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ENVIRONMENTAL GUIDELINES FOR SITE SELECTION, OPERATIONS AND MONITORING OF OFFSHORE AQUACULTURE IN MISSISSIPPI COASTAL WATERS

Prepared for

Mississippi Department of Wildlife, Fisheries and Parks
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FINAL REPORT

Grant No. CZM817/7.3

by

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Abstract

The major potential impacts of offshore aquaculture and actions to quantify, regulate and minimize these impacts have been identified in a variety of state and national studies. The main findings of these studies are:

1. Solid wastes from both net pen and shellfish aquaculture operations will settle to the bottom and affect the benthic community immediately beneath the site. Selecting sites deep enough and with sufficient currents to disperse these wastes will minimize the impact.

2. Important marine habitats, fisheries resources, public lands and endangered or threatened species can be affected by aquaculture operations. Determining appropriate separation distances and selecting sites away from sensitive or important habitats and public lands will minimize this impact. Impacts on piscivorous birds can be further minimized by use of predator control netting and other non-lethal control measures. Control of avian predators must conform with existing federal guidelines.

3. Nutrients released from net pens, especially nitrogen, can contribute to phytoplankton production in stratified, nutrient poor waters. Siting to avoid areas where nutrient depletion occurs and placing limits on total fish production in such areas can prevent adverse environmental effects.

4. Fish culture in warm water conditions can place heavy demands on available dissolved oxygen levels. Selecting sites

deep enough and with adequate current speeds to allow for adequate dispersion of wastes, setting appropriate limits on total fish production and following low waste feeding practices (dry, floating feeds, high digestibility, no fines) will minimize adverse impacts. The use of automatic feeders should be closely watched. The proportion of wasted feed is significantly greater with automatic feeders (overfeeding, fines) than with other feeding methods (Weston 1991a).

5. The effect of aquaculture operations on water movement, quality and on the benthic environment are not detectable within tens of meters of the culture site. Major effects on benthic biota, reduction in dissolved oxygen and increased dissolved nutrient concentrations are limited to within a few meters of the culture site.

6. There is no good evidence for net pens having an adverse impact on fish and other nektonic species, transmitting diseases to wild fish, contaminating resident fauna with antibiotics or in contributing to the development of antibiotic resistant microbial populations threatening to human health.

7. The environmental effects of on- and off- bottom shellfish culture are generally limited to those associated with sediment deposition.

Proper siting of net pens can assure the dispersion of both solid and dissolved wastes and the protection of sensitive areas.

The severity of the environmental effects of net pen and shellfish raft culture are related to the size of the operation.

Site characterization surveys and operations and monitoring guidelines must be related to the size/production level of the facilities, with increasingly extensive requirements for larger facilities.

Because long term data on currents and water quality conditions in the shallow, near shore waters of the northern Gulf of Mexico are so poor, permit requests for offshore aquaculture must be reviewed and evaluated on a case by case basis. Should a permit request be denied because the proposed operation does not satisfy recommended site selection, evaluation, operations and monitoring guidelines presented here, the burden of proof that there will be no significant environmental effect associated with the operation should fall on the applicant.

I. INTRODUCTION

Many of the fish and shellfish species upon which the Gulf seafood industry depends, such as redfish and oysters, have shown dramatic declines in abundance. Similar declines in other areas have affected the harvest of valuable species such as the striped bass. As catches have declined, demand and prices have risen. New techniques for farming fish and shellfish have been developed to meet growing demand. Cultured fish and shellfish have experienced rapid growth in Mississippi, in other parts of the U.S. and in other countries.

Aside from pond culture, one of the most successful approaches to fin fish farming has been net pen culture, where fish are grown in pens or cages moored in open water. Oyster culture in mesh bags on the bottom or suspended from floating long lines has also met with success.

The development of these techniques and the apparent profitability of commercial net pen and suspended shellfish aquaculture elsewhere has created a growing interest in the establishment of such facilities in Gulf of Mexico waters. Interest has also been spurred by some local developments. An on-bottom bag culture system for oysters was developed and tested in the Florida panhandle; a local aquaculturist is evaluating the feasibility of such a system in Mississippi waters. A net pen system moored to an offshore oil platform in 200 feet of water is being evaluated for fin fish culture off the Texas coast.

The rapid growth of offshore aquaculture industries (defined as fin fish net pen culture and the cultivation of mollusks in floating or on-bottom structures) in other regions has brought attention to the potential environmental effects of open water aquaculture. Regulatory agencies in these areas have examined these issues and have developed siting, operations and monitoring guidelines to measure and limit the potential negative environmental effects of open water aquaculture. Through an analysis of these regulations, associated reports and the related scientific literature, this report attempts to identify the potential environmental effects of off shore aquaculture, to evaluate the importance of these effects in the northern Gulf of Mexico, and to provide guidelines for the siting, operation and monitoring of such operations. These guidelines are intended to aid both the industry, by identifying criteria for selecting appropriate sites and scales of operation, and the regulatory agencies, by creating a framework for the permit review process.

II. OPERATIONS

Commercial net pen culture of fin fish in the marine/coastal waters of North America focuses on various species of salmon or steelhead trout culture. Other fin fish species are also cultured in cages, such as yellowtail in Japan and red sea bream in Taiwan and the Mediterranean region. Research is underway in Europe exploring the feasibility of raising cod, turbot and other species in cages.

Because of recent advances in production technology, the most likely fin fish candidates for warm water marine net pen aquaculture in the U.S. are redfish and hybrid striped bass. This review will focus on conditions associated with the potential cultivation of these two species in Gulf waters.

Net pen culture

A brief description of commercial salmon operations (from Weston 1986a) will serve to introduce the technology used in net pen operations. In Washington, fish are held in net enclosures with 10 - 30 mm mesh, depending on the size of the fish. The dimensions of the enclosure vary among facilities. A small net pen may be only a few meters on a side, while larger net pens may measure 12 x 12 m. Net pens usually extend 2 - 4 in below the surface. At most facilities, net pens are moored together to form a single large farm unit, with individual pens separated by walkways (Fig. 1). Buildings for shelter, equipment and feed storage and/or processing may be incorporated as well.

Fingerlings are stocked into the pens in the spring of each year, but usually spread over several months to insure a steady supply of product. Stocking density of salmon depends on several factors but is usually 15 kg/m^3. "Pan-sized" fish (0.3 kg) are held for 6 - 11 months while market fish are held for 18 - 24 months, until they reach 2 - 5 kg size.

Salmon can be fed a variety of diets, including dry, moist and wet (minced fish) feeds. U.S. growers use dry feeds almost exclusively. Feed may be delivered by hand, by demand feeders or by automatic feeders. Salmon are usually fed 2% of body weight per day. This varies greatly with fish size, water temperature and other factors. Feed conversion ratios of 1.5 - 2:1 (feed:fish weight) are commonly achieved.

Proper husbandry practices (esp. stocking density), vaccination or addition of medicated feeds minimized loss to stress and disease mortality. Use of overhead netting, especially over pens holding smaller fish, excludes bird predators. Predation by fish and aquatic animals is prevented by use of a large mesh outer net around the facility. Nonlethal fish and marine mammal deterrents (e.g. acoustic devices) are also used.

Shellfish culture

Two approaches are used to grow oysters in containers (Field and Drinnan 1988). "Off bottom" culture refers to methods used to grow oysters by suspending them from surface floats. In "on bottom" culture, oysters are grown in or on structures placed directly on the bottom. In both approaches, seed oysters from wild or hatchery sources are used.

The distinguishing feature of off-bottom culture is the floatation system. Two basic types are used (see Magoon and Vining 1981, Nosho 1989): long lines and rafts. A long line consists of a 50 - 300 m long, 12 - 25 mm thick rope which is buoyed at 10 m intervals or less along its length, and well anchored at both ends. Strings or structures holding the oysters (usually nets or mesh bags) are suspended from the long line. Because of their inherent flexibility, long lines are more suited to open water situations. Rafts, on the other hand, have a rigid structure and are more suitable for sheltered locations. The most common raft type is of beams and crossbars bolted together and mounted on a series of floats. Rafts are used for tray culture, where the oysters are held in mesh trays suspended from the rafts.

The most common on-bottom systems use either mesh bags, linked into belts, or rigid stacks of cages, both of which are anchored to the bottom (Magoon and Vining 1981, Nosho 1989). The "flexible belt" method (Cresswell et al 1990) appears to be the more economically promising approach in Gulf waters. Regardless of the approach, seed oysters are initially placed into small mesh trays or bags. The oysters are periodically moved to larger mesh containers as they grow, and the containers are regularly cleaned of fouling organisms.

III. POTENTIAL ENVIRONMENTAL EFFECTS

1. Water Circulation Effects

a) Water Circulation Effects Within the Structure

Empirical studies of net pens on water circulation indicate substantial reduction of current velocities inside net pens (Inoue 1972). For pens 3 x 3 x 3 m with 2.4 cm mesh no fouling and no fish, it was estimated that current velocities would be reduced to 70 - 80% of initial velocity after passage through the first pen, and to 10 - 25% of initial velocity of after passage through 3 pens. Stocking density of fish, mesh size, pen volume, fouling and other variables can dramatically increase the resistance of the net pen to water flow (Weston 1986a). Water flow within shellfish rafts was measured at 12 - 14% of outside current velocity (Arakawa et al 1971). At a depth of 1 m below the culture strings no consistent current effects were evident.

b) Water Circulation Effects Outside the Structure

While any object placed within a current will alter water circulation, there have been no measurements of the effects of net pens or mollusk culture structures on water circulation. Based on the estimated effects of solid structures on water flow, Weston (1986a) estimated porous structures such as net pens or shellfish rafts will reduce current velocity upstream for a distance about equal to the dimension of the net pen perpendicular to the current flow. Current velocity at the sides of the structure was estimated to be 95% of the free stream value at a distance of about two structure diameters. Downstream current velocity was estimated to return to 95% of the free stream value within 20 structure diameters.

While Weston (1986a) provided no estimate on the vertical extent of current velocity reduction by floating aquaculture structures, the effect should be detectable at least to a depth of two structure heights. Where cages are moored in water just exceeding this depth, additional turbulence and boundary effects of the bottom on current flow will have to be considered in estimating reductions in current velocity and potential sedimentation effects.

These figures are only order-of-magnitude approximations since variables such as mesh size, extent of fouling and current variation will affect the calculations significantly. Fouling of the net mesh or use of smaller diameter mesh will significantly increase the distances where currents are reduced.

c) Sedimentation

The reduction of current velocity in the vicinity of the aquaculture structures will cause suspended particles to settle out, increasing sediment deposition below net pens or rafts. As discussed here, sedimentation is distinct from sedimentation of waste material from the culture operation. This effect may especially significant for on-bottom shellfish culture structures, and for floating net pens or shellfish rafts moored in shallow water. If such structures are located close enough to the bottom to restrict water flow, deposition of the suspended sediments and trapping of solid wastes from the net pens will probably occur. The problem may be magnified in areas of high suspended sediment loads.

d) Circulation and water quality

The reduction of current velocity within and outside the culture units may affect water quality by preventing an adequate supply of oxygenated water on inhibiting the removal of waste material. For shellfish culture, reduced current velocities within the structures may also reduce the quantity of food reaching interior or downstream shellfish, causing poor growth or mortality (Incze and Lutz 1980).

Inoue (1972) estimated that current velocity in net pens will be one-half of the upstream velocity. To estimate current velocity through pens on a model salmon farm, Weston (1986a) incorporated the tidal variation in current velocity with net pen effects to derive an estimated average current flow into net pens of 20 - 40% of the peak ebb current velocity.

Operations located in areas of low current velocity (less than 5 cm/sec) will have to take measures to minimize the effects of the structure on water circulation. Multiple net pens should be arranged perpendicular to current flow with an optimal spacing between pens or rafts of two diameters or more. This arrangement will minimize the effect of each unit on water circulation and water quality. Water depth below the lowest point of the structure should exceed two times pen height.

2. Water Quality

a) Waste Inputs

Waste inputs from net pen aquaculture are unutilized feed and the metabolic products of food breakdown (Weston 1986a, 1986b, 1991a, 1991b, Weston and Gowan 1988). The inputs are:

Ammonia - the principal nitrogenous excretory product of fish and shellfish. Can be present in ionized (NH_4^+) or unionized (NH_3) form. At the temperature range (15 - 30 °C) and Ph (about 8.0)of Mississippi coastal waters, the percent of toxic unionized ammonia will be 1.5 - 4.0%.

Nitrate and Nitrite - produced by the microbial degradation of other nitrogenous compounds; elevated concentrations may be expected in the vicinity of net pen aquaculture due to bacterial oxidation of ammonia.

Organic Nitrogen - urea is the principal component, produced as an end product of protein metabolism.

Phosphate - excreted in urine and leached from waste food and feces.

Oxygen - respiration by the cultured organisms and the consumption of oxygen by decomposition of waste material (the biochemical oxygen demand on BOD) lower dissolved oxygen (DO) levels.

b) Waste Loading

Little information is available on nutrient or BOD loading from marine net pen culture. Most of the information has been developed from studies of salmonid culture in cool, freshwater systems. Reviews of published data for intensive raceway systems (and marine net-pen systems (Weston 1986a) suggest that loadings are extremely variable depending on type of feed, quantity and frequency of feeding, temperature, fish size and proportion of suspended solids in the effluent stream. As a result, loading values from any one aquaculture operation cannot be used to accurately predict loading values from another.

