected during previous studies.

*DMR currently collects this type of hydrographic data as part of its leasing program.*

__Diver__. The purpose of the diver survey is to identify any potentially significant habitats under and near the proposed farm site. The design of the survey (number and spacing of transects) should be done by the Department of Marine Resources based upon information available on the site. A diver should note the presence or absence of *Beggiatoa*, substrate type, and densities of species such as lobster, scallops, demersal fish, clams, eelgrass, and other species identified by the Department of Marine Resources. The abundance of other invertebrates and fishes should be classified as "common", "rare", etc.

*DMR completes a diver survey of all farms applying for a lease.*

Completion of the site characterization with the other required lease information should give regulatory agencies sufficient background information to determine the potential effects of the proposal on the environment.

## PUBLIC NOTICE & REVIEW

In addition to the public notification presently included in the regulations, the lease application package should be distributed for comments to all resource agencies with relevant expertise such as the Department of Environmental Protection and U.S. Coast Guard. In addition, groups with a potential interest in the application such as the Maine Lobsterman's Association and the Scallop Draggers should be contacted early for their comments. This review and comment phase early in the siting process would allow potential issues to be considered in an organized framework.

*Maine requires some public notification of aquaculture leases. This recommendation expands the list of groups to provide input to the siting process.*

## SITING GUIDELINES

Until site-specific information is gathered from Maine farms through lease reports, we recommend using the depth-current guidelines developed by Dr. Weston for the State of Washington as a conservative approach to siting farms.

All available information was analyzed and synthesized in development of the Washington Guidelines. A graphical approach incorporating the pertinent variables of water depth, current velocity, and production was used to simplify application of the Guidelines. The positions of the oblique lines defining the boundary between permissible and non-permissible sites were fixed based upon information from studies of net-pens throughout the world and observations of the Puget Sound fish culture industry.

Preferring a formula to the original graphical approach, the Maine Department of Environmental Protection has developed a regression which closely approximates the original Guidelines. By knowing the anticipated production (P) and the mean current velocity (V) the applicant can calculate the depth of water required under the pens ($Z_{min}$) as:

$$Z_{min} = 0.0003\,(P) - 0.425\,(V) + 31$$

The principal difference between the formula and the graphical approach is that production is a continuous function in the formula, but was grouped into three discrete categories in the graphical approach (Class I - less than 20,000 lb/yr; Class II - 20,000 to 100,000 lb/yr; Class III - greater than 100,000 lb/yr). The change from a discrete to a continuous production variable results in a slight relaxation of depth requirements for farms with a production under 50,000 lb/yr and more stringent requirements for larger farms.

The regression equation appears to be a reasonable alternative to the graphical approach, because the depths required under the two systems are very close. One advantage of the regression equation is that organic loading is indeed a continuous function of production as is implied in the equation. A disadvantage is that users may ascribe some special status to the constants in the equation, without recognizing they were empirically derived to approximate the original graphical guidelines. We are concerned that these constants could take on "a life of their own" without any real basis.

Current velocity in the Washington Guidelines is measured 6 ft below the surface and halfway between the bottom of the pens and the seafloor to give some idea of the current regime to which the settling particle would be exposed. Additional requirements for multiple measurements at several depths were considered to place excessive demands on the applicant.

We believe it would be preferable to measure velocity three ft above the sea bottom instead of mid-way between the bottom of the pens and the seafloor. This near bottom parameter, known as $u_{100}$, is a standard measurement in studies of erosion and deposition, and would be a valuable measurement should erosion-based guidelines be adopted at a later date. Because northern Maine has such a large tidal range, there may be an opportunity with further research to establish a minimum velocity that would erode all excess feed and fecal material from a farm. Appendix B describes the concept and the known limitations.

