The Impacts of Salmon Aquaculture:
The Difficulties of Establishing Acceptability Limits and Standards

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Introduction

The environmental impacts of salmon aquaculture have been extensively studied and documented around the world and are generally well understood. Yet, despite the intensity and extent of these studies, the definition of acceptable limits of impact has remained elusive.

There is little debate over whether impacts occur or not, for they do. These impacts, however, vary widely depending on the physical conditions in which an operation is installed, the level of production, the technologies employed, and the husbandry practices of the operator. Furthermore, the marine environment is extremely dynamic and net-pen facilities therefore represent a diffuse source of pollution and the boundaries of effect are consequently difficult to define.

The impacts of net-pen aquaculture can be generally separated into water column and sea floor, or benthic, effects. Water column effects, because of the dissolved or suspended nature of the pollutants, are far more difficult to measure and track than benthic effects. Fortunately, advances in computing technology, combined with extensive modeling efforts, now allow simulation and, to a certain extent, prediction of water column, as well as benthic, effects. The application of modeling to the environmental impacts of net-pen aquaculture are discussed by Silvert, (2000).

This paper focuses principally on dealing with the determination of acceptable limits for benthic impacts. To this end, summaries are provided of the various approaches taken around the world by the major salmon growing countries to define acceptable and unacceptable limits for impacts. Any discussion of determination of acceptability, however, requires an understanding of the data collection process that has provided the information necessary to make such determinations. The paper is therefore separated into two parts. The first describes the Finfish Aquaculture Monitoring Program of the State of Maine and presents the results obtained since its implementation in 1992. The second discusses the regulatory framework in which determinations of acceptability/unacceptability are made, drawing heavily on the Maine experience, and summarizes similar efforts from around the world.

Part I. Summary of Maine Finfish aquaculture Monitoring Program and Results 1992-1999

The Maine Finfish Aquaculture Monitoring Program (FAMP) consists of five principal components:

- Monthly confidential production reporting by lease-holders
- Annual dissolved oxygen water column profiles in September
- Spring video monitoring beneath and adjacent to the net-pens in May/June
- Fall video monitoring beneath and adjacent to the net-pens in September/October
- Biennial Fall benthic macrofauna community analyses

The first component is used by the Maine Department of Marine Resources (DMR), first, to track changes in production at sites over time against which monitoring results are compared and, second, for assessment of a production tax that is used to fund the monitoring program. The remaining four components comprise the field monitoring portion of the FAMP. The following is a brief explanation of each of these components and includes a description of the procedures used, a summary of results to-date, and how the results are interpreted. A full explanation of procedures, results and interpretation can be found in Heinig, (2000).

Water Column Monitoring

Dissolved Oxygen Monitoring (D.O.)

According to the Maine FAMP procedures and protocols, dissolved oxygen profiles are taken once annually at all active net-pen sites between September and October, the period of highest temperature-production. Profiles are collected at three specific distances from the net-pen structures: 1) at 100 meters, or ~300 feet, upcurrent of the structure, 2) within 5 meters, or ~15 feet, downcurrent of the structure, and 3) within 100 meters, or ~300 feet downcurrent of the structure. Profiles are collected using a SeaBird SBE 19 SEACAT Profiler.

The results obtained at all sites are summarized each year in an annual Water Quality Report prepared for the Maine DMR. The report includes a list of the ***minimum*** dissolved oxygen saturation values observed for each cast with specific reference to site and distance from the structures. The SeaBird SBE 19 SEACAT Profiler collects sensor data every 0.5 seconds and records between 20 to 40 scans during an average descending cast from surface to bottom in 50-60 feet of water; each scan contains a data point for each parameter measured. As a result, the minimum reported value for each cast represents the worst situation recorded during a given cast. This minimum value is used to determine whether a violation of water quality standards occurs *anywhere* in the water column, but it may not necessarily be representative of the entire profile or the entire water column at the station. Indeed, D.O. throughout the water column is usually substantially higher than the minimum reported value for a cast.

Table I-1, below, summarizes the composite results of dissolved oxygen monitoring around net-pen systems in Maine for the years 1994-1998, excepting 1997 when sampling was not conducted.

Table I-1Summary of mean, maximum, and minimum D. O. percent saturation for all distances across all sites for each year of sampling

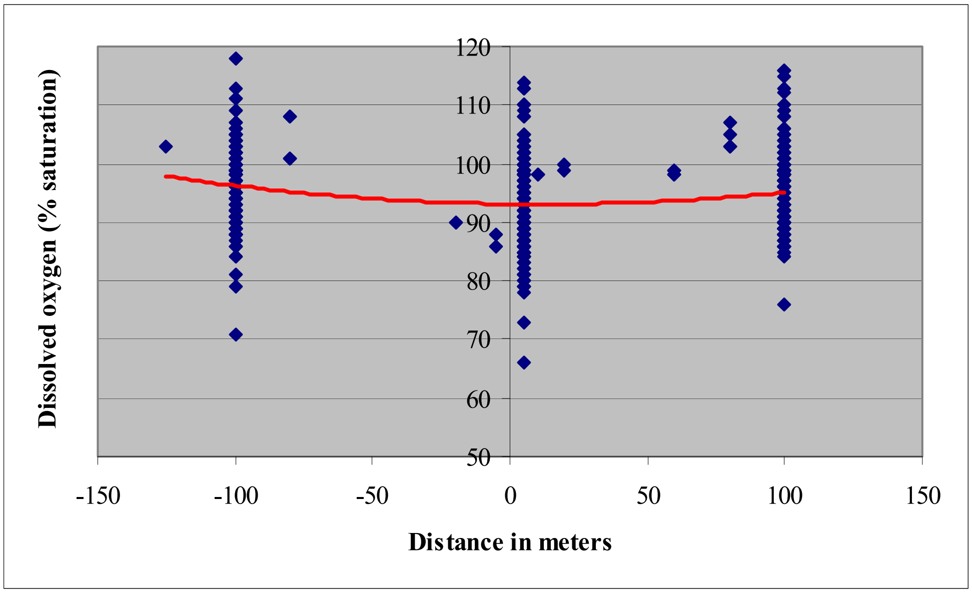
Year		**100m UP***	**5m DN***	**100m DN***	**Diff. 100U-5D**	**Diff. 100U-100D**
1994	**Mean**	**101.6 ± 1.3**	**96.7 ± 2.6**	**100.2 ± 1.4**	**4.8 ± 2.2**	**1.4 ± 1.1**
	Max	108.0	105.0	107.0	22.0	6.0
	Min	93.0	80.5	92.5	-0.8	-4.0
1995	**Mean**	**90.0 ± 0.8**	**87.4 ± 0.7**	**89.0 ± 0.6**	**2.7 ± 0.9**	**1.0 ± 0.7**
	Max	94.0	92.0	92.5	8.5	4.8
	Min	84.0	84.0	86.0	-1.5	-3.5
1996	**Mean**	**95.5 ± 1.4**	**92.7 ± 1.6**	**93.7 ± 1.2**	**2.8 ± 1.1**	**1.8 ± 0.7**
	Max	104.5	103.0	103.0	9.5	5.3
	Min	89.5	86.0	89.8	-1.5	-2.5
1997		**No dissolved oxygen sampling conducted**				
1998	**Mean**	**102.3 ± 2.0**	**97.6 ± 2.4**	**99.9 ± 2.3**	**4.6 ± 1.4**	**2.3 ± 1.4**
	Max	118.0	113.5	115.5	16.0	14.4
	Min	96.5	85.5	88.4	0.0	-5.0

As the summary data show, the difference between upcurrent and downcurrent values in D.O. saturation are generally small, that is, the impact on ambient dissolved oxygen levels is relatively small, the vast majority of readings being well above the 85% saturation threshold established by the Maine Department of Environmental Protection (DEP).