Waste loads for net pen aquaculture are difficult to estimate for warm water marine systems. Several values are commonly cited. Estimated loadings per kg of fish produced per day (g/kg fish/day), based on salmonid data from Ackefors and Enell (1990), are a BOD of 0.90 g, 0.23 g total nitrogen and 0.03 g total phosphorus. Weston (1991a) used these values to estimate warm water net pen aquaculture waste loads in Chesapeake Bay. Approximations of waste loads generated by net pen salmon farming in Puget Sound, valued on a g/kg fish/day basis, are: ammonia - 0.3, nitrate 0.1, organic nitrogen - 0.04, total nitrogen - 0.6, phosphate -0.1, total phosphorus -0.1, BOD - 3.0 (Weston 1986a). Huguenin and Colt's (1989) estimated waste load values for cool and warm sea water systems closely match the values derived from fresh water and cool water culture systems.

These estimates of waste loads include both dissolved nutrients that enter the water directly and nutrients which reach the bottom as waste feed or feces. Most of the nitrogenous waste will be released in dissolved form, while in marine waters most of the phosphorous will be part of the particulate material (Weston 1991a, 1991b). Most of the BOD is associated with the particulate material.

Waste loading from shellfish culture is based not on inputs of external feed but on concentration of phytoplankton from the water column (Incze and Lutz 1980). There is no addition of new nutrients into the system. Generalizing from studies of cultured mussels, about 40% of the nutrients removed by shellfish are released directly back into the water column, 30% falls to the bottom as particulate material and 30% are removed in the harvest (Ackefors and Södergren 1985).

A frequent comparison contrasts waste loads from net pen operations with other nutrient discharges (e.g. Weston 1986a, 1991a). These comparisons are misleading. The relatively high BOD associated with net pen culture reflects the efficiency of sludge treatment at sewage plants, not an inherently greater BOD of fish wastes in comparison to domestic sewage (Weston 1991a). Similarly, while BOD and nutrient loadings from net pen operations appear to be comparable to industrial or domestic effluents, the concentrations of these wastes are far lower (Weston 1986a). Inputs of nutrients from farm and urban and sewage treatment effluent runoff, channeled by river flow into

Mississippi coastal waters, is a much greater source of enrichment.

c) Dissolved Oxygen

Fish and shellfish culture can be expected to reduce the dissolved oxygen content of the water by two mechanisms: respiration of the organisms and the biochemical oxygen demand of the waste feed, feces and urine. Because oxygen consumption of fish will depend upon fish species, size, water temperature, swimming speed and other factors, it is impossible to determine the oxygen needs of a net pen operation with any degree of precision. This assessment is complicated further by the fact that existing oxygen consumption data for hybrid striped bass and redfish is very limited. The same limitations hold true for shellfish culture.

Oxygen consumption rates of juvenile hybrid striped bass (20 - 100 g) at 24 ^{0}C were estimated to be 200 - 260 mg O_2/kg fish/hr at a swimming speed of 1 cm/sec, and 320 - 400 mg O_2/kg fish/hr at a swimming speed of 10 cm/sec (Kruger and Brocksen 1978). Respiration data for hybrid striped bass at higher temperatures are not available. Rosati (1990) suggests a rule of thumb approximation: a fish consumes 1/4 pound of oxygen for each pound of feed (about 114 g O_2/kg feed). Colt and Tchobanoglous (1981) provide a range of respiration rates, 6 - 40 kg O_2/1000 kg fish/d, for various species of freshwater fish. While their synthesis does not provide any information on swimming speeds, they report 100 g rainbow trout held in 15°C water consumed about

312 mg O_2/kg fish/hr while 100 g channel catfish consumed nearly three times as much oxygen, 812 mg O_2/kg fish/hr. Hybrid striped bass held in 30°C water would have an oxygen requirement close to the upper end of this range which no oxygen consumption data for redfish are available, limited observations of redfish juveniles indicates that their critical oxygen concentrations are unusually high for warm water fishes, suggesting an elevated oxygen consumption rate (Neill 1987).

These dissolved oxygen consumption rates may effectively limit the size of net pen operations in Mississippi waters of the northern Gulf of Mexico. The solubility of oxygen at 25 ppt salinity and 28 °C is 6.8 mg/l, 7.3 mg/l at 24 °C (Colt 1980). Assuming the water exits the net pen at a dissolved oxygen concentration of 5 mg 0^2/l (the minimum culture requirement), this leaves 1.8 and 7.3 mg 0^2/l for fish respiration at 25 ° and 24 °C, respectively.

A load of 250,000 kg of fish, consuming 600 mg O_2/kg/m, in a 3 cm/sec current <u>inside</u> the cage would use about 0.6 mg O_2/l of flow. Halving the current flow will <u>double</u> the oxygen consumption. As noted earlier, current velocities within cages are 20 - 40% of maximum ebb current velocities.

Field investigations around net pens have reported decreases in dissolved oxygen. Dissolved oxygen concentrations 0.2 - 2.5 mg O_2/l less than ambient were observed around yellowtail and sea bream cages in Japan. There was no evident oxygen depletion beyond the immediate boundaries of the farm. This is an extreme case where circulation was limited and a large quantity of fish (400 mt) were being held. In most cool water conditions, net pen aquaculture operations did not have any measurable effects on dissolved oxygen content.

Similarly, no evidence of dissolved oxygen depletion was noted around commercial scale suspended mussel operations in Sweden or New Zealand (see references in Weston 1986a). Suspended shellfish culture operations in the northern Gulf of Mexico are not expected to have significant effects on dissolved oxygen concentrations or on other water quality parameters.

Oxygen consumption can be estimated for planned shellfish culture operations in the northern Gulf of Mexico. Average oxygen consumption rates for oysters have been reported to be 303 ml O_2/kg of wt tissue/hr (Hammen 1969). The rate of oxygen consumption, however, increases as salinities decrease. Shumway (1982) describes this function. At 28 ppt salinity and a water temperature of 30 °C, the oxygen consumption rate is 200 ml O_2/kg wet tissue/hr or 39 ml/kg/hr for whole oysters. Long line culture of mussels supports an additional 15% biomass of fouling organisms (Weston 1986a). While fouling biomass for Gulf oyster culture is not known, biomass estimates for oxygen consumption calculations should be adjusted upwards by at least this amount.

d) Nitrogen and Phosphorus

Because feed is not added, shellfish culture does not add "new" nitrogen and phosphorous to the environment. Shellfish do, however, increase the rate at which these nutrients are recycled.

By ingesting phytoplankton and excreting a large part of their constituent nutrients, shellfish make dissolved nutrients more readily available for use by other organisms. The potential for this increased nutrient cycling to stimulate phytoplankton blooms has been noted (Tenore and Gonzales 1975) but field studies have failed to find any effect of shellfish culture on phytoplankton productivity (Weston 1986a, 1986b).

Feeds are the main source of waste nutrients in net pen culture. Ammonia and, to a lesser extent, urea, are the principal nitrogenous wastes associated with net pen culture. Ammonia can be present as the non-toxic ammonium ion (NH_4^+ or as the toxic unionized form (NH_3). At the temperatures and pH of marine waters in the northern Gulf of Mexico, 0.2 - 5% of ammonia will be in the toxic form (Huguenin and Colt 1989). At these levels ammonia toxicity is not likely to be a problem.

Phosphorus is also introduced with feeds. In marine systems only limited amounts enter into the environment through urine. Leaching from waste feed and feces is an important source of dissolved phosphorous.

The form of nitrogen and phosphorus input and their potential impacts are very different. Nitrogen is released largely in the soluble form, while phosphorus in sea water is associated primarily with feed and feces. The phosphorus initially deposited in the sediments can later be released into the water column, particularly under anaerobic conditions (Weston 1991a, 1991b).

Localized increases in nutrient concentrations have been reported in the immediate vicinity of net pen culture sites. Such observations are common and should be expected. The extent of measurable enrichment will depend upon hydrographic factors, but dilution is generally very rapid and nutrient increases have been limited to within tens of meters of the net pens.

The primary concern associated with dissolved nutrient input is the effect it may have on phytoplankton production. Tagaki et al. (1980) and Arakawa et al (1973, cited in Weston 1986a) related phytoplankton blooms to oyster culture and Nishimura (1982, cited in Weston 1986a) to fin fish culture in Japan. This may be of particular importance where potentially toxic phytoplankton species are involved. The neurotoxin-producing diatom, Nitzschia pungens f. multiseries, has been identified from the northern Gulf (Fryxell et al 1991). A related form has been implicated in shellfish poisoning in Canada. Other toxic algal blooms involving Ptychodiscus brevis and Gonyaulax monilata have been reported from the Florida and Texas (Snider 1987).

It is important to remember that while nutrient discharges have been implicated as potentially contributing factors in phytoplankton blooms, this input alone will not cause a bloom. Many environmental factors must interact to provide the conditions suitable for rapid phytoplankton growth. Phytoplankton population also require several days to increase to bloom proportions, while dilution and water movement mix the nutrient rich effluent with the surrounding water on a scale of meters and hours. Only in static systems have studies shown a measurable effect of net pen culture on productivity (see references in Weston 1986a).

It is only in areas with reduced nitrogen concentrations that the additional input of nutrients may have a measurable effect on productivity. Areas with a high degree of vertical stratification because of fresh water inflow or minimal tidal mixing would be particularly susceptible to nitrogen depletion in surface waters. Japanese researchers have suggested nitrogen concentrations of 0.35 mg/l (Takagi et al 1980), and 0.1 mg/l (Iwasaki 1976, cited in Tagaki et al 1980), the limit proposed by Weston (1986a, 1986b), to identify nitrogen depleted areas susceptible to phytoplankton blooms. Stratification of the waters south of the Mississippi barrier islands is frequent (Kjerfve and Sneed 1984), and surface waters depleted of nitrogen are common under these conditions. Studies by USEPA (1990) in the area have revealed total nitrogen concentrations below 0.1 mg/l.

In areas where nutrients are limiting to phytoplankton growth, any input would, by definition, stimulate production. However, in most areas dilution by a current action and surface mixing would minimize any potential localized effects on productivity. Siting culture operations away from nutrient depleted, stratified waters, following correct feeding procedures, feeding only dry pellets, eliminating fines, reducing waste and using highly digestible feeds will all contribute to reducing waste impacts on water quality.

3. Benthic effects.

a) Solid Waste Production

Excess feed, fecal material and debris from structures are the main solid wastes associated with offshore aquaculture.

The amount of wasted feed (that which passes through the cages) is highly variable, depending upon culture practices such as feed type used (dry, moist, wet), feeding methods (hand, automatic, demand) and frequency of feeding. Estimates of waste feed for net pen operations in Maine (Maine Department of Marine Resources 1991) and Washington (Weston 1986a) are about 5%, but can be as high as 20%.

Fecal production is the second major source of solid waste. While fecal production rates for net pen culture are not available, trout fed dry pelleted feed under laboratory conditions lost 25 - 38% as feces on a dry weight basis (Butz and Vens-Capell 1982). Weston (1986a) assumed about one-third of the feed ingested was lost as feces in commercial net pen culture in Washington.

Assuming a dry feed is used and a feed conversion ratio of 2:1, the production of 1 kg of fish will result in an estimated production of 0.7 kg (dry weight) of solid waste, using Weston's (1986a) assumption. Of the two kg of feed fed, approximately 5% (0.1 kg) is wasted. The remainder, 1.9 kg, is ingested by the fish. About one-third or 0.6 kg is lost as feces. This is a best case situation with a minimal amount (5%) of feed wastage. Using these assumptions, a large facility producing 250 metric tons of fish per year is estimated to produce about 175 metric tons of solid waste per year (Weston 1986a).

In warm water areas, such as the Gulf of Mexico, the sloughing off of fouling organism from net pen and shellfish culture structures may also be a significant solid waste input. The contribution of fouling organisms to the solid waste stream is not known but is expected to be significant in warm water situations where fouling may be severe.

The Institute of Aquaculture (1988, cited in Weston 1991a) estimated solid waste production of 520 kg per metric ton of fish, assuming 20% feed wastage and 30% feces loss. This may be a more accurate estimate of solid wastes.

Solid waste production rates are very sensitive to changes in feed conversion ratios (FCR) and feed wastage. Reducing FCR from 2:1 to 1.5:1 would reduce sediment production by about 25%.

Shellfish culture also produces solid waste in the form of feces and pseudofeces, shells lost from the structure and fouling organisms sloughed off during cleaning. Arakawa et al (1971) and Kusuki (1977) estimated that a single raft holding 350,000 - 630,000 oysters can produce 16 metric tons (dry weight) of feces and pseudofeces and an additional 4.5 tons of feces from fouling organisms in a nine month growing season.

b) Sedimentation

Sedimentation rates have been estimated for a variety of culture situations using net pens and floating rafts (see review in Weston 1986a). Much of the data, based on sediment trap results, is of questionable value because of re-suspension and artifacts related to trap size and shape. The data are useful, however, in obtaining estimates of sedimentation beneath net pens/rafts relative to a reference area with a similar current regime. Sedimentation rates beneath net pens have been found to be 2 - 10 times greater than in reference areas (Pease 1977, Weston and Gowan 1988).

Rates of deposition beneath mussel long lines have been reported to be 2 - 4 times greater than surrounding areas (Dahlbäck and Gunnarsson 1981). Arakawa et al (1971) reported that approximately 20 - 30% of the 20 tons of solid waste were generated by an oyster raft and deposited in the vicinity of the raft.

