A WHITE PAPER
ON THE STATUS AND CONCERNS OF
AQUACULTURE EFFLUENTS
IN THE NORTH CENTRAL REGION

Prepared by

Harry Westers
Aquaculture Bioengineering Corporation

for the
North Central Regional Aquaculture Center

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TABLE OF CONTENTS

INTRODUCTION AND JUSTIFICATION OF THE DOCUMENT

U.S. aquaculture has shown significant growth during the last two decades. During the 1980s, the production of food fish tripled. This average 30% annual increase was primarily the result of a 700% increase in catfish production and a doubling of the trout output. These two species represent over half the food-fish production in the U.S., grown primarily in industry-scale farms in the states of Mississippi and Idaho. Expansion of the catfish industry is in jeopardy due to drawdowns of the once abundant groundwater sources in the Delta Region (Tucker 1996) and expansion of the Idaho trout industry is on hold as it must meet a 40% reduction in phosphorous discharges (Goldberg and Triplett 1997).

The growth during the 1990s was reduced to an annual average of about 15%. It is rather interesting to note that this more modest growth is mostly the result of new, non-traditional, species entering U.S. commercial aquaculture. These are the net pen operations for salmon in the states of Maine and Washington, the production of hybrid striped bass and tilapia in recirculation systems, and, even more recently, we are witnessing serious efforts to raise newcomers such as yellow perch and walleye as food fish.

This change to new species clearly reflects an increased interest in commercial aquaculture, prompted by the promotional efforts by several organizations and government agencies to counter projected declines in captive fisheries and increases in seafood consumption and imports. For instance, in 2002, seafood import value of tilapia and salmon was $992 million, greater than the $978 million for all U.S. aquaculture production for 1998. The 2002 value of all domestic and imported fish products was for less than the $3.4 billion value of imported wild and farm-raised shrimp (Summerfelt, 2003).

Authors have addressed issues of expansion of aquaculture to convey ideas on how to integrate aquaculture into society. Growth of aquaculture must proceed in a sustainable manner, meaning that it must meet economic, social, and environmental goals simultaneously (Bardach 1997). Boyd (1999) considers the term sustainability, when used in environmental context, as a worthless word because there are many definitions, and no one knows what it means. Boyd suggests that sustainability, where used in the environmental context, should be replaced with the term environmental management. Both Bardach and Boyd have valid points, mainly, aquaculture must be economically viable, socially acceptable, and strive to reduce negative environmental impacts, i.e., it must be sustainable on all fronts.

The Food and Agricultural Organization of the United Nations has defined sustainable development as the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant, and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable. These are major challenges the growing aquaculture industry faces, challenges it can neither ignore nor circumvent, nor can a fledgling industry support the needed research and development efforts to accomplish all of these goals.

The U.S. government has acknowledged that a healthy aquaculture development is in the best interest of the nation, and modest research and extension dollars have been channeled through the U.S. Department of Agriculture (USDA) to five Regional Aquaculture Centers.

Since 1989 the North Central Regional Aquaculture Center (NCRAC), encompassing twelve states, has funded a variety of major projects in extension, improved culture technology of a number of species (e.g., yellow perch, hybrid striped bass, walleye, etc.), economics and marketing, wastes/effluents, and several drug-related projects.

Each year, priority areas are identified by the Center and the Industry Advisory Council in consultation with the Technical Committee. These are then presented to the NCRAC Board of Directors (Board). Each year focuses may change, interrupting continuity.

At their 1998 annual meeting the Board decided, after consultation with the various committees, that a series of white papers should be developed, addressing the most urgent areas for research and extension activities. Each white paper is to identify the current status, the critical factors limiting sustainable development, and recommendations as to the research and extension agenda that should be considered in future work plans. During 1999-2000, eight "species" white papers and this one on effluents and the environment were completed..

The Board has recognized that the image of the industry and its future may be in jeopardy unless it deals effectively with environmental issues. Environmentalists are already in an attack mode in the U.S. as evidenced by the 1997 Environment Defense Fund publication of "Murky Waters: Environmental Effects of Aquaculture in the United States" (Goldberg and Triplett 1997). Also, the U.S. Environmental Protection Agency (USEPA) has decided that aquaculture must comply with the Clean Water Act.