Over the period dissolved oxygen sampling has been carried out, the mean difference between the 100m upcurrent saturation minima and the 5m downcurrent saturation minima, or mean dissolved oxygen saturation depression, across all sites ranges between 2.7 and 4.8 percentage points with individual cast readings ranging between a saturation depression of 22.0 percentage points and a saturation increase of 1.5 percentage points. The mean difference between the 100m upcurrent and 100m downcurrent saturation minima, again across all sites and all years of sampling, ranges between 1.0 and 2.3 percentage points. The individual cast values for the 100m upcurrent versus 100m downcurrent range from a saturation depression of 14.4 percentage points and a saturation increase of 5.0 percentage points.

The composite data for all sites, for ***all*** years of sampling, are presented graphically in Figure I-1.

Figure I-1
Dissolved oxygen (% saturation) at various distances from net pens, 1992-98



The Y-axis represents percent saturation of dissolved oxygen. The X-axis represents the distance in meters from the net-pen at which samples were taken, where -100 meters represents the *upcurrent* sampling stations, 0 meters the *net-pen* system, and +100 meters the *downcurrent* sampling stations. Although sampling normally takes place at 100 upcurrent, 5 meters downcurrent and 100 meters downcurrent, at times the net-pen configuration require samples to be taken at other distances, thus accounting for the points that are out of alignment from the three main distances.

As the trend line shows, the impact on ambient dissolved oxygen levels is relatively small with both upcurrent to downcurrent averages of ~95% saturation.

With respect to violations, since 1994, only 47 violations of the of 85% saturation regulatory threshold have been recorded out of the 1085 profiles taken. With few exceptions, all of the violations have been recorded within 5 meters of net-pens and represent only 4% of the total number of profiles taken between 1992-98.

In summary, all of the data collected to-date suggests that, with only a few exceptions, finfish culture operations have limited impact on ambient dissolved oxygen levels, and even where D.O. depression occurs adjacent to the net-pen, D.O. levels recover rapidly to near upcurrent, or ambient, levels within a short distance of the net-pen. This is consistent with conclusions reached elsewhere.

Benthic impacts

Video monitoring

Video monitoring is carried out semi-annually in the Spring and Fall of each year. The primary purpose of the underwater video recording is to provide a visual record of conditions adjacent to and beneath net-pens systems for objective, rapid, albeit superficial, documentation and evaluation of changes in conditions beneath and adjacent to net-pen systems. This component of the monitoring program provides an instantaneous view of conditions beneath and adjacent to the net-pens, but also serves as a comparative tool for evaluation of visible changes over time.

Video recordings are begun at the distant end of a 60m transect, continue either adjacent to or directly beneath the net-pen(s) and extend along a transect line to a distance 60m downcurrent of the net-pen(s). The recordings are reviewed as soon after being taken as possible, in some cases immediately following the inspection dive. During review, observations are made of sediment type, existence and extent of bacterial mats, *Beggiatoa* sp.-type, outgassing, the abundance and distribution of resident flora and epifauna, and the presence of any net-pen-related debris, *e.g.* nets, net-pen parts, etc.

Since the FAMP's implementation in 1992, a total of 707 video recordings have been made representing approximately 220-250 hours of footage. As a monitoring tool, video recording has proven to be a relatively inexpensive, rapid, and highly effective means of visually representing and documenting conditions beneath and adjacent to net-pen systems. Furthermore, the video recordings, combined with "hardcopy" graphic representations of those images, have proven to be an effective way of comparing sequential observations.

Generally speaking, with the exception of a few selected sites, conditions adjacent to and directly beneath finfish net-pen systems, based on visual observations, appear to have improved since the initiation of the FAMP in 1992. The trend toward improvement, or at least stabilization, of conditions beneath and adjacent to net-pen systems in Maine was initially reported in 1995 (Heinig, 1995) and appears to be continuing at most sites. This trend toward improvement may be attributable to several factors. Two factors stand out as most important: 1) the continued use of dry feed over moist feed and 2) the need for improved cost-efficiency in response to increased global competition.

Regarding the first, the increased structural integrity of the dry feed pellets appears to have significantly reduced the amount of non-intercepted feed reaching the bottom, thus reducing the carbon load to the bottom. Dry feed pellets tend to retain their integrity within the water column longer than moist feed and have less "fines" or dust associated with them. Consequently, dry feed appears to have a higher rate of interception within the net-pen, resulting in higher consumption by the fish and reduced export beyond the net pen. This has ultimately reduced the organic load to the bottom in the vicinity of the net-pen(s). The reduction in fines similarly reduces loading to the bottom by minimizing the amount of feed material too small for interception. With respect to the second, the increased competition in the marketplace has significantly depressed the price of salmon over the past several years. This, in turn, has significantly impacted the profitability of salmon farming, necessitating cost reductions, particularly in the areas of labor and feed, and improved efficiency. Consequently, considerable attention has been focused on the automation, control, and efficiency of feeding. The increased use of sophisticated computer/camera-assisted feeding systems and increased attention to efficiency on the part of feeding teams have also resulted in less feed reaching the bottom.

Nevertheless, significant deterioration of the bottom beneath and immediately adjacent to net-pens has been observed at certain sites over the years as evidenced by extensive *Beggiatoa* sp.-type mats, anoxia, and occasional gassing. Excessive deterioration is usually associated with excessive feeding or extended use of a site at high production levels. The FAMP has been successful at detecting these situations and, in most cases, swift corrective action has been taken by industry.

However, despite the improvement in benthic impacts related to organic loading, attention has recently been drawn to the numbers of both predator and grower nets found beneath net-pens. The temporary lowering of nets to the bottom for a limited time to allow natural cleaning is a common practice, for there are times when fouling on the nets is great enough to preclude their being raised out of the water. At certain sites, however, nets have been repeatedly seen in the same location indicating that the nets are being left on the bottom for prolonged periods of time.

The potential alteration of the benthos associated with this practice is discussed further in Part II, but perhaps of greater, immediate concern is the fact that many of the nets are slowly becoming buried in the bottom. If not removed, these will eventually become completely buried making detection difficult, if not impossible. Since these nets are made of synthetic materials they will likely persist in the bottom for a considerable period of time and could eventually pose an obstruction and hazard to mobile fishing gear if and when the aquaculture operations temporarily or permanently cease and floating structures are removed. Recognizing the actual and potential problems posed by these nets, beginning in the Spring of 1998, the scope of work for the FAMP was expanded to include a task specifically focused on the location and tagging of aquaculture-related nets found on the bottom.

Infauna analyses

The benthic monitoring component of the Maine FAMP focuses on impacts to the sea floor directly beneath and adjacent to the net-pens. The purpose of benthic monitoring is to detect and document any changes that take place in the macrofaunal community structure on the sites as a result of the net-pen system operations. This component previously included sediment analyses of composition, or granulometry, visual redox level, and Total Organic Carbon (TOC). These analyses were dropped in the Fall of 1996 after little correlation could be found between results of these analyses and environmental effects.

Since the FAMP began in 1992, 476 samples have been processed, (Heinig, 1995, 1996, 1997, 1998, 1999). Benthic monitoring and the associated macrofaunal community structure analyses represent the most time-consuming and expensive part of the FAMP. Although costly, these analyses yield a great deal of information and provide a clearer understanding of the subtle, yet complex changes which take place beneath the net-pen systems once the systems are installed and operations begin.

Net-pen operations are first subject to benthic monitoring after the first 18-months of operation, *i.e.* at the end of first year-class production, and every other year thereafter. Sampling is carried out immediately adjacent to and at various distances from the net-pens, the distances being site-specific depending on currents, net-pen arrangement, production levels, depth, etc.