Placement of net pens or rafts in shallow water will significantly increase rates of sediment deposition by lowering current velocity beneath the structures. Water depth beneath the bottom of the net pens should be at least two structure heights to eliminate the effects of current reduction. Results from an analysis by Weston (1986a, 1986b) suggest that sediment accumulation is likely if net pens are located where water depths under the pens are less than 15 m. Braaten et al (1983) suggests a clearance of at least 10 m beneath net pens and further suggests sites with strong currents. Washington State has adopted the recommendations of Weston (1986a), using the size of an operation to determine minimum acceptable water depths and current speeds for siting a net pen operation (Washington Department of Fisheries 1990). British Columbia requires a minimum of 6 m of water depth below the bottom of net pens, New Zealand 7.5 m (see references in Weston 1991a, 1991b). While Maine has no rigid depth requirements for sites, they consider the Washington guidelines and local site conditions in previewing permit applications (Maine Department of Marine Resources 1991).

c) Effects on Sediment Chemistry

Under hydrological conditions typical of the northern Gulf of Mexico, much of the fecal matter, waste feed and debris will settle in the immediate vicinity of the net pens or shellfish rafts. The area receiving solid wastes from fish culture net pens will be visibly affected and are described in a number of sources (e.g. Weston 1986a, 1986b, 1991a, Washington Department of Fisheries 1990) Aside from the presence of food pellets, the area beneath shellfish culture rafts are similar in appearance (Dahlbäck and Gunnarsson 1981). Food pellets will be readily detectible and the feces may form a flocculent deposit 5 cm or more in thickness. Sediment color changes to anoxic black in highly enriched conditions, or to shades of red or orange if only moderately enriched. A common indicator of enrichment is the presence of the filamentous, sulphide-reducing bacteria, *Beggiatoa*, found in dense whitish mats on the sediment surface.

The area affected by solid waste from the aquaculture facility has been reported to be relatively small. Visible accumulations of solid waste from net pen facilities have generally been reported to be within 30 m of the culture facility (Weston 1986b), while significant changes in sediment chemistry have generally been written 15 m (Pamatmat et al 1973, Weston 1986b, 1991a, 1991b). Arakawa et al (1971) and others (Dahlbäck and Gunnarsson 1981, Mattsson and Linden 1983) report that the area affected by sedimentation from shellfish culture does not extend more than about 20 m.

The fate of solid wastes produced by a culture facility depends, in part, on the current velocity, water depth and sinking speed of the particles. Dispersion of waste particles increased with increasing depth and current velocity and with decreased sinking speeds.

Solid wastes provide a source of labile carbon and nitrogen. It is the re-mineralization of carbon that produces the changes in sediment geochemistry typical of organic enrichment Weston 1986a, 1991b). Sediment organic carbon inputs are an important measure of the impacts of fish farms on the marine environment. These can be measured by changes in benthic oxygen consumption, reduction-oxidation (redox) potential, total organic carbon, total volatile solids, sulfide concentrations and levels of nitrogenous and phosphorus compounds.

In general, only about 20% of the carbon supplied to the farmed fish in feed is removed with the harvest. The 80%

remaining is lost, with a seasonally variable amount (30 - 70%) accumulating in the sediments in the short term (Hall et al 1990). Over the long term, the sediment serves as a sink for about 18% of the total carbon input (Weston 1991a).

Re-mineralization of carbon rich sediments consumes substantial amounts of oxygen. The biochemical oxygen demand (BOD) of fish feces and other metabolic wastes may consume 1.5 - 3 times as much oxygen as respiration (Liao and Mayo 1974). Rosati (1990) provides a rule of thumb estimate of 750 g of BOD oxygen consumption for each kg feed used. Since most of the BOD is associated with solid waste, most of the oxygen required to meet this demand will be provided by bottom waters and sediment pore waters. Dahlbäck and Gunnarsson (1981) measured sediment oxygen demand beneath a mussel culture operation to be 1.4 l O_2/m^2/day (at 15 $_0$C and a sedimentation rate of 2.4-3.3 g organic C/m^2/day).

Rates of biochemical oxygen consumption beneath net pens were found to be between 2 - 3 times and six times greater than reference values in two Washington state studies (Pease 1977, Pamatmat et al 1973). Even higher rates have been reported elsewhere (Weston 1991a). Because organic enrichment was limited to the vicinity of both fish and shellfish culture operations, elevated oxygen consumption rates were not detectable away form the site (Pamatmat et al 1973).

The depletion of pore water oxygen in the sediments results in a shallowing of the aerobic portion of the sediment column, measurable by both sediment color changes and more negative reduction - oxidation (redox) potentials in the sediment (Dahlbäck and Gunnarsson 1981, Weston and Gowen 1988, Weston 1991b). In fine sediments, the aerobic layer may be very shallow and the addition of organically enriched sediments may increase oxygen demand to the point where bottom water dissolved oxygen is depleted. This may well be the case in Mississippi coastal waters where large areas of silty sediments occur.

An important chemical effect of reduced sediment oxygen levels is the production of toxic hydrogen sulfide (Dahlbäck and Gunnarsson 1981, Weston and Gowen 1988, Weston 1991b). In the absence of oxygen, the microbial degradation of organic matter in seawater is accompanied by the reduction of sulfate to hydrogen sulfide. Hydrogen sulfide production has been associated with both net pen (e.g. Weston and Gowen 1988, Weston 1991b). and suspended shellfish culture operations (Dahlbäck and Gunnarsson 1981). Because hydrogen sulfide is toxic, it can be harmful to both the culture organisms and to resident farms. Fish farms in Japan and Europe, located in shallow, enclosed waters, have been forced to relocate because of hydrogen sulfide toxicity from accumulated wastes (Weston 1986a, 1991a).

The redox potential measures sediment oxygen content, defining the depth of the boundary (redox potential discontinuity or RPD) between aerobic and anaerobic sediments. This gives a measure of relative enrichment of the sediments, and is the recommended method to measure enrichment impacts beneath fish farms. It is effective, relatively inexpensive and can be used in field conditions (Weston and Gowen 1988). The drawback is that in fine sediments, the RPD is so close to the surface that it may not be readily measurable. Measurement of total organic carbon (TOC) and total volatile solids (TVS) can also be used to document organic enrichment beneath aquaculture facilities.

d) Biological changes due to organic enrichment

Azoic zones (zones devoid of any animals) are reported under most fish farms and under shellfish rafts. The affected areas are limited to those immediately below the farm (Dahlbäck and Gunnarsson, Weston 1986a, 1991a, 1991b). Stewart (1984) and others (e.g. Weston and Gowen 1988) observed these conditions to extend to about 3 m (10 ft) from the farm perimeter. This zone is usually demarcated by a "halo" of dense *Beggiatoa* mats, which covers and stabilizes the underlying sediments. In areas of poor water circulation, the water immediately above the substrate may become anoxic, precluding *Beggiatoa* growth. No live animals are present in this zone, gas bubbles (methane) are evident and redox potentials are severely depressed.

Pearson and Rosenberg (1978) related general changes in the benthic communities as the result of increasing organic enrichment. Benthic communities are altered along a gradient of organic enrichment from the background community of unaffected environments in towards the fish or shellfish farm. It must be noted that the transitions from one zone to another occur along a continuum with no clear boundaries. Depending upon the amount of organic material deposited and the existing benthic community, the more affected zones may or may not be present under any specific operation. Major alterations to benthic communities are generally limited to the area immediately beneath culture facilities and for short (<30m) distances away from the site. These are, respectively, the "footprint" and "shadow" impact areas.

A stable, diverse benthic community is comprised of filter and sediment feeding organisms and predators exists in undisturbed sediments. Many of these animals are large and live in the sediment. As organic matter is introduced into an undisturbed environment, it provides an additional source of nutrition for the benthic organisms. This additional organic matter benefits the existing filter and deposit feeders, and encourages colonization by additional species. Thus, both species diversity and biomass (total weight) of the benthic organisms increase, and the benthic community is enhanced. Pearson and Rosenberg (1978) refer to this as the "transition zone".

As the level of organic input increases, the normal community changes as many species, especially filter feeders, are displaced. The sediments become progressively dominated by various opportunistic deposit feeders, which flourish under these conditions. The most notable deposit feeder is the small, common polychaete worm *Capitella capitata*, indicative of organic enrichment. Under these conditions, the abundance of these opportunistic species can reach very high densities, to the exclusion of other species. Elimination of the larger, deeper borrowing animals further reduces the ability of oxygen to penetrate the sediments. Thus, while the number of organisms increases dramatically, the diversity of species declines.

At higher rates of sedimentation, even the opportunists cannot survive. At this point, the anoxic layer reaches the sediment surface, depriving the animals of oxygen and exposing them to toxic H_2S. In these sediments, the surface is black and devoid of any animals (azoic). Methane and toxic H_2S are produced and escape as bubbles into the water. Gowen et al (1988) estimated that input of organic matter at rates greater than about 8 g carbon/m^2/day resulted in the production of methane and azoic conditions. This rate of input has been associated with large scale intensive fish (see reviews in Weston 1986a, 1991a) and shellfish culture (Cabanas et al 1979, cited in Dahlbäck and Gunnarsson 1981).

Accumulation of organic material may cause the mortality of non-mobile macro-fauna. The area affected would be limited to the zone of organic enrichment in the immediate vicinity of the aquaculture site. Significant effects on fish or mobile microfauna are to be expected. Only where limited flushing leads to waste accumulation and hypoxia of the near bottom water or other deleterious changes in water quality. Where water quality is maintained, fish and mobile macrofauna are attracted to aquaculture sites (Weston 1986a), even to those where azoic zones have been created. At low concentrations, H_2S can affect fish health through gill damage and at higher concentrations be toxic to fish or shellfish in the farm above the sediments (Braaten et al 1983). Such effects have only been reported in stagnant areas with little water circulation.

The extent of the effects of net pens or other aquaculture structures depends on the extent of alterations in sediment chemistry, itself a function of the degree of waste dispersal by water movements and depth, as well as culture practices (Weston 1991a, 1991b). As the potential for waste dispersal increases with increasing depth and current speed, the possibility of significant impacts on the benthos decreases. Recovery of affected benthic communities may take months or years. However, the benthic sediment chemistry appears to recover to normal levels relatively rapidly. In Puget Sound, Pamatmat et al (1973) observed normal benthic oxygen consumption 2 months after pen removal. Dixon (1986, cited in Washington Department of Fisheries 1990) noted that bottom sediments appeared normal at two pen sites in the Shetland Islands, 12 months after removal of the farm.

Biological recovery may take longer depending on the successional colonization of the area by different species and normal recruitment cycles (Pearson and Rosenberg 1978). Species abundance will recover more quickly than biomass due to the growth rates of the larger animals. Gowan et al (1988) observed virtually no faunal recovery 8 months after cessation of net pen operations. Mattsson and Linden (1983) found only limited recovery of the macrofaunal community 18 months after the removal of mussel long-lines.

While the chemical and biological impacts of aquaculture operations on the benthos are readily described, they are not as readily predictable. Weston (1986a, 1991a, 1991b) concluded that the primary factors responsible for patterns of sediment enrichment were current velocity, water depth and loading (weight of fish held). Depth and current conditions in Mississippi waters are not be sufficient to completely avoid the effects of organic enrichment of offshore aquaculture on the benthic community. Recognizing this limitation, it is important that operations be located and designed so as to minimize the accumulation of solid wastes.

Gowen et al (1988) and Weston and Gowan (1988) present a conceptually simple model of sediment deposition from a fish farm. The model has proven a good predictor of general sediment impacts at farm sites, despite inherent limitations. The model has the added ability to evaluate the effects of different pen sizes and configurations under different siting conditions, making it valuable for selecting suitable sites and designing farm capacity and layout.

Minimizing feed wastage is especially important in reducing environmental impacts, reducing potential threats to the crop and improving operation economics. Gowan et al (1988) estimated that reducing feed wastage from 30% to 5% would reduce the organic load to the benthos from 5.5 to 3.5 g carbon/m^2/d.

Rotation of sites is sometimes practiced. This will not reduce benthic impacts significantly Weston 1991a, 1991b). The response of benthic communities to enrichment is rapid (weeks to months) while recovery is much slower (months to years). Unless the rotation is timed to allow complete recovery (an unlikely situation) it is not a useful means of minimizing environmental impact. Rotation and dredging to remove accumulated waste from beneath net pens may, however, provide some benefit to the cultured animals.

4. Chemical usage.

Fouling control and the treatment of diseases are essential for the maintenance of suitable culture conditions in net pen aquaculture. Chemicals used for these purposes pose a threat to the marine environment only when their potential for environmental damage is not fully known or the substances are misused.

a) Anti-fouling compounds

The best example of an anti-fouling chemical adversely affecting the marine environment is tributyltin (TBT). Treatment of boat hulls and nets with TBT has proven to be toxic to marine life in the parts per trillion range. The compound has been banned from use in many areas.

The use of anti-foulant chemicals is probably unavoidable, given the rapid rate of fouling development in warm waters. Any restriction of water movement through the nets by fouling could have profound effects on water quality within the net pens, potentially threatening the health of the crop. At the same time, the cost of labor involved in frequent cleaning and changing of nets would be prohibitive.