The Joint Subcommittee on Aquaculture (JSA) has identified these "challenges" and states: "As U.S. aquaculture continues to expand, it must be sustainable and environmentally compatible. We need substantially better knowledge about possible interactions between aquaculture and natural environments to minimize the potential for habitat degradation, disease transmission, genetic dilution of wild stocks through interbreeding with cultivated strains, introduction of non-indigenous species into natural waters, and discharges of wastes, toxins, and excess nutrients."

CURRENT STATUS ON EFFLUENT AND THE ENVIRONMENT

Concerns and controversies about potential environmental degradation by aquaculture have gone hand in hand with its phenomenal growth and promotion.

A BRIEF HISTORICAL PERSPECTIVE

Prior to 1970, there were no articles of any significance concerning aquaculture as a source of pollution in the U.S., but Earth Day 1970 was a wake-up call. It spurred an awareness about a broad range of environmental issues, including pollution of our surface waters.

Consequently, in 1972, the Environmental Protection Branch of Michigan's Department of Natural Resources (MDNR) became proactive by conducting an extensive evaluation of the water quality downstream from nine state fish production facilities. Results of 41 water quality surveys showed that the fish culture activities generally resulted in increased concentrations of biochemical oxygen demand, suspended solids, organic nitrogen, ammonia nitrogen, orthophosphate phosphorus, and total phosphorus. None of the facilities had any form of waste treatment incorporated in their design (MDNR 1973).

No evaluation was made as to the real impacts on the receiving waters, but shortly after three facilities were completely renovated and designed with solids treatment features, some were discontinued while the remaining facilities were outfitted with simple full flow solids settling ponds.

In 1975, Caufield (1975) reported on the water chemistry of five Columbia River Basin hatcheries and concluded that the variance within a data parameter was so high that the analyses were inadequate to provide reliable quantitative information. This problem is still with us today (Cho et al. 1991).

In 1974 the USEPA drafted regulations entitled "Development document for proposed effluent limitations and standards of performance for fish hatcheries and farms." Final regulations were not promulgated and where regulations have been established, they have been inconsistent due to the lack of a properly prepared guidance document, along with the fact that fish culture methodology was not adequate to predict the time at which effluent limits would be exceeded in any fish culture situation.

During the 1990s and into the new millennial, many additional studies to characterize aquaculture effluents and their environmental impacts have been conducted and reported on, both in the U.S. and Europe (Cowey and Cho 1991; DePauw and Joyce 1991; Rosenthal et al. 1993; SRAC 1998; Black 2000; Tomasso 2002).

Most of the ensuing literature shows great variability in reported waste loadings and their environmental effects. This variability is a reflection of the difficulty to develop a uniformly clear picture of aquaculture effluents and environmental impacts. This difficulty stems from differences in culture systems, production rates and timing, quantity and quality of source and recipient waters, hydraulic retention time, fish species and age, feed types and feeding rates, and management procedures such as cleaning and effluent treatment. Bardach (1997) points out that impacts of low dilution, high volume, aquaculture discharges are extremely difficult to determine due to insufficient knowledge about very complex ecological relationships among members of the aquatic community.

Impacts can be beneficial where primarily aquaculture generated dissolved nutrients are added to relatively sterile waters, enhancing its productivity in a positive way. For instance, in the 1950s there were attempts in Michigan to fertilize sterile, unproductive streams with phosphorus. These attempts failed because the phosphorus quickly became unavailable as it bound with the substrate.

Hatchery effluents, on the other hand, function as "drip treatment" systems, continuously adding phosphorus at very low concentrations, allowing most of it to be assimilated by the biota of the receiving water. In other situations impacts are hardly noticeable as they are within the limits of natural fluctuations. In a few situations there have been reports of undesirable, damaging water quality degradations where receiving waters are overburdened by aquaculture waste in the form of settleable and suspended solids and dissolved nutrients. Net pen operations in particular have the capability to cause localized degradation due to poor siting, or, when placed in confined bodies of water they can cause hyper-eutrophication. An example for the North Central Region (NCR) is represented by the net pen culture in Minnesota mine pits. These operations were, in essence, shut down by the state's Pollution Control Agency as they were unable to intercept and remove solids and nutrients to prevent excessive eutrophication and solids deposition (Axler et al. 1996; Hora 1999). Other cases may involve industrial-size operations, such as Idaho's trout industry's impact on the Snake River. Overall, the majority of aquaculture operations in the NCR are small, they show no measurable negative impacts, while larger operations appear to be well managed, causing minimal water quality impacts (GLFC 1999).