Procedurally, single sediment cores for benthic macrofauna analysis are taken at pre-selected stations around and under the net-pen systems using 4 in. diameter PVC pipe coring devices. These are inserted to a depth of 10 cm or to resistance, whichever is reached first. The contents of the cores are washed through a U.S. Standard No. 50 sieve (1.0 mm mesh), the retained material is fixed in 10% formalin, and the organisms sorted according to standard procedures.

Four indices are used to evaluate the benthic condition. First is *abundance*, a derivative of the total number of organisms, reported as number of organisms per $0.1m^2$, or

$$\textit{Abundance} = \text{total no. organisms} \quad 12.34$$

where 12.34 is the coefficient to convert the surface area sampled by the 4-inch diameter corer to $0.1m^2$.

Second*, species richness,* is simply the number of individual species represented in the sample. Species richness serves as an index of diversity indicating either a heterogeneous community where numerous species are represented, or a homogeneous community where only a few species are present.

Third is *relative diversity*, also referred to as *evenness*, an index that relates the number of species represented to the number of individuals of each species and reflects the extent of dominance of one or more groups of organisms over the others. Elaborating briefly, while a large number of species may be represented in a given core sample, most of the species may be represented by a small number of individuals, while one or more may be represented by the majority of the individuals found, a condition referred to as *hyperdominance*. Consequently, while the species richness of a sample may be high, the representation of the species, *relative to one another*, may be far from even. The diversity index *H* used in the FAMP (Shannon, 1948) is expressed as

$$H = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

where n is the total number of organisms in the sample, k is the number of species in the sample, and f_i is the number of individuals in each species i.

The theoretical maximum diversity is given as

$$H_{max} = \log k$$

and the following proportion can be used to compare the actual and theoretical maximum diversity, thus yielding a relative diversity *J*

$$J = H/H_{max}$$

Theoretically, under natural, unaffected conditions actual diversity (H) should approach the theoretical maximum diversity (H_{max}) and *J* should therefore approach 1, (today, *natural, unaffected* conditions are virtually impossible to find in Maine due to the extent of fishing activity along the bottom). Where environmental degradation favors certain tolerant species, the *actual* diversity can be considerably less than the theoretical maximum and *J* may approach 0. Theoretically then, the smaller *J* becomes, the more affected the environment is assumed to be, although this is not *always* necessarily the case.

The fourth index is *hyperdominance*, expressed as the percent of the total population represented by the indicator species *Capitella capitata*. *C. capitata* is ubiquitous, is very tolerant of hypoxic, or oxygen depleted, conditions and is therefore often used as an indicator of environmental degradation, particularly degradation associated with organic loading. A determination of % *C. capitata* therefore allows a comparison of this species' relative abundance from one sample to another and provides some indication of the bottom conditions.

Summary of results

Relative diversity (RD), although sometimes difficult to interpret, has proven to be a fairly good indicator of condition of the benthos. The range of distribution of the RD values is similar at the three primary sampling distances, 0, 30 and 60 meters, reflecting the wide range of impacts that net-pen systems can have depending on location, level of production, and husbandry practices. Despite the broad range, the clustering of values changes significantly with distance from the net-pen. Near the net-pen, values are nearly equally distributed along the entire range from 0.0 to 1.0. At 30 meters, the values are clustered between 0.4 and 1.0, and at 60 meters, between 0.6 and 1.0, a clearly upward trend. Extrapolation of these results suggests that the maximum theoretical value is reached at a distance of just over 80 meters from the net-pens. Values calculated from baseline survey samples under pre-development conditions indicate that relative diversity values for ambient conditions normally range between 0.75 and 0.90, thus, the range of values observed at the 60 meter distance indicates that benthic conditions, at least as represented by this index, reach or approach ambient values only a short distance from the net-pen systems. These results continue to support the conclusion that the effects of the net-pen operations are generally confined to within 60-80 meters of the structures.

Species richness generally shows a slight upward trend over distance from the net-pens. However, species richness, as a function of time, has declined somewhat steadily from 1992 through 1998 as shown in Table I-2.

Table I-2Species richness data for FAMP samples taken during the period 1992-98

Year	No. samples	Mean no. species	Max. no. species	Min. no. species
1992	54	26.9.	70	1
1993	42	22.8	49	1
1994	64	23.1	60	1
1995	63	16.7	48	0
1996	57	12.2	39	1
1997	43	13.0	37	1
1998	66	10.9	30	1

This downward trend may be cause for concern if it continues, but some of the observed decline in species richness can be attributed to changes made in the FAMP procedures and protocols, as well as operational changes within the industry. The fluctuations observed between 1992, 1993 and 1994 are likely due to the changes made during that period in the type of feed used and the delivery systems and practices, already discussed above. The sharp decline seen in 1995 is directly related to the change in the FAMP sieving protocol that changed the standard sieve mesh size from 0.5 mm to 1.0 mm. The reasons for the continued decline since 1995 are not as clear, but may simply be related to the difference in habitats sampled in alternate years, as well as the proportionally greater number of samples taken in close proximity to the net-pens in recent years as a result of the FAMP's increased focus on areas of greatest impact.

Abundance generally decreases significantly with distance from the net-pens, particularly at high production sites in the macrotidal, *i.e.* tidal amplitudes of 7-8 meters, areas of the State where abundance can vary by an order of magnitude over 60 meters. By contrast, at moderate-level production sites located in mesotidal, *i.e.* tidal amplitudes of 3-4 meters, areas where benthic impact is often greater immediately adjacent to the net-pens, abundance is often reduced within close proximity to the net-pens, but increases, albeit moderately, with increasing distance.

As with species richness, analysis of abundance as a function of time has been confounded by the protocol change in the FAMP. Nevertheless, data within the periods 1992-94 and 1995 to present can be compared directly. Between 1992 and 1994 there was a significant decrease in the range of abundance. This decrease has been attributed, at least in part, to the shift from moist to dry feed already discussed above. Since 1995, abundance has remained relatively constant industry-wide, although significant fluctuations still occur within sites in response to changes in production.

Hyperdominance by *C. capitata*, as a percent of total population, varies widely from site-to-site and can range from 0% to nearly 100% at any given distance from the net-pens, even though dominance by *C. capitata* generally declines with distance. The wide range of values reflects an inherent difficulty in interpreting percent dominance data, for similar percent dominance values seldom correspond to similar population densities. For example, complete species dominance (90-100%) may in one case (93.0%) represent a very dense population, *i.e.* ~90,000 *C. capitata*/0.1 m^2, yet in another similar case (93.3%) represent only a moderate population density, *i.e.* ~2,000 *C. capitata*/0.1 m^2. Therefore, hyperdominance values need to be interpreted cautiously and only as they relate to other indices.

Indeed, while each of these indices provides a means of interpreting the complex of data generated through the benthic analyses, no single index, taken alone, can be relied upon to reflect the complete and complex nature of the benthic community. The danger of relying on a single parameter can be further illustrated by the case where two samples have similar J values, *e.g.* 0.335 and 0.314, with corresponding % *C. capitata* values of 69% and 79%, and species richness values of 64 and 10, respectively. Based on J or % *C. capitata*, the two samples may appear rather similar, but the fact that the first sample comes from an area supporting 64 species and the second from conditions supporting only 10 species suggests that the latter may represents a more degraded environmental condition than the former.

In summary, all of the benthic data presented above support the conclusion that impacts to the benthos resulting from finfish net pet aquaculture operations are generally confined to the immediate vicinity of the net-pens, *i.e.* within 30 meters of the net-pens. This conclusion is not unique to the FAMP or to Maine. Findlay, *et al.* (1995) arrived at a similar conclusion after intensive study of a site off of Swans Island, Maine. Crawford, *et al.* (1999) reached the same conclusion after analyzing benthic data from salmon farms in Tasmania. Additionally, the time series data, with the exception of species richness already discussed, further suggest that the impacts also appear to be decreasing with time. However, the changes made in the FAMP procedures and protocols in 1995 and 1998 make it difficult to interpret and directly compare all of the data across time. It therefore remains to be seen if the data continue to show this trend toward improvement under fully standardized procedures and protocols.