Copper-based anti-foulants, in widespread use in Mississippi and Gulf waters, should be used. Newly developed anti-fouling waxes for nets would also be appropriate. In any event, the intent to use anti-foulants should be reported and reviewed by BMR in advance. The use of anti-fouling compounds with a known adverse effect on (non-target) marine life or human health should be restricted.

b) Pharmaceuticals

Fish culturists in the United States have extremely limited chemotherapeutic options (G. Jensen, National Program Leader, USDA Aquaculture Extension, Washington, DC, personal communication). Only one topical treatment and three feed additive antibiotics are currently licensed by the Food and Drug Administration for food fish culture in the United States. One antibiotic, sulfamerizine, is no longer marketed. Romet 30, a potentiated sulphonamide approved for use in catfish and salmonids has not been approved for either redfish or hybrid striped bass culture. The work on the remaining antibiotic, oxytetracycline, and formalin, the topical anti-ectoparasite, on striped bass/hybrids has been completed and has been sent to the FDA for review (*op. cit.*).

Formalin treatment has been approved for a variety of fish species and will probably gain approval for use on hybrid striped bass in the near future. Because formalin is generally applied as a bath to fish held in tanks for treatment (Federal Register 1986a) and is not applied to open water net pens, there is no expected environmental effect so long as the treatment waste is disposed of in an approved manner.

Oxytetracycline (OTC) is a broad spectrum antibiotic useful in the treatment of many fish diseases (Weston 1986a, 1991a). It shows great potential for use in warm water marine fin fish culture and, when approved for use on hybrid striped bass, is likely to become the drug of choice for net pen culture in the Gulf. Oxytetracycline is administered as a food additive at a rate of 2.5 - 3.75 g per 45 kg (100 lbs.) of fish per day over a 10 - d treatment period (Federal Register 1986b). A 21 day holding period is required before fish treated with oxytetracycline can be harvested for human consumption.

The heavy use of antibiotics in the fish farming industry of some countries has prompted concern about the quantity of antibiotics released into the marine environment and the potential effects of these releases. There are four major areas of concern (Weston 1991a): 1) antibiotic accumulation in marine biota, 2) persistence of antibiotic residues in marine sediments, 3) development of antibiotic resistant bacterial strains (and the potential transmission of this resistance to human pathogens), and 4) alteration of sediment microbial community structure. Data on these environmental effects is severely limited.

This discussion (based on Washington Department of Fisheries 1990, Weston 1986a, 1991a) will focus on how these effects relate to oxytetracycline use because of pending FDA approval for use of this drug in striped/hybrid bass culture and because the scanty research on the environmental effects of antibiotic usage have concentrated on this drug.

OTC is widely used as a human medicine. It is also used as a routine feed supplement in the diets of chickens, pigs and cattle. However, unlike its use in humans or fish culture, where it is only used for periodic disease treatment, it is given to livestock on a continuous basis. Despite extensive use of OTC in treatment of fish diseases in the U.S. and elsewhere, there has been no demonstration of significant environmental effects (Weston 1986a, 1991a). Many investigators and others have raised the issue of potential adverse effects of antibiotic use in net pen aquaculture, but, with few exceptions, the discussion has remained speculative. There has been no evidence of any detrimental effect and little or no data to argue against an effect (see reviews in Weston 1986a, 1991a).

a. Antibiotic accumulation. A large proportion of the oxytetracycline supplied to fish through medicated feed will be released into the environment through waste feed and, because of the limited digestive absorption of the drug in fish (Cravedi et al 1987), through feces. This has been cited as a potential threat to oysters, shrimp, crabs, and fish living close to culture sites. However, the probability of this presenting a problem is remote. The concentrations of antibiotics outside the immediate vicinity of the fish farm are regarded by most investigators as too low to have any adverse effects (Washington Department of Fisheries 1990).

Austin (1985) reviewed the effects of antimicrobial compounds escaping into the marine environment from fish farms. While data on the quantities of these materials entering the environment are not available, research results provide estimates of probable concentrations for freshwater situations. As a worst case scenario, Austin (1985) estimated the dilution of OTC to be 1:50,000,000, leading to the conclusion that only minute quantities of the drug reach the environment. Weston (1986a) calculated a concentration level of 3 ppb OTC in a parcel of water passing through a net pen receiving medicated feed.

Field and laboratory research have demonstrated that OTC does not bioaccumulate (Bureau of Veterinary Medicine 1983, cited in Weston 1991a). Katz (1984, cited in Washington department of Ecology, 1989) concluded that there should be no bioaccumulation of OTC in treated lobsters. Oysters suspended near net pens containing fish fed medicated feed were free of OTC residues (Tibbs et al 1988, cited in Weston 1991a). There are, however, some reports of OTC residues in wild fish and shellfish in Scandinavian studies (see Weston 1991a). These results suggest that additional information on the environmental persistence of

OTC under varying conditions is needed. However, there appears to be no threat of antibiotic accumulation in resident marine fauna in the vicinity of aquaculture operations because of dilution and dispersion of OTC bearing waste (Maine Department of Marine Resources 1991, Washington Department of Ecology 1989, Washington Department of Fisheries 1990, Weston 1986a, 1991a).

b. Persistence of antibiotics in sediments. OTC appears to persist in marine sediments, especially under the anoxic conditions common under most net pen fish farms (Weston 1986a, 1991a). Laboratory studies and field observations indicate a half-life of OTC in sediments of at least 10 weeks. (Jacobsen and Bergind 1988). Because there has been no demonstrated detrimental effect of sediment antibiotics on resident macrofauna on the microbial community (Weston 1991a), the significance of this is open to speculation.

c. Antibiotic resistance. Austin (1985) noted that the use of antibiotics in fish culture could lead to increased antibiotic resistance among the resident bacteria in the facility effluent. Oxytetracycline resistance has been noted in two common catfish pathogens, Edwardsiella (Sinderman 1990) and Aeronomas (MacMillan 1985), and resistance may persist for long periods in bacterial populations (Levy and Novick 1986), until diluted with non-resistant strains.

While the development and persistence of antibiotic resistance among opportunistic fish pathogens is of obvious concern to the fish culturist, other potential consequences are unclear. As will be discussed in a subsequent section, wild fish are less susceptible to disease than stressed, closely held cultured fish. Infection of wild fish has not been viewed as a concern (Maine Department of Marine Resources 1991, Washington Department of Ecology 1989, Washington Department of Fisheries 1990, Weston 1986a, 1991a).

There has been speculation that antibiotic resistance can potentially be transferred to bacteria of human health significance. This is not a concern. Fish pathogens possibly developing antibiotic resistance are not pathogens of humans (MacMillan 1985, Sinderman 1990). Transfers of antibiotic resistance among species of bacteria appear to be laboratory phenomena that require highly controlled conditions. While local water temperatures (25°C/77°F) meet one of the requirements for drug resistance transfer (Toranzo et al 1984), such an event is highly unlikely. There is no evidence of such a transference occurring in Japan, where conditions are suitable, a wide range of antibiotics are extensively used and human pathogens are present in the culture water (Washington Department of Fisheries 1990, Weston 1991a). Sewage effluent and runoff from livestock growing areas are greater sources of antibiotics in coastal waters than the aquaculture industry could be in the near future (Weston 1991a).

d. Impacts on microbial community structure and function. The levels of OTC expected to reach the sediments under worst-case conditions (Weston 1986a, 1991a) are not expected to have an inhibitory effect on non-pathogenic bacteria (see review in Washington Department of Fisheries 1990). Samuelson et al (1988) and others (see Weston 1986a, 1991a, 1991b) have reported decreases in sediment microbial density associated with antibiotic treatment. However, the significance of these findings is questionable. Effects were not consistent and were often associated with antibiotic types and dosage rates prohibited in the U.S. There is no indication that application of OTC or other FDA approved antibiotics, following established FDA and industry guidelines, would significantly alter the structure or function of the sediment microbial community.

e. Mitigation of antibiotic effects. Mitigation of antibiotic effects follows two approaches. Only antibiotics approved by the FDA should be used, in approved doses and following approved treatment methods. Second, the culturist should follow good husbandry practices. The frequency of antibiotic use is a function, in part, of fish husbandry practices. Many of the bacteria of concern to aquaculturists are facultative pathogens, becoming a problem only when the fish are stressed. The frequency of infection and the resulting need for antibiotics can be reduced by keeping stocking density and waste loads within the capacity of the site, maintaining clean nets to maximize water flow and removing dead fish promptly. Critical to good husbandry practices are a thorough understanding of site water quality characteristics, their variation and the carrying capacity (maximum loads of fish and feed).

f. Other pharmaceuticals. Two points should also be considered in planning and regulating future use of pharmaceuticals in net pen aquaculture.

Vaccines have been developed for salmonids and other fish species. Vaccines reduce the probability of infection among immunized fish, leading to less antibiotic use. While vaccination will never replace antibiotic treatment (immunity does not last the life of the fish and stress can reduce immunity as well), it can significantly reduce the quantity of antibiotic used per unit of production. Development and use of vaccines for warm water fish in Mississippi coastal waters should be encouraged.

Hormones are commonly used for gender control or to induce ovulation. While little is known of the potential environmental effects of these hormones, the quantities used are so small that no adverse impact is anticipated. No human health concerns are associated with hormone use in fish culture (Weston 1991a) because they are either administered to juveniles long before human consumption or to broodstock that would not be marketed.

5. Interactions With Resident Species.

a) Genetic impacts. The escape of cultured fish from offshore net pen operations is inevitable. This has raised concerns in other regions about possible detrimental impacts on local fish populations (Maine Department of Marine Resources 1991, Washington Department of Ecology 1989, Washington Department of Fisheries 1990, Weston 1986a, 1991a). This concern does not appear to have merit for Mississippi or northern Gulf waters.

Genetic impacts may be important where native species or distinct stocks of fish may be threatened. Because net pen culture in coastal Mississippi waters in the near future would probably be limited to species already present in Mississippi waters (e.g. redfish or hybrid striped bass), no genetic threat is evident.

Redfish will not be genetically affected. It has not been clearly established whether Gulf redfish can be separated into identifiable sub-populations associated with specific areas (Gulf of Mexico Fishery Management Council 1984). "Exotic" redfish will not be introduced. Seed stock for redfish culture are produced from primarily Gulf coast brood stock. Cultured redfish have been repeatedly released in all of the Gulf states' waters.

Gulf and Atlantic race striped bass as well as hybrid striped bass have been stocked in northern Gulf waters since the 1960's (Lukens 1988). There is no evidence of discrete sub-population of striped bass or hybrids (Weston 1991a). Hatchery-produced fish, which from the basis of the Mississippi striped/hybrid bass population, are derived from parental stock taken from a variety of areas. These observations suggest that there is no threat of detrimental genetic effects associated with escaped fish.

b) Introduction of exotic species. The introduction of non-native species and associated pathogens probably represents the greatest environmental threat of aquaculture. If offshore aquaculture is limited to species from the Gulf and Atlantic waters, the probability of an accidental introduction of either is low. Broodstock, reproductive products and fingerlings of redfish, striped/hybrid bass and oysters have a long history of movement between Gulf and Atlantic waters. There do not appear to be any diseases within the ranges of these species that could potentially be introduced by future transfer of seedstock. Similarly, there do not appear to be any macrofaunal pest species that could be transferred from Atlantic waters with seedstock. Purposeful introductions of non-native marine species are controlled under the provisions of the Mississippi Aquaculture Act.

c) Transmission of disease from cultured to wild fish. Concern has been expressed that cultured fish could act as reservoirs of disease infecting wild fish populations. Despite the proliferation of cage culture world wide, such an occurrence has never been documented (Washington Department of Fisheries 1990). In fact, there are several examples of diseases that have had adequate opportunities to infect wild fish but have failed to do so (Weston 1986a). Viral hemorrhagic septicemia and whirling disease, both thought to be endemic to Europe, are serious diseases of rainbow trout imported to Europe and held in cage culture. Wild fish have failed to show symptoms of the disease, even after experimental infection.

Diseases observed in the culture of striped/hybrid bass and redfish are non-exotic. They exist naturally in the marine environment. In a farm environment, these diseases may originate from wild fish, infecting cultured stock. Vibriosis is a disease of many fish species caused by the bacteria *Vibrio* species. *Vibrio* spp. are a natural component of marine microbial communities world wide and commonly present on wild and cultured fish. *Vibrio* spp. are not pathogenic unless the host fish is stressed, as is often the case under culture conditions of density and water quality. Other common diseases are also caused by facultative pathogenic bacteria.

While there are many examples of wild fish transmitting diseases to cultured fish (see review in Weston 1986a, Washington Department of Fisheries 1990), there are no known examples of a culture operation providing a reservoir for infection of the wild fish population (Weston 1991a). A review of the technical literature suggests that the risk of transmission of disease from farmed to wild stock is minimal. Existing regulations will prevent the importation of exotic pathogens that could potentially pose a threat to native fish. Control of potential disease vectors at the facility, such as removal of dead fish, will prevent the spread of any potential infectious agent.

At least one author has speculated that shellfish can be reservoirs for fish pathogens such as viruses (Meyers 1984). Although viruses pathogenic for freshwater fish have been isolated from oyster stocks, there is no evidence to suggest that there is a mechanism for disease transmission from shellfish stocks to wild fish (Washington Department of Fisheries 1990).

Vibriosis has also been reported to affect oysters, especially larval stages (Elston 1984). The problem, however, appears only under intensive hatchery culture conditions and is controlled by improved husbandry practices. There is no evidence that vibriosis is important in limiting natural populations of oyster larvae (Washington Department of Fisheries 1990). There does not appear to be any potential for disease transmission from cultured fish or oysters to natural fish or shellfish populations.

d) Interactions with protected species. Thirty three species of cetaceans (six endangered) have been reported from the Gulf of Mexico (Minerals Management Service 1991). Existing regulations provide adequate protection, and offshore aquaculture is not expected to significantly affect these species.

