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AN ENVIRONMENTAL EVALUATION OF FINFISH NET-CAGE CULTURE IN CHESAPEAKE BAY

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ABSTRACT

The declining harvest of striped bass in Chesapeake Bay and the success of finfish aquaculture elsewhere has renewed interest in the culture of striped bass or its hybrids in net-cages within Chesapeake Bay proper or its tributaries. Culture may take the form of small operations of only a few net-cages producing 1 to 2 metric tons of fish for supplemental income. Larger commercial ventures will require 5 to 20 net-cages and are likely to produce over 50 metric tons of fish per year. The histories of the salmonid net-cage culture industry in Washington State and Maine are described, and these experiences suggest that growth of the industry in Maryland will require that potential environmental consequences of culture be addressed. This report summarizes data on the environmental effects of net-cage culture throughout the world, puts these data in the perspective of the Chesapeake Bay environment, and suggests means to minimize the impacts. Environmental effects within five principal areas are evaluated.

<u>Benthic effects</u> - The deposition of fish fecal matter and waste feed on the seafloor results in physical, chemical and biological changes in the sediment typical of organic enrichment in general. Based on past experience, net-cage culture in Chesapeake Bay is likely to result in dramatic changes in the composition of the benthic community, quite possibly to the point of creating areas devoid of animal life. The areal extent of impact is, however, likely to be very restricted; generally under the farm and to a distance of 50 m or less. Changes in the benthic community under the farm are likely to occur within a matter of a few months, while recovery will require several years after removal of the farm. Most areas of Chesapeake Bay are too shallow to provide the depth of water recommended for net-pen culture by environmental management agencies elsewhere. This limitation suggests benthic impacts are a virtual certainty, farmers may have to reduce stocking densities, and the cultured fish may be confronted with health problems caused by sulfide release from organically enriched sediments.

Water quality - Finfish culture will decrease the dissolved oxygen content in surface waters by fish respiration and in bottom waters by the biochemical oxygen demand (BOD) of organic-rich solid wastes. These effects are likely to be localized and, in part, self-limiting through adverse impacts on the cultured fish themselves. Nitrogen, phosphorus and BOD loading from net-cage culture can be significant and comparable in magnitude to treated sewage wastes from a small city or a large food processing facility. Elevated nutrient concentrations are often measured surrounding net-cage farms, but there is usually no measurable effect on phytoplankton biomass or productivity. Nutrients from fish culture are readily utilized by phytoplankton and will stimulate primary productivity if nutrients are limiting algal growth at the time. Rapid dilution of soluble wastes in most marine environments, however, would make this increased productivity unmeasurable by conventional environmental monitoring except in areas of very limited circulation.

Chemical usage - Antifoulants are likely to be required for successful net-cage culture in Chesapeake Bay. Tributyltin, which has received much recent attention, would not be used, and it is likely that the industry would rely on copper-based compounds similar to those widely used on boat hulls. Striped bass culturists are extremely limited in the choice of chemotherapeutants that could be legally used to combat disease in their fish. At present the use of all antibiotics would be precluded and even the regulatory status of chemicals generally recognized as safe (e.g. salt, sodium bicarbonate, acetic acid) is in question. It is presumed that the antibiotic oxytetracycline will ultimately be approved for use on striped bass. This compound persists in marine sediments for months after treatment and stimulates antibiotic resistance in microorganisms, but the environmental or human health implications of these impacts are unclear.

Genetic impacts - Interbreeding of escaped cultured fish with wild populations raises concern about reduction in genetic variability, reduction in population fitness, and wasted reproductive efforts by the wild fish. The culture of hybrid striped bass raises additional concerns since it seems reasonable to expect that hybrid fish are capable of backcrossing with wild striped bass within Chesapeake Bay. The genetic implications of this interbreeding will depend upon the size of the escaped population relative to the wild breeding population, and as yet unanswered questions on the existence of sub-populations of striped bass within Chesapeake Bay. These concerns can be alleviated by restricting culture to unhybridized striped bass, Chesapeake Bay stocks only, or triploid fish.

<u>Disease transmission</u> - The transfer of fish or their reproductive products for aquaculture can result in the unintentional and undesirable importation of a pest or pathogen. As currently envisioned, however, culture of striped bass within Chesapeake Bay will not require the importation of fish from distant sources. There is no evidence to suggest that net-cages act as epicenters for disease that can spread to wild fish. Most diseases of concern to culturists are caused by facultative pathogens which exhibit no pathogenic effects unless the fish are stressed by poor water quality, malnutrition, over-crowding or other factors. Thus the cultured fish may be at risk, but wild fish are not placed at greater risk by virtue of their proximity to the culture site.

AN ENVIRONMENTAL EVALUATION OF FINFISH NET-CAGE CULTURE IN CHESAPEAKE BAY

1.0 INTRODUCTION

The Chesapeake Bay and its tributaries have been a major source of seafood for many years, with harvest relying almost entirely upon wild stocks. Many of the fish and shellfish species upon which the seafood industry depends, however, have shown dramatic declines in abundance over the past twenty years including the striped bass, white perch and oyster. Bay-wide commercial striped bass harvests, for example, have decreased from a peak of 3200 metric tons (7 million lb) in 1973 to less than 450 tons (1 million lb) just prior to Maryland's imposition of a fishing moratorium in 1985. Over about the same period new techniques for finfish aquaculture have been developed and the finfish aquaculture industry has experienced phenomenal growth in Japan, Chile, New Zealand, and parts of North America and Europe. The decline in wild stocks within the Bay and the apparent viability of commercial aquaculture ventures elsewhere has created interest in the establishment of aquaculture facilities within Chesapeake Bay waters. The species most often cited as a potential candidate is the striped bass, Morone saxatalis, and its hybrids, although white perch (M. americana) and yellow perch (Perca flavescens) have also been identified as having culture potential.

As a result of the rapid growth of finfish aquaculture in recent years, there has been a great deal of work on the effects of aquaculture on the surrounding environment, including the indigenous species. As noted in a recent report by the International Council for the Exploration of the Sea:

> "Aquaculture effluents from conventional farming systems were, in the past, considered to be 'clean' and 'natural' and the possibility that aquaculture may affect the environment has largely been overlooked. Like any other industry, aquaculture has the potential to generate pollutants which are continuously released into the natural environment.
> Ecological concerns can no longer be ignored and have become a

risk factor for the industry itself." (Rosenthal et al., 1988, p. 2)

The response of regulatory bodies in other states and countries to rapid industry growth indicates a need to examine potential environmental issues. In Norway there has been a great deal of concern about the potential effects of Atlantic salmon culture on the genetic integrity of the wild populations, and a salmon gene bank has been created. In Sweden there is concern that nutrient loading from aquaculture may accelerate eutrophication of the Baltic, although the most recent analysis suggests nutrient contributions from aquaculture are small in comparison to other sources (Ackefors and Enell 1990). The states of Maine and Washington have enacted, or are on the verge of enacting, strict siting guidelines to reduce benthic enrichment from culture and requiring National Pollutant Discharge Elimination System (NPDES) permits of net-cage culture facilities. The State of Alaska has entirely prohibited open water fish culture in response to pressure from the salmon fishing industry, citing the possible importation of exotic diseases.

Environmental issues are of particular concern with respect to open water net-cage aquaculture facilities. Unlike upland culture sites where settling basins or effluent filtration may be used, collection and treatment of solid wastes is greatly complicated at open water sites. At present there are no means available for the farmer to remove the biochemical oxygen demand (BOD), nitrogen or phosphorus from the waste stream other than by modification of fish diet and feeding strategy. Chemical treatment of culture water for therapeutic purposes or effluent disinfection is more difficult, and release of chemicals to open water is unavoidable. The opportunity for escape of the cultured fish due to physical damage to the culture structure is greatly increased, and thus the potential for displacement of or interbreeding with wild species is also greater.

This report examines the potential environmental impacts of finfish net-cage culture in open water within Chesapeake Bay and its tributaries. This study does not address culture in freshwater, including pond culture as presently practiced. Section 2.0 discusses the current state of finfish aquaculture within Maryland, makes assumptions on future growth, and describes husbandry techniques insofar as they relate to potential environmental impacts. Section 3.0 provides case histories of net-cage culture within the states of Washington and Maine, the only other areas of the country with significant net-cage culture in marine waters. The history of the industry in these areas provides valuable insights into environmental concerns and the regulatory approaches available for their management. Section 4.0 summarizes the environmental effects of net-cage aquaculture based upon research conducted at sites throughout the world. Much of this past work pertains to the culture of salmonids at higher latitudes, but when possible the data are put in the context of the environmental conditions found within the Chesapeake Bay. Most of the potential environmental impacts are independent of the fish species being cultured, but when necessary, differences are noted between salmonid culture, from which most of the data are derived, and striped bass culture, the primary focus of this report. Approaches for mitigation of potential environmental impacts are also identified.

2.0 BACKGROUND

The production of the Maryland finfish culture industry is small in comparison to the production of many other states (e.g. catfish culture in the southeast and salmonid culture in the northeast and northwest). Production has, however, rapidly increased over the past few years and further growth is anticipated (Table 1). Hybrid striped bass comprise the majority of Maryland finfish production, both in terms of biomass produced and harvest value. As a result of recent legislative action, the sale of striped bass and its hybrids from aquaculture facilities became legal as of January 1, 1990. The first farm-raised hybrid striped bass from Maryland were marketed in August 1990. Total state-wide hybrid striped bass production for 1990 was estimated at 113 metric tons (250,000 lb), based on questionnaires sent to culturists by the Department of Agriculture. This production could increase substantially over the next few years as several new facilities, now in the planning and construction phases, become operational.

The culture of hybrid striped bass to a marketable size is currently practiced in many states including Maryland, South Carolina, North Carolina, New York and California. In some of these areas culture remains in the experimental or demonstration stages, while in other areas full-scale commercial culture has been on-going for several years. There are currently 85 to 90 farms for hybrid striped bass culture in Maryland (B. Powers, pers. comm.). Most of these are small operations, and the vast majority of fish are in the hands of four or five operators. All Maryland finfish culture, including hybrid striped bass, is currently conducted in upland facilities; either raceways, tanks, ponds, or net-cages within ponds. Water supplies range from fresh to brackish water.

The emphasis of this report is on net-cage culture within open waters of Chesapeake Bay and its tributaries. There has been very little prior finfish culture activity in open water within the Bay. The Department of Natural Resources (DNR) and the Cecil-Harford County Watermen's Association attempted net-cage culture in the Susquehanna River, but the attempt failed for a variety of operational reasons, unrelated to the feasibility of culture general. Striped bass are

Table 1
Maryland finfish culture production (in metric tons with thousands of pounds in parentheses) as based on a producer survey by the Maryland Department of Agriculture (MDA).

Species	1988	1989	1990	1991
Hybrid striped bass	(sale of cultured bass not legalized)		113 (250)	136 (350)
Catfish	43 (94)	43 (94)	49 (108)	128 (282)
Trout	3 (7)	5 (12)	22 (49)	27 (60)
Tilapia	5 (12)	10 (22)	10 (22)	35 (78)
Ornamental fish	(data considered confidential by MDA)			
Yellow perch	(data considered confidential by MDA)			

occasionally held in net-cages at the DNR/National Marine Fisheries Service facility at Oxford for experimental purposes, but not for commercial culture. DNR has recently obtained approval for construction of a striped bass demonstration net-cage farm near the Bay Bridge, and stocking will commence in the spring of 1992.

In order to evaluate potential environmental effects of culture activities it is necessary to have some concept of construction and operational factors in finfish net-cage culture, but this effort is complicated by the absence of any existing farms in Chesapeake Bay. It is, however, possible to speculate on how a "typical" farm may be constructed and operated based on experience in upland culture of striped bass and its hybrids and open water net-cage culture of other species, most notably salmonids.

A net-cage farm generally consists of a floating walkway, three to five feet in width, in a square configuration. The perimeter of the net is attached to the walkway, while the lower corners are weighted to keep the net from deforming due to water currents. A small cage may be only a few meters in each dimension, including depth. Commercial facilities would have to employ much larger nets, perhaps 6 x 12 m, 8 x 8 m, or 12 x 12 m. These larger nets would extend 4 to 6 m below water level. Any number of net-cages could be grouped together depending on the intended production level. A facility providing fish only for supplemental income may require only a few small cages and produce 1 to 2 metric tons (2200-4400 lb) of fish annually. Large commercial ventures are likely to require 5 to 20 large cages and produce 50 to 150 tons (110,000 to 330,000 lb) of fish annually. The largest salmonid net-cage farms in the United States are capable of producing over 450 tons (1,000,000 lb) of fish annually.

A few small net-cages may be located alongside an existing dock, but larger farms are likely to be anchored some distance from shore and serviced by small boats. There are generally few structures above the waterline other than the walkways, railings, and on the larger farms, a shed for storage of feed and shelter for workers. Predator nets are likely to be necessary over the tops of the net-cages to prevent loss of fish to herons and other piscivorous birds. Predator nets below the water line, as are used to prevent seal and sea lion predation on salmon farms in the northeastern and northwestern United States, would not be necessary in Chesapeake Bay and would only compound the fouling problems that the farmer is likely to face.

Based on the results of several experimental net-cage trials (Swingle 1971; Powell 1972; Valenti et al. 1976; Williams et al. 1981; Woods et al. 1983) it is apparent that either juvenile (2 to 6 g) or advanced juvenile (about 40 g) striped bass or its hybrids can successfully be stocked in net-cages, although survival is greatest when using the larger fish. A period of 8 to 12 months, depending on water temperature and size at initial stocking, would be required to grow marketable fish within the size range of 300 to 500 g (0.7 to 1 lb). Throughout the culture period the fish would be fed a pelleted dry feed, dispensed either by hand or automatic feeder. The fish are generally provided feed at a rate of 2 to 3% of their body weight per day, although this rate can be substantially greater (5 to 10%) for juvenile fish. At present there are no foods formulated specifically to meet the nutritional requirements of striped bass. Upland growers now use a salmon or trout pelleted diet, and it is likely the same foods would be used in open water net-cage culture. Feed conversion efficiencies (ratio of the amount of food provided to the biomass of fish produced) are likely to be initially between 1.5 and 2, although with continued refinement of culture techniques and feed formulation conversion efficiencies may decrease to 1.3 to 1.5.

There are few data from which to estimate optimal stocking densities. In experimental net-cage culture of striped bass and its hybrids densities as low as 16 kg m^{-3} and as great as 88 kg m^{-3} have been used without apparent problems (Powell 72; Valenti et al 76). Salmonid farmers generally maintain about 12 kg m^{-3}, although Norwegian growers have attained stocking densities as high as 40 kg m^{-3}. The higher stocking densities are likely to exacerbate problems with water quality and fish diseases.

3.0 CASE HISTORIES

3.1 Washington State

The Washington net-cage industry is primarily dedicated to the culture of Atlantic salmon (Salmo salar) although an indigenous species, the coho salmon (Onchorhyncus kisutch), is also cultured at some farms. The chinook salmon (O. tshawytscha) and steelhead (O. mykiss) have been cultured on an experimental basis. Commercial net-cage culture in Washington began in 1971 with the construction of a small farm operated jointly by the National Oceanic and Atmospheric Administration and private industry. By 1975 four farms were in operation. Currently there are 16 farms either in place or permitted, and an additional 9 facilities used for delayed release (holding time in the cages of one to six months). Annual production has increased from 60 metric tons (130,000 lb) in the early 1970's to 4,400 tons (9.7 million lb) at present. A typical Washington farm covers two acres (at the water surface), is comprised of 30 to 50 cages, and produces 200 to 400 tons (440,000 to 880,000 lb) of fish annually.

The state's first attempt to develop regulatory policies specifically for mitigating environmental effects of net-cage culture industry occurred in 1986 with the release of regulations known as "the Commissioner's order". The Commissioner of the Washington Department of Natural Resources announced that in order for a new farm to obtain a lease for subtidal lands from the state, the cage complex must be under two acres in size and be at least 1 mile from any existing farm.

