A Review of the Potential Environmental Effects of Net Pen Aquaculture in the Northern Gulf of Mexico[1]

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Abstract: This report reviews the environmental and social concerns associated with net pen aquaculture in coastal waters, identifies potentially significant impacts of operations in the northern Gulf of Mexico, and proposes site selection and planning guidelines. There are 5 major areas of potential environmental concern: water quality alterations and their consequences, sedimentation and benthic effects, chemical usage, disease transmission, and escaped fish (exotic species, genetic impacts). Social concerns focus on conflicts between net pen operations and navigation interests, commercial fishermen, recreational users, waterfront property owners, and conservation interests. Environmental impacts are minimized by selecting sites with adequate water exchange and waste assimilation capacity. Zoning to exclude or limit aquaculture (facility size, spacing, materials, feed type, etc.) in waters important to traditional marine resource user groups has been successful in reducing conflicts. This planning effort requires detailed information on physical and chemical processes, biological resources, and patterns of resource use in coastal and marine waters. Until such plans are developed, net pen aquaculture permits should be evaluated on a site specific, case by case basis.

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The apparent profitability of commercial net pen aquaculture at higher latitudes has created an interest in net pen farming of hybrid striped bass (*Morone saxitalis* X *M. chrysops*) and redfish (*Sciaenops ocellatus*) in Gulf of Mexico waters. The rapid growth of commercial net pen aquaculture has also brought into focus the potential environmental and social effects of such activities. Regulatory agencies worldwide have attempted to identify and limit the negative impacts of the industry on the marine environment and on traditional marine resource user groups (see reviews in Ackefors 1983, Braaten et al. 1983, Beveridge 1984, Ervik et al. 1985, Weston 1986, 1991*a;* Crown Estate 1987, Pedersen et al. 1988, British Columbia Ministry Environ. 1990, Washington Dep. Ecol. 1989, Washington Dep. Fish. 1990, Maine Dep. Mar. Resour. 1991). Because most of the potential environmental and social effects are independent of species cultured (Weston 1991*a*), existing information can be used to assess impacts, develop criteria for site selection, and suggest a rational framework for evaluating the potential effects of net pen aquaculture in the Gulf of Mexico.

Potential Environmental Effects

Factors that affect water quality and the benthic environment at net pen sites are related to water retention time and bottom conditions. These include site exposure, bottom topography, water depth, frequency and pattern of water column mixing and tidal flushing, extent of areas with no circulation, and the presence of depositional areas (Weston 1986, Faris 1988, Håkanson et al. 1988). Sites can be evaluated on a case by case basis to determine the ability of the site to maintain adequate water quality for fish health and simultaneously limit the extent and severity of environmental damage (Weston 1986, 1991*a;* Caine 1988, Håkanson et al. 1988, Washington Dep. Fish. 1990, Maine Dep. Mar. Resour. 1991, New Brunswick Dep. Fish. and Aquacul. [no date]). In some regions, areas with conditions unsuitable for net pen aquaculture areas have been identified and excluded from consideration (Parametrix 1990*a*, 1990*b;* Pedersen et al. 1988, Washington Dep. Fisheries 1990). Because of relatively shallow depths, low current speeds, and seasonal stratification/hypoxia in northern Gulf coastal waters, it may be more appropriate to evaluate permits on a site specific, case by case basis. This will require a survey of pre-operational site conditions and estimates of potential waste loads, respiratory oxygen demands, and biochemical oxygen demands, sedimentation and nutrient inputs based on farm size, net pen design, array, stocking rates, and feed use.

Water Quality

Current marine net pen designs assume a current velocity not less than 10 cm/sec within the net pens (Aarsnes et al. 1990), conditions not often encountered in the inshore waters of the Gulf of Mexico. Current velocities inside net pens can be reduced to 35%–80% of outside velocity, depending on net characteristics, stocking density, fouling, and other variables (Aarsnes et al. 1990). Because reduced water flows limit dissolved oxygen and waste transport (Braaten et al. 1983, Ervik et al. 1985, Silvert et al. 1990), current velocities at a site have important implications on farm size and net pen design, orientation and spacing, and distances between farms.