In addition to the depth-current guidelines, farms should not be sited where their presence will adversely affect ecologically important areas, or disrupt traditional uses. Farms should be sited:

- at least 1,000 ft from all public parks
- at least ¼ mile from wildlife refuges and habitats of threatened and endangered species
- at least 500 ft from all habitats determined by the Department of Marine Resources to be of significance. These areas could include eelgrass beds and important feeding and spawning habitats for lobsters, scallops, salmon, shellfish, and other important indigenous species
- at least ½ mile from other existing fish farms unless there is a mutual agreement between farms to be closer.

*The Army Corps of Engineers Section 10 permit requires farms in Maine to be at least ¼ from federally designated areas such as national parks, wilderness areas, or wildlife refuges. This recommendation is broader in scope and is intended to include state and local recreation areas. Lease regulations in Maine require a 2,000 ft separation between farms.*

## ANNUAL MONITORING SURVEYS

Because the aquaculture industry is new and little information exists on the effects of farms in the Maine coastal environment, annual environmental surveys should be conducted. These surveys should provide adequate information to regulatory agencies to determine if adjustments to operating practices are warranted. Also, after a few years of data collection this information can be used to determine if further monitoring of a site is necessary, and whether the depth-current guidelines should be revised to reflect the specific environmental conditions in Maine.

After reviewing the monitoring programs in British Columbia, Scotland, Ireland, and Washington (Guidelines and NPDES); we recommend using the surveys established for the Washington Guidelines. These Guidelines represent an adequate balance between sufficient data collection and reasonable annual costs for monitoring. The monitoring requirements will again be based on the annual production of the farm. The monitoring program for Maine should have two components: (1) a baseline survey, and (2) annual monitoring.

### Baseline survey

Class III farms should be required to complete a baseline survey. The baseline survey provides information in addition to the site characterization completed for the lease application. The baseline survey should be undertaken once the pens are in place, but before fish are added to the pens. If the diver survey completed for the site characterization shows potential areas of concern near the proposed site, DMR should require that the baseline survey include a diver survey to be completed once the pens are in place as a position reference.

Six stations should be established for the baseline survey. Five of these stations should be located at distances of 0, 20, 50, 100, and 200 ft from the perimeter of the pens in the downcurrent direction as determined by the prevailing currents measured during the site characterization. Because environmental changes unrelated to aquaculture can occur over a large area, a sixth station should be selected as a reference station. This station should be at least 500 ft from the pens and should have similar biological and physical characteristics as the area under the pens.

The baseline survey comprises two elements: (1) sediment chemistry analysis, and (2) benthic infauna sampling.

Sediment chemistry. At each station, three replicate samples should be collected. These samples can be collected by a diver core, or by taking a subsample from a grab or box corer. Cores must be inserted at least two inches into the sediment. Each replicate must be analyzed as a distinct sample and should be analyzed for:

- total organic carbon
- total nitrogen
- grain size distribution (median phi, percent gravel, sand, silt/clay).

In addition, transparent cores should be used to note and record the redox potential discontinuity depth (change in sediment color from brown to black).

*The Section 10 permit requires new farms to collect this type of baseline data.*

**Benthic infauna**. Three replicate samples should be collected at each of the six stations. Samples can be collected by a diver using a core sampler having an area of at least 0.01 $m^2$, or by a grab or box corer having an area of at least 0.1 $m^2$. If subsamples are taken from a grab or box corer for the sediment chemistry analysis, then the remaining sample should be used for benthic analysis; provided no more than one-quarter of the surface of each sample has been removed for the sediment chemistry analysis. Each benthic sample should be sieved on a 0.5 mm screen or nested 1.0 and 0.5 mm screens. All macrofaunal organisms retained on the screen(s) should be identified to the lowest practical taxonomic level. A discussion of analysis follows later in this chapter.

**Annual monitoring**

The purposes of annual monitoring are to identify any effects of farms on sediment and water quality, and to provide data in which to review the depth-current guidelines for possible modification in the future. Annual monitoring should be required by the State of Maine as part of its lease requirements until the Department of Marine Resources determines on a case-by-case basis that a specific farm at a specific site is not having an adverse effect on the environment. The annual monitoring program should consist of two components: (1) a benthic survey, and (2) water quality sampling. Class I facilities should be exempted from annual monitoring requirements, and Class II farms should be required to conduct only a diver survey (included in the benthic survey for Class III farms).