Nutrient Monitoring

Testing for nutrients, *i.e.* NO_3, NO_2, NH_4, TKN, and PO_4, was formerly part of the U.S. Army Corps of Engineers/National Marine Fisheries Service's aquaculture site environmental monitoring requirements. After several years of testing, however, no specific effects were observed and the requirements were consequently dropped in the early 1990s. At the time nutrient testing was being conducted, most sites were located in the macrotidal area of Cobscook Bay or in close proximity to open ocean. A study conducted in Cobscook Bay and coordinated by The Nature Conservancy, (Garside, 1997), showed that, at certain times and under certain conditions, the nutrient contribution from net-pen operations could become important to the overall nutrient flux, but under normal circumstances was relatively small compared to the contribution from renewal water brought in from the open ocean on each tide. Nevertheless, recent applications for aquaculture lease sites in more confined areas, removed from the open ocean and having lower rates of flushing, have rekindled concerns over the potential impact of finfish aquaculture on nutrient flux. In response to these concerns, the DMR has recently undertaken a study to determine whether certain embayments are, indeed, nutrient limited. If these studies indicate that nutrients, principally nitrogen, are limiting factors in primary productivity in these areas, nutrient monitoring, whether system-wide or site-specific, may be incorporated into the FAMP.

Chemicals and therapeutants

The use of antibiotics in Maine is strictly on an acute basis, that is, in response to specific clinical symptoms, and not on a prophylactic basis and is subject to U.S. Food and Drug Administration (FDA) regulations. Antibiotics are incorporated directly into salmon feed by the manufacturers. The use of antibiotics, however, has been generally declining as new vaccines and rapid vaccination methods have become available. Maine does not currently monitor for antibiotics in the environment, either in the water column or in sediments beneath the net pens.

Treatment for sea lice, *Lepeophtherius salmonis*, in Maine is carried out using EXCIS, a cypermethrin-based product specifically formulated for use in the marine environment. EXCIS is currently under investigation by the FDA under its Investigational New Animal Drug (INAD) Program - EXCIS (Cypermethrin) INAD 9554. Use of EXCIS is tightly regulated and controlled under the INAD program, and is administered using specifically developed procedures and protocols (Opitz, 2000), where infected fish are treated by temporarily enclosing the net-pen with a tarpaulin and exposing the fish to the EXCIS solution for a one-hour period. Since the use of cypermethrin is currently under FDA control, monitoring of cypermethrin is not currently part of the FAMP.

Finally, the only other chemical products introduced routinely into the environment are copper-based antifoulants used to control fouling on nets. These products are similar to antifoulant paints used on commercial and recreational vessels. No studies have been conducted in Maine to determine the amount of copper discharged by net pens into the water column or sediments. The FAMP does not include copper or any other metals monitoring.

Although other chemical compounds and products, *e.g.* gasoline, oils, formalin, iodine, etc., are used periodically at net pen sites, no specific monitoring of these products is included in the FAMP. Operators of net pen sites, as all other users in Maine, must comply with the DEP's regulations concerning the use and proper disposal of these products.

Part II. Determination of Acceptable and Unacceptable Impacts: Defining Performance Standards and Mixing Zone

Despite the numerous studies, monitoring efforts and discussions throughout the world over the past two decades concerning the environmental impacts of aquaculture, specifically salmon net-pen aquaculture, the determination of what constitutes acceptable and unacceptable impacts remains generally undecided and controversial. Consequently, the establishment of industry performance standards and definition of the mixing zone in which those standards must be met has been exceedingly difficult.

There are multiple reasons for why this is true. First, there is the fundamental question of how to define "acceptable" *degree* of impact, and second, to what *extent*, spatially, should such impacts be allowed. The data, particularly biological data, are not "cut and dry" and are consequently open to interpretation. There is also the question of perception, that is, depending on ones point of view, certain impacts may be either clearly acceptable or clearly unacceptable. And, from a regulatory point of view, unlike an "end-of-pipe" source of pollution, aquaculture represents a diffuse pollution source, which by necessity, is often located in a highly dynamic environment, thus making the detection or tracking of specific pollutants much more difficult than simply sampling the effluent discharged from the end of a pipe.

These difficulties are not unique to a particular state or region but are encountered by regulators in all countries where net-pen culture is practiced. A few examples taken from Maine's experience in dealing with the development of performance standards and regulations can serve to illustrate the difficulties faced in this process.

The environmental quality of Maine's coastal waters is regulated through the Maine DEP's Water Classification system (38 MRSA Chapter 3: 4-A:§ 465-B. Standards for classification of estuarine and marine waters). Responsibility for administration of the regulations, as applied to aquaculture, rests with the DMR. The DEP system classifies coastal waters into three categories, SA, SB, and SC. Class SA waters are found around State and Federal parks and preserves and are to remain "pristine". Class SB waters are general purpose waters for use in swimming, boating, and commercial and recreational fishing. Class SC waters are for industrial use. The dissolved oxygen threshold for each category, measured as percent saturation, is "no change from ambient", 85%, and 70%, respectively. All aquaculture operations in Maine are located in Class SB waters.

Dissolved oxygen is relatively easy to measure, either chemically or electronically. Indeed, it is one of the most commonly measured parameters in the marine environment, along with temperature and salinity. Further, the thresholds and potential impacts of hypoxia are fairly well known and clear, quantitative regulatory limits have consequently been established. However, dissolved oxygen, expressed as percent saturation, may not be the most appropriate criterion upon which to establish impact limits or performance standards.

The solubility of oxygen in water is directly dependent on the temperature and salinity of the water. The relationship is inverse, that is, the higher the temperature and/or salinity, the lower the D.O. In other words, the actual amount of oxygen dissolved in water depends directly on the water's temperature and salinity. At a salinity of 32 ‰, the normal salinity of Maine's coastal waters, the concentration of oxygen in the water at 100% saturation is 9.20 mg/L at 10^{O} C, 8.81 mg/L at 12^{O} C, and 8.29 mg/L at 15^{O} C. Applying the 85% threshold to these values, the concentration of oxygen in the water at 85% saturation would be 7.82 mg/L at 10^{O} C, 7.49 mg/L at 12^{O} C, and 7.05 mg/L at 15^{O} C.

Based on the minimum dissolved oxygen percent saturation values and corresponding dissolved oxygen concentration for all 42 non-anomalous violations of the 85% threshold observed in Maine over the past eight years, the lowest D.O. concentration recorded is 6.1 mg/L; the mean concentration for all violations is 7.2 ± 0.73 mg/L (@ 95% conf.).

According to the U.S. Fish and Wildlife Service (Piper *et al.*, 1982), the desirable level of dissolved oxygen for warm freshwater pond fish is 5.0 mg/L or greater, and percent saturation should not drop below 80% in intensive culture systems such as raceways. Between 5.0 and 1.0 mg/L fish will survive, but growth will be slowed and deformities may occur if the exposure time is long. Different species of fish differ in their oxygen requirements, but the minimum safe level for most species is 5.0 mg/L. Research by the U.S. Environmental Protection Agency's Research Laboratory in Narragansett, Rhode Island and the Connecticut Department of Environmental Protection Marine Fisheries Division also suggests that dissolved oxygen concentrations of 5.0 mg/L or greater result in few adverse effects on marine organisms. The results of these studies and associated recommendations are summarized in Draft *Ambient Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras* (EPA, 1999). The Federal Register of January 19, 2000 stated that the EPA is considering using the values presented in this document as its recommended national 304(a) criteria for dissolved oxygen in saltwater. According to the draft document, oxygen concentrations above 4.8 mg/L are considered to be acceptable within the study area. Dissolved oxygen concentrations ≤2.0 mg/L are considered critical and concentrations between 4.8 mg/L and 2.0 mg/L are considered to be of concern.