Later in 1986 the Department of Ecology released the "Interim Guidelines" (SAIC 1986) which, in practice at least, have largely superseded the Commissioner's order. The Guidelines do not have any statutory basis, but were promulgated as guidance to the industry in selecting sites and to state managers in reviewing applications. The guidelines include: 1) a minimum depth beneath the cages of 20 to 60 feet (depending on currents and farm production) intended to maximize feed and feces dispersion and thus minimize benthic enrichment; 2) limits on production within specified embayments in order to avoid eutrophication; 3) a site characterization survey to assess site-specific hydrographic conditions and benthic community composition before cages are installed; and 4) annual monitoring of water quality, sediment chemistry and macrofaunal community structure to document any environmental changes. Items 3 and 4 have since been formalized as lease requirements by the Department of Natural Resources. Items 1 and 2 remain only advisory, but have been the basis for most siting decisions over the past few years.

In 1989 the state initiated an industry-wide Programmatic Environmental Impact Statement (PEIS) in order to formalize the previous ad hoc management of the industry, and to serve as a basis for a future management plan. The PEIS addressed both impacts to the natural environment (e.g. benthic enrichment, eutrophication, introduction of exotic species) as well as impacts to the built environment (e.g. noise, odor, conflicts with commercial species, aesthetics). The document concluded that the environmental effects of salmonid net-cage culture were within acceptable levels if mitigated by minor modifications of existing regulations (Parametrix 1990a).

For the most part Environmental Impact Statements (EIS) have not been required of individual operators. They were required in only two instances. In the first case the applicant withdrew the permit request after soliciting bids for the EIS (cost estimated at $100,000). In the second case the EIS was completed, but after continued permitting delays and loss of financing the second applicant also withdrew.

In May 1989 the State of Washington determined that NPDES permits would be required of all net-cage farms in the state. The first farms to be permitted through this mechanism received their permits in April 1990. These permits require: 1) water quality monitoring (dissolved oxygen, turbidity, inorganic nitrogen); 2) sediment trap collections (total solids and total volatile solids); 3) sediment chemistry monitoring (organic carbon, nitrogen, grain size); 4) macrofaunal community analysis; 5) underwater video survey by diver or remotely operated vehicle; and 6) under certain conditions the measurement of antibiotic resistance in the sediment microbial communities under the farm. Three farms have been issued NPDES permits.

The growth of the salmon net-cage culture industry in Washington has provoked extraordinary public controversy. Among the concerns raised are aesthetic impacts, potential devaluation of shoreline property values, economic and space conflicts with commercial fisheries, interference with water-based recreational activities, and environmental degradation. The primary stumbling blocks to permit approval have been at the county level. Most state agencies have been supportive of the industry, and the state has designated aquaculture as a "preferred use" in shoreline management. The federal government has not taken an active role. Established environmental groups (e.g. Greenpeace, Sierra Club, Audubon Society) have generally remained out of the debate or voiced only mild concern. The principal industry antagonists have been local citizen groups established in response to specific net-cage applications (e.g. Save our Shores, Griffin Bay Preservation Committee, Frenchman's Cove Defense Fund). As a result of pressure from local residents, and in contrast with policy at the state level, three Washington counties have enacted moratoria on new applications. In the remaining counties the applicant can expect protracted and divisive permitting battles with a significant chance of permit refusal. The 16 existing farms in Washington State provide a stark contrast to nearby British Columbia where the regulatory climate has been very receptive to the industry and about 200 farms are in operation.

3.2 Maine

As elsewhere throughout the world, net-cage farming in the State of Maine is a recent phenomenon, with most of the industry growth occurring in the past 5 to 10 years. There are currently 41 sites leased for finfish culture, although only about half of these have farms in place at present. It is estimated that 1990 production from these farms will be in the range of 1800 to 3400 metric tons (4 to 7.5 million lb) of Atlantic salmon. For comparative purposes, this production is about one half of that of Washington State and only about 2% of that of Norway, the world's largest salmon producer.

Maine net-cage facilities tend to be small in comparison to those of Washington, typically consisting of only 5 to 20 cages per farm.

Water depths at the Maine sites tend to be much shallower (10-15 m vs >25 m), current speeds are greater, and many of the sites are located over hard bottoms.

Maine state agencies have been very supportive of the industry as a whole and smaller growers in particular. The Maine Department of Marine Resources is responsible for issuing subtidal leases, which, although not required of a culturist, do afford some legal protection of the site. Lease regulations require a 2,000 ft. separation between farms unless reduced by mutual consent of the growers. Prior to considering a lease application the state will conduct a site review including a diver survey of marine resources at the site, collection of both phyto- and zooplankton samples, and hydrographic analyses using drogue tracking. After lease approval annual monitoring may be required including water quality monitoring and diver-collected samples for sediment chemistry analysis. It is noteworthy that the Maine Department of Marine Resources conducts and bears the cost of both the initial site survey and annual monitoring, whereas in Washington the farmer would generally be required to hire a consultant for these surveys.

The Maine Department of Environmental Protection (DEP) is a second state agency with a major role in net-cage aquaculture regulation through its issuance of a Water Quality Certificate. DEP requires that feed be provided in a pellet form, that dead fish and viscera are not disposed of in state waters and that only state-registered antifoulants be used (Parametrix 1990b). The Department also requires a minimum separation between the bottom of the cages and the seafloor of 10 ft. (3 m) and up to 60 ft (18.3 m) for larger farms in areas of slow currents. These requirements are based on Washington's Interim Guidelines, and are currently under evaluation for their applicability in Maine waters.

The federal government has taken a very active role in regulating net-cage culture in Maine through both Section 10 permits (Army Corps of Engineers) and the NPDES program (Environmental Protection Agency). The Corps regulations are currently in draft form, but many requirements are comparable to those of the state agencies. One notable addition is that the applicant must confirm that all fish or eggs will originate from east of the Continental Divide, and that only North American stocks will be used after 1995. The Environmental Protection Agency will be requiring NPDES permits from net-cage operations, but the operational and monitoring requirements will not be determined until after completion of an on-going Ocean Discharge Criteria Evaluation.

The growth of the net-cage culture industry in Maine has been as controversial as it has elsewhere, with the primary opponents being local citizen groups, upland property owners and commercial fishing interests (principally lobstermen). These conflicts have intensified as the industry moves from the sparsely-populated northern coast to the more populous shorelines in the southern portion of the state. Faced with mounting criticism, regulatory agencies hastily adopted many of the siting and monitoring requirements of Washington State. With monitoring data from Maine sites now available, these requirements are now under review by both state and federal agencies. More permanent management approaches and greater stability in regulatory programs can be anticipated in the near future.

4.0 ENVIRONMENTAL ISSUES

4.1 Benthic effects

Solid waste production

Fecal material and waste feed are the primary solid wastes associated with finfish net-cage culture. Fecal production of trout fed a diet of dry pellets is approximately 28% of ingested feed (dry weight basis, Butz and Vens-Capell 1982). Waste feed is the portion of the feed provided to the fish that passes through the cages without being ingested. In the worst case the quantity of waste feed can be as great as fecal production, but feed wastage is highly dependent upon the type of feed provided (dry, moist, wet), the method of feeding (hand, demand feeders, automatic feeders) and the frequency of feeding. Because of these variables, estimates of the amount of waste feed vary widely from only 1 to 5% of feed provided (VKI 1976) up to 40% (Thorpe et al. 1990).

Summing the contributions of feces and waste feed, it has been estimated that the production of 1 kg of salmon in a net-cage system will result in the production of 0.5-0.7 kg of solid waste (Weston 1986; Gowen and Bradbury 1987). The lower limit approximates a best-case situation with little food wastage. No figures are available specifically for solid waste production in striped bass culture, although the magnitude of waste production is likely to be comparable.

Sediment chemistry

At most net-cage sites, especially those where conditions are similar to those in Chesapeake Bay, much of the fecal matter and waste feed settles to the seafloor in the immediate vicinity of the farm. At some sites a visible accumulation of flocculent, organic-rich material overlies the natural sediment. This flocculent layer is often less than 5 cm thick but can exceed 30 cm under worst-case conditions (Braaten et al. 1983; Ervik et al. 1985; Kaspar et al. 1988; H. Rosenthal, pers. comm.).

Fecal matter and waste feed represent a source of labile organic carbon, and the remineralization of this material results in changes in sediment geochemistry that are typical of organic enrichment in general.

Carbon cycling - Carbon fluxes in trout and salmon net-cage culture have been estimated by several investigators (Penczak, et al. 1982; Gowen and Bradury 1987; Hall et al. 1990). In general only about 20% of the carbon supplied to the farm in the form of feed pellets is removed with the harvest. The remaining 80% is lost to the environment, either as dissolved carbon (CO_2 produced by respiration and urea) or particulate carbon. The proportion of carbon reaching the sediments is seasonally variable and dependent upon the period of observation. Hall et al. (1990) estimated that on a seasonal basis 29 to 71% of the carbon provided to a farm was accumulated in the sediment. Over the long-term, and allowing for release from the sediment back to the water column (e.g. microbial remineralization to CO_2, epibenthic grazing, methane ebullition), the sediment serves as a sink for 18% of the carbon input. It is therefore not surprising that sediment organic carbon concentrations have been used as one measure of the environmental effect of finfish net-cages (Hall and Holby 1986; Weston 1990).

Sediment oxygen consumption - The remineralization of organic-rich sediments removes substantial amounts of oxygen from pore waters and/or the overlying bottom waters. The biochemical oxygen demand (BOD) of sediments beneath a finfish net-cage system in Washington State was approximately six times greater than the BOD of reference sediments (Pamatmat et al. 1973). Two-thirds of the total oxygen uptake was due to microbial respiration, while the remainder represented the chemical oxygen demand. Sediments beneath a farm in Sweden had a BOD 12 to 15 times greater than normal (Hall et al. 1990). The depletion of pore water oxygen results in a shallowing of the aerobic portion of the sediment column, measurable by both sediment color changes and more negative reduction-oxidation potentials in the sediment (Brown et al. 1987; Weston and Gowen 1988). In some cases the dissolved oxygen concentrations in bottom water can be reduced as well (Brown et al. 1987).

Sulfur cycling - In the absence of oxygen, microbial degradation of organic matter is accompanied by the reduction of sulfate in seawater to hydrogen sulfide. Thus organically enriched sediments are characterized by low sulfate concentrations, high sulfide levels, and elevated sulfate reduction rates (Dahlbäck and Gunnarsson 1981). The microorganism Beggiatoa is found at oxic/anoxic boundaries and acquires energy by the conversion of sulfide back to sulfate. It is commonly observed as a white mat on the sediment surface under and in close proximity to net-cage farms (Brown et al. 1987; Kaspar et al. 1988; Weston 1990). In areas of extreme enrichment, gas bubbles containing hydrogen sulfide will be released from the sediment; a phenomenon of importance to the culturist since hydrogen sulfide is highly toxic to fish. Many farms have been forced to relocate as a result of sulfide release from enriched sediments.

Nitrogen and phosphorus cycling - Both nitrogen and phosphorus are introduced to the environment in the feed and approximately one-fourth of both elements are removed with the harvest. There are considerable differences between nitrogen and phosphorus in the environmental fate of the remaining three-fourths. Phosphorus is primarily associated with the particulate wastes, while nitrogen is primarily excreted as soluble metabolites (ammonium and urea). Continued biodegradation of nitrogenous compounds will result in the diffusion of ammonium and dissolved organic nitrogen back into the water column, but nitrification (conversion of ammonium to nitrate) and denitrification rates (conversion of nitrate to nitrogen gas) are negligible due to the absence of oxygen in the enriched sediments commonly found under farms (Blackburn et al. 1988; Kaspar et al. 1988).

Macrofaunal community structure

The deposition of organic-rich material from mariculture, and the consequent changes in the physical and chemical properties of the substratum, have profound influences on the structure and functioning of benthic communities. While structural changes in meiofaunal communities have been reported, such as high abundance of large nematodes near fish culture sites (Weston 1990; D. Duplisea, pers. comm.), most investigations have focused on the effects of organic enrichment on benthic macrofauna.

The depletion of dissolved oxygen and/or the high concentrations of dissolved sulfide in the pore waters of organically enriched sediments result in the mortality or emigration of most species characteristic of unperturbed soft-sediments. Since few species possess the behavioral, physiological or reproductive adaptations to exploit such environments, a reduction in macrofaunal species richness is a widely reported phenomenon in the vicinity of mariculture operations (Pease 1977; Brown et al. 1987; Ritz et al. 1989; Weston 1990). The effects are often dramatic such as a 90% reduction in species richness relative to undisturbed conditions (Figure 1) or, in the worst cases, a total absence of all macrofaunal species (Brown et al. 1987).

Often accompanying the reduction in the number of species is an increase in total macrofaunal abundance, largely reflecting the high densities of opportunistic polychaetes that are either absent or in low densities in surrounding, unimpacted sediments. The most widely reported of these enrichment opportunists are members of the _Capitella capitata_ species complex. _C_. _capitata_ appears to have a physiological requirement for organically enriched conditions (Tsutsumi et al. 1990), and is commonly associated with sewage outfalls, log rafting areas, pulp mill effluents and other sources of labile organic carbon. _C_. _capitata_ has been reported in the sediments surrounding mariculture operations in Europe (Aure et al. 1988), North America (Pease 1977; Rosenthal and Rangeley 1989) and Asia (Tsutsumi and Kikuchi 1983). Densities of _C_. _capitata_ in the vicinity of culture sites are commonly in the range of 1,000 to 10,000 individuals m^{-2}, although densities can fluctuate widely over time at a given site (Mattson and Linden 1983; Tsutsumi 1990).

In contrast to the increased abundance of certain polychaete species in enriched habitats, echinoderms, as a group, generally show the greatest decrease in abundance. They are the first species to disappear with increasing organic enrichment (Mattson and Linden 1983) and are often found only in unimpacted sediments far from culture areas (Tsutsumi and Kikuchi 1983; Kaspar et al. 1985).