PRESENT SITUATION

Recent efforts to classify aquaculture as agriculture have a downside. Agriculture is recognized as a leading source of water pollution in the U.S., even when point source impacts are included in the analysis. Non-point source (NPS) assessment reports produced by each state indicate that agriculture accounts for 41% of NPS problems in rivers, 23% in lakes, 81% in wetlands, and 7% in estuaries (Weinberg 1991). Associating aquaculture with agriculture automatically raises flags and promotes negative environmental perceptions via NPS pollution and feedlots, despite vast differences in magnitude. For instance, during 1988 in Finland the nutrient load caused by fish farming was only 2% of all phosphorus inputs and 1% of nitrogen inputs, compared to 40% and 24%, respectively, from agriculture (Eskelinen et al. 1991). We are indeed witnessing increasing concerns about potential negative environmental impacts caused by aquaculture (Goldberg and Triplett 1997). As a result, regulatory constraints may become even more restrictive and, as such, may actually become the major impediment to the growth of aquaculture into the next decade. To counter this the government (USEPA) and industry must establish and maintain open channels of communication to negotiate practical and sound resolutions to these various environmental issues.

In 1989, the Natural Resources Defense Council, Inc., and Public Citizen, Inc., filed an action against EPA, alleging that EPA had failed to comply with the Clean Water Act with respect to various point source categories, including aquaculture. As a result, EPA initiated efforts in late 1999 to develop regulations for Concentrated Aquatic Animal Production Systems (CAAP), in consultation with the JSA's Aquaculture Effluent Task Force (AETF). Proposed rules were published in September 2002; final rules will be released by June 2004.   The responsibility to enforce the regulations, in most cases, will fall on state pollution control agencies, which can set tougher standards than those imposed by EPA.

CRITICAL LIMITING FACTORS AND RESEARCH/OUTREACH NEEDS

The rapid growth of aquaculture, in response to the projected shortage of seafood and the promotional efforts by the government, created a climate of excitement resulting in unrealistic optimism causing a "running-before-walking" response. As a result, social, economic, and environmental problems have plagued aquaculture as a new and rapidly growing industry for which technology and management methods are being developed (Boyd 1999). For example, investments made on “turn-key” systems have often failed due to unrealistic, if not outright false, claims about production and performance capabilities.

Aquaculture, eventually, will reach the required performance as the technology pushes itself, but in this process there will be failures (Bardach 1997). Indeed, we have witnessed some failures, including a number of relatively large, high-tech operations, making it more difficult to obtain capital for new ventures.

Technology is the critical factor as it must accomplish multiple goals of biological, economic, social and environmental requirements simultaneously.

In a nutshell, according to Midlen and Redding (1998), design and management of aquaculture systems are the critical factor leading to reduced waste output, but unless these functions are affordable, economic failures will occur. In other words, the applied technology must be cost effective. Midlen and Redding (1998) suggest that an incremental approach regarding regulations, combined with improvements in technology, can result in processes more harmonious and sensitive to the economic status of the industry. At the same time it is important to protect traditional small-scale operations from unrealistic or over-burdensome regulations.

The existing, traditional “industry” in the NCR consists mostly of a great diversity of small-scale, low-tech operations. It is pointless to insist on rigid controls for such traditional, relatively small and localized aquaculture facilities where the impacts are low or non-existent (Pillay 1992). Even where there are some adverse impacts recognized, be it minimal, such impacts are not irreversible and can often be avoided with simple measures (Boyd 1999; D. Gollon, Gollon Bait and Fish Farm, Dodgeville, Wisconsin, personal communication). Unfortunately, in some cases, small aquaculture facilities are subject to the same costly permit fee, monitoring, and discharge requirements applied to large industrial facilities (Rubino and Wilson 1993). It seems most reasonable, in such cases, that permits are negotiated on a case by case basis with as important considerations available treatment methods and the ability of the receiving water to assimilate the effluent. It is clear that this “cottage-type” industry cannot supply the future demand of food fish, but they can fulfill an important role by serving limited niche markets. In the proposed rules it appears that the EPA has been mindful of this by excluding systems with annual production less than 100,000 pounds.