Five species of marine turtles are found in the Gulf of Mexico (Minerals Management Service 1991). The loggerhead has been reported to nest on the Mississippi barrier islands, and the green turtle may occasionally nest in the northern Gulf as well. Offshore Mississippi waters are areas of significant use by sea turtles. Because they feed chiefly on marine invertebrates, offshore fin fish or oyster aquaculture should not attract sea turtles as predators. However, the potential for interaction among sea turtles and off shore aquaculture remains unknown.

Concerns have been raised, however, that lights on offshore structures may affect the behavior of nesting and hatchling sea turtles. The recommended separation distances should be adequate to avoid having activity on the structures or on-board lights disturb sea turtles nesting on the barrier islands. A proportion of hatchling sea turtles have been reported to be disoriented and drawn towards lights immediately after emerging from the nest. This orientation towards light is known to affect hatchlings in their passage between the nest and the sea. Information on the effect of surface lights on swimming hatchlings is incomplete. Recommended separation distances between potential nesting sites and offshore aquaculture structures should be adequate to protect hatchlings from disturbance or disorientation. Because there is no evidence to support or refute the suggestion that hatchlings will be drawn towards and congregate around aquaculture structures, a subjective determination of adequate separation distance between lighted offshore aquaculture facilities and nesting beaches will have to be made by the Bureau of Marine Resources and the relevant federal agencies on a case by case basis.

Coastal and marine birds are abundant in the northern Gulf (see Minerals Management Service 1991 for a review). Piscivorous species that may be attracted to net pens include waterfowl such as mergansers, shorebirds (e.g. gulls, terns, cormorants), waders and raptors. Bird predation on cultured fish stocks, especially juveniles, is of concern to aquaculture operations while the effects of predator control measures is of concern to regulatory agencies. Of particular concern are endangered and threatened bird species which may prey on cultured fish. These include bald eagles (which nest on the barrier islands) and brown pelicans.

Control of bird predation must follow established federal guidelines for such activities and conform to the requirements of the various regulations in place to protect threatened, endangered and migratory birds. Proposed control plans should be coordinated with the responsible agencies through the Bureau of Marine Resources.

Setting appropriate separation distances away from nesting areas or important habitats will minimize impacts on these species. Based on reviews of regulations in other states and provinces with commercial net pen aquaculture industries (see summary in Owen 1988, and Maine Department of Marine Resources 1991, Washington Department of Fisheries 1990), a 1/4 to 1/3 mile separation between bird habitats and culture sites has been generally agreed upon as adequate. Impacts on piscivorous birds can be further minimized by use of predator control netting, especially over pens holding small fish, and other non-lethal control measures.

Recommended Guidelines

A synthesis of the available studies on the environmental impacts of net pens draws two important conclusions. First, the proper siting of net pens can assure the dispersion of both solid and dissolved wastes and the protection of sensitive areas. Second, environmental effects of net pen culture are reversible. Sediment chemistry can recover on a scale of months, biological recovery will follow on a scale of months to years.

The major potential impacts of offshore aquaculture and actions to quantify, regulate and minimize these impacts have been identified in a variety of state and national studies. The main findings of these studies are:

1. Solid wastes from both net pen and shellfish aquaculture operations will settle to the bottom and affect the benthic community immediately beneath the site. Selecting sites deep enough and with sufficient currents to disperse these wastes will minimize the impact.

2. Important marine habitats, fisheries resources, public lands and endangered or threatened species can be affected by aquaculture operations. Determining appropriate separation distances and selecting sites away from sensitive or important habitats and public lands, in cooperation with the Bureau of Marine Resources, will minimize this impact.

3. Impacts on piscivorous birds can be further minimized by use of predator control netting and other non-lethal control measures. Control of avian predators must conform with existing federal guidelines, and control plans should be developed and coordinated with the responsible agencies through the Bureau of Marine Resources. In view of the potential impact of bird predation on fish culture operations and the effect of control

measures on the birds themselves, it is recommended that the applicant identify potential bird predation problems (e.g. identify bird concentration points and anticipated foraging behavior of potential bird predators) and develop an approved predation control plan early in the permit application process. Minimum separation distances should consider both existing bird concentration points and their anticipated foraging behavior.

4. Nutrients released from net pens, especially nitrogen, can contribute to phytoplankton production in stratified, nutrient poor waters. Siting to avoid areas where nutrient depletion occurs and placing limits on total fish production in such areas can prevent adverse environmental effects.

5. Fish culture in warm water conditions can place heavy demands on available dissolved oxygen levels. Selecting sites deep enough and with adequate current speeds to allow for adequate dispersion of wastes, setting appropriate limits on total fish production and following low waste feeding practices (dry, floating feeds, high digestibility, no fines) will minimize adverse impacts. The use of automatic feeders should be closely watched. The proportion of wasted feed is significantly greater with automatic feeders (overfeeding, fines) than with other feeding methods (Weston 1991a).

6. The effect of aquaculture operations on water movement, quality and on the benthic environment are not detectable within tens of meters of the culture site. Major effects on benthic biota, reduction in dissolved oxygen and increased dissolved

nutrient concentrations are limited to within a few meters of the culture site.

7. There is no good evidence for net pens having an adverse impact on fish and other nektonic species, transmitting diseases to wild fish, contaminating resident fauna with antibiotics or in contributing to the development of antibiotic resistant microbial populations threatening to human health.

8. The environmental effects of on- and off- bottom shellfish culture are generally limited to those associated with sediment deposition.

Siting Guidelines

1. Operation size.

Because the rate of accumulation of feed, feces and organic debris under net pens are related to farm size, regulatory programs to detect and control potentially deleterious environmental effects should be linked to the size of the operation. The recommended degree of monitoring required increases with farm size. The following classifications are presented as a model. Either may be readily used for northern Gulf conditions. While it is recommended that site evaluation and monitoring requirements be geared to farm size/production level, the number of farm classes is subjective.

There are two established methods of classifying net pen operations by size. Weston (1986a) and Washington Department of

Fisheries (1990) use annual fish production to divide net pen operations into three size classes: Class I, less than 20,000 lb/yr (10,000 kg/yr), Class II 20,000 - 100,000 lb/yr (10,000 - 45,000 kg/yr), and Class III, over 100,000 lb/yr (45,000 kg/yr). The Province of British Columbia (Ministry of Environment 1988) uses annual feed consumption, calculated on a dry weight basis (see Appendix D), to classify fish farms: Class A operations use less than 120 mt of feed (dry wt) per year, Class B 120 - 630 mt and Class C over 630 mt annually.

2. Depth and Current Speed

Site current and depth characteristics are matched with production level or feed usage rates to determine the extent of environmental impact. However, because of the relatively shallow depths and low current speeds in Mississippi waters and in the northern Gulf, it may be more appropriate to evaluate permits on a site specific basis. This will require a thorough survey of pre-operations site conditions, and estimates of potential waste loads, DO and BOD demands, sedimentation and nutrient inputs based on net pen design, array, loading and feed use. This would be most effective if the survey and monitoring requirements were geared to farm size.

A precedent for this approach exists. Maine does not adhere to rigid farm size definitions but considers each permit request on a site specific basis. This approach requires that hydrographic and benthic data be collected in advance of construction to adequately characterize the site. Because the state assumes the responsibility for the collection and analysis of this data in Maine, farm size is less of an issue. Where the permit applicants are required to collect this data, the requirements are geared to farm size.

Regardless of size, minimum recommended water depth (MLW) beneath the bottom of net pens should be at least two times the height of the side facing the prevailing current. Maintaining this depth will insure that current velocities beneath the pen are not reduced by the structure.

The main functions of currents are to supply dissolved oxygen, to dilute dissolved nutrients and to disperse solid wastes. Current speeds and direction in coastal Mississippi waters are seasonally variable and generally weak. Surface and bottom currents in the area often differ in speed and direction as well.

Low current velocities have several implications. The arrangement of the net pens will be affected. the velocity of currents passing through net pens is appreciably reduced. In weak current areas, below 5 cm/sec velocity, passage through even a single cage will reduce velocity to near zero. In such areas, net pens must be arranged in a single row perpendicular to the prevailing current.

Depending on the site, the direction and velocity of the surface currents may change on several time scales (daily to seasonal). Major seasonal changes may require periodic relocation of the net pens.

Spacing between net pens should be at least 2 structure diameters. Rows should be at least 20 structure diameters apart. Based on experiences in other states, distances between farms should be no closer than 600 m (2000 ft).

The availability of dissolved oxygen for respiration and BOD will be limited by low current velocities. Oxygen consumption rates of the fish species targeted for net pen culture in the Gulf are not well known. In warm water conditions, oxygen consumption levels of redfish will be "high" (Neill 1987), and hybrid striped bass will consume up to 800 mg/l (Kruger and Brocksen 1978). Summer DO saturation levels are expected to be relatively low (say, 6.8 mg/l at 28°C and 25 ppt). Under these circumstances, low current velocities within the net pens may seriously affect fish culture operations.

Assuming that current velocities within cages are reduced to 40% of upcurrent velocities and that most sites in Mississippi coastal waters will have surface currents less than 8 cm/sec, both loading rate (fish/m^3) and total farm size will be limited by current velocity and available dissolved oxygen.

Prevailing current velocities in coastal Mississippi will be insufficient to appreciably disperse solid wastes from beneath the net pens. Because the BOD of the solid waste can be up to three times the respiratory oxygen demand of the fish, oxygen depletion of bottom waters is a very real concern. Farm size and loading rates will have to be limited by current speed and seasonally variable dissolved oxygen levels available for both respiration and BOD. Because of anticipated high BOD and low summer DO levels, minimum depth below the net pen must be determined by the anticipated maximum waste load. While the determination of current speeds within net pens and the calculation of waste loads, sedimentation rate and dispersion, and respiration and biochemical oxygen demands are imperfect, the suggested methods should serve as a basis for the evaluation of potential environmental impacts of aquaculture.

3. Areas With Chronic Water Quality Problems.

Net pens should not be located in areas subject to nutrient depletion in surface waters (total nitrogen less than 0.1 mg/l) or in areas subject to vertical stratification of the water. A stratified water column tends to be depleted of nutrients, while bottom waters are prone to reduced dissolved oxygen conditions.

Large areas of the northern Gulf, in Louisiana coastal waters are subject to periodic anoxia resulting from stratification. Mississippi coastal waters are often partially stratified in the spring and summer months (Kjerfve and Sneed 1984, Minerals Management Service 1991, USEPA 1990).

Nutrient inputs to nitrogen-poor surface waters may contribute to unwanted phytoplankton productivity. Solid waste inputs may compound near bottom dissolved oxygen problems in stratified water bodies. These effects will be magnified in areas with fine sediments, where BOD is already high.

To minimize the likelihood that aquaculture operations will adversely affect water quality or contribute to phytoplankton productivity, limits may be placed on fish production within Mississippi coastal waters, pending the collection of essential current and water quality data to allow an evaluation of the site. On a qualitative basis, production levels will be limited in stratified waters, nutrient depleted waters and, assuming a standard pen height of 4 m, in waters less than 12 m deep.

4. Habitats of Special Significance.

Habitats and species of special significance to be protected from adverse environmental effects have been identified in all regions. Selecting sites away from sensitive or important habitats and public lands will minimize impact from offshore aquaculture. Maine requires a minimum of 1/4 mile separation between aquaculture sites and parks, wilderness areas, critical habitats for endangered/threatened species and sensitive fisheries related habitat. Washington defines a variety of minimum separation distances from 300 feet to 1,500 feet. British Columbia and New Brunswick require 1000 m. However, external activities that impact park values and resources, even those falling outside park jurisdictional areas, may require greater separation distances based on site specific conditions.

Because of reduced current velocities in Mississippi waters, the effects of aquaculture operations would be spatially limited. While it appears that only minimum distances (150 - 300 ft.) would be required to avoid impacts on seagrass beds, oyster reefs, artificial reefs, spawning areas and other fishery resources, actual separation distances will have to be determined on a case by case basis. As with other separation distance guidelines, permits should identify that separation distances may be increased to reduce any potential impacts on these habitats. Following recommended depth guidelines will minimize the potential for locating aquaculture operations in close proximity to sea grass beds.

Prudence dictates avoiding net pen locations in areas with large concentrations of piscivorous birds (e.g. pelicans, terns), their nesting sites or near nests of fish eating raptors (ospreys, eagles). In view of the potential impact of bird predation on fish culture operations and the effect of control measures on the birds themselves, it is recommended that minimum separation distances should consider both existing bird concentration points and their anticipated foraging behavior. Based on federal and state guidelines of aquaculture in other regions a minimum of 1/4 mile separation between bird concentration areas and the net pens is recommended.

Net pens located closer than a certain minimum distance from bird nesting or concentration areas (1/4 mile in northern regions) may serve as an "attractive nuisance", drawing birds to the site. Based on limited observations, however, birds appear to visit sites located beyond this minimum distance (but within the normal foraging range) with about equal frequency. It is critical to identify and establish this minimum distance (buffer zone) for all bird species that may be affected by the operation. The permit should specify that the separation distance requirement may be increased if it is determined that the number of bird visits exceeds an accepted frequency.