The USEPA has not previously used specific criteria for dissolved oxygen in seawater due to an insufficiency of data. However, it now appears that sufficient data exist for the region between Cape Cod and Cape Hatteras to allow such criteria to be established. Unfortunately, similar data for the Gulf of Maine appear to remain insufficient and similar criteria for the region north of Cape Cod have not yet been developed. Given the naturally higher levels of dissolved oxygen found in colder water, it is reasonable to assume that cold water organisms would likely require higher levels of dissolved oxygen. Nevertheless, the Cape Cod to Cape Hatteras region criteria can be used as general guidelines.

If the 4.8 mg/L criterion is applied to the statutory violations observed in Maine, none would violate this criterion. Even if the Cape Cod to Cape Hatteras minimum "safe" criterion is increased by an arbitrary 20% (0.96 mg/L) to 5.76 mg/L, all of the violations still exceed this level, most by a significant amount. Again, it should be emphasized that all of the violations, with the exception of only two, were recorded immediately adjacent to the net-pens. Unfortunately, in the absence of qualifying data on actual D.O. concentration, any violation of the 85% saturation threshold is currently being interpreted as posing a biological threat to the environment. In view of the potential for misinterpretation of the significance of a violation of the 85% threshold, the Maine DEP is currently reviewing the existing standard, not only as it applies to aquaculture, but to all effluent discharges in the State. As shown later, several countries have now adopted absolute dissolved oxygen concentration as a performance standard, either independent of or in combination with dissolved oxygen percent saturation.

As difficult as interpretation of dissolved oxygen impacts is in the context of current regulatory language, interpretation of diffuse benthic impacts is even more difficult. The results of the Maine FAMP and efforts elsewhere have shown rather clearly that the benthic impacts of aquaculture are generally more significant and extensive than impacts on dissolved oxygen. The methods for measuring and quantifying benthic community structure and the indices used to evaluate results are very well established. However, as discusses earlier, interpretation of results is often difficult. This difficulty of interpretation is exacerbated in the context of vague, ill-defined regulatory language. For example, according to Maine's Water Classification law, "...discharges to Class SB waters shall not cause adverse impact to estuarine and marine life in that the receiving waters shall be of sufficient quality to support all estuarine and marine species indigenous to the receiving water without detrimental changes in the resident biological community...". The phrase "detrimental changes in the resident biological community" can be interpreted to include any changes that would result in the displacement of resident species as established by the pre-development baseline survey. More recently, a draft National Pollutant Discharge Elimination System (NPDES) permit developed by the EPA for a proposed aquaculture site in Maine includes a limitation on adverse effects to the benthic community "... as evidenced by a significant shift in benthic community structure, sediment type..." As in the case of Maine's regulations, "significant shift in benthic community structure" can be interpreted as any change, regardless of whether such change is negative or positive.

In the case of aquaculture in Maine, any activity associated with the installation and operation of a net-pen facility can be expected to result in some change in benthic community structure. For example, many of the net-pen operations in Maine have been installed in areas where the pre-development sea floor was relatively hard, *i.e.* cobble and rock, due either to high currents or repeated dragging of the bottom by commercial fishing. The normal benthic infauna in these areas is dominated by echinoderms, *e.g.* sea urchins, sea stars, brittle stars, sea cucumbers, etc., and molluscs. Under such conditions, the mere installation of the net-pen structures will have an effect on the composition of the bottom, regardless of whether fish are introduced into the net-pens. First, the resistance to the current caused by the surface area of the nets will significantly reduce the current velocity in the immediate area of the net-pens. This reduction in current velocity will, in turn, result in increased sedimentation, eventually leading to "softening" of the sea floor. Similarly, if the area is actively dragged for scallops or sea urchins, the repeated disturbance to the bottom as a result of this activity tends to resuspend and remove finer sediments. Precluding such activity by installing the net-pens, however, allows sedimentation to occur within the area immediately beneath and adjacent to the net-pens, particularly if dragging activity and sediment resuspension continues around the general vicinity of the net-pen installations. In either case, natural deposition of fine sediments over the cobble will lead to the filling of interstitial spaces, perhaps eventually completely covering the cobble layer. This certainly constitutes a significant shift in sediment type, but not only that, it represents a significant alteration of the habitat. This altered, softer sea floor habitat is no longer suitable for echinoderms, but now offers significantly greater opportunities for colonization by infauna, particularly polychaetes. Indeed, post-development species richness is often greater than that found prior to installation of net-pens. Thus, the change in sediment type can results in a significant shift in benthic community structure, all before any fish have been introduced to the net-pens or any feed has been distributed.

Once fish are introduced to the net-pens and feed distribution begins, organic material, *i.e.* carbon, almost inevitably begins to be deposited on the sea floor as excess feed and feces, the amount of which varies with the hydrodynamic conditions of the site, the sophistication of the feed distribution methods and systems, and the general husbandry practices of the site operator. Once on the sea floor, the carbon serves as a nutrition source for the benthos, often in amounts capable of supporting a significantly higher biomass than prior to net-pen installation, resulting in a biostimulation phase that closely follows the organic enrichment process described by Pearson and Rosenberg (1978).

The change in sediment type, the shift in benthic community structure, and the increased biomass represent a substantial departure from the ambient, pre-development condition. Strict adherence to the aforementioned DEP and EPA language could lead to an interpretation of these changes as being unacceptable. However, some would argue, likely successfully, that these changes do not necessarily constitute a negative change or shift. In fact, it might even be argued that such changes represent a significant improvement over the highly altered pre-installation condition, since the shift towards a polychaete community offers greater feeding opportunity for foraging epibenthic species such as flounders and lobsters. Indeed, data developed under the FAMP suggests that at certain sites the population of lobsters has increased significantly following installation and operation of net-pens in the area.

A period of biostimulation, such as just described, normally follows initial installation and operation at most net-pen sites. As organic loading continues, this period of biostimulation is usually followed by a period of further degradation, the rate and extent of which varies depending on site conditions and operations. According to most models (Pearson and Rosenberg, 1978; Silvert and Sowles, 1996), this period of continued degradation, resulting from the constant deposition of carbon on the bottom, ultimately leads to stabilization at some level of benthic degradation. Although these models use arbitrary units to describe levels of degradation, it appears to be generally believed that stabilization occurs at a state of heavy, excessive degradation characterized by near azoic, anoxic conditions. Monitoring data, however, suggest that, although such conditions are reached at certain sites under certain conditions, this is not the obligate end point for all sites. Not surprising, current velocity and depth are major factors in determining the degree and extent of degradation.

Experience has shown that, at sites with relatively high current velocities the degree of benthic impact, as measured through visual observation as well as benthic community analyses, can be relatively low even after prolonged occupation of the site, *i.e.* stabilization is reached at a relatively low level of degradation. However, the distance beyond the net-pen systems over which these low-level impacts are observed can be substantial, *i.e.* 30-60 meters beyond the net-pen systems. In contrast, at sites where current velocities are relatively slow, the degree of benthic degradation can be high, even reaching anoxic/azoic conditions. But in such cases, these high-level impacts are usually confined to the immediate vicinity of the net-pens, *i.e.* 3-5 meters, and little evidence of impact can be detected at 10-15 meters beyond the net-pens. The difference in the nature of these impacts is generally attributed to the role of current in mitigating the impacts of organic deposition through physical removal and dispersion of feed and feces. However, several sites have been found to have substantial organic deposition beneath the net-pens that support a diverse and abundant benthic community with little evidence of anaerobic conditions. This suggests that the role of current in providing an adequate oxygen supply to support an aerobic benthic community may be more important than its role in physical removal of organic material.