As has been true for farming of the land, farming of the water must be intensified to reduce environmental effects and to improve efficiency (Boyd 1999). Intensive aquaculture can be classified as concentrated feed-lot operations, which are subject to water quality regulations under the Clean Water Act. The operations must be as efficient in feed utilization as possible to reduce solid and dissolved wastes.

According to Nijhof (1992) a thorough knowledge on relationships between feed intake and growth should be applied in effluent assessment. Water quality monitoring should be interpreted in close conjunction with basic knowledge on growth and production data to avoid unrealistic estimations.

Cho et al. (1991) address this same concern. The accuracy of effluent analyses suffers from changes in production efficiency or management activities at the moment of sampling. They have shown that modeling the theoretical effects of feeding, based on diet composition and feed conversions, is simple, relatively inexpensive, and more accurate than sampling the effluent.

The development of nutrient dense, high energy, low phosphorus diets have made it possible to reduce waste output. But Nijhof (1992) points out that as the proportion of dietary lipids increase, at the expense of protein, the total waste discharge increases when expressed as biochemical oxygen demand, although the nitrogen discharge is reduced. The most significant waste contribution can come from spilled feed according Nijhof's model. This often is a problem at fish farms and can be as much as 30% of the ration fed (Verdegem et al. 1999). To eliminate this potential waste, fish farmers in Denmark must accomplish a feed conversion of one or less.

No matter how efficient the diet is, there still will be waste and, as a minimum, solids should be intercepted and removed from the waste stream. Intercepting solids relatively intact and removing them from the waste stream also reduces the discharge of phosphorus and nitrogen. The new technology of micro-screening has worked well in recirculation systems, but shows relatively low efficiency where solids concentrations are very dilute. This is the case with flow-through systems. For example, at a loading of 8.3 lb/gpm (1.0 kg fish/Lpm) and a feeding level of 1.0% body weight, 0.4 oz (10 g) of feed is fed per day per Lpm. If this feed generates 0.1 oz (2.5 g) of solid waste, its average concentration in the effluent is 1.75 mg/L.

For flow-through systems, suspended solids concentrations generally range from 2.0–6.0 mg/L. The large discharge volumes in flow-through systems also result in very dilute concentrations of nitrogen and phosphorus. Warren-Hansen (1982) reports concentrations of total nitrogen in the range of 0.5–4.0 mg/L and total phosphorus from 0.05–0.15 mg/L.

Still, low concentrations in high flow rates can exceed established total daily maximum loads (TDML). For example, 1.0 mg/L in a flow of just 264 gpm (1,000 Lpm) represents 3.2 lb/day (1.45 kg/day), 95.2 lb/month (43.2 kg/month), and 1,142 lb/year (518 kg/year).

Flow-through systems export most, if not all, of the burden for water treatment to the receiving water. These systems have a greater environmental impact than either pond or recirculation systems (Verdegem et al. 1999). Instead of traditional flow-through systems, facilities can be designed and operated as partial recirculation systems. Recent advances in solid waste management have been accomplished through the use of a double drain design in circular rearing units. A bottom drain continuously removes up to 90% of the solids by means of the self-cleaning action created by as little as 10% of the operating flow rate (Summerfelt 1998). Before discharging this effluent it can be treated with micro-screens because solids concentrations are now ten-fold the "normal" 2.0–6.0 mg/L. Also, this flow, if sufficiently small, can be treated further by means of constructed wetlands or "polishing" ponds to remove nutrients. The 90% clean water exits the tank through a drain placed near the surface or at mid-depth and is recirculated with 10% "virgin" water added to it.