In arrays oriented parallel to the current direction, downstream net pens experience progressively decreasing water exchange rates. Because such arrangements may result in unacceptable downstream water quality in low current areas, net pens should be oriented into the current to allow for adequate water exchange.

While there have been numerous studies of net and current forces on net pens, there have been few direct measurements of the effects of net pens on currents outside the structure. Weston (1986) estimated net pens will reduce current velocities to 95% of free stream values for a distance about equal to 1 structure diameter upstream, 2 structure diameters to either side, and 20 structure diameters downstream. These current velocity reductions suggest that net pens should be separated by at least 2 structure diameters and rows of net pens by at least 20 structure diameters (Weston 1986).

Cumulative effects of net pens on the environment and on fish production are poorly understood. Based on recommendations adopted in other regions (e.g., Ackefors 1983, Caine 1988, Washington Dep. Fish. 1990, Maine Dep. Mar. Resour. 1991, New Brunswick Dep. Fish. and Aquacul. [no date]), minimum distances between farms should be no less than 600 m.

Water quality around net pens is also affected by the introduction of waste products, primarily excreted ammonia and urea, and the products of microbial breakdown of solid wastes (Ackefors 1983, Ervik et al. 1985, Weston 1986, 1991*a;* Gowen and Bradbury 1987). Quantities of solid and dissolved waste generated by net pens vary with fish density and size, feed conversion efficiency, feed type and composition, water temperature, and other variables (Beveridge 1984, Gowen and Bradbury 1987). While no data on waste production are available for net pen culture of hybrid striped bass or redfish, the magnitude of the effects is expected to be comparable to waste loads created in salmon production (Weston 1991*a*). For example, the net pen production of about 150,000 mt of trout and salmon in Norway discharged an estimated 14,000 mt of nitrogen, 2,000 mt of phosphorous, and 120,000 mt (dry weight) of particulate organic material into coastal waters (Ervik and Hansen 1990).

High protein (45%) commercial pelleted feed contains about 7.7% nitrogen and 44% carbon (Ackefors 1983, Gowen and Bradbury 1987). Studies of commercial net pen facilities indicate about 15%–30% of the ingested nitrogen is lost in particulate form and about 50%–65% is excreted directly into sea water (Gowen and Bradbury 1987, Håkanson et al. 1988, Weston 1991*a*). Gowen and Bradbury (1987) estimate 45–55 kg of ammonia are excreted per metric ton of fish produced. Between 15% and 30% (Gowen and Bradbury 1987, Håkanson et al. 1988) of the consumed carbon is lost as feces. In marine waters about 15%–25% of the available phosphorous is lost in the soluble form, and 55%–60% as particulate waste (Ackefors 1983, Weston 1991*a*).

Increases in dissolved phosphorous and ammonia have been detected near net pens (Beveridge 1984, Pease 1977, Brown et al. 1987, Rensel 1990, Wildish et al. 1990*a*) but rapid dilution minimizes any enrichment effect (Rensel 1990, Weston

1991*a*). Recognizing that nutrients from net pens may stimulate phytoplankton production in poorly flushed, nutrient depleted waters (Braaten et al. 1983, Ervik et al. 1985, Håkanson et al. 1988), many regions have closed such area to fish culture (Ackefors 1983, Caine 1988, Pedersen et al. 1988, Washington Dep. Fish. 1990).

Warm water areas are particularly subject to eutrophication effects (Turner and Rabalais 1991). Correlations between intensive net pen fish culture, increased nutrient loading, and harmful phytoplankton blooms have been documented in warm, poorly flushed coastal waters (Nishimura 1982, Lee et al. 1991). While the potential contribution of nutrients from net pen fish culture should be considered, many factors must interact to provide suitable conditions for bloms (Wildish et al. 1990*a*, Turner and Rabalais 1991). Blooms of toxic phytoplankton are not uncommon in Gulf waters (Turner and Rabalais 1991). To protect fish health, farms should avoid areas where blooms have occurred.