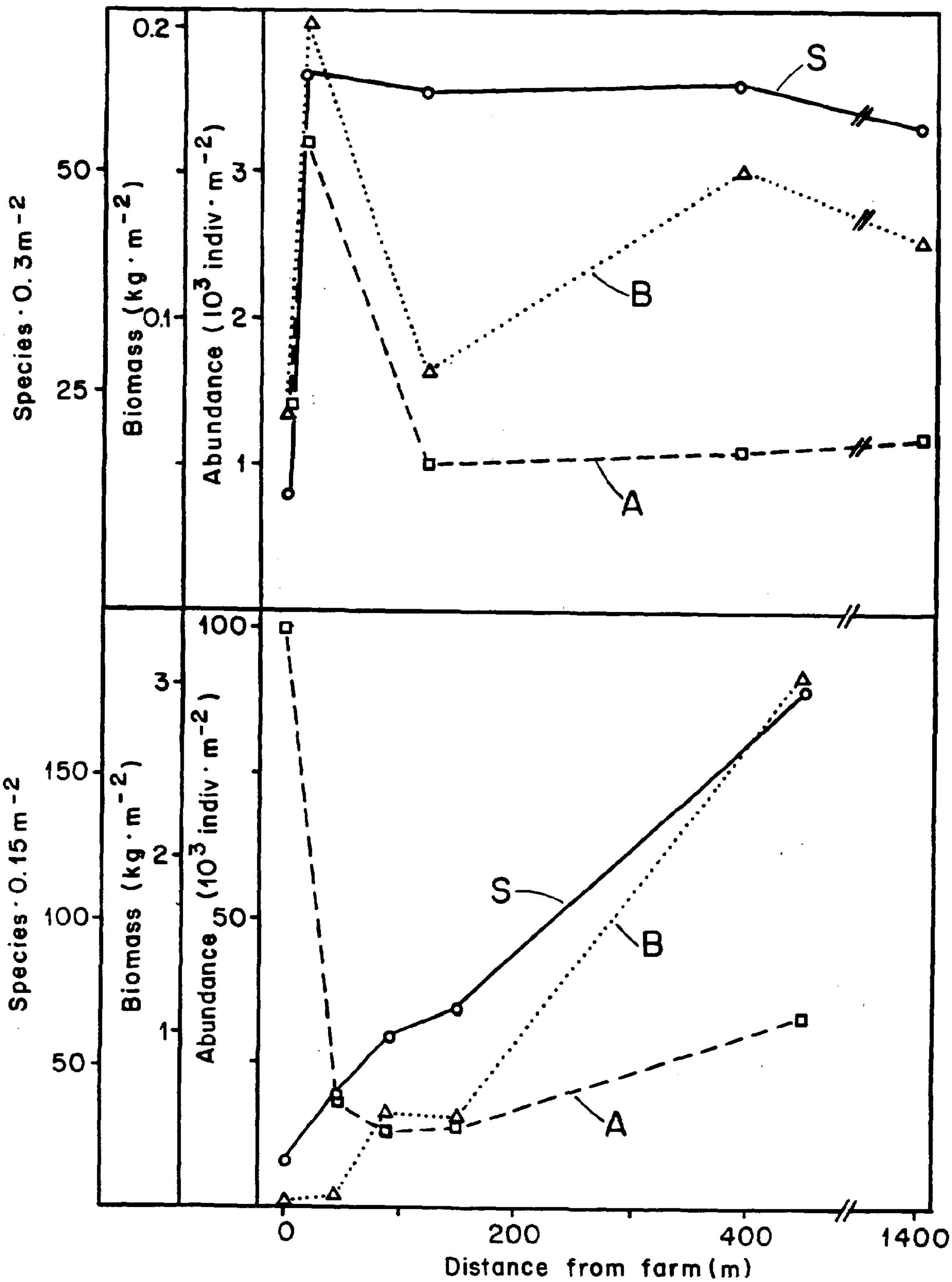

Figure 1. Trends in areal species richness (S), biomass (B), and abundance (A) of macrofauna at two salmon net-cage sites. Data in upper figure from Scotland (Brown et al. 1987); data in lower figure from Washington State (Weston, 1990).

Macrofaunal biomass shows no consistent linear relationship with the degree of organic enrichment. While it will, of course, be reduced as azoic conditions are approached, lesser degrees of enrichment do not result in consistent responses in community biomass. Several authors have reported a decreased biomass (relative to controls) in the vicinity of fish and shellfish farms (Tenore et al. 1982; López-Jamar 1985; Weston 1990), while others found little effect of culture on macrofaunal biomass (Kaspar et al. 1985). Brown et al. (1987) reported an increased biomass corresponding to peak densities of opportunists, and then an abrupt decrease with further increases in enrichment. It is not possible to predict either an increase or decrease in macrofaunal biomass as a result of enrichment since the parameter will be highly dependent upon the size and density of opportunistic species.

If the flux of organic material is not great enough to substantially alter sedimentary reduction-oxidation conditions, it is conceivable that low levels of organic enrichment from culture activities could provide an enhanced food supply to the benthos. This phenomenon, termed biostimulation (Pearson and Rosenberg 1978), is characterized by an increase in species richness and macrofaunal biomass. Two investigators have reported this effect near fish farms (Ervik et al. 1985; Brown et al. 1987), but in both cases the evidence presented was inadequate or open to alternative interpretations. Despite the lack of conclusive evidence specific to mariculture, biostimulation has been documented near sewage outfalls (Swartz et al. 1985), and the appearance of a biostimulated zone at some distance from a net-cage facility appears plausible.

<u>Animal size and vertical distribution</u>

It has been predicted that in areas subject to organic enrichment, the average macrobenthic individual has a smaller body size and that there is a shift in the vertical distribution of infauna towards the sediment-water interface (Pearson and Rosenberg, 1978). One of the few tests of these predictions is that of Weston (1990) near a salmon mariculture facility. Two principal conclusions could be made with respect to the effects of enrichment on animal size.

Interspecific measures of animal size do, in fact, decrease with increasing enrichment. Organic enrichment selectively eliminates the largest species among the macrobenthos, resulting in a decrease in the mean individual size in the community (i.e. total sample biomass divided by total sample abundance). However, since these large species are relatively rare even in unenriched environments, measurement of enrichment effects based on mean size is prone to a high degree of interreplicate variability.

Intraspecific measures of animal size often increase with increasing enrichment. Among those species able to exploit enriched habitats, the organic input results in an increase in food quantity and quality, supporting growth to a larger body size. Individuals of *Capitella capitata* and other enrichment tolerant species may be 3 to 5 times larger in the enriched area than individuals from populations at unenriched sites only a few hundred meters distant (Tsutsumi 1990; Weston 1990).

Organic enrichment also results in a shift in the vertical distribution of infauna within the sediment column, but this shift is best measured by the vertical distribution of biomass rather than abundance. The large species eliminated by organic enrichment are often deep burrowers. Consequently, their disappearance reduces the proportion of community biomass deep within the sediment column, and shifts the biomass profile towards the sediment-water interface. Since these species are relatively rare, their loss has little effect on the abundance profile. About 90% of macrofaunal individuals are found typically in the upper 5 cm of the sediment column regardless of the degree of enrichment (Weston, 1990).

Spatial scales of disturbance

While the effects of mariculture on benthic communities may be dramatic, the areal extent of impact is generally very localized. Investigators studying net-cage farms of small to moderate size report dramatic community changes to distances of 15 to 50 m from the farm perimeter (Doyle et al. 1984; Brown et al. 1987; Aure et al. 1988; Weston and Gowen 1988; Lumb 1989). Even at a very large salmon net-cage facility (620 metric tons annual production) dramatic effects extended 45 to 90 m from the farm, while more subtle macrofaunal changes were apparent at least 150 m distant (Weston 1990). While the effects of a single farm may be localized, it should be recognized that the benthic community of large areas can be altered by the cumulative effects of many closely-spaced farms (Arakawa et al. 1971; Tenore et al. 1982; O'Connor et al. 1989).

Temporal scales of disturbance

The rate at which the benthic community is altered after installation and stocking of a mariculture facility, and the rate at which that community recovers after harvest or removal of the farm depends upon a wide variety of physical (e.g. currents, bathymetry) and biological variables (e.g. timing of recruitment cycles). As a general rule, however, alteration of the benthos occurs over the course of a few of months while recovery requires a period of years.

Mattson and Linden (1983) studied macrofaunal changes following installation of mussel longlines, and reported the appearance of dense populations of Capitella capitata and the disappearance of echinoderms three months after culture began. Other species present prior to culture gradually disappeared over about the first year. Similar results were reported in studies beneath a small salmon net-cage farm in Puget Sound (10-30 metric tons standing stock - Weston and Gowen 1988; Dickison, unpub. data). A baseline survey conducted one month before stocking of the cages, found no Capitella capitata and little difference in species richness among the sampling stations. Six months after initiation of culture C. capitata appeared near the farm perimeter (Figure 2), although species richness at all stations remained high. Eleven months after the start of culture, and in later samples, C. capitata attained densities of >1500 individuals m^{-2} and species richness within 6 m of the farm declined relative to control stations. Several other investigators of net-cage farms have reported evidence of benthic community changes after about one to three months (Gowen et al. 1988; Lumb 1989; Ritz et al. 1989; Rosenthal and Rangeley 1989).

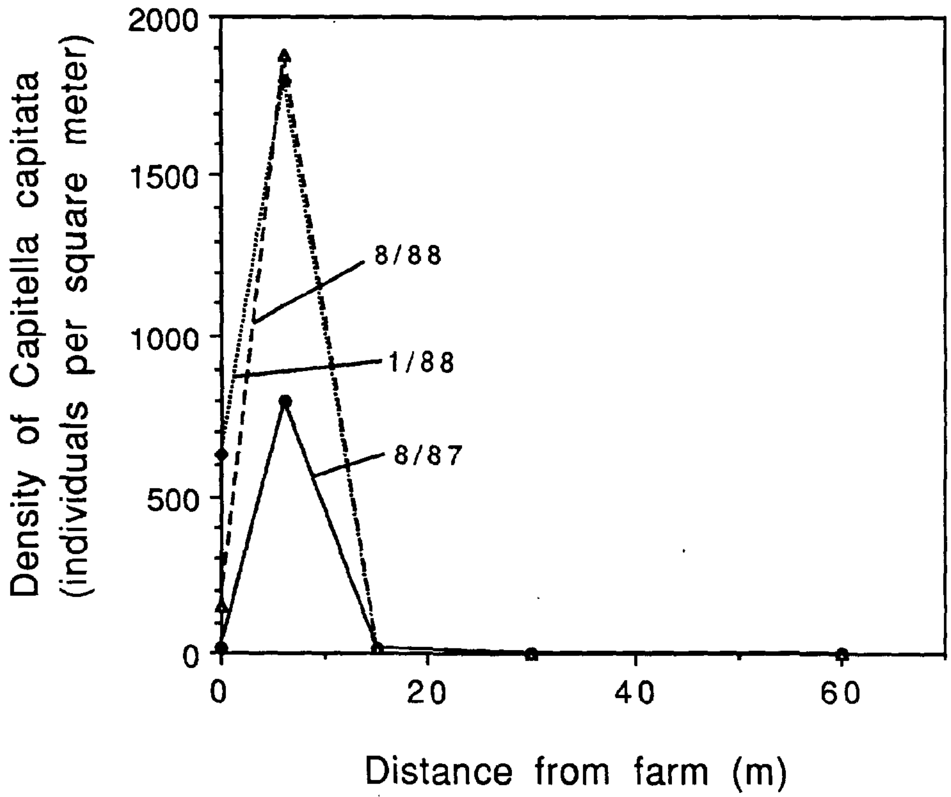

Figure 2. Density of the polychaete Capitella capitata with distance from a salmon net-cage farm. No C. capitata were found at any stations in January 1987. Fish were placed in the pens for the first time in February 1987 (2/87). From Weston and Gowen (1988).

The rate and successional sequence of benthic recovery following harvest of a mariculture product or removal of the culture structures is not well documented largely because the studies have been too short in duration. The macrofaunal community beneath a former mussel longline site remained very different from that of the surrounding areas one ar a half years after removal of the longlines (Mattson and Linden 1983). The benthic community beneath a former net-cage site showed virtually o recovery 8 months after cessation of culture (Gowen et al. 1988). T only study to find a rapid response to the cessation of organic inpu was that of Ritz et al. (1987) who reported partial recovery of the benthos beneath a net-cage farm only ten weeks after feeding of the fish was stopped. Recovery of the benthos following closure of a pulp mill required 3-8 years (Rosenberg 1976), and it is likely that complete recovery of an area enriched by aquaculture would require a comparable period. The time required for recovery will depend upon the rate at which erosional/depositional processes and microbial activity reestablish the sedimentary reduction-oxidation profile to that typical of unenriched conditions, as well as the life history of the resident species and the timing of their reproductive cycles relative to availability of suitable habitat.

Mitigation strategies

The simplest means of reducing the benthic impacts of net-cage mariculture is to minimize feed wastage. The magnitude of wastage can usually be assessed by diver inspection, and correction of the problem is both straightforward and of obvious economic benefit to the farmer. At one farm it was estimated that reduction in feed wastage from 30% to 5% would reduce organic loading to the benthos from 5.5 g carbon m^{-2} d^{-1} to 3.5 g C m^{-2} d^{-1} (Gowen et al. 1988).

Rotation of cages among several culture sites is practiced in Norway. When sediments at a site become enriched to the point where the health of the cultured fish is threatened, the farmer may move to a second site and allow a year or more for recovery of the first site. While rotation of culture sites may be of some use in minimizing the adverse consequences of sediment enrichment on the cultured animal, it is of dubious value as a means to minimize environmental impact. Since, the response of benthic communities to organic enrichment is so rapid (a few months), and the rate of recovery so slow (a few years), it is unlikely that farm sites could be rotated rapidly enough to avoid disturbance or slowly enough to allow complete recovery. Similarly, other techniques which allow farmers to exploit marginal areas, such as periodic dredging of enriched sediments (Rosenthal and Rangley 1989), may provide some benefits to the culturist but offer little environmental protection.

Large funnel-like devices suspended beneath the cages have been used to capture solid wastes from freshwater net-cage culture. The use of these devices have been limited to experimental applications in Sweden (Enell et al. 1984), Finland (Leminen et al. 1986) and Poland (Tucholski and Wojno 1980). The Polish studies reported retention of 45% of the solid wastes, and a 15 to 20% reduction in nitrogen and phosphorus loading. The Swedish investigators reported a 71% reduction in phosphorus input to the environment. These techniques have not progressed beyond the experimental stage, and significant engineering hurdles remain in application of the technology to marine sites where water currents are likely to be greater than at the lake sites where the devices have been tested.

The best mitigation approach generally used is the selection of sites where water currents will distribute wastes over a very broad area and accumulation beneath the farm is maintained to some acceptable level. In some areas of net-cage mariculture the objective has not been to protect the benthic environment, but only to protect the cultured fish from the toxic effects of hydrogen sulfide released from enriched sediments. In one study from New Zealand a 7.5 m separation under the cages was recommended to prevent problems with sulfide toxicity (Rutherford et al. 1988). British Columbia requires 10 m total water depth, and since the cages themselves typically occupy about 4 m, a distance of 6 m would be maintained beneath the bottom of the cages and the seafloor.

In other areas concern has extended beyond the protection of fish health and focused on protection of the benthic environment. The best example of this approach are the depth and current guidelines of Washington State (SAIC 1986 - Figure 3). The guidelines are based on the premise that the effect of net-cage culture on the benthic environment will be minimized if the wastes are dispersed over a very broad area. Solid waste loading per unit area of seabed is minimized by increasing the opportunity for horizontal transport of a settling particle (either by increasing current speed or water depth) or by reduction in farm size (i.e. fish production). The Washington guidelines require 20 to 60 ft (6 to 18 m) beneath the cages, and allowing for the cages themselves the total water depth would have to be about 10 to 22 m. It its not yet clear if the Washington guidelines totally eliminate benthic impacts, but substantial alteration of benthic biology and chemistry is expected at sites that fail to meet the siting guidelines.

Given the depth and current conditions of Chesapeake Bay and its tributaries, it is unlikely that many sites could be found with sufficient depth and currents to avoid the effects of organic enrichment of the benthos. If net-cage culture is to be permitted in the Bay alteration of the benthic community at least to the stage of dominance by opportunistic species, and possibly to the point of azoic conditions, must be expected. These effects, however, would be localized to the area under the farm and within about 50 m from the farm perimeter. Net-cages should not be located over harvestable shellfish beds, near seagrass beds, or any other areas where substantial alteration of the benthos would be deemed unacceptable.