**Benthic survey**. This survey is intended to assess the extent of solids accumulation under the pens and the biological effect of this accumulation. Benthic surveys for Class III farms includes three elements: (1) diver observations, (2) sediment chemistry, and (3) benthic sampling. As previously mentioned, Class II benthic surveys should only require diver observations.

Divers should follow the same transects as established for the site characterization effort. If accumulation is visible beyond the 200 ft transect limit, then the transect should be extended. The diver should estimate the depth of feed and feces accumulation at 20 ft intervals along each transect, and should note the distance at which the accumulation is no longer visible. In addition, the diver should survey the area for the same organisms as surveyed in the site characterization (i.e. *Beggiatoa*, lobsters, and demersal fish).

As part of the annual monitoring requirements for Class III farms, sediment chemistry and benthic infauna samples should be collected and analyzed. The station locations and protocols should be the same as those described under the baseline benthic survey.

*Presently, some farms in Maine are submitting annual monitoring reports to DEP in support of their water quality certificate. These reports include a diver survey and benthic sampling. However, the location and number of the sampling stations varies from site to site, replicate samples are not taken at each station, and sediment chemistry analyses are not done.*

*If a farm does not meet Army Corps of Engineers siting guidelines, they may be required to supply annual monitoring information. The recommendations presented here are similar to what is required by the Corps.*

Water quality survey. Class III farms should complete water quality sampling on an annual basis. The survey should be conducted during the summer months when dissolved oxygen and nutrient enrichment are of greatest concern.

Three stations should be sampled at a depth mid-way between the surface and the bottom of the pens: (1) 100 ft upcurrent of the pens, (2) 20 ft downcurrent, and (3) 100 ft downcurrent of the pens. The stations should be located so that the sample represents water passing through the greatest number of pens. Sampling should take place within one hour of slack tide. Samples should be analyzed for the following parameters:

- dissolved oxygen
- temperature
- pH
- ammonia
- nitrite/nitrate (separate or combined)
- concentration of un-ionized ammonia should be calculated.

*Water quality data is not presently collected as part of the DEP annual survey. As discussed above for the benthic survey, the Army Corps of Engineers may require this type of information for its Section 10 permit.*

## ANALYTICAL PROTOCOLS

The intent of baseline data collection and an annual monitoring program is to determine if a significant environmental change is occurring. The focus of all environmental monitoring programs related to salmon aquaculture throughout the world is on the potential changes to water quality and benthic communities. Both of these areas are dynamic in nature and are constantly in a state of flux. Water quality parameters such as dissolved oxygen vary naturally through the year because of a variety of influences, and the number and type of species in benthic communities change due to factors such as the interaction between species.

This section describes the approach we recommend for evaluating the potential effect of farms. Water quality data can be compared against general standards for selected parameters. Annual monitoring data that varies significantly from the standard would be a cause for concern. Standard ecological indices are available to assist in evaluating whether annual monitoring data indicates a change is occurring in benthic communities as a result of a farm. However, caution is necessary in using these formulas. There are no clear thresholds for determining what constitutes a significant benthic impact. These indices are suggested as a starting point for evaluation, but they should be interpreted by a qualified marine ecologist familiar with indigenous benthic community dynamics.

Water quality

Water quality data analysis should be done for all parameters measured. The data analysis should compare data between the stations and should compare annual data to the baseline data. Comparison between the 100 ft upcurrent and 100 ft downcurrent stations is made for temperature, DO, and pH. A direct comparison should use the average of the three replicates at each station.