Demands on water column dissolved oxygen near net pens come from fish respiration and the rapid nitrification of excreted ammonia (Ackefors 1983, Beveridge 1984). Water quality models for well mixed, cool water sites predict a decrease in downstream surface dissolved oxygen concentrations of 0.30–0.35 mg/liter (Weston 1986, Silvert et al. 1990), values supported by field studies (Braaten et al. 1983, Ervik et al. 1985, Washington Dep. Fish. 1990). Dissolved oxygen reductions can be even more pronounced in warm, poorly flushed sites. Decreases of 2.0–2.5 mg 0_2/liter below ambient have been reported around net pens in warm waters with limited tidal exchange (Kadowaki and Hirata 1984). Lee et al. (1991) reported periodic basin-wide low dissolved oxygen levels in warm, poorly flushed coastal waters used heavily for net pen culture.

This has important implications on the proposed culture of redfish and hybrid striped bass in warm coastal waters of the Gulf of Mexico. As water sea water temperature increases, saturation levels of dissolved oxygen in decline while respiratory oxygen demands of fish increase (Colt and Tchobanoglous 1981). In warm salt water (>26° C), 100-g striped bass consume 200–400 mg 0_2/kg fish/hour (Kruger and Brocksen 1978). Based on models developed for other warm water fish (Colt and Tchobanoglous 1981), second year fish may consume an estimated 800–1,600 mg 0_2/kg fish/hour. Fouling, rapid and intense in coastal Gulf waters, many further reduce water exchange rates and exacerbate dissolved oxygen deficits in the net pens (Aarsnes et al. 1990). Meeting anticipated oxygen demands in the warm, shallow, poorly flushed coastal waters of the Gulf may significantly affect choices of farm size, net characteristics, maintenance and stocking density, all of which reflect on economic performance.

Benthic Effects

Excess feed, fecal material, and debris from the structures are the main solid wastes associated with net pen aquaculture. Reductions in current velocity around floating net pens may also increase sediment deposition (Ervik et al. 1985, Silvert et al. 1990). Estimates of waste feed when using dry pellets vary widely. Most current net pen environmental models assume a 10% feed loss (Gowen and Bradbury 1987, Parametrix 1990*a*, Silvert et al. 1990) although sediment carbon analysis suggests a 15% loss (Weston and Gowen 1990). Assuming about one-third of ingested feed is lost as feces (Ackefors 1983, Gowen and Bradbury 1987, Parametrix 1990*a*, 1990*b*), a feed wastage rate of 10% and a feed conversion of 2:1, an estimated 0.8 kg (dry weight) of solid waste will be produced for each 1 kg of fish (Weston 1986, 1991*a*). Field measurements report similar values (Brown et al. 1987, Gowen and Bradbury 1987, Ervik and Hansen 1990).

The chemical and biological effects of particulate wastes from net pens are identical to associated pulp mill and sewage treatment plant discharges (Gowen and Bradbury 1987, Weston 1991*a*, 1991*b*). The spatial and temporal extent of benthic impacts depends upon production level, management practices, and bathymetric and hydrological conditions (Braaten et al. 1983, Håkanson et al. 1988, Weston 1986, 1991*a*, 1991*b*). Field studies (see reviews in Brown et al. 1987, Gowen and Bradbury 1987, Washington Dep. Fisheries 1990) and sedimentation models (Parametrix 1990*a*, 1990*b*; Weston and Gowen 1990) suggest that dispersal of particulate wastes increases with increasing current velocity and, to a lesser degree, water depth beneath the net pens. Depth appears to increase dispersal of particulate wastes only in very high current areas (Parametrix 1990*b*, Silvert et al. 1990).