Partial recirculation systems such as this require minimal or no biofiltration. A 10% flow-rate replacement greatly exceeds a daily 10% volume replacement a conventional recirculation aquaculture system may have. For instance, a 3.28-ft (1.00-m) diameter circular rearing unit which operates at a depth of 4.20 ft (1.28 m), has a rearing volume of 35.67 ft^3 (1.01 m^3). If operated at a water exchange rate of 1.5 exchanges/hour (40 min retention time) the incoming flow is 6.6 gpm (25 Lpm), the 10% cleaning flow 0.7 gpm (2.5 Lpm). This 0.7 gpm (2.5 Lpm) represents a daily volume of 951.0 gal (3,600 L). On the other hand, if operated as a true recirculation aquaculture system at 90% efficiency, the 10% daily replacement would be 26.4 gal (100 L) for the rearing volume plus an additional 13.2 gal (50 L) for the rest of the system which may include the biofilter, for a total of 39.6 gal (150 L) versus 951.0 gal (3,600 L) for the partial recirculation system, a ratio of 1:24.

Designing "future" flow-through systems as partial recirculation systems can alleviate many of the concerns expressed by environmentalists. They use less water, effluents can be treated effectively, fish escapes can be prevented to a large extent, antibiotics, of which there are few, are mostly intercepted with the solids and, over time, are neutralized. Many federal and state culture operations are of flow-through design. Future renovation plans of existing flow-through hatcheries should consider partial recirculation system designs.

Additional potential advantages of these systems are application of wetland construction and utilization of solids as fertilizers (Yeo and Binkowski 1999). Also, without biofiltration, it will be easier and safer to treat the recirculation flow with ozone or pretreat the new water if needed.

Unless free heat (waste heat) is available, it is not economically feasible to heat water for a partial recirculation system because of the high, daily, water requirement relative to a recirculation aquaculture system. This "new" technology should be tested along with continuing research and development on traditional recirculation technology.

As future rearing systems move toward solids recovery through partial recirculation systems or recirculation aquaculture system designs, and dilution is increasingly abandoned as a waste disposal solution, aquaculturists will have to deal with the disposal and potential reuse of lowered volumes of more concentrated wastes. Aquaculture waste sludges have high water content and can present costly storage, odor, and transportation problems. Like other agricultural manures they may need further stabilization and remineralization of their organic content. Following which they can provide a supplemental source of slow-release nitrogen and have beneficial soil conditioning properties.

The challenge will be to find environmentally appropriate, cost effective, and properly scaled means of disposing and/or beneficially reusing these by-products. In spite of being more concentrated and recoverable, the quantity produced by a typical operation may still be relatively too small to meet the needs of large scaled field agriculture. Transportation costs for hauling waste to reuse or municipal disposal sites may be prohibitively high. Aquaculturists may need innovative strategies for dealing with on-site disposal of these concentrated wastes that can no longer be discharged through dilution into public waters (Yeo and Binkowski 1999).

Existing and developing technologies for nutrient recovery and solid waste disposal (Adler et al. 1996) will have to be adapted to aquaculture facility needs. Improved land application, constructed wetland, and septic system designs that are appropriately scaled to aquaculture waste production are needed.

Pioneering efforts by investigators attempting to integrate recirculation aquaculture systems, nutrient recovery, and solids utilization for producing plant crops have highlighted the difficulties of matching the scale of waste production with the requirements of the plant crop. Further investigation of these types of strategies will take on increased significance as rearing systems move toward greater water recirculation and waste recovery (Adler et al. 1996).

SUMMARY OF RESEARCH AND EXTENSION PRIORITIES

(Not in rank order)

RESEARCH

Nutrition

- Develop low-polluting diets requiring little fish meal and producing stable fecal pellets for non-traditional species.
- Develop predictive models of nutrient retention by the fish and excretion of solids and dissolved wastes for these diets (Cho et al. 1991; Nijhof 1992; Westers 1995).

Technology

- Test the performance of partial (semi) recirculation systems by evaluating critical water quality parameters, especially ammonia, under different production and water use intensities (Summerfelt 1998; Westers 1999).
- Evaluate commercial scale recirculation aquaculture systems: rearing water quality parameters, production capabilities, water demand, waste management, and economics.
- Evaluate appropriately scaled management strategies and technologies for recovery of nutrients and solids concentrated from partial and full recirculating aquaculture systems.

EXTENSION

- Keep abreast of the technological developments in aquaculture in the U.S. and Europe.
- Conduct workshops on best management practices for environmental management and effluent control.

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