A minimum of 1/4 mile should separate aquaculture operations from any park, wilderness area, beach or areas used or frequented by protected animal or bird species. This would include sea turtle nesting grounds. No sensitive areas for marine mammals have been identified in Mississippi coastal waters. However, any permit granted to a aquaculture facility should specify that if any critical habitats or sensitive areas are identified and are affected by the operation, the permit may be altered. An alteration of permit conditions may also be required should aquaculture operations affect threatened or endangered species.

5. Dredged material disposal areas, maintained waterways and other areas of concern.

While not technically an environmental concern or habitat of special significance, navigation channels, open water disposal areas and other sites permitted for specified uses are not suitable for siting aquaculture operations. Because of the potential conflict arising between dredging and disposal and aquaculture operations, net pens and shellfish culture operations should not be located in close proximity to these activities. On-bottom shellfish structures should not be within 1500 feet of either a dredged channel or a disposal area. Because most suspended sediment effects of dredging are confined to bottom waters, net pens in water over 12 m deep should be located no closer than 500 ft. of a navigation channel. At least 1500 ft. should separate shallow (<12 m) net pen operations from maintained navigation channels and separate all net pen facilities from designated open water disposal sites. Seasonally variable current direction and velocity negate any possibility of closer siting "up current" of dredging or disposal operations. These distances should be reviewed and established on a case by case basis.

While these guidelines do not specifically address esthetics issues, it is important to note that these considerations will be taken into account in reviewing permits. Specifically, the presence of wilderness areas, marine sanctuaries, recreational areas and national seashores in the northern Gulf of Mexico will affect the siting, operations and monitoring requirements for aquaculture operations. No attempt has been made in this report to address other important concerns such as conflicts with other users, social impacts and related issues.

<u>Pre-operations requirements</u>

These guidelines are not intended to be all-inclusive. Rather, they identify some of the important pre-operations requirements that bear directly on operational and monitoring guidelines.

1. Permit applicant must document financial resources for the proposed project, demonstrating the capability to perform as specified in the permit conditions.

2. The permit applicant must provide information regarding the professional expertise of the on-site operations staff. This must be sufficient to demonstrate an ability to accomplish the proposed project.

3. Permit applicant may be required to post a performance bond to ensure compliance with operations and monitoring conditions. An additional bond may be required to ensure cleanup in the event of a fish kill or other pollutant discharge, or to allow for the and cleanup of the site after destruction or abandonment.

4. Working with the Bureau, the permit applicant must identify shellfish beds, submerged vegetation beds and essential habitats/endangered or threatened species found in the surrounding area.

5. Should a permit request be denied because the proposed operation does not satisfy recommended site selection, evaluation, operations and monitoring guidelines presented here, the burden of proof that there will be no significant environmental effect associated with the operation should fall on the applicant.

Site Characterization Survey.

Because of the large number of areas in Mississippi waters where potential water quality problems and adverse environmental impacts may occur, it is essential that all sites considered for aquaculture operations be surveyed and characterized. This survey must be completed before the permit application and should include: a) a bathymetric survey, b) hydrographic survey and c) a diver survey to visually assess the area and its biological resources. Applicants for permits should be strongly encouraged to consult with the Bureau of Marine Resources officials prior to completing a permit application and designing the site characterization survey. Appendix B provides an outline of a baseline survey.

An overview of the information needed to coordinate the survey is provided in Appendix A, including site location, development plan and operations plan. These will be combined with survey data to determine the suitability of the site for the described operation, any potential adverse environmental impacts and any proposed mitigation approaches.

Operations Guidelines

1. A baseline survey should be completed for large (>630 mt of feed used, dry weight, per year; in excess of 100,000 lbs. fish annually) operations after construction but before operations commence. Recommended guidelines for the baseline survey are shown in Appendix B.

2. All waste discharge permits should have the condition that discharges meet state water quality standards (State of Mississippi 1991) for dissolved oxygen, temperature, Ph, turbidity, toxic or deleterious materials and fecal coliforms (temperature and Ph effects are not expected to occur).

3. The receiving water mixing zone will be defined by the State and water quality standards will not apply in the mixing zone adjacent to or surrounding the site. The area/volume of the mixing zone should be limited so as to minimize mortality of important fish or shellfish. A suggested mixing zone of 100 ft. around the perimeter of the facility should be sufficient to mitigate discharge and turbidity effects of both normal culture and cleaning operations.

4. Discharges of any fish carcasses, fish processing waste, sewage or other waste beyond feed, fish feces and debris from fouling organisms should be prohibited.

5. To minimize nutrient inputs, only dry pelleted feed should be used. Floating pellets, preferably formulated specifically for the cultured fish species to maximize digestibility, should be used. Fines should be removed prior to feeding and automatic feeders should be discouraged.

6. Operations should use non-lethal methods of predator control and all methods must comply with state and federal requirements.

7. Toxic and deleterious substances

a) Net fouling control chemicals. The discharge of antifoulants which may affect water use or adversely affect aquatic biota or human health should be prohibited. The intended use of antifouling agents should be reported and reviewed by state environmental management agencies.

b) Only antibiotics licensed by the FDA for use on the target fish species should be allowed for use. Oxytetracycline and formalin are expected to receive approval soon for use in hybrid striped bass culture. Only two other theraputants, Romet-30 (a combination of sulfadimethoxine and ormetoprim) and sulfamerazine (not presently marketed), and an anaesthetic, MS 222 or Finquel, have FDA approval for use on fish.

Antibiotics should be used strictly on a short term basis for disease treatment or prevention. Long-term prophylactic use should be prohibited. The Bureau should be notified of all antibiotic use at the time of treatment and notified of the disease condition treated and type of dosage of antibiotic used.

Concern about the environmental risks by disease prevention medications appears to be minimal. Although it is expected that antibiotic use in fish culture will be relatively frequent, given the warm water temperatures and other potentially stressful conditions in this region, there does not appear to be a risk of the development of antibiotic resistant bacteria or accumulation of antibiotics in marine organisms. Similarly, there does not appear to be a risk of disease transmission from farmed fish to wild stocks.

Should the frequency of antibiotic use at a fish farm increase markedly, measures to reduce the frequency of infection and the need for antibiotics should be employed. These include reducing stocking density, more frequent net cleaning, prompt removal of dead fish and other measures to improve water quality. Permits should specify that these actions may be required.

Vaccinations are likely to become important in warm water fish culture disease control in the near future. Provisions should be made to encourage the use of vaccinated fish to reduce antibiotic use.

c) Hormones (especially methyltestosterone) have been used in aquaculture. Little is known of their potential environmental impact. While there is no indication that hormones will be used in net pen fish culture in Gulf of Mexico waters, the quantities used are so small and so early in the life of the fish that no major effect is anticipated. Hormone treatment for sex reversal should not be prohibited.

8. All importation, transfer and possession of live fish or their reproductive products must comply with state and federal regulations.

Monitoring Guidelines

Monitoring programs should be geared to the size of the operation. Washington State guidelines recommend annual monitoring surveys for net pen operations over 20,000 lb annual fish production (Appendix C). These include a benthic survey and a diver survey for operations producing between 20,000 - 100,000 lbs. annually. Large operations (>100,000 lb/yr) are required to complete a more comprehensive survey, including sediment chemistry, benthic infauna, water quality sampling and current information in addition to diver and benthic surveys.

The British Columbia government has developed a model annual monitoring program (Appendix D). With modifications, this is a useful model for Mississippi waters. This system divides farms into three size categories by the quantity of feed used and prescribes increasingly complex monitoring requirements with increasing quantity of feed used. Data forms and standard methods for use in the annual monitoring program have been developed as well and are attached as Appendices F and G.

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Appendix A. Environmental Surveys.

The effect of development on the marine environment is a major consideration, so certain site-specific information is required for permit review. In order to assess the suitability of a site for net-pen or on/off bottom shellfish culture and to evaluate the extent of environmental effects after the start of culture operations, several environmental surveys are required. These include a site characterization survey, a baseline survey, and annual monitoring. The components of each of these surveys are summarized in Table A1 and discussed in the following sections.

< add table A1 here>

A. **Site Characterization Survey.** A site characterization survey is required prior to permit application. This survey serves two principal functions. The primary purpose is to provide state and local governments with the information necessary to evaluate the potential extent of environmental effects. The site characterization survey also provides the applicant with information on determining the suitability of a site for culture. A site characterization survey is composed of four principal elements: (1) initial consultation with state and local government; (2) a bathymetric survey; (3) a hydrographic survey; and (4) a diver survey.

1. Consultation with state government. After selecting a potential culture site, but prior to performing the site characterization field survey, the prospective applicant should contact state resource management agencies (Departments of Wildlife, Fisheries and Parks - Bureau of Marine Resources, Environmental Quality, Agriculture). Initial contact should be made with the MDWFP Bureau of Marine Resources (BMR). This agency will then facilitate consultations with all other appropriate state and federal agencies.

While these consultations cannot be required of the applicant, they are highly recommended. They provide state and federal local officials with an opportunity to comment on the potential site at an early stage in the planning process. They also ensure that the required evaluation surveys will be designed to meet established requirements. Resource management agencies may be able to identify nearby habitats of special significance or existing conditions that would make the site unacceptable for development. Other government agencies may also need to be contacted if the potential site is likely to affect land or resources under their jurisdiction.

One of the principal purposes of these consultations is to determine the proximity of the potential site to habitats of special significance. BMR staff may be aware of nearby critical habitats or major shellfish beds. BMR may also be able to

Table A1

RECOMMENDED ENVIRONMENTAL SURVEYS FOR MISSISSIPPI NET-PEN CULTURE

	Site Characterization Survey	Baseline Survey	Annual Monitoring
Class I Facilities	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey - Current velocity and direction • Diver survey	• None	• None
Class II Facilities	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey - Current velocity and direction • Diver survey	• None	• Benthic survey - Diver survey
Class III Facilities	• Recommended consultation with state and local authorities • Bathymetric survey • Hydrographic survey - Current velocity and direction - Drogue tracking - Vertical hydrographic profiling • Diver survey	• Sediment chemistry sampling • Benthic infauna sampling	• Benthic survey - Diver survey - Sediment chemistry - Benthic infauna • Water quality sampling • Current velocity and direction

identify bird nesting sites and colonies, wilderness areas, public beaches and parks and other areas of significance. BMR can obtain information on endangered, threatened, and protected species that may occur in the vicinity of the proposed site.

State and local government officials should be given an opportunity to comment on the proposed field surveys (i.e., bathymetric, hydrographic and diver surveys). The survey content should be determined in consultation with BMR and those agencies having permit authority. The survey protocol described below is intended to provide the information necessary for a standardized and cost-effective permit review. This should be adequate in most instances, but there may be certain site-specific concerns that would require minor modifications. For example, the diver survey may be modified to devote particular attention to areas of special concern. Departure from this protocol should be allowed only with strong justification, and modifications should generally result in the collection of more, rather than less, data.

2. Bathymetric survey. A bathymetric survey should be performed in order to determine depth and to identify the presence of any bathymetric features which might affect bottom accumulation of excess feed and fecal material. All permit applicants will be required to perform a bathymetric survey. The area of concern is the seabed directly under the floating or on-bottom structures and within 300 feet of the perimeter of such structures. Multiple fathometer transects should be established with a density and spacing so as to adequately characterize the bathymetry under and around the pens. The position of the transects will depend upon the intended configuration of the planned structures. Figure A1 provides a recommended survey design given a rectangular configuration. The bathymetric survey report should note the period during the tidal cycle when the survey was made, and it should relate the measured depths to MLLW (mean lower low water).

<add Figure 1A here>

3. Hydrographic survey. Information on current velocities and directions is necessary to determine if current velocities will be adequate for dilution and dispersion of excess feed and wastes from net pen culture. Current information will also be needed for floating shellfish facilities to estimate the potential dispersion of wastes. These data are important for operations planning, providing essential information on the supply of dissolved oxygen supplied by the water flow.

The hydrographic survey includes three components: (a) current velocity and direction; (b) drogue tracking; and (c) vertical profiles of temperature, salinity and dissolved oxygen. Class I and II net pen facilities, as defined in Table A2 (AppendixC) will not be required to perform the drogue tracking studies because of their small size and reduced potential for water quality degradation. Floating shellfish culture facilities will only be required to describe current velocity and direction. Only vertical temperature, salinity and oxygen profiles only will be required for on-bottom shellfish culture.

3a. Current velocity and direction should be monitored at the center of the proposed site. Both near-surface and mid-depth measurements should be made. The near surface measurements should be taken at a depth of 6 feet or at one-half the depth of the structure. The mid-depth measurements should be taken mid-way between the maximum depth of the proposed net-pens and the sea floor. At both depths current velocity and direction should be monitored throughout one complete tidal cycle (one flood tide, one ebb tide). Collect a 15-minute sample at each of the three depths. A minimum of ten measurements evenly spaced throughout the tidal cycle should be made at each depth. "Mean current" is to be determined by an arithmetic average of these ten or more measurements. The measurements should be made during a period of "average" tides, and should not be representative of either extreme neap or extreme spring tides. Subsurface current meters are preferred. However, flow meters may be used, but surface direction must be estimated. Please provide the current data in a tabular format and include the date and tide predictions for that day. The report of results should note any conditions (e.g., weather, wind speed and direction, tidal gauge data for that day) that might make the data unrepresentative of "typical" conditions. If there is reason to believe the data do not reflect "typical" tidal currents and direction, resampling may be required, but all data collected may be used in determining a mean velocity.