A final example of the difficulty of determining the acceptability of an impact is the development of mussel beds, *Mytilus edulis*, beneath net-pens resulting from net-cleaning or dropping of nets onto the bottom. In either case, the mussels deposited on the sea floor often thrive, sometimes covering the entire "footprint". This represents a significant alteration of the benthic community beneath the net-pen systems, however, mussel beds are hardly foreign to the Maine coast. Whether the replacement of a polychaete-based infaunal community by an epibenthic bivalve-based community is beneficial or detrimental may be debatable, but it certainly constitutes a significant change.

Clearly, the level of degradation found beneath or around any net-pen system, both with respect to degree and extent, falls somewhere within a spectrum of observed impacts. The extremes of these spectra are fairly easy to establish and agree upon. In terms of degree of impact, anoxic, azoic conditions accompanied by the evolution of methane and hydrogen sulfide gas are clearly unacceptable; at the other extreme minor shifts in benthic community structure associated with nearly imperceptible changes in sediment composition would be generally acceptable. Similarly, with regard to extent over which impacts occur, confinement of impacts to the immediate vicinity of the net-pen systems might be acceptable while impacts, regardless of degree, would be unacceptable at a considerable distance from the net-pens. The area over which allowable impacts or effects can occur is referred to as the impact zone, mixing zone, or zone of dilution, depending on the nature of the impact. The issue, then, becomes one of defining how much impact is acceptable at what distance from the net-pens.

Several attempts have been made to establish limits for both degree and extent of impacts. The approach to establishing these limits varies considerably from country to country and even from region to region within a country.

As explained in the previous discussion on dissolved oxygen, Maine does have a fixed standard for D.O. saturation in Class SB waters, that is, an “acceptability” threshold of 85% that must be attained within 5 meters of the net-pen system. With respect to benthic impacts, general standards of unacceptability have been established, specifically that azoic, anoxic conditions, either with or without spontaneous or disturbance outgassing, *i.e.* evolution of methane and/or hydrogen sulfide gas, must not exist anywhere within the lease area. Beyond this specific definition of unacceptability, threshold *guidelines* have been established for acceptable impacts. Beneath the net-pen system and within a 5-meter perimeter mixing zone, hyperdominance, or dominance by any taxa, must not exceed 90%, and coverage by sulfur-reducing bacterial mats, *Beggiatoa* sp.-type, commonly referred to a bacterial-mold, must not exceed 50% of the surface area. These guidelines were developed by the Maine DEP as non-regulatory performance standards which the industry has voluntarily agree to comply with. Since these standards are not codified in regulation, failure to meet the standard carries no pre-established consequence. However, failure of attainment results in official notification to the operator and a request for a corrective action plan. This is usually followed by a consultation between the site operator and the Maine DMR and/or DEP.

This approach, although considerably less stringent than others used elsewhere, has proven to be very effective at responding to unacceptable impacts. Indeed, since 1988, when monitoring was first implemented, formal notification of non-compliance has almost consistently been met with timely and satisfactory problem correction through structural and/or husbandry modifications. In five cases, formal notification has resulted in voluntary permanent removal of net-pen systems, that is, outright abandonment of the site or portion of the site, or temporary removal of structures for a minimum 6-month fallowing period. Only on very few occasions has the State found it necessary to threaten an operator with possible revocation of a lease in order to gain compliance; the State has never been forced to initiate formal revocation proceedings.

Norway, despite it long history of salmon farming and position as the world's largest producer of farmed salmon, has not developed a codified environmental monitoring program nor has it established specific environmental performance standards for the industry, even though stringent standards are applied to processing and fish health bio-security. Although surprising in view of actions being taken by other salmon growing countries, there are several good reasons for this. First, despite decades of intensive farming in Norway, no significant, broad environmental consequences have been observed; environmental impacts have been determined to be restricted to the immediate vicinity of the net-pens. Second, disease has been identified a the foremost threat to salmon farming in Norway by both the government and the industry and regulation, therefore, focuses on disease prevention; Norwegian fish farmers recognize the need to maintain optimum environmental conditions at their farm sites to reduce the risk of disease and optimize fish growth. Third, government authority over aquaculture is decentralized and resides at the county and local levels (Jørn Vad, pers. comm.).

The Ministries of Fisheries, Environment, Agriculture, and Local Government and Labor share regulatory authority over aquaculture in Norway; lead responsibility for administration rests with the Ministry of Fisheries. Application and enforcement of regulation, however, are delegated to county and local level authorities, and consequently vary substantially around the country. Maroni, (2000) offers an overview of Norway's regulatory framework.

Management of environmental impacts relies more on proper siting of net-pen operations than on environmental monitoring. The Norwegian State Pollution Control Authority, (NSPCA) has developed an environmental quality classification system for fjords and coastal waters based on a set of parameters that includes nutrients, organic matter, micropollutants and fecal bacteria; the system serves as the basis for determining the suitability of waters for various uses. Suitability for siting marine net-pen operations falls into four categories, based on a range of values for each parameter within each category, examples of which are shown in Table II-1, below.

Table II-1 Suitability classification parameters (partial) for fish farming in Norway (NSPCA, from Maroni, 2000)

Parameter	Well Suited	Suited	Less Suited	Not Suited
Total P ug/L winter	<21	21-25	25-42	>42
Total N ug/L winter	<295	295-380	380-560	>560
Oxygen at depth ml/L	>4	4-2.5	2.5-1	<1
Thermostable colibacterial/100 ml	<10	10-100	100-300	>300

These guidelines are used only to determine suitability for use in fish farming and are not used in determining the environmental impacts of a farm.

Norway is developing an environmental modeling-monitoring system, Modeling-Ongoing fish farms-Monitoring, (MOM). MOM, which focuses principally on benthic impacts, is still undergoing refinement and is not currently used as a regulatory tool. The model integrates several sub-models (fish, dispersion, sedimentation, water quality) and monitoring results. Three levels of monitoring, classified as A, B, and C-investigations, are used to develop data for input to the model. The simplest, A, looks only at sedimentation rate and is infrequently applied. The B-investigation includes quantitative determination of presence/absence of fauna, sediment pH and redox potential (Eh), and visual determination of presence/absence of gassing, thickness of organic material (sludge) on a scale of 0-4, and sediment odor, color, and consistency. The C-investigation includes quantitative analysis of benthic macrofauna, organic content of sediment (loss of ignition), granulometry, water column dissolved oxygen, and the visual determination of B-level. At present, the B-investigation, with or without pH and redox measurement, seems adequate for most situations, and C-investigations will probably only be conducted in a few, special cases

Regulatory authorities do not conduct environmental monitoring; individual farm operators are responsible for voluntary monitoring of their sites to ensure no adverse effects are occurring as a result of their operations. A farm is considered to exceed environmental quality standards when conditions beneath the net-pens become azoic.

Tasmania has taken the concept of determination of suitability further by developing marine farming zones as provided for in its Marine Farming Planning Act 1995. According to the Act, zoning of an area for marine farming includes four steps: 1) preparation of a Marine Farming Development Plan for a specified area, 2) development of an Environmental Impact Statement, 3) establishment of management controls and enforcement mechanisms to regulate marine farming activities, and 4) allocation of leases within the marine farming zone. Additional provisions specify how these are to be accomplished.

A baseline environmental survey, including but not limited to sediment granulometry, sediment carbon content, redox potential, water and current flows, and benthic community structure, is required prior to initiation of operations. Post-development environmental monitoring requirements are permit-specific and responsibility for collection, analysis, and reporting of findings rests with the permittee; environmental monitoring is not carried out by the regulatory authority. Specified testing procedures and standards must be followed and sample collection and analysis must be performed "by persons approved and authorized by the Secretary". Monitoring is required within the lease area, at a distance of 35 meters from the lease boundary, and at a reference site(s) as prescribed by the permit specifications.