In evaluating data from annual monitoring reports, a standard is needed for comparison. Some states such as Washington have established a system of classifying the water quality of all water bodies based on commonly measured parameters such as dissolved oxygen, pH, and temperature. Based upon an ambient water quality monitoring program, this system provides a means of determining baseline conditions in an area, and whether or not an activity is having an impact on the environment. The State of Maine's water quality classification system (SA, SB, and SC) uses two quantifiable criteria: (1) the percent saturation of dissolved oxygen, and (2) number of enterococcus bacteria of human origin.

The suggested water quality limits in Table 3 are taken from typical water quality standards for marine waters and from estimates of reasonable effluent characteristics found in the literature.

Based on the water quality criteria given in Table 3, no comparison between stations is necessary if the upper limit is exceeded at both stations, or if both stations are less than the lower limit. If one station is outside the allowable limit, then the maximum difference between stations is given by the increase or decrease limit.

There is no specific limit for nitrogen. The recommendation is to locate farms in areas that will not be subject to substantial increases in algae (micro- and macro-) from the additional nitrogen. The objective is to locate fish farms in areas where the additional nitrogen is small compared to the natural flux of nitrogen. In areas of high flushing that have a high degree of exchange with the open sea, nitrogen inputs from fish farms are not likely to have a measurable effect on algal production. Enclosed embayments would be most susceptible to increased algal production from fish farms. In these areas, water quality models could be used to estimate the effect of the farms on nitrogen concentrations or phytoplankton biomass.

One approach used in Washington to assess the potential effect of farms on phytoplankton production is to estimate the tidal flux of nitrogen. The tidal flux of nitrogen is computed as the product of the tidal volume and the nitrogen concentration in the tidal waters. This is a conservative estimate because it ignores any nitrogen input from tributaries and sediments. The nitrogen contribution from the fish farm can be estimated using standard literature values for ammonia and urea excretion from salmon culture. If the nitrogen flux from the farm is less than 1 percent of the natural nitrogen flux, no significant algal blooms would be expected from the farming operation. Although an acceptable level of increase in the nitrogen concentration is not known, the 1 percent figure is considered conservative.

Table 3. Water quality criteria for maximum allowable difference between stations.

| Parameter | Condition |
|---|---|
| Dissolved Oxygen (mg/L) | |
| lower limit | 6.0 |
| decrease limit[a] | 0.2 |
| Temperature (°C) | |
| upper limit | 16 |
| increase limit[b] | 0.3 |
| pH | |
| range limit | 7.0-8.5 |
| inc./dec. limit[c] | +/-0.5 |

[a] decrease limit if either station less than 6.0 mg/L
[b] increase limit if either station greater than 16 °C
[c] increase or decrease if either station outside of range

The monitoring results should also be compared to the baseline survey using a simple t-test. The mean at each station is compared to the mean from the baseline survey. The test hypothesis is that the baseline sampling mean and the mean at each station are statistically equal. The recommended level of significance is 0.05.

Finally, the monitoring results should be compared to previous monitoring results to observe trends in the water quality parameters tested. This can be as simple as plotting the annual monitoring results and looking for increasing or decreasing trends to the data. A trend analysis is useful to project future conditions and to look for potential adverse effects. If the water quality trends show a continual adverse trend, it may be necessary to do a more detailed study of the bay or inlet to identify sources of the problem.

Benthic analysis

Interpreting results from benthic data collected in a monitoring program should be done by a person knowledgeable in local benthic community dynamics. Relative populations of benthic organisms will vary from site to site, and changes in those benthic populations over time can also occur naturally. The following standard ecological indices are recommended as analytical tools, however, the results should be interpreted by a person familiar with local benthic communities. Definitive threshold numbers for the indices that could be universally applied to all sites on the coast of Maine to determine whether fish farms are having an impact on the environment cannot be derived.

Sample Replication. To ensure the validity of the analyses, sample replicates need to be taken from the same community or benthic organism assemblage (Hurlburt 1984). Replication can be determined using the Bray Curtis index with an arbitrary value of the index used to determine replication. Sample comparisons should be based on species-sample matrices from individual station replicates. The analysis can be run on that matrix using any appropriate clustering algorithm. Results are best displayed as optimally rotated dendrograms.