Sedimentation rates beneath net pens have been found to be 2–10 times greater than in reference areas (Ackefors 1983, Pease 1977, Brown et al. 1987, Parametrix 1990*a*, Weston and Gowen 1990) but can be 100–200 greater in poorly flushed areas (Kadowaki et al. 1980; Ervik et al. 1985; Weston 1986, 1991*a*; Gowen and Bradbury 1987; Håkanson et al. 1988). The area affected by solid wastes is relatively small, usually within 20–45 m of the net pens (Brown et al. 1987, Parametrix 1990*a*, Silvert et al. 1990, Weston and Gowen 1990) although very large facilities may have effects detectable at 150 m (Weston 1991*b*).

The remineralization of carbon and nitrogen in waste feed and feces consumes substantial amounts of oxygen and produces major changes in sediment geochemistry, including production of toxic hydrogen sulfide (Ervik et al. 1985, Håkanson et al. 1988, Wildish et al. 1990*b*). Rates of benthic oxygen consumption 2 to 3 times reference values have been reported beneath commercial net pens (Brown et al. 1987, Gowen and Bradbury 1987, Håkanson et al. 1988, Wildish et al. 1990*b*). Benthic oxygen demand is greatest for net pens in areas with limited water exchange (Pease 1977, Braaten et al. 1983, Ervik et al. 1985, Brown et al. 1987).

The accumulation of organic material strongly affects benthic communities up to 30 m from the net pens (Weston 1991*a*, 1991*b*). Except for net pens located in deep water (at least 20 m clearance beneath the net pens) and/or in high current areas (>5 cm/second minimum average current), zones devoid of animal life are reported under most fish farms (Ervik et al. 1985; Weston 1986, 1991*b*; Gowen and Bradbury 1987; Washington Dep. Fish. 1990). While benthic communities respond rapidly to increased organic loading, recovery may take months or years (Gowen et al. 1988, Weston 1991*a*, 1991*b*).

Current models of net pen particulate waste deposition (Parametrix 1990*a*, 1990*b*; Silvert et al. 1990; Weston and Gowen 1990) indicate much of the fecal matter, waste feed, and debris will settle in the immediate vicinity of the net pens under hydrological conditions typical of the Gulf of Mexico. Because of warm summer water temperatures in the northern Gulf of Mexico, frequent density stratification and associated hypoxia of bottom waters (Turner and Rabalais 1991), the biochemical oxygen demand imposed on near bottom waters may have severe effects on the benthic environment and on the health of cultured fish.

Chemical Usage

The environmental effects of chemicals used in aquaculture are poorly understood. Antifoulants, fungicides, wood preservatives, and therapeutic drugs may pose a threat to the marine environment when their potential for environmental damage is not fully known or the substances are misused. Most jurisdictions view antifoulants approved for use in marine waters as acceptable for use in aquaculture (British Columbia Ministry Environ. 1990). Pesticides must generally be approved prior to use. In general, except for feed, feces, and fouling debris, discharges from net pen operations are prohibited (Ackefors 1983, Braaten et al. 1983, Washington Dep. Ecol. 1989, British Columbia Ministry Environ. 1990, Maine Dep. Mar. Resour. 1991).

Of the 3 feed additive antibiotics and 1 topical treatment registered for use in food fish culture in the United States (Food and Drug Admin. 1988; G. Jensen, unpubl. rep. 91-8, U.S. Dep. Agricul. Ext. Aquacul. Prog., Washington, D.C., 1991), none has been approved to date for use in either redfish or hybrid striped bass culture. However, research work needed to approve use of oxytetracycline (OTC), an antibiotic, and formalin in striped bass/hybrid culture has been completed and sent to the Food and Drug Administration for approval (G. Jensen, unpubl. rep. 91-8, U.S. Dep. Agricul. Ext. Aquacul. Prog., Washington, D.C., 1991).

Formalin is applied as a bath to fish held in tanks for treatment (Food and Drug Admin. 1988), so there will be no environmental effect as long as the treatment waste is disposed of in an approved manner. OTC is applied as a food additive (Food and Drug Admin. 1988). Because >90% of the dosage is released via the feces (Weston 1991*a*), the drug may accumulate in the sediments below a farm, raising concerns about inhibition of sediment microbial communities, development of OTC resistance by pathogens, transference of resistance to human pathogens, and accumulation in the tissues of resident macrofauna (Weston 1986, 1991*a*, 1991*b*; Washington Dep. Fish. 1990).