4.2 Water quality

Dissolved oxygen

The culture of finfish can be expected to reduce the dissolved oxygen content of the surrounding water by two mechanisms: 1) respiration of the fish; and 2) the biochemical oxygen demand (BOD) of the feces, urine and unused food. The oxygen consumed by fish respiration will depend upon fish size, water temperature, swimming speed and many other factors so it is impossible to determine the oxygen needs of a net-cage operation with a high degree of precision. This

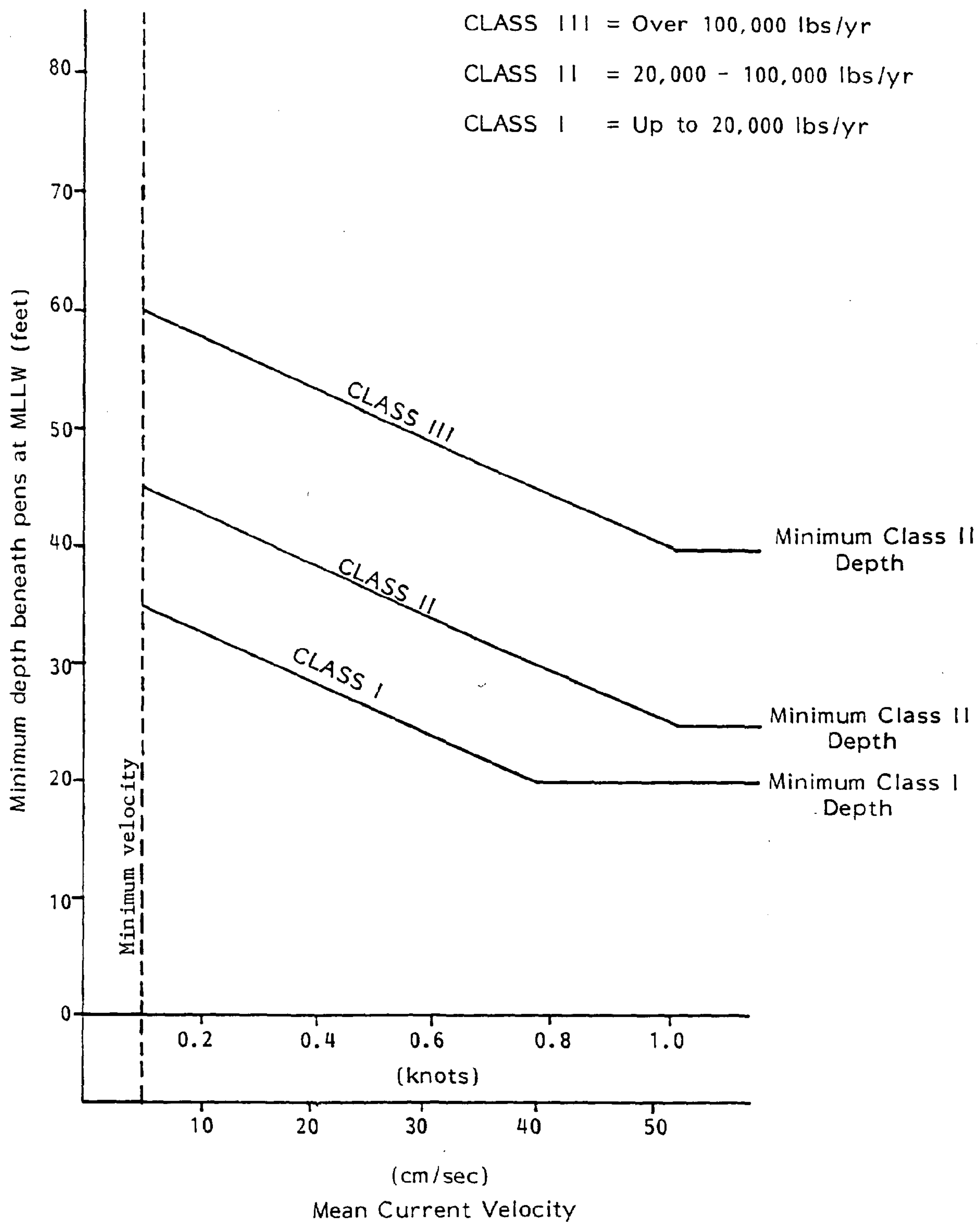

Figure 3. Minimum depth for siting net-cages under the Interim Guidelines of Washington State (SAIC 1986). For example, a culturist wishing to produce 50,000 lbs per year (Class II) in an area where average currents are 30 cm per second must locate the net-cages where the distance between the bottom of the cages and the seafloor is 35 feet or greater.

assessment is made even more complicated by the fact that existing information on oxygen consumption by striped bass is largely for juvenile fish, and there are no data for fish >100 g in size. Nevertheless, if a water temperature of 16°C, a relatively slow swimming speed of 5 to 10 cm sec^{-1}, and fish sizes of 20 to 100 g are assumed, then respiration rates are likely to be in the range of 180 to 260 mg O_2 kg $fish^{-1}$ hr^{-1} (Sherk et al. 1972; Kruger and Brocksen 1978).

The BOD of waste products can consume at least as much oxygen as respiration alone (Willoughby et al. 1972; Liao and Mayo 1974; Kalfus and Korzeniewski 1982; Institute of Aquaculture 1990). Most of this BOD is associated with particulate matter (i.e. feed and feces) and thus the oxygen would be provided by near-bottom waters, unlike respiration that would remove dissolved oxygen from surface waters.

Field investigations around net-cages have reported decreases in dissolved oxygen concentration of both surface and bottom waters. As a worst case example, Kadowaki and Hirata (1984) reported a decrease of about 2 mg l^{-1} in dissolved oxygen concentrations of surface waters among yellowtail and sea bream cages (Figure 4). It should be recognized, however, that the farm under investigation contained 400 tons of fish, a size several times greater than the largest likely to be located in Chesapeake Bay.

Depression of near bottom water dissolved oxygen due to the BOD of feces and waste feed has been observed at several farms. A small salmon farm in Puget Sound usually had no measurable effect on dissolved oxygen levels, but on one occasion there was a 5 mg l^{-1} decrease in bottom water dissolved oxygen while at the same time surface water dissolved oxygen concentrations were reduced 2 mg l^{-1} (Pease 1977). A decrease in dissolved oxygen of up to 2 mg l^{-1} was reported in bottom waters beneath a salmon farm in Scotland containing only 35 tons of fish (Brown et al. 1987). Oxygen concentrations of bottom water returned to normal levels at a distance of 15 m from the farm.

It would seem that the consumption of dissolved oxygen through fish respiration is, from an environmental perspective, likely to be a self-regulating impact. Large active fish such as striped bass are among the most sensitive animals to oxygen depletion, and would be

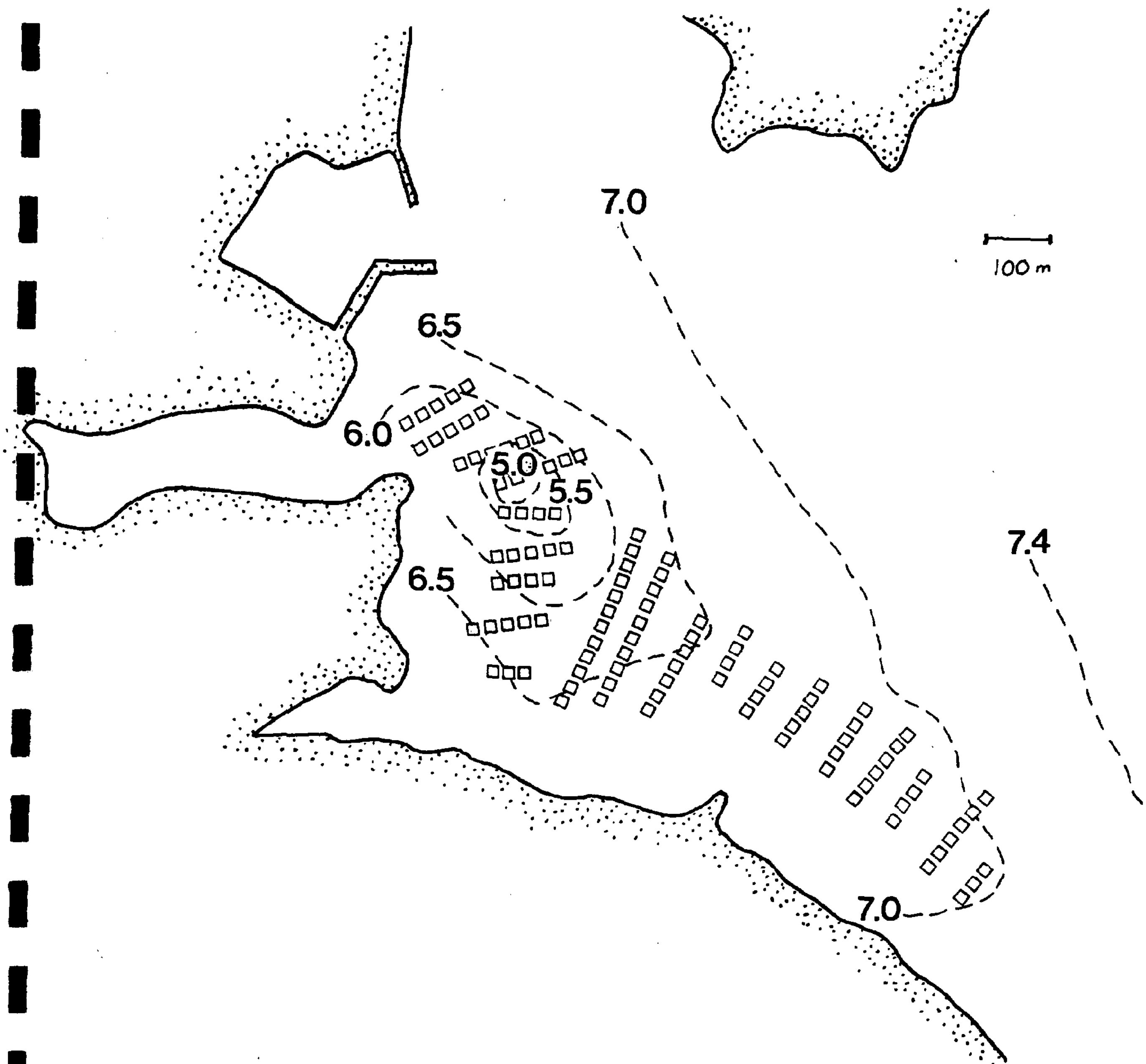

Figure 4. Dissolved oxygen concentration of surface waters around a net-cage farm in southern Japan containing 400 tons of yellowtail and sea bream. From Kadowaki and Hirata (1984).

stressed if dissolved oxygen levels dropped below about 5 mg l^{-1} for extended periods. Should fish respiration decrease dissolved oxygen concentrations to biologically limiting levels, the fish themselves would be the first to suffer the consequences and standing stock within the farm would decrease to sustainable levels.

Decreases in bottom water dissolved oxygen because of the BOD of solid wastes could affect benthic invertebrates and wild demersal fish without adverse consequences to the cultured fish themselves, although the work of Brown et al. (1987) suggests impacts would be limited to the seafloor in the immediate vicinity of the farm.

Nitrogen and phosphorus

Ammonia, and to a lesser extent urea, are the principal nitrogenous wastes associated with fish culture. Both are produced as a result of the metabolism of proteins provided in the feed. Ammonia may be present either as the non-toxic ammonium ion (NH_4^+), or as the toxic un-ionized form (NH_3). The relative proportions of the two forms is dependent upon both pH and temperature, with formation of the toxic NH_3 favored by high temperature and high pH. Given the variability of pH and temperature within Chesapeake Bay it is difficult to determine the proportion of NH_3 without site-specific data. Generally speaking, however, at temperatures typical of most of Chesapeake Bay (<30°C) and pH values typical of marine waters (7-8) only about 0.2 to 5% of ammonia will be in the form of NH_3 (Trussell 1972) and ammonia toxicity is not likely to be a significant problem. The greatest concern regarding ammonia input is more likely to be potential effects of the nutrient on phytoplankton communities.

Phosphorus, as phosphates, are also introduced with the feed and are released to the environment through urine and by leaching from the feces. Many feed manufacturers have substantially reduced the phosphorus content of the feed in recent years because of concern for nutrient loadings to the environment, particularly in the Scandinavian countries.

The environmental fate, and hence potential impacts, of nitrogen and phosphorus inputs from net-cage culture are very different

(Figure 5). Nitrogen is largely released in soluble forms, with only a small fraction in bottom deposits. Conversely, phosphorus is largely associated with feces and waste feed, and the vast majority of phosphorus from net-cage culture is initially deposited in the sediments. A large proportion of this phosphorus can later be released to the water column, particularly under anaerobic conditions (Enell and Lof 1983).

Field studies at marine net-cage sites have generally reported increased nutrient concentrations within the immediate vicinity of the cages. At a salmon farm in the northwestern United States there was a three-fold increase in ammonia concentrations within the cages and a two-fold increase 30 m downcurrent (Milner-Rensel Assoc. 1986). At another small farm in the same area up to an eight-fold increase in ammonia concentrations was reported in the vicinity of the cages (Pease 1977), and a farm in Finland was responsible for a two-fold increase in dissolved nitrogen. A small salmon farm (6 net-cages totalling 18 x 30 m) in Scotland caused a four-fold increase in ammonium concentrations at the farm site but no measurable change at the next nearest stations 1 km away (Gowen et al. 1988). Such increased nutrient concentrations are not universal, for example a Swedish trout and salmon net-cage farm with an annual production of 33 tons caused no measurable change in nitrate and phosphate (Müller-Haeckel 1986). Nevertheless localized increases in nutrient concentrations around marine net-cage sites appear quite common and would be anticipated in Chesapeake Bay waters. The spatial extent of measurable nutrient enrichment will depend upon hydrographic factors, but at all sites studied to date dilution of nutrients has been quite rapid and measurable increases have been limited to within ten's of meters of the farms.

Quantification and comparison of waste loadings

In order to evaluate the potential environmental significance of nutrient input from finfish net-cage culture it is obviously necessary to have an estimate of the amount of nitrogen and phosphorus released from such facilities. Unfortunately, however, there is a complete absence of effluent monitoring data from upland striped bass culture

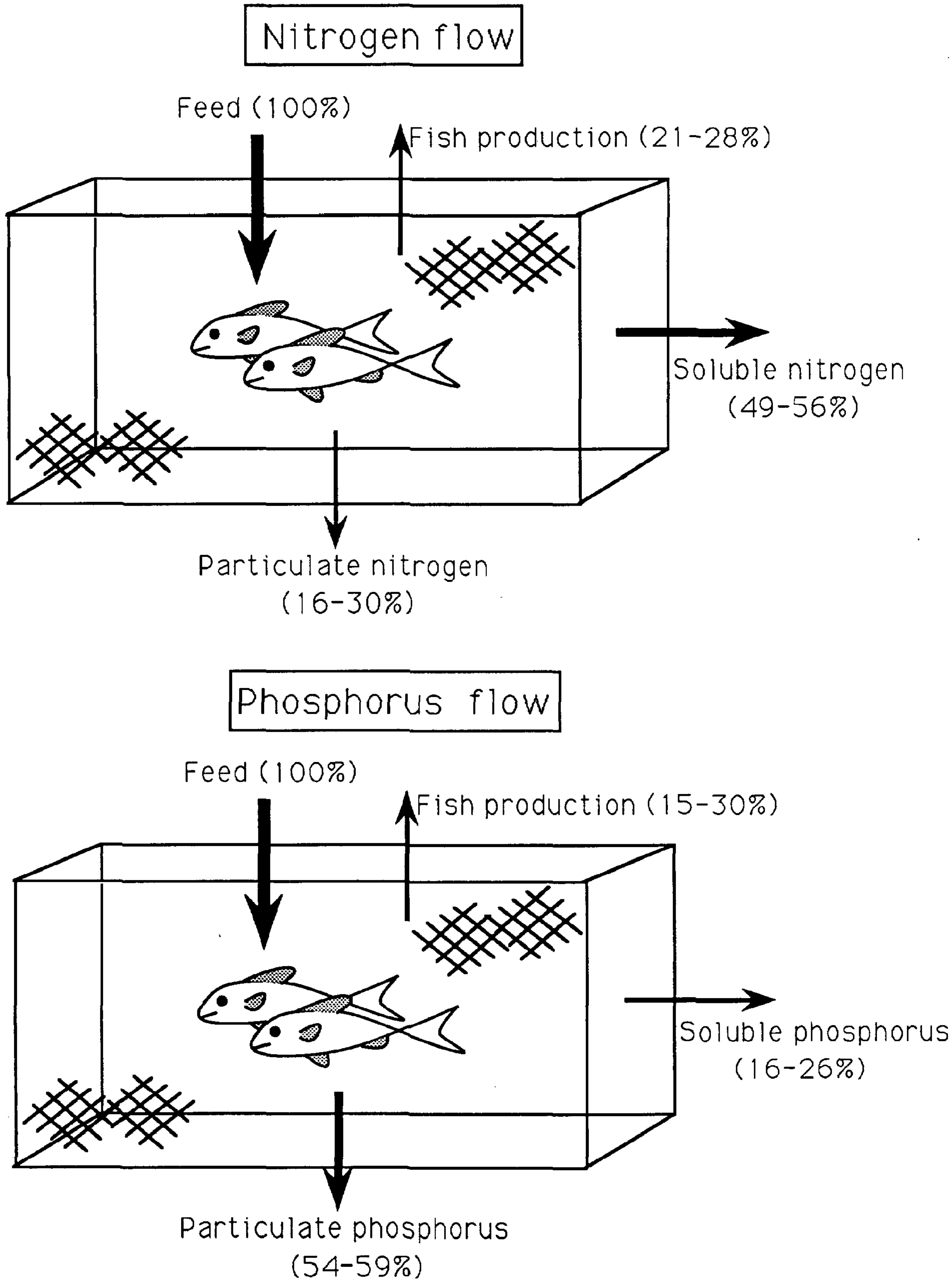

Figure 5. Nitrogen and phosphorus flow through salmonid net-cages, assuming 100% of each nutrient is provided in the feed. Based on data in Ackefors and Enell (1990) and Phillips and Beveridge (1986).

sites and laboratory-derived data are limited to a single study on nitrogen excretion by juveniles (Tuncer 1988). It is therefore necessary to rely on data from salmonid culture as a rough approximation of potential waste loadings from striped bass. While it is recognized that there are likely to be significant differences in excretion and digestion between striped bass and salmonids, the data for salmonids are so variable and dependent upon numerous variables such as fish size, feed conversion efficiency and feed composition, that these data are probably acceptable alternatives for the degree of resolution necessary for this analysis.