3b. Drogue tracking is needed to estimate the potential fate of particulate material and the potential for eddy circulation (i.e., the same parcel of water is repeatedly cycled through the area of the net-pen). Two drogues should be released from the center of the potential net-pen site. One should be set at a depth of 6 feet. The second drogue should be set at a depth mid-way between the bottom of the potential net-pens and the sea floor. The trajectory of these drogues should be followed for as long as daylight permits, and not less than 8 hours. The drogues may be reset at the original release site during this 8-hour period if they are transported beyond a practical tracking range.

3c. Vertical profiles of salinity, temperature and dissolved oxygen may be used to evaluate the intensity of water column stratification, a factor important both from the standpoints of environmental protection and the health of the cultured fish. Prospective applicants should provide any existing hydrographic information on the site. Site-specific studies have been completed in the northern Gulf of Mexico by the

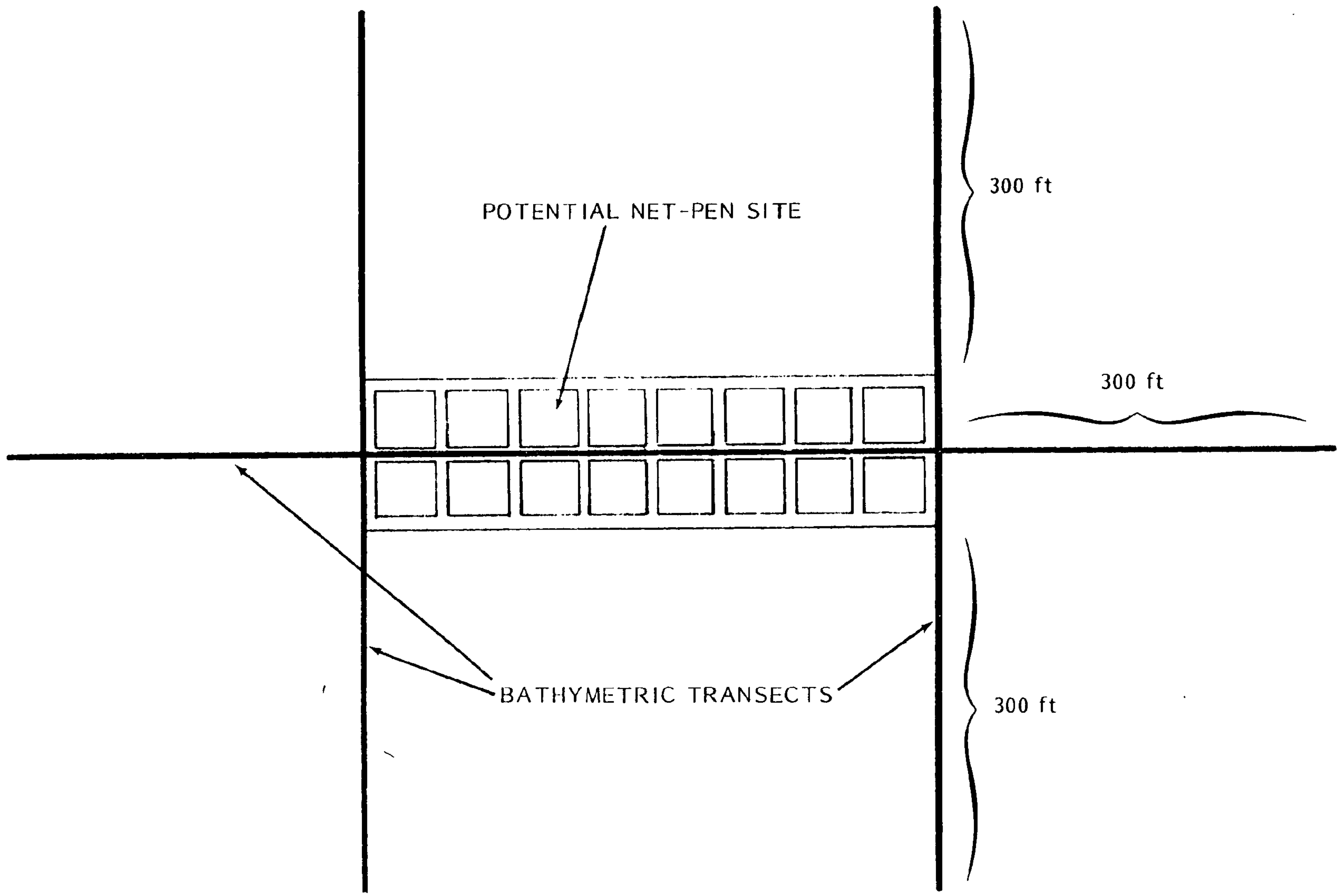

Figure A1 RECOMMENDED BATHYMETRIC SURVEY TRANSECTS FOR SITE CHARACTERIZATION

Environmental Protection Agency, Corps of Engineers (Mobile District), Minerals Management Service and researchers working out of the Gulf Coast Research Laboratory.

Measurements of temperature, salinity and dissolved oxygen should be taken throughout the water column at the center of the potential site during the summer months, June through September. Measurements should be made at depths of 1, 10, 20, 30 feet, and at 30 foot intervals thereafter. The deepest measurement should be made 3 feet above the sea floor. Water samples may be collected or an electronic membrane probe may be used. The sampling schedule should include one sample taken within one hour of slack low water.

Although the preferred method is the ''Winkler Titration'' (Azide modification), described in Standard Methods, the use of the membrane electrode is acceptable if the zero and standard calibration methods described in the instrument manufacturer's instructions are followed. If the membrane probe is used, the first and last reading of each run must be verified with a Winkler Titration of a water sample collected just prior to the instrument readings. The verification samples must be fixed when collected and titrated in the laboratory as soon as possible after collection. The verification samples should be reported next to the same readings performed by the probe.

4. Diver survey. The diver survey is primarily intended to determine if habitats of special significance are present in the vicinity. Because much of the biological activity in offshore Mississippi waters occurs spring through fall, the diver survey should be performed April through November. The requirements for a diver survey during site characterization depend on the water depths in the vicinity of the site. A diver survey is required if water depth (MLLW) at the site or within a 300 foot radius of the potential location is less than or equal to 75 feet. If any portion of this area is in depths of 75 feet or less, it may be subject to accumulation of feed and fecal material.

The design of the diver survey should be formulated in consultation with BMR, who will take the lead role for the state in design of this survey. The dive should be conducted along the axis of the prevailing current. The number and spacing of the transects will depend on the particular site and will be established during these consultations. As a general guide, 3 to 5 transects, each 200 feet long, should be surveyed per acre of pen/raft surface. A larger complex would require additional transects. A diver should follow marked transects making observations of substrate type, bottom features (noting erosional or depositional areas), presence/absence of Beggiatoa mats, and relative abundance of flora/fauna. Abundance may be characterized approximately as follows: a) abundant: always present within the diver's view; b) common: seen occasionally throughout the dive, may be patchy; rare: only seen once or in a few places throughout the dive. If eelgrass is present, counts of turion density in 0.25 m^2 quadrats will be required. Where oysters are present, density (per m^2) and average size should be provided.

5. Report. The results of the bathymetric, hydrographic and diver surveys should be assembled in a site characterization report to be submitted to the BMR. The report should be a summary, analysis and interpretation of the data. The diver survey should be described in narrative form with quantitative data provided when required or available.The report should also include identification of habitats of special significance in the vicinity as determined in consultation with the BMR and the applicant's own surveys.

The BMR may require that the diver survey shall be documented with a video camera or photographs. One copy of the video tape on standard VHS tape format should accompany the application. While video format is preferred, photographs taken at 30 foot intervals may be submitted if video is not available. A brief narrative with the tape or photos describing reference points should be provided. All documentation must include the dates on which it was taken.

Information to be provided in the report should include:

A. Vicinity Map. Use a NOAA chart or USGS Topographic map to show the waters and shorelands within the general vicinity of the lease area. Any aerial photos must have been taken during the twelve month period prior to the filing of the application and the date on which it was taken must be noted.

B. Plan View. Exact location of lease tract(s) described as follows:

a. Mark each tract and entire lease boundary. Mark true north with arrow. Include scale used.

b. Show depth contours and indicate mean low water and mean high water on all land adjacent or nearest site.

c. Show primary ebb and flood directions.

d. A figure of the drogue trajectories should be also be included.

e. The position of the diver transects.

f. Label the location of Federal projects, navigational channels, any structures, weirs, existing leases, parks, etc. within 1 mile. An enlargement of a NOAA chart or USGS topographic map is suggested to provide this information. Also provide:

g. The latitude, longitude and LORAN coordinates for each corner of the entire lease.

h. The metes and bounds of each 5 acre tract.

C. Site development. This section is intended to provide accurate plans depicting the physical structures of the proposed operation. The site characterization report should include a figure of the proposed net-pen site in plan view at a scale of 200 feet or less to the inch.

a. Single pen/raft schematic. Provide top view, cross section, identify dimensions, materials, labels, etc.

b. Pen system schematic. Provide top view and cross section, identify dimensions, mooring connections, labels, etc.

c. On-site support structures. Describe structures such as barges, sheds, feed sheds, etc., to be located on-site. Provide dimensions, drawings, materials, etc.

- Describe the storage and use of oil, gasoline or other hazardous material on this facility.

- Describe the type and location of any sanitary facility.

d. Mooring plan.

- Cross section. Provide a schematic and description of materials of the mooring system in place on the sea-floor. Include depths from the bottom of the structure to sea-floor relative to MLW and MHW.

- Mooring system adequacy. Provide a schematic of the mooring array for a pen system and a description of its ability to withstand severe storms, surge, equipment break-up, etc. Include dimensions and materials, etc.

e. Pen system and mooring array schematic. Provide a schematic of the maximum area to be utilized by pen systems and moorings on the proposed lease.

f. Upland facilities. Describe shoreside facilities or holdings to be used for various activities including feed transport, processing, etc.

D. Operations.

a. List and describe your activities including boat traffic, feed schedule, feed techniques, monitoring schedule, transport schedule, predator control methods, net cleaning and maintenance (methods, frequency and location), antibiotic usage, harvest schedule, harvest technique, processing methods.

b. Describe the start-up and projected maximum production on a 12 month basis per pen and pen system. Also state the maximum stocking density, in pounds per cubic foot for fish and per square foot of structure for shellfish.

c. Estimate the monthly pounds of feed per pen system over 12 months at start-up and maximum production.

E. Area resources.

a. Habitats of special significance/endangered species. Oyster beds, submerged vegetation beds and other marine resources. Provide a description of any oyster beds, sea grass beds and other marine resources in the surrounding area. Provide a map showing the location of these resources if within a mile of the proposed site.

Projects cannot be located within one mile of any habitat of special significance, such as wilderness areas, critical habitats for endangered/threatened species, sensitive fisheries habitat, grass beds, bird concentration points, etc. Applicants will be required to provide a signed statement to confirm the proposed lease either does not fall within one mile of such habitats.

b. Surrounding area use.

Provide a tax map, chart, or topographic map showing the locations of any adjacent or nearby lease tract(s) or riparian/littoral property located within 1000 feet of the lease tract(s) Property lines must be clearly marked. List the names and addresses of every lease holder or owner of riparian rights shown on the map. Identify any fish or shellfish culture leases. The map and list of owners must be certified by the tax collector or clerk of the municipality in which the lease tract is located as being an accurate copy of this information as maintained by the municipality.

List all other aquaculture leases held by the applicant or in which the applicant has a financial interest. Describe the navigational or other uses (ocean disposal, cable, etc.)

within one mile of the area. Describe the degree of exclusive use required by the proposed lease.

c. Point source discharge. Describe the location and proximity of the proposed lease to any point source discharges or facilities (sewage treatment plants, seafood processing plants, power plants, industrial facilities, stormwater drains, etc.).

F. Technical capability. Provide information regarding professional expertise such as a resume and documentation of technical expertise and practical experience necessary to accomplish the proposed project.

G. Financial capability. Provide documentation to prove the applicant has the necessary financial resources for the proposed project. Provide documentation of accurate and complete cost estimates of the proposed aquaculture activities. The applicant must post a performance bond, the amount of which will be determined by the nature of the aquaculture activities proposed and set by the BMR.

Appendix B. **Baseline Survey.**

The baseline survey is intended to characterize bottom conditions at the site, before they could potentially be altered by culture activities. and benthic infauna sampling. The baseline survey is required for Class III net-pen operations only and will not be required of Class I and II operations or for shellfish culture. The baseline survey is to be completed after emplacement of net-pens but before stocking.

The Baseline Field Survey may include components for diver observation, hydrography and water quality, but focuses primarily on benthic analyses, sediment analyses and sediment chemistry, The sediment sampling plan must include the number and location of sediment samples to be collected for grain size, chemical and biological analysis. The proposed plan should be coordinated with BMR to insure that the quality of the sediment analysis and infaunal data will be acceptable. Stations should be established along a transect on the "downcurrent" side of the pens as determined by the prevailing currents (as measured at the mid-depth station in the site characterization survey). Stations should be established along this transect beginning directly under the perimeter of the net-pens and extending away from the net-pens at distances of 20, 50, 100, and 200 feet in the direction of prevailing currents. Each site should be sampled by three replicate diver cores or three replicate grab or box corer samples from which sub-cores are removed.

Cores should be collected for analysis of total organic carbon, total Kjeldahl nitrogen and grain size distribution (median phi, percent gravel, sand, silt/clay). Cores should be inserted to a depth of four inches in the sediment. Care should be taken to insure that the core is representative of the undisturbed sediment column. Transparent cores should be used so that the redox potential discontinuity (RPD) depth can be noted and recorded. The position of the RPD is reflected by change in sediment color form brown to black. Each core should be homogenized for analysis, but the replicates should be treated as distinct samples and not pooled prior to analysis.