Despite extensive use of OTC in treating fish diseases, there had been no demonstration of significant environmental effects (Weston 1986, 1991*a*, 1991*b*; Washington Dep. Fish. 1990). OTC shows little potential for bioaccumulation in fish or shellfish even under worst case conditions (Washington Dep. Fish. 1990, Weston 1991*a*). OTC concentrations may remain stable in deeper sediments (>5 cm, Nygaard et al. 1992, but see Washington Dep. Fish. 1990), the half-life of OTC in the surface sediments is about 10 to 12 weeks (Jacobsen and Berglind 1988, Samuelson et al. 1988, Nygaard et al. 1992).

Decreases in the density of sediment microbial communities following antibiotic treatment have been reported (Samuelson et al. 1988). Interpretation of the Jacobsen and Berglind (1988) study indicates that the highest observed sediment antibiotic concentrations, under conditions where permitted OTC doses greatly exceeded FDA limits, were just above inhibitory levels (Washington Dep. Fish. 1990). Further, estimates of OTC levels likely to reach the sediments (Weston 1986, 1991*a*) suggest that sediment concentrations will be below levels inhibitory to non-pathogenic bacteria (<1 ppm. Washington Dep. Fish. 1990).

While increased bacterial resistance to OTC in experimentally treated sediments has been reported from Norway (Nygaard et al. 1992), treatment levels were at least 10 to 500 times greater than OTC residues in sediments beneath commercial fish farms in the same region (Jacobsen and Berglind 1988). Other reports of antibiotic resistance are from very intensive aquaculture operations, using varieties and dosages of antibiotics not permitted in the United States. Similarly, transference of antibiotic resistance to a human pathogen has been observed only under laboratory conditions, never in nature, even in areas of intense, unregulated antibiotic usage (Washington Dep. Fish. 1990).

It appears that the type of antibiotics used, the antibiotic mix, the dosage rate, and frequency of application determine the severity of potential environmental threats. There is no indication that application of OTC or other FDA approved antibiotics, following established FDA and industry guidelines, would have significant environmental or human health effects.

Impacts on Wildlife and Fisheries

The escape of cultured fish from offshore net pen operations is inevitable, giving rise to concerns that important fish resources could be affected. Concerns include introduction of exotic fish species, disease transmission, and genetic impacts on wild stocks (Phillips et al. 1985, Faris 1988, Washington Dep. Fish. 1990, Maine Dep. Mar. Resour. 1991, Weston 1991*b*).

Escape of exotic species of fish does not appear to be a significant concern because there are no plans to culture exotic fish and intentional introductions are regulated in the Gulf coast states. Stocking programs have introduced Atlantic and Gulf races of striped bass, plus escaped hybrid stripers from inland reservoirs, into Gulf coastal rivers over the last 30 years (Nicholson et al. 1986). Redfish broodstock from throughout the Gulf are used in some state stocking programs. As a result, interbreeding of hatchery stocks with native striped bass and redfish populations may already occur. As restoration programs continue to grow, however, efforts to preserve genetic integrity of local stocks may arise (Parker and Miller 1987).

Aquaculture does not appreciably add to the disease risk to wild stocks (Beveridge 1984, Phillips et al. 1985, Faris 1988, Weston 1991*b*). Despite the proliferation of net pen culture world wide, the transmittance of endemic diseases from domestic to wild stocks has never been documented (Weston 1986, 1991*a*, 1991*b*; Caine 1988; Faris 1988; Washington Dep. Fish. 1990). Hatchery stocks have infected wild fish in only a few cases, where exotic pathogens were introduced (Washington Dep. Fish. 1990). While hatchery stocks of striped bass/hybrids are known to carry the infectious pancreatic necrosis virus, hatchery fish have been widely used in Atlantic and Gulf coast stocking programs with no apparent disease introductions (Nicholson et al. 1986, Parker and Miller 1987).