Table 2 presents a summary of studies on nitrogen, phosphorus and BOD loading from salmonid culture. Most of these studies are based on data from rainbow trout cultured in freshwater. Most are also based upon effluent monitoring data, but two (Gowen and Bradbury 1987; Ackefors and Enell 1990) are based entirely on theoretical calculations and assumptions of feed wastage, feed conversion efficiency and the nitrogen and phosphorus contents of the feed. It is apparent that there is a high degree of variability among these studies, particularly among those studies in which waste concentrations in effluent were repeated measured. Such variability is not at all surprising given difference in operating practices compounded by differences in feed conversion efficiency and feed composition. The effect of these variables on nutrient loading is clearly evident in Figure 6. For example, decreasing the feed conversion efficiency from 1.3 to 2 (decreased efficiency = greater numerical value) results in a doubling of the nutrient load to the environment. The farmer has considerable control over nutrient loading by minimizing feed wastage and using feeds with the lowest nitrogen and phosphorus contents possible without comprising fish growth.

Figures 7-9 put estimated nutrient and BOD loadings from fish net-cage culture in perspective with loadings from other discharges to Chesapeake Bay. A variety of sewage treatment plant (STP) loadings are shown, from the small facilities which serve Queenstown and Prince Frederick to the large plant which treats sewage wastes from Annapolis. All loadings shown are based on effluent monitoring following treatment

Table 2
Loading of nutrients and BOD from fish culture

Reference	Total nitrogen	Total phosphorus	BOD
	Loading as g (kg fish)$^{-1}$ d^{-1}		
Bergheim and Selmer-Olsen 1978	0.3-0.8	0.05	1.6-4.6[a]
Bergheim et al. 1982	0.13-3.8	0.005-0.43	1.6-2.7[a]
Korzeniewski et al. 1982	0.12	0.10	
VKI 1976	0.38	0.1	1.8[b]
	Loading as kg (ton fish produced)$^{-1}$ yr^{-1}		
Alabaster 1982	37-728	22-110	510-990
Ackefors and Enell 1990	78[c]	9.5[c]	
Gowen and Bradbury 1987	123[d]		
Ketola 1982		9.1-22.8	
Penczak et al. 1982	100	23	
Solbé 1982	68	16	285[b]
Warrer-Hansen 1982	83	11	350[b]

[a] BOD_7

[b] Unspecified whether value is BOD_5 or BOD_7

[c] Based on a feed conversion efficiency of 1.5

[d] Based on a feed conversion efficiency of 2

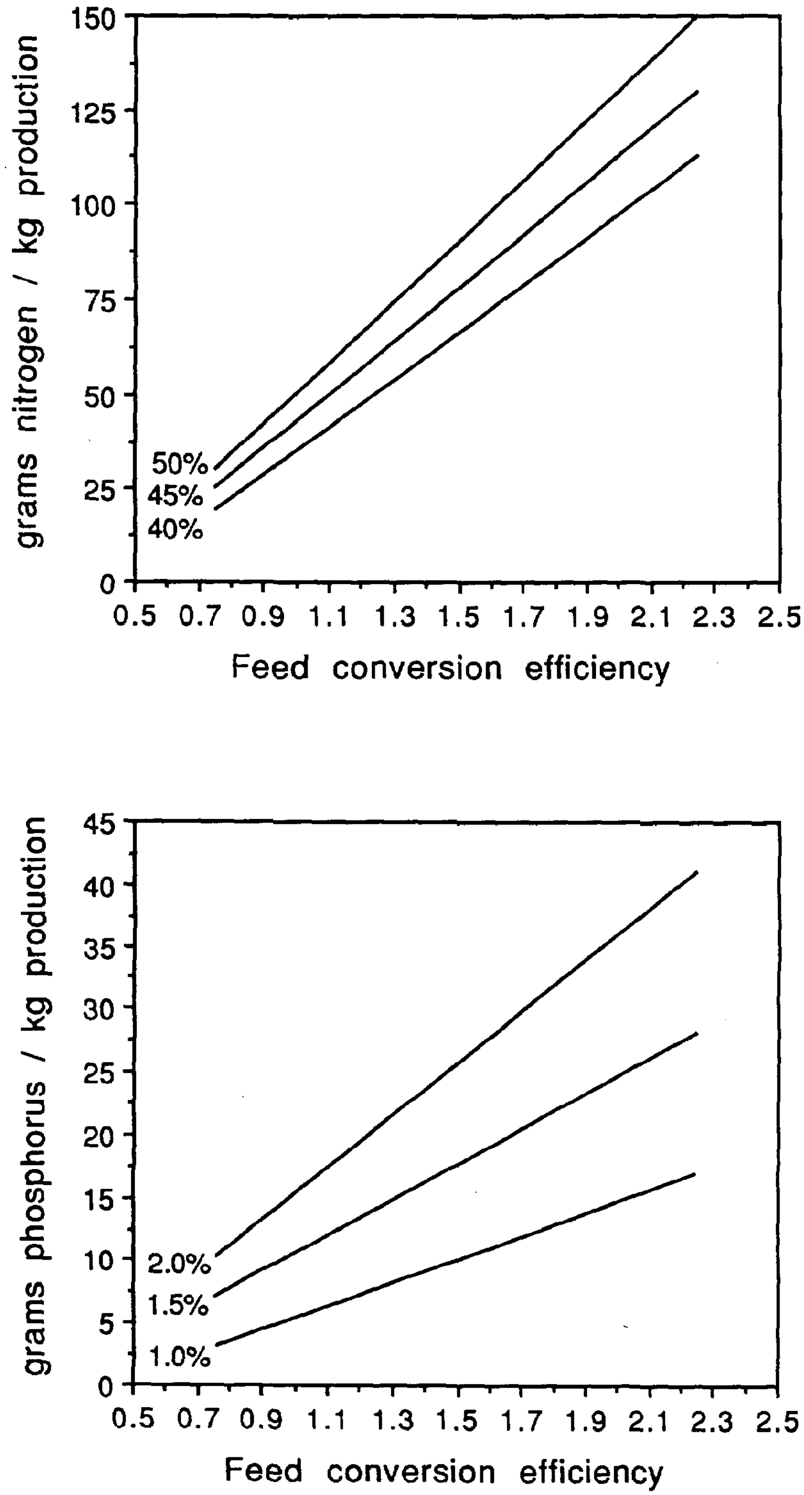

Figure 6. Nitrogen and phosphorus loading to the environment from salmonid culture as a function of feed conversion efficiency. Loading is shown for feeds with 40 to 50% protein and phosphorus contents of 1.0 to 2.0% phosphorus. From Hakanson et al. (1988).

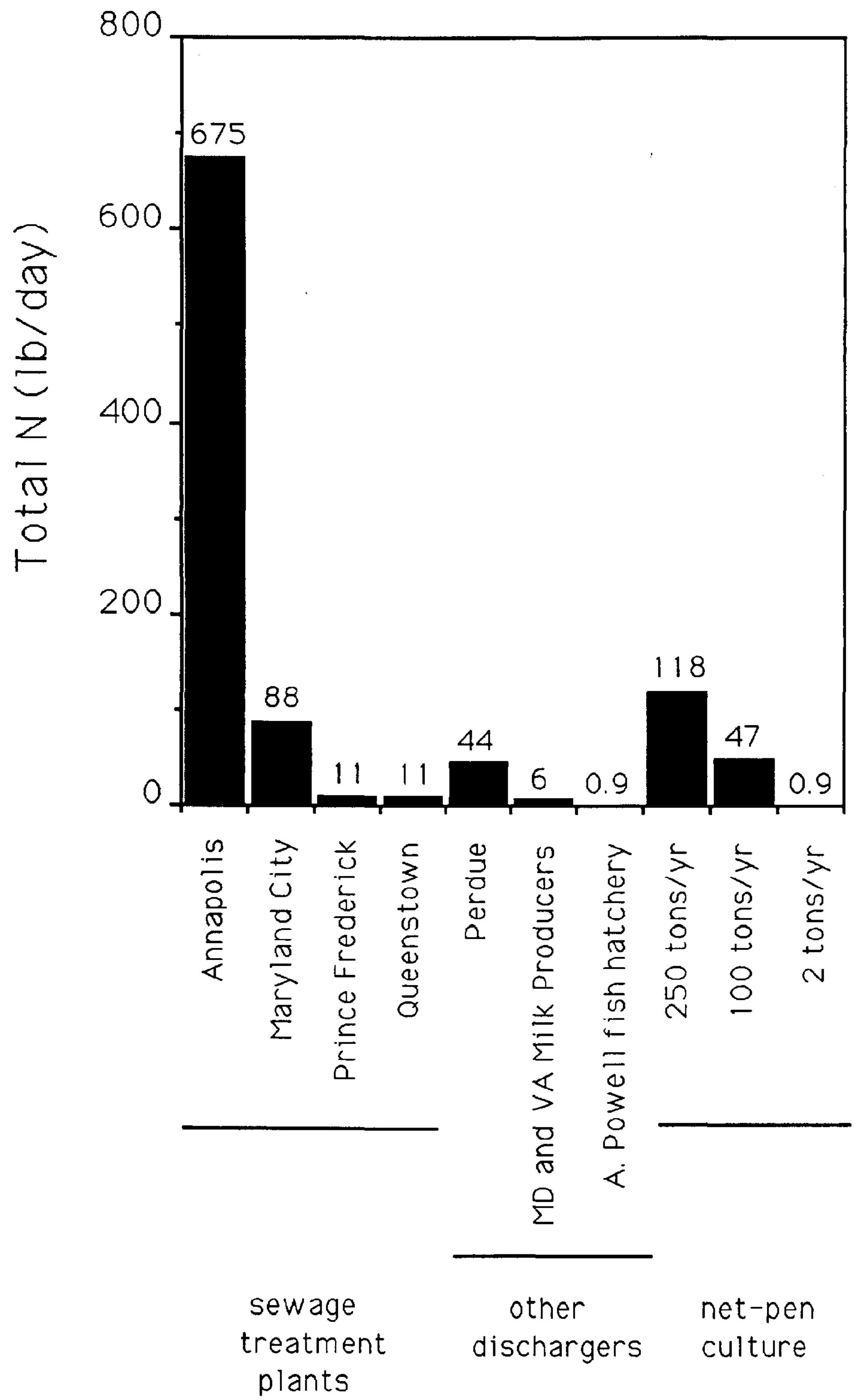

Figure 7. Nitrogen loading from net-cage farms of various sizes in comparison to loadings from other discharges to Chesapeake Bay.

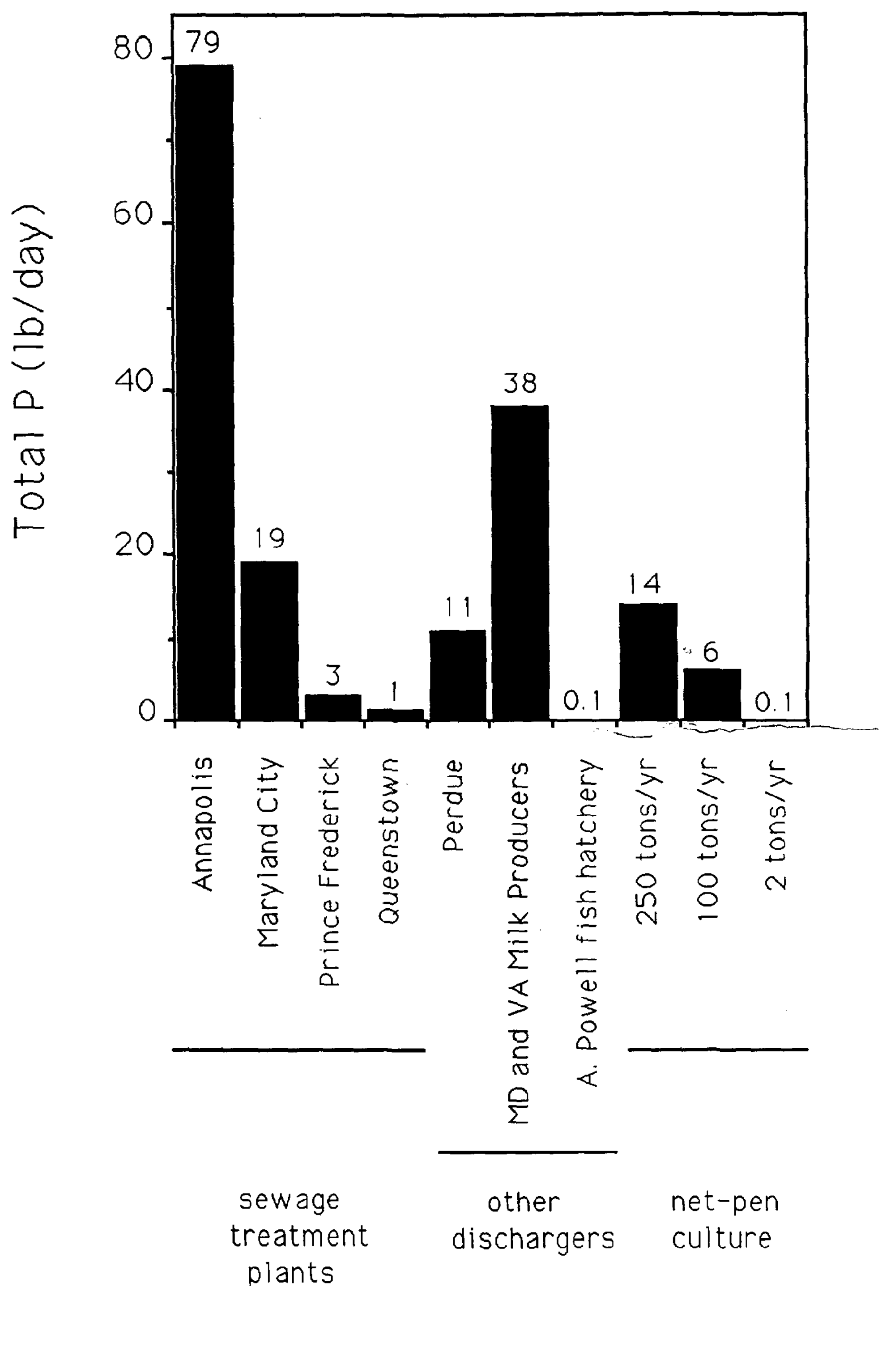

Figure 8. Phosphorus loading from net-cage farms of various sizes in comparison to loadings from other discharges to Chesapeake Bay.