Benthic infauna samples may be collected either 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. The same stations sampled for sediment chemistry (0, 20, 50, 100 and 200 feet from the net-pens) should be sampled for benthic infauna. Three replicate samples should be collected at each site. The same grab/box corer samples used for sediment chemistry should be used for benthic infaunal analysis provided no more than one-quarter of the surface of each sample has been removed for sediment chemisrty sampling. Each benthic infauna 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, generally species.

The results of the baseline benthic survey should be assembled in a report consistent with the report guidelines provided for the site characterization survey and the annual monitoring. The baseline report should be submitted to BMR, who will take responsibility for distribution to other agencies for comment and action.

Appendix C. Annual Monitoring.

Upon issuance of a state lease and State and Federal permits a monitoring program will be required. The annual monitoring program is designed to serve two purposes. First, it is intended to monitor potential changes in water and sediment quality resulting from culture activities. Secondly, it provides data with which to review the current environmental requirements for possible future modifications. As additional data are obtained on the environmental effects of net-pen or on- or off-bottom shellfish culture, the annual monitoring protocol may be substantially revised. It is also possible that monitoring at some culture sites may be curtailed or eliminated entirely if little or no measurable effect on environmental quality is found after several years of operation. The determination to curtail or eliminate monitoring at any site will be made after BMR review of survey results.

The annual monitoring program consists of three principal elements:

(1) a benthic survey, including diver observations and sampling of sediments and benthic infauna;
(2) water quality sampling; and
(3) a hydrographic survey.

Class I facilities should be exempted from annual monitoring. Class II net-pen fish culture facilities and on- and off-bottom shellfish culture facilities should be required to conduct only a diver survey.

The potential for water quality impacts related to net pen fish culture will be directly related to the amount of feed used on the farm. The annual monitoring requirements have been designed to require more extensive monitoring for farms using larger quantities of feed.

FEED USE CATEGORIES.

Three categories of monitoring have been established based on annual feed usage. As each category has different monitoring requirements, the first step is to identify the correct monitoring schedule for each level of operation. Each permit holding facility is considered to be a separate farm and must be reported independently.

Estimate the total **dry weight** of fish feed to be used in the ensuing calendar year on the farm site. Although this feed will normally be in the form of wet feed (or silage), moist feed, or dry feed, total feed should be calculated in terms of dry weight only. Note that **the amount of dry feed is not equivalent to dry weight.** Dry weight of feed can usually be determined by referring to the feed manufacturer's product specifications. These specifications should include the moisture content of the feed. This content can then be subtracted from the total weight of the feed to yield total dry weight. If moisture content specifications are not provided by the feed supplier or manufacturer, it is the responsibility of the farmer to make this determination. Percent moisture is defined as the percent loss in weight of feed when dried to a constant weight at a temperature of 105 degrees Celsius.

For example, if annual feed requirements for a net pen fish farm are:

- 500 metric tons dry feed with 10% moisture content
- 80 metric tons moist feed with 35% moisture content
- and 50 tons wet feed with 70% moisture content,

then the total feed usage in terms of dry weight will be:

= (500 - 10%) + (80 - 35%) + (50 - 70%)
= (500 - 50) + (80 - 28) + (50 - 35)
= 450 + 52 + 15
= 517 metric tons dry weight

If the total dry weight of feed is less than 120 metric tons (mt, 1 metric ton = 2200 lbs), only a minimum of record keeping information is required. If the total dry weight of feed is between 120 mt and 630 mt inclusive, additional requirements for basic oceanographic data and a diver survey of bottom sediments will be needed. Farms using in excess of 630 mt dry weight of feed annually are subject to the most intensive monitoring. Table A2 shows the farm category associated with each feed use category.

TABLE A2. Farm Categories.

Dry Weight of Feed (metric tons)	Farm Category
< 120	I
120 - 630	II
> 630	III

BENTHIC SURVEY

The benthic survey is intended to assess the extent of solids accumulation on the bottom in the vicinity of the culture operation and the biological effect of this accumulation. The survey consists of diver observations and sampling of sediment chemistry and benthic infauna. Diver observations are required if any portion of the sea bottom within 300 feet of the site is at a water depth of 75 feet or less. Documenting the diver survey with either continuous video footage or with photographs taken at 20-foot intervals may be required. A brief narrative with the tape or photos describing reference points should also be included. All documentation must include the dates on which it was taken.

Four transects, each at least 200 feet in length, should be established as illustrated in Figure A2. The transects should be extended if feed or feces accumulation is visible 200 feet from the pens. Additional transects may be required to survey habitats or resources of special concern. Divers will not be required to operate in depths greater than 75 feet.

A diver survey shall be conducted twice a year, between January and February and again between August and September. One of the principal objectives of the diver survey is to document the depth and lateral extent of solids accumulation. The diver should estimate the depth of feed and feces accumulation at 20-foot intervals along each transect, and should note the greatest distance from the net-pens that visible accumulation is present. The diver should also note the presence/absence of Beggiatoa mats and estimate densities of demersal fish, crabs and other invertebrates.

The annual monitoring benthic survey for Class III operations will also include collection of sediment and benthic infauna samples. The station location and sampling protocol should be exactly as described in the baseline benthic survey (Appendix B). Benthic monitoring will be required during the first period of peak feeding. This will generally coincide with the first harvest at the end of the growing season. After this monitoring will occur at the peak feeding period every year, except for semi-annual diver surveys.

a. Sediments. Sediment cores are to be analyzed for sediment grain size (% gravel, sand, silt, clay); the depth of the redox discontinuity layer, the depth of the unconsolidated organic layer and TOC. Plexiglas type corer is to be used. Single core samples collected according to the approved sampling plan must be inserted to 4 inches. The depth of the discontinuity layer and the depth of the unconsolidated organic layer are to be measured from the surface.

Grain size analyses should be performed using the Wet Seiving method. The standard sieve sizes for gravel, sand, silt and clay are to be used. Full analyses of the silt-clay fractions may be calculated as the difference in dry weight between the original

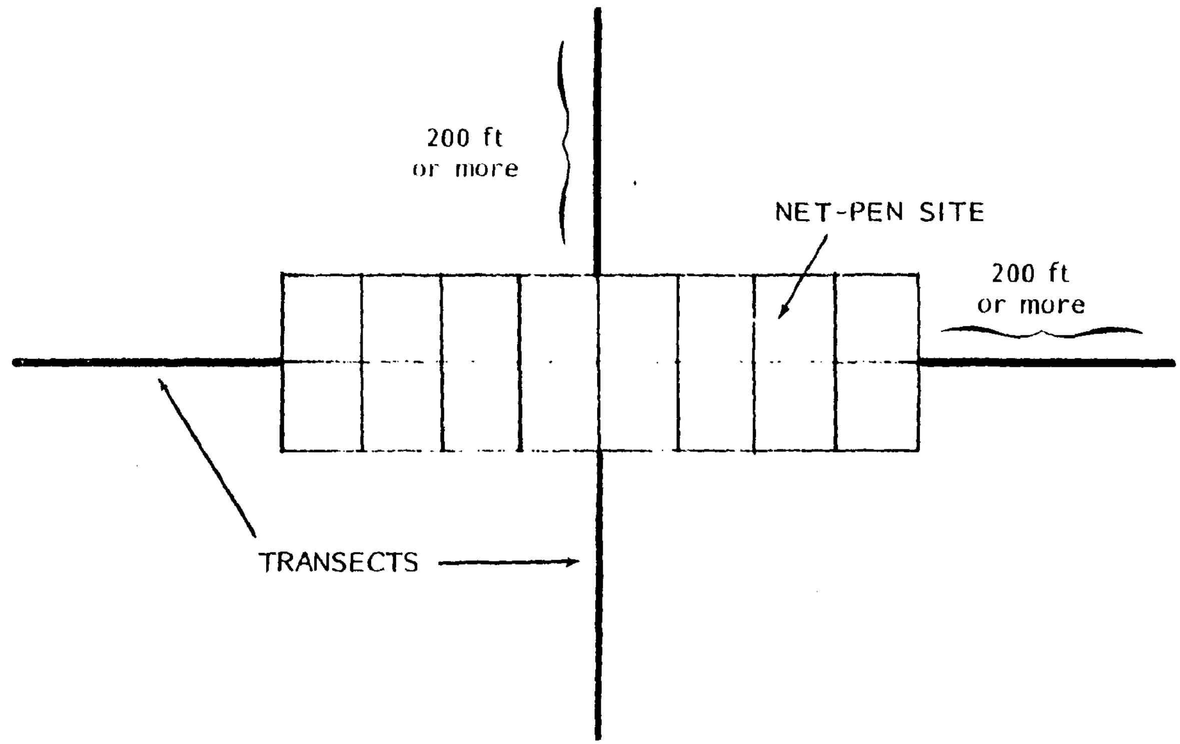

Figure A2 RECOMMENDED DIVER TRANSECTS DURING THE ANNUAL MONITORING SURVEY sample and the sum of the sieve fractions down to the 0.062 mm sieve (very fine sand). The fraction in each sieve should be reported in grams (dry weight) and percent of total (dry weight) including the total dry weight of the initial sample. The unconsolidated material and the top 2 cm of inorganic sediments shall be collected for the analysis of TOC. The applicant must insure that a minimum of 30 grams are collected for analysis. Multiple cores (which include the top 2 cm of inorganic material) if warranted, will be required. Total Organic Carbon should be analyzed using established methods.

b. Infauna. Benthic infauna samples may be collected either 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. The same stations sampled for sediment chemistry (0, 20, 50, 100 and 200 feet from the net-pens) should be sampled for benthic infauna. Cores should be taken during the season of maximum feeding. Three replicate samples should be collected at each site. The same grab/box corer samples used for sediment chemistry should be used for benthic infaunal analysis provided no more than one-quarter of the surface of each sample has been removed for sediment chemistry sampling. Each benthic infauna 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, generally species.

WATER QUALITY SURVEY

Water quality sampling is intended to document the effect of culture activity on dissolved oxygen and nutrients in the water passing through the culture structure. The survey should be conducted every two weeks from June to September, inclusive, of each year that the facility is in operation. Sampling during the summer and early fall months is recommended since it is during this period that dissolved oxygen reductions or nutrient enrichment are of greatest concern. Three stations should be sampled: 100 feet upcurrent of the net-pens; 20 feet downcurrent; and 100 feet downcurrent. The precise location of the stations will depend on net-pen configuration, but they should be located so as to monitor the water passing through the greatest possible number of net-pens. Sampling should be conducted within one hour of slack tide. Three replicates should be taken at each station at a depth mid-way between the water surface and the bottom of the net-pens. Samples should be analyzed for the following parameters: dissolved oxygen; temperature; salinity; pH; ammonia; and nitrite/nitrate (either separate or combined). The concentration of unionized ammonia should also be calculated.

Also, during the peak feeding period a one-time detailed analysis of dissolved oxygen, temperature and salinity will be prepared for each station, consisting of 10 equally-spaced samples over the entire vertical depth of the station.

Water samples may be collected or an electronic membrane probe may be used to measure the concentrations. Temperature and salinity measurements should be used to determine percent saturation of dissolved oxygen and stratification. Although the preferred method is the "Winkler Titration" (Azide modification), described in **Standard Methods** , the use of the membrane electrode method is acceptable, provided recommended procedures are followed. If the membrane probe method is used, appropriate verification procedures (described in Appendix A) must be used.

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 feet downcurrent of the net-pens concurrently with collection of the water quality sample from this station. Loading estimates (g/kg fish/day) should be calculated for ammonia and nitrite/nitrate based on:

(1) the net increase in concentration between the upcurrent station and the 20 foot downcurrent station;
(2) the current velocity 20 feet downcurrent;
(3) the cross-sectional area of the net-pen complex; and
(4) the weight of fish on hand at the time of the water quality survey.

REPORT PREPARATION

The comments made regarding the site characterization report apply here as well. Specifically, analysis and interpretation of the data should be provided, not merely presentation of the raw data. However, the raw data should be provided in appendices so as to permit independent assessment of conclusions.

In addition to a description of methods and data analysis and interpretation, the annual monitoring report should also include information on operational practices over the past year. This information should include:

1) General description of facility (species cultured, size at which fish will be marketed, etc.).

2) Size, number and configuration of net-pens at time of sampling.

3) Significant changes in size, number and configuration of net-pens over the previous year.

4) Annual production (live weight, pounds) cumulative to the end of the reporting period.

5) Estimated weight of fish on hand during survey (pounds).

6) Stocking density (average and range, lbs/ft^3).

7) Type of feed used, percent moisture, quantity used of each type and feeding method employed.

8) Types of antibiotics used, amount, date, form administered over the past year.

9) Interactions with birds and marine mammals and a summary of types and frequency of predator control measures used.

10) Types of antifoulants employed and frequency of net treatment, net cleaning. List all materials directly or indirectly released to the water (anesthetics, cleaners, pigments, hormone treated feed etc.), date, amount and how they were applied.

11) Waste disposal. Indicate methods used to dispose of dead fish and any processing wastes generated on site. Give dates, quantities involved and names of any contractors used.

12) Provide an estimate of projected feed usage for the upcoming year, based on production plans.

The annual monitoring report should be submitted to BMR within 30 days of the end of the reporting period set by the agency. The BMR take responsibility for distribution to other appropriate authorities.

Appendix D. Monitoring Program, British Columbia