No specific performance or environmental quality standards have been developed for the marine farming industry although general environmental quality control guidelines have been established (DPIWE, 2000). These guidelines refer to "...no unacceptable environmental impact, to the satisfaction of the Secretary, 35 m outside the boundary of the marine farming lease area." The Environmental Controls Relating to Carrying Capacity section of the Marine Farming Development Plan specifically states that if "hydrogen sulfide and/or methane gas form in the sediment and rise to the surface" the lessee must provide for fallowing of the area as soon as practicable.

Chile adopted a formal aquaculture environmental policy in 1997, based on its environmental law, Ley de Bases del Medio Ambiente, that calls for the evaluation and monitoring of aquaculture projects. Application of performance standards is limited at present, but a proposal currently under review includes recommendations for additional sediment-based performance standards.

As elsewhere, Chile recognizes the difficulty of relating net-pen water column effluents to specific environmental effects and the latter to specific aquaculture operations. Evaluation and monitoring of aquaculture sites previously included measurement of bathymetry, granulometry, oxygen concentration, and organic matter concentration. However, since no limits or standards have been established for these parameters, the program now focuses strictly on macrofaunal concentration. Accordingly, the installation of net-pen operations is prohibited in areas where the macrofaunal concentration is ≤ 2 Families/m^2. Using this same siting criterion as a performance standard, if a net-pen operation is found to have reduced the macrofaunal concentration below 2 Families/m^2, the operation is required to relocate and reduce culture density by 10% until the macrofaunal concentration returns to a level above 2 Families/m^2. The attainment or mixing zone for this standard has been specifically defined as the area directly beneath the net pen structures. Benthic monitoring within the attainment zone and at control/reference stations is required every six months. In addition to environmental monitoring data, additional reporting is required on chemical product(s) usage, marine mammal and bird interaction, among others.

Responsibility and authority for the regulation and monitoring of marine net-pen operations in Scotland rests with the Scottish Environment Protection Agency (SEPA). SEPA's policy on monitoring and guidance on the regulations governing marine net-pen fish farming are published in the Fish Farming Procedures Manual (SEPA, 2000). Environmental criteria or targets for both water column and sediment impacts, referred to in the manual as Environmental Quality Standards (EQS), have been developed or adapted from existing standards. These are summarized in Tables II-2 and II-3, following.

Table II-2. Environmental Quality Standards for Water Column*

Parameter	EQS	Application
Dissolved oxygen	7 mg/L or 80% air-saturation value	Whichever is least
Dissolved oxygen	7 mg/L	median concentration
Dissolved available inorganic N	168 μg/L	winter values
Dissolved available inorganic P	6.2 μg/L	winter values
Chlorophyll-α	10 μg/L	summer values
Zinc	40 μg/L	dissolved, annual mean
Copper	5 μg/L	dissolved, annual mean
Sulphide	10 μg/L	MAC, undissociated
pH	≥ 7 and ≤ 9	quarterly monitoring
Suspended solids	≤ 30% increase over background	quarterly monitoring
Salinity	≤ 40 psu	monthly monitoring
Dissolved oxygen	≥ 70% average	monthly monitoring
Trace metals	as specified in EC Dangerous substances Directive	half-year monitoring

* These standards are derived from the EC Directives, UK EQS's and are advised as being relevant to net pen culture. There presence in the manual does not imply that monitoring is necessarily carried out to this frequency in relation to fish farming.

The regulations distinguish between continuous and intermittent discharges and SEPA has established a separate AZE for each. The AZE for continuous net-pen discharges, *i.e.* nutrients, antifouling chemicals, etc., is 100 meters from the net-pen structure, similar to the AZE for all other marine discharges. SEPA acknowledges that, given the nature of these discharges, the AZE for intermittent discharges in the water column, such as those associated with sea lice treatment, cannot be realistically defined by a standard measured distance. Site-specific 3-hour and 72-hour dispersion modeling is being employed to predict dispersion to determine an appropriate AZE based on environmental quality standards derived from risk assessment. The regulations state that, after 72 hours "...residual concentrations of the substance should comply with the corresponding 3-day EQS and the area of the AZE should not exceed 0.5 km2 or 2% of the system (whichever is the least)".

Table II-3. Environmental Quality Standards/Target Criteria for Sediments[1] (SEPA)

Component	Determinant	Action level w/in AZE[2]	Action level beyond AZE[2]
Benthos	Number of taxa	< 2 polychaete taxa present	≥50% of reference station
Benthos	Number of taxa	> 2 replicates with no taxa present	
Benthos	Abundance	Organic enrichment polychaetes present in abnormally low densities	Organic enrichment polychaetes must not exceed 200% of ref. sta. value
Benthos	Shannon-Weiner Diver.	N/A	≥60% of reference station
Benthos	Infaunal Trophic Index (ITI)	N/A	≥50% of reference station
Sea bed	Beggiatoa sp.	N/A	Mats present
Sea bed	Feed pellets	Accumulation of pellets	Pellets present
Sediment	Teflubenzuron	10.0 mg/kg dry wt/5cm core applies as an average in AZE	2.0 mg/kg dry wt/5cm core
Sediment	Copper	Probable/Possible effect 270/108 mg/kg dry sed.	34 mg/kg dry wt/5cm core
Sediment	Zinc	Probable/Possible effect 410/270 mg/kg dry sed.	150 mg/kg dry wt/5cm core
Sediment	Free sulphide	4800 mg/kg dry wt	
Sediment	Organic carbon	9%	
Sediment	Redox potential	≤ -150 mV average for profile ≤ -125 mV 0-3 cm surf. sed.	
Sediment	Loss on ignition	27%	

[1] **These standards have been derived by SEPA and are applied regularly in a near-cage monitoring strategy**

[2] **AZE - Allowable Zone of Effect**

With respect to sea floor impacts, SEPA is currently adhering to an early recommendation that calls for a 25 meter AZE in all directions beyond the net-pen structures (ADRIS, 1991). SEPA, however, recognizes the inadequacies of this definition in view of the potentially disproportionate level of impact in any given direction due to the dynamic nature of the receiving waters and is considering alternative approaches. One alternative approach that has been proposed would allow extension of the AZE in one direction, with a compensating reduction in the AZE in another direction, *e.g.* an elliptical AZE of 75 meters in one direction and 0-5 meters in all others instead of 25 meters in all directions. Definition of an appropriate site-specific boundary, however, requires sufficient information to predict the rate of deposition in various directions. A predictive deposition model, DEPOMOD, developed by Cromey *et al.*, 2000, has been adopted by SEPA to assist in this effort. The model outputs a site-specific predicted plume, or footprint, the outer boundary of which defines the AZE according to the appropriate sediment EQS. This model is also being utilized to license the use of "in-feed" sealice treatments.

In New Brunswick, Canada, environmental regulatory authority over net-pen fish farming rests with the Department of Environment and Local Government (DELG). DELG has recently adopted redox potential and sulfide as the standard parameters for determining acceptable and unacceptable impacts, (DELG, 2000), based on the work of Wildish et al. (1999). This study related sediment conditions to results of monitoring conducted for the industry and the rating system used to describe levels of environmental effects. The redox potential and sulfide level rating scale used to categorize sediment conditions is shown in Table II-4.

Table II-4 Sediment Conditions Rating Scale for the Bay of Fundy, New Brunswick, Canada

Sediment Condition/Level of effect	Observed and Measured Conditions
Oxic 1 / low	Redox Potential (Eh) = > + 100 mV $_{NHE}$ / Sulfide = < 300 uM
Oxic 2 / moderate	Redox Potential (Eh) = 0 to 100 mV$_{NHE}$ / Sulfide = 300 - 1300 uM
Hypoxic / higher	Redox Potential (Eh) = 0 to -100 mV$_{NHE}$ / Sulfide = 1300 - 6000 uM
Anoxic / high	Redox Potential (Eh) = < -100mV$_{NHE}$ / Sulfide = > 6000 uM

The Eh and sulfide standards apply directly beneath the net-pen within 10 meters of the center of the net-pen, that is, well within the "footprint" of the net-pen. The zone of attainment, or mixing zone, does not extend beyond the perimeter of the net-pen structure. As applied to salmon aquaculture, unacceptable habitat impacts are reached when the sediment becomes anoxic.