Individual sample replicates with low similarity values to all other replicates of the same sample should be examined, and if necessary, treated separately. The aberrant replicates are assumed to be sampling different, but adjacent patches of organisms, and thus unsuitable as replicates (Hurlburt 1984).

Ecological Analyses. Once replication has been confirmed, or the lack thereof adjusted for, benthic infaunal community structure analysis begins. This requires the comparison of station by station species abundance patterns. The basic data set is a species-abundance list for each station, detailing the taxa, and giving the mean abundances. Often the total species list includes a number of rare taxa unnecessary to characterize the community. For the purpose of describing the sample, all species that account for greater than 1 percent of the individuals at any station should be included. All index calculations, however, need to be done with the complete data set.

In addition, it is often useful to compare the taxa found with a list of known pollution tolerant organisms. Changes in the abundances of these indicator taxa is often indicative of drastic changes in the benthos (Pearson and Rosenberg 1978).

Sample comparisons should be based on species-sample matrices from pooled station replicates. The analysis can be run on that matrix using any appropriate clustering algorithm. Results are displayed as optimally rotated dendrograms.

Comparison of the basic species lists is the first step in the analysis of potential changes. Subsequent evaluations of the Bray-Curtis index quantify any changes. Comparisons utilizing this index give direct, quantitative, measures of change. The values generated with the index can be used to focus specific examination of sample data. For example, if there is low similarity between subsequent samples from the same area, this will be noticeable in examination of the B-C index values, and the specific data can be examined for the changes.

Analyses of the taxonomic data requires the use of basic data such as abundances and dominance, but also ecological indices. Concurrently, three indices are used in the analyses. These are the Shannon-Wiener Index, Simpson's Index, and the Evenness Index (Poole 1974). All three give somewhat different information about the organism distributions. The information from each index is complementary to the others, thus all three are used in analyses.

Upon receipt of taxonomic information from the various specialists, these data are summarized by station and site. Descriptive parameters such as abundance, station diversity (using both the Shannon-Wiener Index, and Simpson's Index), and evenness (the J index) are determined (Poole 1974). From this information, mean values and error estimates for each parameter are derived.

To determine ecological change, there are several useful indices. The first index is the Bray-Curtis Index of (Dis)similarity. This index has many other names in the literature, but is listed most frequently as the Bray-Curtis Index of (Dis)similarity, Czekanowski's Index, or Proportional Similarity.

*Bray-Curtis Index*

$$\text{The Bray-Curtis index} = D = 1 - \frac{\Sigma \mid p_{ij} - p_{kj} \mid}{\Sigma \, (p_{ij} + p_{kj})}$$

Where: $p_{ij}$ = the proportion of taxon "j" in sample "i", and
$p_{kj}$ = the proportion of taxon "j" in sample "k".

The Bray-Curtis index (values range from 0 to 1) measures proportional abundances between stations, and is relatively independent of sample size. As formulated here, 0 indicates complete similarity, and 1 complete dissimilarity. The index can be also be formulated without the initial 1 in the formula. In those cases, 0 indicates complete dissimilarity and 1 indicates complete similarity. Both formulations are commonly used in the literature. Over the range of total numbers of organisms collected here, this index provides replicable and reliable indications of proportional dissimilarity among stations (Bloom 1981).

The ecological diversity of the samples are compared using three indices, the Shannon-Wiener index, the Evenness index, and Simpson's index (Poole 1974).

*Shannon-Weiner Index*

$$\text{The Shannon-Wiener index} = H' = -\sum_{i=1}^{s} p_i \ln p_i \,,$$

where: $p_i$ = proportion of taxon "i" in the sample, and
$s$ = the total number of species in the sample.

The Shannon-Wiener index ranges upward from 0, and gives a measure of the amount of new information contained in each individual specimen collected. Where the sample is dominated by a few taxa, the amount of new information likely to be gained by noting any given specimen is small. Where the sample is diverse, new information is more likely to be gained since each new specimen might be a representative of a previously unsampled species. Consequently, relatively high values for H' indicate diverse (i.e. normal, natural, communities) and low values indicate stressed or polluted communities.