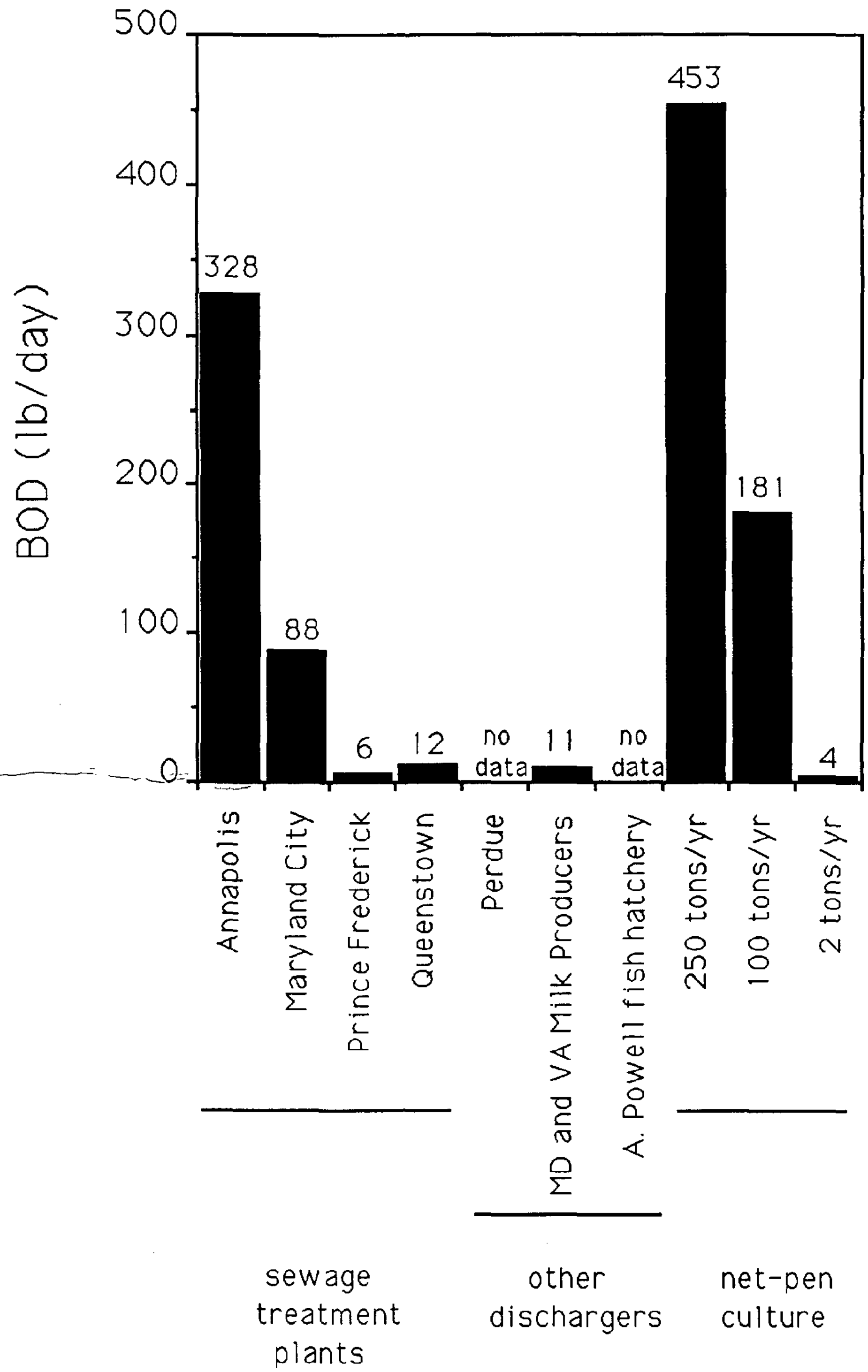

Figure 9. BOD loading from net-cage farms of various sizes in comparison to loadings from other discharges to Chesapeake Bay.

(usually activated sludge and nutrient removal) and reflect actual discharges to the Bay. Other discharges listed are Perdue Inc. (chicken processing), a milk processor, and a trout hatchery. Estimated loadings from fish culture are based on the data of Ackefors and Enell (1990) (78 kg N and 9.5 kg P (ton fish produced)$^{-1}$ yr^{-1}) and a BOD loading of 300 kg (ton fish produced)$^{-1}$ yr-1. These values are probably representative of actual farm loadings within a factor of two. Loadings from three farms of varying sizes are shown. A production of 2 tons yr^{-1} would represent a small farm for supplemental income. A production of 100 tons yr^{-1} would be expected from a commercial venture of moderate size. A production of 250 tons yr^{-1} is comparable to a typical salmon net-cage culture site in the northwestern United States, but may be larger than those farms likely to be located in Chesapeake Bay. It should be noted that the wastes from net-cage culture are untreated, whereas the STPs and most or all of the other waste streams shown are treated prior to release. The relatively high BOD of fish culture wastes probably reflects the efficiency of activated sludge treatment at the sewage treatment plants, and not an inherently greater BOD of fish wastes in comparison to human wastes.

It is apparent from these comparisons that nutrient and BOD loadings from all but perhaps the smallest net-cage farms are not trivial. A commercial venture of moderate size (100 tons yr^{-1}) will release about 7% of the nitrogen and phosphorus, and about half the BOD of the sewage treatment plant serving Annapolis. Loadings of nutrients from a farm of moderate size are comparable to loadings from a sewage treatment plant serving a small city or from a large food processing facility (e.g. Perdue, Maryland and Virginia Milk Producers). The BOD loading from such a farm is substantially greater than from these other sources. The smallest farm shown (2 tons yr^{-1}) has nutrient loadings comparable to those of an upland fish hatchery (e.g. Albert Powell rainbow trout hatchery) and unless released in an area of very restricted circulation, would be unlikely to have a measurable environmental effect.

It should be noted that while nutrient and BOD loadings from net-cage culture are comparable to those of other industries or domestic sewage treatment plants, the concentrations of these wastes are generally far lower (Weston 1986). Because of the open nature of the culture structure, in most situations wastes would be rapidly diluted with large volumes of water. Thus nutrient enrichment from net-cages is often more difficult to measure, and measurable nutrient increases are very localized.

Effects on phytoplankton

The nitrogen and phosphorus released from finfish net-cage culture can be readily utilized by algae, and in fact ammonia, the principal nitrogenous metabolite of fish, is taken up by phytoplankton preferentially over nitrite and nitrate. Not surprisingly, laboratory studies have found that fish carcasses and fish feces enhanced growth rates in the dinoflagellate Gymnodinium sp. (Nishimura 1982). Fish farm wastes could also provide micronutrients (e.g. vitamins) required by algae (Rosenthal et al. 1988). Phytoplankton growth may be limited by a number of factors (e.g. light availability, water column stability), but if limited by the availability of nitrogen and/or phosphorus it seems certain that net-cage culture can provide the limiting nutrients and stimulate algal growth.

Demonstrating an effect of marine net-cage culture on phytoplankton biomass or productivity has proven difficult. Three studies have found no measurable effect on phytoplankton including no change in chlorophyll a concentrations around farms in Washington State (Pease 1977) or Scotland (Gowen et al. 1988) and no change in algal cell density at a farm in Sweden (Müller-Haeckel 1986), although it should be noted that all these farms were relatively small with production of less than 40 tons yr^{-1}. The typical scenario is shown in Figure 10, in which a localized increase in ammonia is evident, but no effect on phytoplankton communities is reported. I am aware of only one report of enhanced primary productivity surrounding a marine fish farm (Halonen 1985), but the region studied was atypical in its lack of tidal currents.

The failure of past studies to demonstrate a change in primary productivity due to net-cage culture is probably attributable to both dilution of the nutrient-enriched water mass and the time lag before

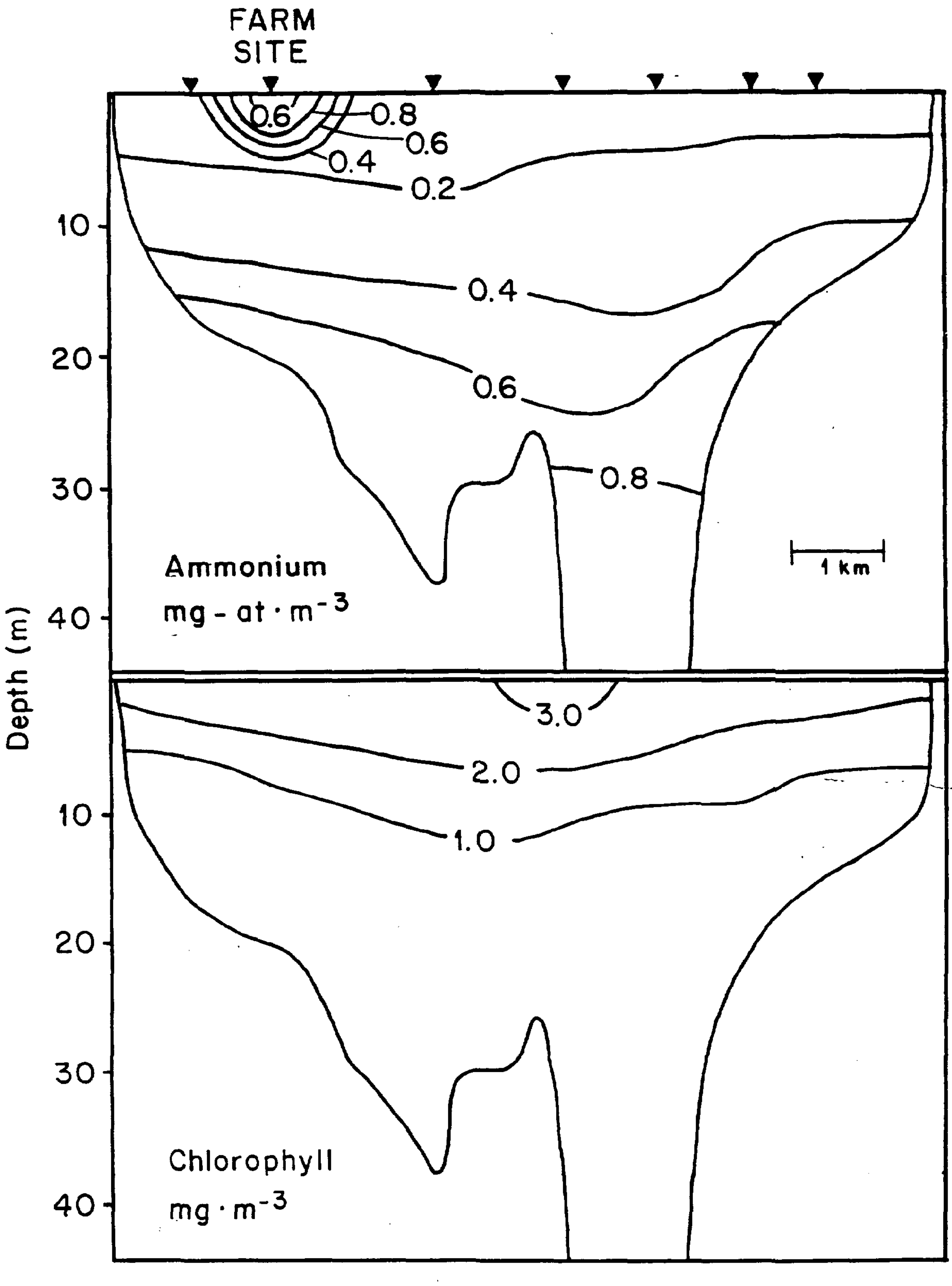

Figure 10. Cross-sectional profile of Loch Spelve, Scotland illustrating the distribution of ammonium and chlorophyll in August 1985. Location of profiling stations indicated on upper figure. From Gowen et al. (1988).

phytoplankton can convert the nutrients to algal biomass. Phytoplankton populations require a day or more to double in number and several days are necessary to increase to bloom proportions (Parsons et al. 1977). In most marine situations the nutrient enriched water would be broadly dispersed within that time and no localized effect on productivity or biomass would be anticipated. Localized effects would only be expected in areas of extremely limited circulations.

Phytoplankton blooms have been a major problem for marine net-cage culturists throughout the world. A bloom of the flagellate alga Chrysochromulina polylepis in Norway in 1988 resulted in the loss of 500 tons of net-cage cultured Atlantic salmon worth an estimated $5 million (Dundas et al. 1989). The flagellate Heterosigma akashiwo has been responsible for large losses in Japan, for mortalities in British Columbia in 1985 and 1986, and for a large kill of cultured salmon in Washington State in 1990. The diatom Chaetoceros spp. has been a major problem for culturists throughout the world, including Washington State where several farms experienced heavy losses in 1989 blooms. In none of these cases was it demonstrated that nutrients from the culture sites caused or contributed to the blooms, and given their spatial extent, regional hydrographic factors rather than culture activities were probably responsible.

In summary, nutrient inputs from finfish culture in Chesapeake Bay are likely to be utilized by phytoplankton in those areas and at those times when nutrients are limiting algal growth. In these instances culture will contribute to an increased phytoplankton biomass and/or productivity. In most cases, however, these increases have been dispersed over such a broad area as to be immeasurable, and the same is likely in most areas of Chesapeake Bay. More detailed assessment requires site-specific data on current regimes, farm production, and nutrient contributions from other sources in the area.

Mitigation strategies

The open nature of the net-cage design prohibits most of the technological solutions to waste stream treatment that would be practiced in an upland culture site. Nutrient or BOD removal would only be possible by suspending funnel-shaped collectors beneath the cages as discussed in Section 4.1. These devices are in the experimental stage of development and would probably remove very little of the nitrogenous wastes.

The only control measures feasible involve reduction of nutrient input to the culture operation rather than removal of nutrients from the effluent. The use of dry or semi-moist feed, now the norm in North American fish culture, results in a substantial improvement in water quality relative to wet feed (i.e. minced fish). Changes in feed formulation can also reduce nutrient loading without affecting fish growth. It has been estimated that even though finfish production in Finland has increased three-fold over the past decade, the loading of phosphorus to the environment has only slightly increased because of the reduction of phosphorus concentration in fish feed (ICES 1988).

Fish farmers in Chesapeake Bay will depend upon water currents to dilute and distribute the wastes, both to maintain environmental quality and protect the health of the cultured fish. In this regard the best sites are those with high current velocities and a high flushing rate. Enclosed, stagnant water bodies should be avoided. Areas considered highly sensitive to nutrient inputs would also be areas of concern for all but the smallest farms. Environmental managers may have to make use of water quality modelling techniques in evaluating permit applications. Swedish authorities require an applicant to construct a nutrient budget for the receiving waters which reflects how nutrient loading from the proposed facility compares with other sources in the area. Several farms in Washington State have been required to do computer simulations of net-cage inputs, illustrating the probable persistence and areal extent of nutrient enriched waters.

4.3 Chemical usage

Aquaculture chemicals

The maintenance of suitable culture conditions requires the use of a wide variety of toxic substances for purposes such as fouling control and treatment of disease. These substances are selected for their toxicity to the target organisms, but when environmental risks are not fully known or the chemicals are misused, they represent a potential threat to the cultured animal, wild fauna and the human consumer.