According to the monitoring protocols and procedures, at a minimum, two transects are required per site or one transect per 100,000 fish on large sites; geographical references must be provided for each sampling location and transect. Transects used for video monitoring must be established such that they begin 50 meters from the net-pen and proceed against the direction of the prevailing current to the center of the net-pen with the highest biomass of fish. Sediment monitoring for redox and sulfide requires that one set of three samples be taken along a 10-meter transect extending from the center of the net-pen out towards the net-pen edge as follows: one directly under the center of the net-pen, one at 10 meters from center net-pen edge and one midway between these two points. In addition to sediment chemistry analysis, diver-video assessments are required. A checklist, Table II-5, is used by the diver to document observed conditions along each transect, using a standard set of descriptors shown in Table II-6.

Table II-5. New Brunswick Site Conditions Checklist

Sampling location	Under Cage	Cage edge	30 m from cage
Water Depth (meters)			
Tidal Conditions			
Current: Vel. and Dir.			
Sediment thickness (cm)			
Sediment color			
Sediment consistency			
Sediment odor			
Gas bubbles			
%*Beggiatoa* coverage			
Presence of feed			
Presence of feces			
Macrofauna/flora			

Table II-6. New Brunswick Site Conditions Standard Parameter Descriptor

Description Requirements	**Descriptor**
Time and Date:	
Depth: in metres	
Tidal Conditions:	flood, ebb, high or low
Current:	velocity and direction
Sediment thickness:.	>8cm; 2-8cm; 0-2cm
Sediment color:	black, gray; brown.
Sediment consistency:	mud; clay; rock; cobble; sand/silt,
Sediment odor:	strong H_2S; putrid; some H_2S or odorless
Gas Bubbles released from sediment:	prevalent; some; rare, none
% *Beggiatoa* coverage:	50 to 100% ; 25 - 50 %, or <25%
Presence of Feed:	prevalent, some, rare or none.
Presence of feces:	prevalent, some, rare or none.
Macrofauna:	none; relative abundance of polychaetes; molluscs, echinoderms and crustaceans.

The Ministry of Environment, Land and Parks (MELP) has regulatory authority over aquaculture in British Columbia, Canada through its Waste Management Act and specifically through the Aquaculture Waste Control Regulation of 1988 (AWC). According to the AWC, any fish farm using more than 630 tons of feed per year must have a Waste Management Permit that includes requirements for information reporting and environmental monitoring. Although previously adequate, given the current level of production, the AWC is now considered inadequate. In response, the MELP has recently decided to adopt performance standards to set environmental quality standards for the industry to meet.

Development of performance standards is focused on sediment impacts since, as elsewhere, no significant effects have been found in the water column. Initially, Total Volatile Solids (TVS) was recommended as the principal performance standard parameter. An “Interim Monitoring Program” was ordered in March 2000 to evaluate TVS, total sulfide, and redox potential as performance standards. Studies are on-going but preliminary results of testing show little correlation between TVS and total sulfides. MELP is interpreting these results as an indication that there may be little correlation between TVS and health of the benthic community, as measure by abundance or diversity. This is similar to the conclusions arrived at in Maine concerning TOC. Although initial focus was placed on TVS, MELP also recognizes the importance of total sulfides and redox potential to environmental quality and is now evaluating total sulfides as its primary parameter, a very similar approach to that taken in New Brunswick. Several sampling protocols, including Wildish (1999), are currently being evaluated, but it remains unclear at this time whether a performance standard, once established, will be used as a trigger mechanism for additional monitoring or as an outright compliance standard.

MELP also recognizes the possible accumulation of zinc and copper in sediments beneath net-pens and is considering inclusion of total zinc and copper as parameters to be monitored. The current sediment quality guidelines for zinc and copper are 270 ug/g and 390 ug/g, respectively.

With regard to mixing zone, MELP recognizes that performance standards are unlikely to be met directly beneath net-pens and is considering a Zone of Influence that might be confined to the area immediately beneath the net-pens, or extend some distance beyond the net-pen structure. The Department of Fisheries and Oceans Canada is now considering options for dealing with the zone under the net-pens in the context of the Fisheries Act.

The State of Washington regulates net-pen discharges through its Sediment Quality Standards (SQS), (WAC, 1995) and the National Pollutant Discharge Elimination System (NPDES) permit process. The SQS uses Total Organic Carbon (TOC) as the primary parameter upon which to evaluate net-pen site impacts. The TOC standard specifies a range of attainment levels based on sediment composition as shown in Table II-7, below.

Table II-7 Puget Sound Reference Total Organic Carbon Values

Silt and Clay (% dry wt.)	TOC (% dry wt.)
0-20	0.5
20-50	1.7
50-80	3.2
80-100	2.6

Requirements for compliance with sediment quality standards and any applicable monitoring are addressed through the NPDES permit. All new installations are required to establish baseline sediment quality for TOC, benthic infauna abundance, and granulometry within the proposed operational area as well as a downcurrent reference location. Existing operations are required to monitor TOC levels within the area of the facility.

The SQS provides, by rule, a Sediment Impact Zone (SIZ) defined as the area “within and including the distance of one hundred feet from the edge of the marine finfish rearing facility structure.” If TOC values within the SIZ significantly exceed the reference values shown in Table II-7 or the facility’s baseline levels, additional benthic infauna sampling is required.

This summary serves to illustrate the wide variety of ways of defining and determining acceptable and/or unacceptable impacts and the significant differences in levels of program sophistication and number and specificity of performance standards. These diverse approaches to solving a common problem are based as much in differences of culture and government/public policy as they are in geography. Nevertheless, there are areas of commonality:

- Water column effects are acknowledged to be difficult to measure and track, and there has been difficulty correlating water column impacts to specific environmental effects;

- Impacts to sediments and benthic communities are considered to be significantly greater than impacts to the water column; these impacts are usually localized and confined to within 30-35 meters of net-pen structures;

- Anoxic/azoic sediment conditions, with or without evolution of gas, are universally unacceptable, including directly beneath net-pens;

- The zone along the sea floor in which Environmental Quality Standards are allowed to be exceeded rarely extends no more than 30-35 meters from net-pen structures but in no case extends beyond 100 meters;

- Environmental monitoring efforts are generally focused on benthic impacts and there is increasing emphasis on sediment chemistry, specifically total sulfides, total organic carbon, and redox potential (Eh), at least as preliminary indicators of benthic condition; detailed benthic community structure analyses are often required if preliminary indicator standards are exceeded;

- There is increasing interest in the development and refinement of models as predictive tools for use in the regulatory process for both development and enforcement of Environmental Quality Standards.

Even though there are several areas of agreement, a final definition of acceptability and development of associated realistic and reasonable environmental quality standards may still take time. Concern has been expressed that, during this time, irrevocable damage might occur. But despite all of the studies and investigations carried out to-date, little evidence exists to support this conclusion. Indeed, studies on recovery indicate this to be highly improbable, for several studies at abandoned salmon aquaculture sites have shown that substantial recovery of the benthos occurs within a relatively short time, *i.e.* twelve to eighteen months, after abandonment (Johannessen *et al.*, 1994; Heinig and Churchill, in prep.; Crawford *et al.*, in press). We should therefore take the necessary time to develop environmental regulations that are protective of the environment and its living resources, but also realistic and reasonable

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