In most regions with successful net pen industries, certain areas are excluded from aquaculture development to reduce impacts on important marine resources. These usually include seagrass beds, shellfish grounds, migratory fish corridors, and areas known to be frequented by protected species (Caine 1988, Faris 1988, British Columbia Ministry Environ. 1990, Maine Dep. Mar. Resour. 1991, Washington Dep. Fish. 1990, New Brunswick Dep. Fish. and Aquacul. [no date]). Until state or regional development plans are completed, responsible federal and state agencies should identify and locate the resources to be protected and determine appropriate separation distances on a case by case basis. Because the area affected by net pen aquaculture is relatively limited, only minimum separation distances would be required to avoid impacts on seagrass beds, oyster reefs, artificial reefs, spawning areas, and other fishery resources. Permits must identify that separation distances may be increased should any detrimental impacts be detected on these resources.

Existing state and federal regulations protect the 33 species of cetaceans and 5 sea turtles found in the Gulf of Mexico. The effects of net pens on nesting behavior and movements of hatchling turtles are not known. Best management practices suggest establishing conservative minimum separation distances between net pens and nesting areas and restrictions on the use of certain lights that may attract hatchlings.

Piscivorous bird species that may be attracted to net pens are abundant in the northern Gulf. Bird predation on cultured fish stocks, especially juveniles, is of concern to aquaculture operations, while the effects of predator control measures on protected bird species are of concern to regulatory agencies. Proposed control plans should be coordinated with these agencies and follow established state and federal guidelines for such activities. Conservative minimum separation distances between net pens and bird colonies and non-lethal predator control measures appear to be the best management practices to minimize interactions with birds.

Social and Economic Effects

Planning aquaculture development is essential to minimizing conflicts with other resource users (Pedersen et al. 1988, Washington Dep. Fish. 1990). Many of the objections to net pen aquaculture involve use conflicts and aesthetic issues. Conflicts with waterfront land owners, navigation rights-of-way, fishermen, conservation interests, leisure activities, and other marine resource users are frequently cited by opponents of net pen industries (Washington Dep. Fish. 1990). Traditional users of the public waters often perceive new coastal zone industries as threats to their livelihoods or activities. As part of their responsibilities for maximizing productivity of public trust waters while preserving the qualities that contribute to that productivity, state coastal management agencies must resolve user group conflicts.

If no significant threat exists, traditional users need to be reassured that aquaculture facilities will not adversely affect their access to public resources. If significant impacts are expected, each state must determine whether or not the public interest is best served by utilizing public waters exclusively for traditional uses or by managing them to allow non-traditional development such as net pen aquaculture. Additional complications arise in certain states when the public trust management agency is mandated by state government to provide for the development of new industries. Management agencies must determine how net pen aquaculture will affect traditional marine resource users and find ways that allow this new industry to coexist with current users of the resource.

Fish farms can be hazards to navigation, posing a threat of collision or entanglement. Navigation fairways and other designated use sites are not suitable for net pen aquaculture operations. Net pens require permits from the U.S. Army Corps of Engineers and/or the Coast Guard.

A variety of commercially important fish species can be affected in numerous ways (Washington Dep. Fish. 1990). The degradation of water quality and the benthic environment can significantly affect fisheries. Net pens may block or disrupt fish movements. Fish farms restrict the movement of fishing vessels, create obstacles to normal fishing patterns and lead to losses of available fishery areas. Large numbers of net pens concentrated in limited areas may displace traditional fishermen, leading to significant economic and social problems. Identification of important fishing areas, fish migration routes, and other critical habitats areas minimize the impact of aquaculture development on commercial and recreational fishermen. State management agencies should include the commercial fishing community and representatives of recreational fishing organizations to identify important fishing areas, to receive public comment on proposed aquaculture development, and to develop site specific recommendations that consider traditional fishery uses.