Aquaculture chemicals generally fall within three broad groups. First, a wide variety of potentially toxic substances may be introduced with the construction materials. For example, mortalities of fish in a private hatchery have been attributed to the release of toxic substances from the plastic lining of the pond (Zitko 1986). Antifoulants may have unwanted adverse effects on both non-target wild fauna and the cultured fish. The best example of these unwanted effects is the past use of tributyltin (TBT) as a net-cage antifoulant. Treatment of net-cages with TBT has been linked to mortalities in the cultured fish (Short and Thrower 1987) and residues of the chemical have been found in cultured fish intended for human consumption (Short and Thrower 1986; Davies and McKie 1987). The chemical has been found in the sediments of harbors throughout the world, including Chesapeake Bay, because of its widespread use as a hull antifoulant (Cleary and Stebbing 1985; Grovhoug et al. 1986). Shell malformations in oysters has been attributed to the use of TBT as an antifoulant on boats moored in nearby areas (Alzieu et al. 1980), and the compound has proven to be toxic to many forms of marine life at concentrations in the parts per trillion range. As a result of the mounting evidence of adverse effects from TBT fish culturists in many areas voluntarily discontinued its use as a net-cage antifoulant, and many states and countries have since enacted legislation banning or severely restricting its use for most applications.

A second category of chemicals in aquaculture is hormones used for gender control (e.g. methyltestosterone) or inducement of ovulation (e.g. human chorionic gonadotropin). Little is known about potential environmental effects of these hormones, although since the quantities used are small major environmental impacts would not be anticipated. There are also unlikely to be any human health ramifications since the hormones are administered either in the juvenile stage years before human consumption or are given to broodstock that would not be marketed.

The third major class of aquaculture chemicals is those used to treat the fish or the culture environment for the purpose of disease therapy, pest removal, or stress reduction. A wide array of antibiotics are potentially effective against bacterial pathogens of cultured fish. Antibiotics of potential use in aquaculture include erythromycin, penicillin, doxycycline, chlortetracycline, streptomycin and chloramphenicol. Erythromycin is used in Canada, England and Norway (ICES 1989). Penicillin has received very limited use in salmonid culture in British Columbia (E. Black, pers. comm.), and doxycycline is used in Japanese yellowtail culture (Alderman 1988). Others, such as chloramphenicol, are used in some countries but have been specifically banned by the U.S. Food and Drug Administration (FDA) for use in the United States because of human health concerns.

Fish culturists in the United States in general, and striped bass culturists in particular, have extremely limited options for chemotherapy. This situation results from the rigorous registration requirements imposed by the FDA and the relatively minor market for aquaculture therapeutants in this country. For many drugs, manufacturers are reluctant to pursue registration and FDA approval because of concerns that a major proportion of marketshare would go to generic substitutes (Schnick 1987). The FDA and U.S. Department of Agriculture are currently attempting to speed the registration process for so-called "minor use" drugs, such as those that would be required by the finfish culture industry in Maryland. The chemicals currently approved by the FDA for use in food fish culture are listed in Table 3. This list includes chemicals likely to find applications in both fresh and saltwater. The chemicals likely to be used in net-cage culture within marine and brackish water would comprise only a small sub-set of this list and would exclude virtually all of the water treatment and dyes, herbicides and algicides, and piscicides.

It should also be emphasized that while all chemicals listed in Table 3 are approved for culture of certain species of food fish or crustaceans, the FDA generally approves chemical usage on a species-by-species basis. A chemical approved for one type of fish (e.g. salmonids) can not legally be used to treat other fish for which the drug manufacturer has not explicitly sought and received approval. Since the striped bass culture industry is still in its infancy, the FDA

Table 3
Chemicals registered or approved by the U.S. Environmental Protection Agency and the U.S. Food and Drug Administration for use in food fish aquaculture. (Modified from Schnick 1988a).

Product	Use
	Therapeutants
Copper, elemental	Antibacterial for shrimp
Formalin	Parasiticide
Oxytetracycline	Bactericide
Sodium chloride	Osmoregulatory enhancer and parasiticide
Romet 30 (sulfadimethoxine and ormetoprim)	Antibacterial
Sulfamerazine	Antibacterial
Acetic acid	Parasiticide
	Disinfectants
Calcium hypochlorite	Disinfectant and algicide
Didecyl dimethyl ammonium chloride	Disinfectant
Povidone iodine	Egg disinfectant
	Water treatment and dyes
Fluorescein sodium	Dye
Calcium hydroxide, Ca oxide, Ca carbonate	Pond sterilant
Oxytetracycline	Dye to mark fish
Potassium permanganate	Oxidizer and experimentally as parasiticide/fungicide
Rhodamine B and WT	Dye
Tetracycline	Dye to mark fish
	Anesthetics
Carbonic acid	Anesthetic
Sodium bicarbonate	Anesthetic
Tricaine (MS-222, Finquel)	Anesthetic
	Herbicides and algicides
Acid blue and acid yellow	Herbicide and algicide
Aluminum sulfate, calcium sulfate, boric acid	Herbicide and algicide
Copper, elemental	Algicide
Copper sulfate	Herbicide and algicide
2,4-D	Herbicide
Diquat dibromide	Herbicide and algicide; experimentally as antibacterial

(Table 3 continued)

Endothall	Herbicide
Fluridone	Herbicide
Glyphosphate (Rodeo)	Herbicide
Potassium ricinoleate	Algicide
Simazine	Herbicide and algicide
	<u>Piscicides</u>
Antimycin A	Piscicide to remove scaled fish from catfish ponds
Rotenone	Piscicide

has not approved any therapeutants for use on striped bass. Formalin has been registered for use on largemouth bass but not striped bass (Federal Register 1986a). The antibiotic Romet 30 is approved for use on salmonids and catfish (Federal Register 1986b; Schnick 1988a), and the antibiotic sulfamerazine is registered only for use on salmonids (Federal Register 1986c). Oxytetracycline is currently registered only for salmonids, catfish and lobsters (Federal Register 1986d; Schnick 1988a). There is even some question regarding chemicals classified by the FDA as "generally recognized as safe" (GRAS). These chemicals would include sodium chloride (salt), acetic acid, carbonic acid (carbon dioxide), sodium bicarbonate (baking soda), and lime (calcium hydroxide, oxide or carbonate). The FDA has not explicitly approved GRAS chemicals for use on striped bass and they have not yet taken a definitive position on whether their use would be allowed (R. Schnick, pers. comm.).

The antibiotic oxytetracycline shows the greatest potential as a registered therapeutant for striped bass culture (Schnick 1988b). The manufacturer has prepared all necessary data to expand usage to striped bass, but has not yet submitted this information to FDA (Schnick, pers. comm.). Given the popularity of oxytetracycline in aquaculture within the United States it is likely to become the drug of choice for finfish culture in Maryland. The discussion below will emphasize oxytetracycline both because its high probability of eventual use in Maryland and because research on the environmental effects of antibiotic usage, while minimal, have largely concentrated on this drug.

<u>Environmental considerations in antibiotic usage</u>

Fish culturists typically administer antibiotics on a therapeutic rather than prophylactic basis; that is they are provided intermittently to combat disease instead of routinely for disease prevention. The need for antibiotic therapy will depend upon water temperature and, to a very large degree, on husbandry practices. Salmon net-cage culturists in the northwestern United States have generally found it necessary to treat the fish with antibiotics two or three times during the summer and fall months, and given the warmer temperatures of Chesapeake Bay treatment is likely to be necessary at least as frequently. Oxytetracycline is administered as a food additive at a rate of 2.5 to 3.75 g per 45 kg (100 lb) of fish per day over a 10-day treatment period (Federal Register 1986d). The FDA requires 21-day holding period before fish treated with oxytetracycline can be harvested for human consumption.

The quantity of antibiotics used in a large, well-established fish culture industry can be astounding. In 1989 the Norwegian salmon net-cage culture industry produced 115,000 metric tons of salmon. This production required the use of 19 metric tons of antibiotics including 5 tons oxytetracycline, 12.6 tons oxolinic acid and 1.3 tons nitrofurazolidone (ICES 1990). Nearly 50 tons of antibiotics were used in Norway in 1987 due to a widespread outbreak of Hitra disease.

The heavy usage of antibiotics by the fish culture industry in some countries and the fact that much of the antibiotic is released to the marine environment has prompted much concern regarding potential environmental effects. Data useful in evaluating potential effects, however, are almost totally lacking. The scientific literature is replete with studies on the efficacy of a particular drug for treatment of a specific disease, but consideration of environmental effects is minimal or lacking. The FDA now requires that new drug applications include information on environmental persistence and degradation products, but data demands are minimal and comparable information on previously registered drugs is lacking entirely. The potential environmental concerns are given below, but all conclusions must be regarded as tentative given the paucity of information.

<u>Antibiotic accumulation in biota</u> - A large proportion of antibiotic supplied to the fish in the form of medicated feed is not absorbed but is released directly to the environment. Waste feed will account for a loss to the environment of at least 5% of the antibiotic and potentially more. In addition the digestive absorption of ingested antibiotics varies greatly depending on the particular drug. For example, over 99% of ingested chloramphenicol is absorbed during gut passage, but the absorptive efficiency of oxytetracycline is only about 8% (Cravedi et al. 1987). Therefore over 90% of the oxytetracycline provided to the

fish is released to the environment via the feces in a microbially-active form.

Concern has been expressed that fish farm antibiotics could accumulate in demersal fishes, crabs and molluscs living in the vicinity of cages, and that the harvest and human consumption of these organisms could result in dietary intake of antibiotics. Harvest of the wild organisms would be unaffected by the 21-day post-treatment holding period for the cultured fish as required by the FDA since there is no way of knowing if or for how long wild organisms were exposed to antibiotics prior to capture. This concern is exacerbated by the fact that demersal fish and crabs are often found in higher densities around fish farms than in the surrounding environment (Weston 1991), and that, because of these densities, farm sites are often popular areas for recreational fishing.

There are reasons to expect that accumulation in wild organisms would not be a major problem. Uptake is likely to be minimal given the low retention of ingested oxytetracycline and the fact that antibiotic-treated material is likely to comprise only a portion of the total diet of the wild organism. In addition, oxytetracycline's octanol-water partition coefficient, often used as a surrogate measure of bioaccumulation potential, is low suggesting little potential for bioaccumulation (Bureau of Veterinary Medicine 1983). Field research on accumulation of antibiotics in wild organisms is conflicting. In two unpublished studies of very limited scope, no antibiotics were found in oysters suspended in the water column near net-cage sites (E. Black, pers. comm.; J. Tibbs, pers. comm.). Scandinavian investigators, however, have found oxytetracycline and oxolinic acid in wild fish and/or mussels (Møster 1986; Björklund et al. 1990; Lunestad, in press).

<u>Environmental persistence of antibiotic residues in sediments</u> - The available data suggest that oxytetracycline may persist in marine sediments for a considerable length of time, particularly under the anoxic conditions that might be expected in fish farm sediments. Jacobsen and Berglind (1980) found oxytetracycline in marine sediment beneath a fish farm 12 weeks after cessation of antibiotic therapy, and

laboratory studies indicated a half-life of 10 weeks. In other experiments (Samuelson et al. 1988) oxytetracycline concentration in organic-rich sediments decreased to 20% of initial concentration after a period of 200 days.

Antibiotic resistance - The use of antibiotics promotes the development of bacterial strains resistant to the same or similar antibiotics, making further treatment less effective. Stimulation of resistance has been noted in the aquaculture industry as a result of antibiotic therapy using oxytetracycline. During treatment of a trout farm with oxytetracycline, 90% of the bacterial isolates from the effluent were resistant to the drug as compared to 0% in the influent (Austin 1985). Resistance to oxytetracycline is now common in the pathogen Aeromonas hydrophila found in catfish farms in the southern United States (MacMillan 1985; Motes 1987). Oxytetracycline resistance has been documented in Edwardsiella tarda, a pathogen of humans and other vertebrates including fish (Sinderman 1990), and resistance to tetracycline antibiotics has been found in the fish pathogen Yersinia ruckeri (DeGrandis and Stevenson 1985). Several factors are probably responsible for the spread of oxytetracycline resistance among the microbial community. Among these are the low efficiency with which animals absorb it, its persistence in sediments, and the absence of other FDA-approved alternatives, forcing over-reliance upon oxytetracycline for most bacterial infections.

Antibiotic resistance is strongly selected during chemotherapy and during the period that antibiotic residues remain in the culture environment. In the absence of selective pressure for resistance (i.e. after completion of chemotherapy) the acquired resistance does not necessarily confer any advantage or disadvantage to the resistant strains. Resistance may therefore persist for long periods and is ultimately lost only by dilution with non-resistant strains (Brazil et al 1986; Levy 1986). There are few data on the temporal patterns of antibiotic resistance. Danish investigators have reported an increased resistance among Vibrio anguillarum-like organisms (VLO) following treatment of cultured trout with oxolinic acid. Two months after treatment resistant VLO populations were found 50 m from the cultured site and 30% of the VLOs directly under the farm were resistant (ICES 1990).

The stimulation of antibiotic resistance and the persistence of this resistance following cessation of antibiotic treatment are both of obvious concern to the culturist, but other potential consequences are unclear. The greatest problem would be encountered if the occurrence of antibiotic resistance in marine microbes decreased the efficacy of antibiotics used in human medicine. The fish pathogens of concern to the culturist are, with a few rare exceptions, unlikely to be human pathogens as well (Sinderman 1990). Antibiotic residues in the environment, however, can stimulate resistance in bacteria other than the target pathogen, and antibiotic resistance can be transferred among bacteria species by plasmid exchange. It is possible that antibiotic resistance resulting from finfish chemotherapy could be transferred to a bacteria of human health significance. *Vibrio parahemolyticus*, for example, is a common marine microbe that can cause gastroenteritis in humans if ingested through uncooked or undercooked seafood. Any linkage between antibiotic therapy in fish culture and antibiotic resistance in human pathogens is entirely conjectural at this point since there is no documentation of any such association. Sewage effluents and runoff from livestock growing areas are undoubtedly far greater sources of antibiotics than the Maryland fish culture industry is likely to be in the near future. The subject, however, is worth further serious evaluation if the fish culture industry grows to a point where appreciable quantities of antibiotics are released to the environment.

Impact of antibiotics on microbial community structure - The sediments near fish culture sites are extremely organic-rich because of feed and fecal matter accumulation. Degradation of this material is highly dependent upon microbial processes. The persistence of antibiotics in sediments could conceivably depress the rate and extent of this degradation. These effects would be manifested as changes in microbial biomass and rates of nutrient regeneration (e.g. sulfate reduction, nitrification and denitrification). There have been few studies of the effects of antibiotics on sediment microbial communities, but decreases in the density of bacteria following antibiotic treatment have been reported (Samuelson et al. 1988; ICES 1990).

Mitigation strategies for antifoulants and antibiotics

The use of antifoulants is probably unavoidable in Chesapeake Bay net-cage culture. In other areas such as the northwestern United States farmers do not require the use of antifoulants. Nets are removed every few months, dried in the sun, and then resubmerged. German aquaculturists have developed spherical cages which are periodically rotated about the axis, located near the waterline. The fouled portion of the net is rotated into the upper position for air-drying while the clean portion is rotated to beneath the waterline.

The rate of fouling growth is very rapid in Chesapeake Bay, and the labor involved in changing or cleaning nets would be prohibitive without the use of antifoulants. Given the restrictions on the use of TBT and trends in the industry elsewhere, it is likely that a copper-based antifoulant would be used. These antifoulants have widespread applications in the marine environment, and it is likely that net-cages would represent a small source of copper to the environment compared to the quantity of copper-based antifoulants used on boat hulls.

The use of chemotherapeutants, and particularly antibiotics, is the other principal issue pertaining to environmental effects of chemical usage by the aquaculture industry. The frequency of antibiotic therapy is, in large part, dictated by husbandry practices. Many of the bacteria and viruses of concern to marine net-cage culturists are facultative pathogens; that is they manifest pathological effects only when the fish are stressed. Outside of the culture environment these diseases are often associated with polluted conditions. In marine net-cage culture they are often attributable to husbandry problems. The farmer can reduce the frequency of infection, and therefore the need for antibiotics, by reducing stocking density, promptly removing dead fish, maintaining unfouled nets, and taking other measures to enhance water quality within the cages.