*Evenness Index*

$$\text{The evenness index} = J = \frac{H'}{\ln(s)}.$$

The evenness index is a measure of the amount of distribution of the individuals in a sample related to the number of taxa in that sample. Evenness is calculated by dividing the Shannon-Wiener index by the natural logarithm of the number of taxa. The maximum amount of diversity of a sample of size "s" is found if each species is represented only by one individual. The evenness index ranges from 0 to 1, and would be 0 if all individuals were found in only one species, and would be 1 if each species was represented by only one individual.

Thus, J measures the amount that the sample deviates from a totally even distribution. Diverse natural communities have J values of 0.5 or higher. Polluted or stressed communities can have values from 0.3 or lower.

*Simpson's Index*

$$\text{Simpson's index} = C = \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)}$$

where: $n_i$ = the number of individuals in species "i", and
$N$ = the total number of individuals in the sample.

Simpson's index ranges from 0 to 1, and measures the degree the sample is numerically dominated by one or a few taxa. Values near 0 indicate a diverse array, while those near 1 reflect dominance by one taxon.

Simpson's index is biased reflecting dominance while the Evenness index reflects dominance and the total number of taxa. The Shannon-Wiener index measures diversity in a strictly comparable, information theory format. Thus they all address somewhat different aspects of the same question.

Relating changes in organism distributions to environmental changes is relatively straight forward. The most important environmental changes are substrate related changes such as changes in sediment particle size distributions.

Comparisons of abundances, biomasses, or other data are made using the appropriate statistical procedure, primarily analysis of variance (ANOVA), as presented by any standard statistical software package such as STATGRAPHICS (STSC 1986-1989). The ecological indices can easily be written in Lotus 1-2-3 as macros using the station species abundance data as the basis. Alternatively, they can be calculated using the Community Analysis System of programs (this is presently undergoing testing, but can be purchased from Ecological Data Consultants, P. O. Box 760, Archer, FL 32618).

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# APPENDICES

## APPENDIX A

## ESTIMATED COSTS FOR TYPICAL MONITORING PARAMETERS

In reviewing the requirements for Washington, British Columbia, Scotland, and Ireland; a number of parameters are common to many monitoring programs. Table A-1 lists the common parameters and an estimated cost for analyzing them. Costs in Table A-1 do not include the costs associated with collecting the samples, analyzing the data, or preparing an organized report.

Table A-1. Environmental parameters commonly evaluated for salmon farming operations and their associated analytical costs (1990).

| Parameter | Range of costs per sample | Hypothetical Farm[a] |
|---|---|---|
| **Water Quality** | | |
| Dissolved oxygen | $5 - 8 | $45 - 72 |
| pH | $5 - 8 | $45 - 72 |
| Salinity | $16 - 20 | $144 - 180 |
| Ammonia | $10 - 13 | $90 - 117 |
| Nitrite/Nitrate | $10 - 13 | $90 - 117 |
| Un-ionized ammonia | $5 - 8 | $45 - 72 |
| | | $459 - 630 |
| **Sediment Chemistry** | | |
| Total organic carbon | $40 - 50 | $600 - 750 |
| Kjeldahl nitrogen | $20 - 25 | $300 - 375 |
| Grain size | $90 - 110 | $1,350 - 1,650 |
| | | $2,250 - 2,775 |
| **Benthic Samples (diver core)** | | |
| Screen and sort | $70 - 90 | $1,050 - 1,350 |
| Taxonomy | $80 - 100 | $1,200 - 1,500 |
| | | $2,250 - 2,850 |
| **Benthic samples (Van Veen grab)[b]** | | |
| Screen and sort | $300 - 400 | $4,500 - 6,000 |
| Taxonomy | $110 - 120 | 1,650 - 1,800 |
| | | $6,150 - 7,800 |

[a] 3 stations, 3 replicates for water quality
5 stations, 3 replicates for benthos and sediment quality

[b] Benthic costs are proportional to the volume of the sample. A Van Veen grab sample is larger than a diver core sample.