Because aquaculturists often prefer to locate facilities in protected inshore waters, the potential for visual impacts is often great. Objections have been raised to locating net pens near wilderness areas, state and national parks, and areas favored by tourists. Waterfront land owners also perceive aquaculture activities to lower waterfront property values and to detract from the pleasure of waterfront home ownership (Washington Dep. Fish. 1990), leading to effective legal challenges to net pen aquaculture.

Siting guidelines, such as those developed for other regions (e.g., Crown Estate 1987, Caine 1988, Washington Dep. Ecol. 1989, British Columbia Ministry Environ. 1990), minimize impacts on the scenic quality of an area and reduce potential conflicts with coastal land owners. It is important to identify the areas requiring protection, define the extent of potential impacts, and develop acceptable mitigation measures. Zoning coastal waters for aquaculture development (e.g., Pedersen et al. 1988, Washington Dep. Fish. 1990) appears to be an effective means of minimizing conflicts with traditional marine resource user groups, conservationists, recreational interests, and waterfront land owners.

Summary of Environmental Effects

There are 3 important conclusions. First, production levels must be matched to the ability of a site to absorb waste and maintain adequate water quality. Second, separation of activities through zoning may be required to protect sensitive resources and to avoid conflicts with other user groups. Third, environmental effects of net pen culture are relatively limited in area and are reversible.

The main environmental effects are:

1. Current velocity is reduced both within and outside net pens. This limits inflows of oxygenated water and outflow of waste bearing water and promotes both sedimentation and the retention of wastes. Selecting sites with sufficient currents is essential.

2. Solid wastes from net pen aquaculture will settle to the bottom immediately beneath and a short distance (tens of meters) away from the site. Selecting sites deep enough and with sufficient currents to disperse these wastes will minimize the impact.

3. The effect of aquaculture operations on water movement and water quality are not detectable within tens of meters of the culture site.

4. Effects on sediment chemistry and the benthic community immediately beneath and within a few meters of the net pens can be catastrophic, but is usually limited to a few tens of meters from the site. Biological recovery occurs on the scale of months to years; sediment chemistry returns to ambient in weeks to months after operations cease.

5. Fish culture in warm water can place heavy demands on available dissolved oxygen levels. Selecting sites deep enough and with sufficient water exchange (tidal flushing, currents, vertical mixing) for dispersion of wastes, setting appropriate limits on total fish production, and following low waste feeding practices will minimize adverse impacts. Stratified and hypoxic water bodies should be avoided.

6. There is no good evidence that net pens contaminate resident fauna with antibiotics or transmit diseases to wild fish. Dissolved waste from net pens may contribute to blooms of toxic algae, but only if other conditions for blooms are already in place. While there is some evidence that under certain conditions antibiotics may accumulate beneath net pens and antibiotic resistant microbial populations may develop, the significance of these findings remains open to interpretation. There does not appear to be any threat to human health.

7. Genetic impacts are probably not of major concern in Gulf waters. The genetic integrity of Gulf coast striped bass/hybrids and redfish may not have been maintained in past stocking programs. However, state restrictions on broodstock sources may limit the introduction of domesticated fish in some areas.

8. Impacts on important marine habitats, protected species (especially birds and nesting and hatchling marine turtles), fisheries resources, and public lands can be significant. Selecting sites sufficiently removed from such areas will minimize impacts.

9. Cumulative impacts of net pen aquaculture are poorly understood but maxi-

mum levels of development exist. Efforts should be made to determine carrying capacities for areas being developed.

10. Control of predators (protected birds, marine mammals, and managed fish) must conform with existing federal guidelines, and control plans should be developed and coordinated with the responsible agencies.

11. Visual and aesthetic impacts can be significant to water front land owners, wilderness areas, public beaches, and other recreational areas. Reducing these impacts will require identifying affected areas, defining the extent of impacts and zoning to reduce interactions.

12. Conflicts with other marine resource users may dominate the permits review or planning process. Important fishing grounds, navigation fairways, sensitive or important habitats, protected areas (e.g., wilderness, sanctuaries, parks), and waterfront residential areas should be identified. Involvement of affected user groups in the planning and allocation of resources among new net pen industries and traditional users may be the best means of reducing these conflicts.

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