Another approach to mitigating the need for antibiotic therapy is vaccination. Initial efforts to combat vibriosis in salmonids, and to some extent current efforts as well, have relied upon antibiotic therapy using oxytetracycline, sulfamerazine, oxolinic acid and other drugs. Vaccination of juveniles, however, is becoming an increasingly popular alternative and is now used routinely for salmon culture in many regions. Vaccination of Atlantic salmon against vibriosis in Norwegian net-cage culture has substantially reduced the quantities of antibiotics used per unit of production. Vaccination is unlikely to totally replace antibiotic therapy since immunity does not last the life of the fish and disease resistance can be dramatically reduced by stress, but vaccination provides the means to substantially reduce the quantity of antibiotics released to the environment.

4.4 Genetic impacts

Potential consequences of interbreeding between cultured and wild fish

Occasional escape of cultured fish from net-cages in open waters is inevitable due to storm damage, ice damage, collision by boats, or poor farm maintenance. In the northwestern United States, for example, fishermen report the occasional capture of Atlantic salmon. Since the species does not occur in the Pacific Ocean except in culture, these individuals clearly represent escapees or their progeny. Net-cage culturists in Chesapeake Bay must also expect escape of some fish and consider the genetic implications of interbreeding of cultured fish with the wild population. This discussion emphasizes the culture of striped bass, although similar considerations would apply to other species.

From a genetic perspective it would be preferable for a culturist to capture wild broodstock and rear the progeny in the waterbody (i.e. James River, Rappahannock River, etc.) from which the parents were taken. This scenario, however, will frequently not be possible. The availability of local juveniles may be limited, or the culturist may wish to raise fish with attributes (e.g. rapid growth rates) that are not characteristic of local stocks. If the cultured fish are obtained from hatcheries or from waterbodies different from that of the culture site, two concerns arise.

First, hatchery stocks often have reduced genetic variability relative to their wild counterparts; a phenomenon that has been repeatedly documented in hatchery trout and Atlantic salmon (Allendorf and Phelps, 1980; Ryman and Stahl 1980; Stahl 1983). Through the use of only a few individuals as broodstock, selective breeding, and a variety of other intentional and unintentional mechanisms hatchery practices often lead to a substantial loss of genetic variability (Meffe 1986). Interbreeding of hatchery-derived individuals with members of the wild population, if it occurred on a large scale, could reduce the fitness of the wild stocks by reducing the genetic plasticity that allows them to survive changing environmental conditions.

Secondly, it is presumed that wild fish have evolved genetic traits making them uniquely suited to the habitat in which they are found. Interbreeding of this native population with fish from other localities would, by definition, result in reproductive effort being wasted on the production of less fit progeny. The Chesapeake Bay stocks of striped bass for example, produce eggs containing an unusually large oil globule for flotation. If eggs produced in a cross between Chesapeake Bay striped bass and individuals from another estuary failed to contain this large oil globule, they might be unlikely to survive, and the reproductive efforts of both parents might be wasted (Kerby and Harrell 1990). This potential reproductive waste is of particular concern for a stock such as that in the Chesapeake Bay that is already depleted.

The concept of stock identity is central to an assessment of the genetic consequences of interbreeding between cultured and wild fish and dictates the preferred sources of fish for culture in a given locality. It is generally accepted that striped bass along the Atlantic Coast can be segregated into four principal stocks: 1) Roanoke River; 2) Chesapeake Bay; 3) Delaware River; and 4) Hudson River (Rago and Richards 1986). It would be preferable to culture fish from the local stock. Any escaped fish would therefore be genetically similar to the wild population and interbreeding would not jeopardize the population fitness. It has not yet been clearly established whether Chesapeake Bay striped bass can be further segregated into identifiable sub-populations associated with specific river systems such as the James, Rappahannock-

York, or Potomac-Patuxent. While some investigators have claimed that these populations can be discriminated by electrophoretic techniques (Morgan et al. 1973), and recent homing studies have demonstrated significant homing ability to a specific river system (Hocutt et al. in press), the data taken together provide inconclusive evidence of the existence of discrete sub-populations of striped bass within the Bay (Waldman et al. 1988).

Striped bass hybrids

Assessment of the potential genetic consequences of net-cage culture is further complicated by the fact that a striped bass hybrid, rather than the striped bass itself, would probably be preferred by most culturists. There are four North American species within the genus Morone, and all are capable of producing fertile hybrids either in the wild or by artificial means (Table 4). Natural hybridizations between white bass and yellow bass (Fries and Harvey 1989), white bass and white perch (Todd 1986), and white bass and striped bass (Crawford et al. 1984) have been documented or are strongly suspected to have occurred. Some crosses may occur only rarely or not at all in the wild but can be induced artificially. For example, female striped bass will not release their eggs in the presence of white bass, but the eggs can be manually stripped and artificially spawned to produce viable offspring (Bishop 1975).

The hybrid cross between a striped bass (M. saxatalis) female and a white bass (M. chrysops) male has been the subject of most of the research. The hybrid exhibits a faster early growth rate, greater disease resistance, and generally greater hardiness than the striped bass parent. This hybrid is now in culture at a number of upland sites throughout Maryland and would likely be the preferred candidate for culture in open water net-cages as well.

Contrary to original expectations and experience with hybrids of many other animal species, all Morone hybrids are fertile and, at least in a hatchery environment, can be used to produce a variety of other crosses. F_1 (first generation) hybrids have been spawned with other F_1 individuals to produce F_2 (second generation) fish, although the F_2 fish

Table 4
Common names of striped bass hybrids recognized by the Striped Bass Committee, Southern Division, American Fisheries Society. From Kerby and Harrell (1990)

Female	Male	Common name
Striped bass (*M. saxatalis*)	White bass (*M. chrysops*)	Palmetto bass
White bass (*M. chrysops*)	Striped bass (*M. saxatalis*)	Sunshine bass
Striped bass (*M. saxatalis*)	White perch (*M. americana*)	Virginia bass
White perch (*M. americana*)	Striped bass (*M. saxatalis*)	Maryland bass
Striped bass (*M. saxatalis*)	Yellow bass (*M. mississipiensis*)	Paradise bass

do not appear to be as desirable for culture as the F_1's. F_1 fish have been "backcrossed" with one of the parental species, and have been "outcrossed" with a Morone species other than the parents. F_1 hybrids produced by crossing of two species (e.g. striped bass x white bass) can be spawned with F_1's from another cross (e.g. striped bass x white perch) to produce a "trihybrid". A summary of the various crosses that have been attempted and the potential for their use in aquaculture can be found in Kerby and Harrell (1990).

Data are very limited on potential genetic interactions between escaped striped bass x white bass hybrids and wild striped bass within Chesapeake Bay, but experience from hybrid releases in several freshwater sites indicates that the hybrid is capable of backcrossing with at least the white bass parental species and/or naturally reproducing among themselves to produce F_2's. Both white bass and white bass x striped bass hybrids were stocked in Lake Palestine, Texas. Later sampling revealed that 12 of 41 Morone individuals collected were the products of F1 individuals reproducing with white bass or other hybrids (Forshage et al. 1986). White bass x striped bass hybrids were stocked in the Savannah River drainage in which both white bass and striped bass wild stocks existed. In a later survey of 642 fish from the Savannah River system, six fish had genotypes not expected of either a first generation hybrid or a parental species, and one of these fish was clearly a product of hybrid reproduction (Avise and Van Den Avyle 1984). Although the authors concluded that there was minimal hybrid reproduction in the Savannah River system, they presented data from other localities where hybrid reproduction appeared more common. Given experience with hybrids in these freshwater systems, and lacking evidence to the contrary, one would conservatively have to assume that hybrid striped bass escaping from net-cage facilities could backcross with wild striped bass populations within Chesapeake Bay. This interaction, if occurring with sufficient frequency, could compromise the gene pool of the wild striped bass population.

Mitigation strategies

A primary consideration in assessing potential genetic consequences of escapement from aquaculture is the size of the escaped population relative to the breeding population of the wild stocks. Genetic concerns become increasingly important as the number of fish in culture increases. Genetic concerns would also be greater if striped bass exhibited a strong homing ability (e.g. as do salmonids) and discrete sub-populations could be identified. In this case fish escaping from a culture facility may interbreed with only one specific sub-population and their potential genetic influence would be greater. There is now only limited evidence that these sub-populations exist.

The Maryland Aquaculture Taskforce has recommended that striped bass hybrids be grown only in upland sites where there is better protection against escape, and that net-cage culture be limited to unhybridized striped bass (MDA 1988). Furthermore, the Taskforce recommended that only Chesapeake Bay stocks be cultured in net-cages. Given the concerns and potential genetic interactions discussed above, these policies seem prudent and adequately protective. It should be noted, however, that such policies require the cooperation of all states surrounding Chesapeake Bay. Fishery management agencies in Pennsylvania are currently stocking hybrid striped bass in rivers and reservoirs having direct connection to the Susquehanna River, and hybrid striped bass already comprise 10-20% of the winter gill net catch in the upper Chesapeake Bay.

The induction of triploidy in hybrid striped bass provides one option for culturing the hybrid without concern for the potential genetic consequences of escapement. Triploid fish contain three sets of chromosomes rather than the normal two sets (diploidy), and can be produced by subjecting eggs to high hydrostatic pressure or thermal shock soon after fertilization. From a management point of view, triploid hybrid striped bass would be preferable for culture since they are sterile and should they escape, would present no risk to the gene pool of the wild striped bass. From the culturists perspective, triploid fish may be preferable since they sometimes exhibit faster growth and better survival rates than diploid fish. Past attempts to induce triploidy in striped bass have been very limited and have had only limited success (Kerby and Harrell 1990). Nevertheless the success of triploid induction in other fish such as grass carp and salmonids suggests that further efforts are warranted.

4.5 Disease transmission

Introduction of exotic pathogens

The transfer of fish from one region of the world to another is commonplace, and in fact much of the worldwide aquaculture industry is based upon the culture of exotic (non-indigenous) species. In the past these transfers have been done with little regulatory control. Without adequate safeguards, transfers can result in the unwanted introduction of a parasite or bacterial or viral pathogen into areas where it had not previously been found, and the infection of wild populations.

There are many examples of fish transfers, usually for purposes of fisheries enhancement, being responsible for the introduction of exotic parasites or pathogens. The protozoan Myxosoma cerebralis, the causative agent of whirling disease in salmonids, has been spread throughout the world because of fish transfers (Hoffman 1970). The infectious hematopoietic necrosis (IHN) virus is believed to have been introduced to Japan by eggs imported from the United States and has since spread throughout the country (Sano et al. 1977). Aeromonas salmonicida, the bacterium causing furunculosis, may have been introduced into Europe by the introduction of rainbow trout from North America (Rosenthal 1980). In the late 1970s the trematode parasite Gyrodactylus salaris began appearing in many Norwegian rivers. It has since spread to several dozen rivers, and has caused massive mortalities among wild salmon. In some cases authorities have treated the rivers with rotenone to remove the infected fish and thereby control the parasite. The parasite is believed to have been introduced by stocking of infected salmonids (Johnsen and Jensen 1988).

Fortunately, finfish net-cage culture in Maryland, as presently envisioned, will not require the importation of fish or their reproductive products from distant locales. At present the industry is dependent upon the capture of wild striped bass broodstock, and these fish are likely to come from the Chesapeake Bay watershed. Even if a striped bass x white bass hybrid is cultured, the white bass is likely to be obtained from freshwater bodies within the southeastern states. As the industry matures, domesticated broodstock may be developed, reducing the dependence upon wild fish and further reducing the risk of accidental transfer of a parasite or pathogen.

Transfer of disease to wild fish

Concern has been expressed that fish aquaculture facilities could function as reservoirs of disease, spreading infections to wild fish in the vicinity (Mills 1982; Sinderman 1990). In this scenario the pathogen may be naturally present in the environment (i.e. not exotic) but cause no clinical symptoms in the wild fish unless they are exposed to atypically high pathogen densities as might be encountered near a net-cage facility experiencing a disease outbreak.

Such a scenario has never been documented. There are numerous instances of wild fish transferring parasites and disease to caged fish (Munro and Waddell 1984; Harrell and Scott 1985), but no examples of transfer in the opposite direction -- a result that is probably at least in part due to the comparative difficulty of documenting disease in wild fish.

Forty-five parasitic organisms from viruses to Metazoa have been recognized in striped bass from Chesapeake Bay (Paperna and Zwerner 1976). There are, however only four diseases anticipated to be significant problems in marine net-cage aquaculture of the species (Mitchell 1984; Hughes et al. 1990).

Vibriosis - Vibriosis is a disease of striped bass and many other fish species caused by the bacteria *Vibrio*, most often *Vibrio anguillarum*. *Vibrio* species are ubiquitous in marine and brackish environments and many are facultative pathogens. Vibriosis has plagued salmon culture throughout the world, and *Vibrio* spp. have been isolated from moribund striped bass within Chesapeake Bay (Toranzo et al. 1983).

Pasteurellosis - This disease, caused by the bacterium Pasteurella piscicida, has caused large losses among yellowtail (Seriola quinqueradiata) culturists in Japan. It has killed striped bass in culture (Hawke et al. 1987) and has been caused extensive mortalities in wild white perch (Morone americanus), and to a lesser degree striped bass, in Chesapeake Bay (Snieszko et al. 1964). The disease is most severe at high water temperatures (>23°C) when water quality is poor (Fryer and Rohovec 1984).

Aeromonas/Pseuodomonas - Bacteria of these genera are capable of causing fin rot and motile aeromonad septicemia (MAS) in striped bass and other cultured fish. These bacteria are most often problems in freshwater culture, but can infect fish held in brackish and marine waters. Cultured striped bass became infected with Aeromonas hydrophila when held in warm (32°C) brackish water (Hawke 1976). It should be noted that A. salmonicida, the causative species for furunculosis and the cause of large losses for salmonid culturists is primarily a disease of salmonids and had not been reported to be a problem in striped bass culture.

"Velvet disease" - This disease is caused by the protozoan parasite Amyloodinium ocellatum which attaches to the gills and skin of the host fish. It is a serious problem for striped bass in environments having a salinity over 3 ppt. A. ocellatum is generally controlled by placing the fish in a bath containing a copper solution.

Of the four diseases listed above, three are of bacterial etiology and are stress related. The bacterial species are ubiquitous inhabitants of brackish and marine environments but exhibit no pathogenic effects in marine fish unless the fish are stressed in some manner. Cultured fish may be stressed as a result of handling, over-crowding, malnutrition, poor water quality or other factors, and thus bacterial pathogens have become a significant problem for fish culturists. It is unlikely, however, that wild fish would be any more likely to contract such diseases simply by virtue of their proximity to the farm provided that the wild fish have not been made more susceptible to disease as a result of other environmental factors.

Mitigation strategies

It has not been demonstrated that net-cage culture facilities function as epicenters of diseases that would spread beyond the farm into the wild fish populations. The very limited data available suggest this is not likely to be a problem in striped bass culture in Maryland, but nevertheless it would seem prudent and of obvious advantage to the farmer to reduce the incidence of disease in the farm. This can be accomplished by reducing stocking density, minimizing handling, and taking other precautions to reduce stress on the fish.

It is clear that an exotic pathogen could be introduced to Chesapeake Bay as a result of fish transfers for aquaculture purposes, but as presently envisioned the Maryland striped bass culture industry is not likely to require transfers from beyond the southeastern United States. Should this situation change, the state would need to establish policies for importation of fish and their reproductive products. For example, the salmon net-cage culture industry in the northwestern United States is in part dependent upon eggs from European sources. Any importation must be accompanied by a disease-free certification, the eggs must be surface disinfected, and the fish are held in quarantine for 90 days after swim-up (i.e. depletion of the yolk sac and initiation of feeding). Comparable programs may have to be initiated in Maryland depending upon the frequency of transfers, the location of the source, and disease history of the area.

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