## APPENDIX B

## THE POTENTIAL FOR SITING GUIDELINES BASED ON EROSIONAL CURRENT VELOCITIES

The Washington Guidelines were based upon the maximization of horizontal dispersion of solid wastes during settling. In addition to siting farms based on the depth under the pens and existing currents, another approach to siting farms would be to allow farms to be sited regardless of depth under the pens if near-bottom current velocities were adequate to erode feed and fecal matter on a frequent basis.

Defining these conditions, however, is difficult for several reasons. It is not clear if attainment of erosive velocities in every tidal cycle is necessary, or how long velocities of this magnitude must persist to avoid no net deposition. It is also difficult to model the erosion of fish fecal material, and the necessary velocities are likely to depend upon the extent of bacterial adhesion among the particles. As an approximation, however, "back-of-the-envelope" calculations can be made to predict the velocities necessary to erode feed pellets. Since pellets are much larger and denser than fecal matter, feces should be eroded at considerably lower velocities, and the approach should be very conservative.

The current velocity needed to erode a feed pellet, as measured 1 m above the substrate ($u_{100}$), can be calculated using a Shield's plot and the following equations:

$$D_* = \frac{(\rho_s - \rho)\, g\, D^3}{\rho \gamma}$$

$$\tau_c = \tau_* (\rho_s - \rho)\, g\, D$$

$$\mu_{100} = \sqrt{\frac{2\, \tau_c}{\rho\, C_D}}$$

where
$\rho$ = density of water (1 g/cc)
$\rho_s$ = density of feed pellet
$g$ = acceleration due to gravity (980 cm/sec)
$D$ = diameter of feed pellet
$\gamma$ = viscosity of water (0.01 cS)
$C_d$ = drag coefficient. A generic value of 0.003 based on a survey of Puget Sound sediments has been used (Sternberg 1972)

The above calculations require the knowledge of feed pellet diameter and density. The size of the feed pellet provided will vary depending upon the life stage of the fish, but is likely to vary between 3 and 10 mm. Feed density will vary depending upon the feed type used since dry feed has a moisture content of less than 20 percent and moist pellets have water contents between 20 and 50 percent. No specific information could be found on pellet density and given the variation among feed types, precise quantification is unwarranted, so it assumed that density is likely to be in the range of 1.3 to 1.7 g/cc. Given this range of density and pellet size, Table B-1 shows the velocity needed to erode feed pellets.

Table B-1. Calculated current velocity (cm/sec) 1 m above the bottom ($u_{100}$) necessary to erode feed pellets of different sizes.

| Pellet density (g/cc) | Pellet size (mm) 3 | 6 | 10 |
|---|---|---|---|
| 1.3 | 54 | 76 | 106 |
| 1.7 | 77 | 121 | 160 |

It is apparent that a velocity of about 100 cm/sec (roughly 2 knots), measured 1 m above the bottom would erode all but the largest feed pellets, and that fecal material is likely to be removed at a considerably lower velocity. For comparative purposes, a $u_{100}$ of 94 cm/sec will erode coarse sand (less than 2 mm diameter). Therefore, in areas where sand has been eroded, such as pebble, cobble and boulder substrates, there is unlikely to be accumulation of feed except in depressions.

It may be possible to use erosion calculations such as these in siting decisions, but several difficulties exist. As discussed, there is considerable uncertainty involved in calculating the velocities required for erosion of feed and especially for feces. The conservative approximations done here would probably be adequately protective, but many areas would lack the required 100 cm/sec flow. There are also many questions regarding the frequency at which erosive velocities must occur and how long they should persist. Without further research, it would seem more prudent to use a dispersion-based siting approach rather than to permit deposition beneath the farm on the presumption of erosion at a later time.