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Abstract

Aquaculture is the production of aquatic organisms, both plant and animal under controlled or semi-controlled conditions. The "controlled or semi-controlled conditions" distinguishes aquaculture from traditional "hunt-and-capture" fishing of wild stocks of marine and freshwater fish, shrimp, and shellfish. The combination of world aquaculture and commercial catches (wild stocks) have grown from 98.6 million metric tons (mmt) in 1990 to 126.2 mmt in 1999, but in 1990 aquaculture was only 13.2% of the total compared with 26.4% in 1999.

Disciplines

Aquaculture and Fisheries | Environmental Public Health

Comments

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Introduction

Robert C. Summerfelt

Aquaculture versus Hunt-and-Capture Fisheries

Aquaculture is the production of aquatic organisms, both plant and animal under controlled or semi-controlled conditions. The “controlled or semi-controlled conditions” distinguishes aquaculture from traditional “hunt-and-capture” fishing of wild stocks of marine and freshwater fish, shrimp, and shellfish. The combination of world aquaculture and commercial catches (wild stocks) have grown from 98.6 million metric tons (mmt) in 1990 to 126.2 mmt in 1999, but in 1990 aquaculture was only 13.2% of the total compared with 26.4% in 1999.

U.S. Aquaculture

In the U.S., individuals and public agencies have propagated fish for food and for stocking lakes and streams for recreational fishing for more than 130 years. “A Manual of Fish Culture, published in 1897 by the United States Commission of Fish and Fisheries (CFF), described culture practices of 25 stations or hatcheries of the CFF for salmon, trout, lake trout, whitefish, black basses, crappies, rock bass, yellow perch, muskellunge, lake herring, American shad, edible frogs, cod, mackerel, lobster, oysters, and other species. The contents of the Manual of Fish Culture demonstrated practical techniques for spawning these species, but relatively little science or engineering based technology, and fish hatchery effluents were not a consideration.

In 1998, the first national census of fish culture in the U.S. reported the value of the aquaculture sector, both commercial and noncommercial at \$978 million (USDA 2000). The noncommercial operations—Federal, State, or Tribal facilities—distributed their production for purposes of restoration or conservation; the value of their production was estimated. Culture systems include drainable and nondrainable ponds, raceways, recirculation (“closed recirculation tanks”) and cages. Most marine culture systems employ net pens for salmonids and prepared bottoms for shellfish, but oyster culture more often relies on a variety of off-bottom techniques (e.g., rafts, trays, containers). The food fish category accounted for the highest relative value at 70.7% of U.S. aquaculture sector, followed by mollusks 9.1%, ornamental fish 7.0%, baitfish 3.8%, crustaceans (crawfish and shrimp) 3.7%, sport or game fish 0.8%, and other fish and animal aquaculture 4.9%. The next census is scheduled for 2002, but probably not reported until 2004.

Per capita consumption

Because the value of the food fish category dominates aquaculture production, changes in U.S. population and per capita consumption are major forces driving production. Between 1990 and 2001, total fish and shellfish consumption (pounds per capita per year) in the U.S. ranged from 14.3 to 15.2. Between 1997 and 2000, there was a positive trend in per capita consumption, increasing each year, going from 14.3 in 1997 to 15.2 lbs/capita in 2000. However, after Federal Reserve Chair Alan Greenspan exposed the “irrational exuberance” that unduly escalated asset values of stocks and following the collapse of the exuberant “dotcoms”, the per/capita consumption declined to 14.7 in 2001, demonstrating a close association between

the economy and consumer response to the relative prices of seafood, poultry, pork and beef.

In spite of changes in consumption of all sources of fish and shellfish, the percentage of per capita consumption coming from aquaculture has been rising; e.g., catfish sales by processors had an increase of 7.1% in 2002. Also, the quantity and value of imported fish rose even more; e.g., tilapia rose 19 and 36%, respectively, and Atlantic salmon, which totaled 413 million pounds with a value of \$818 million, showed a 15% increase in quantity and 6% in value over one year (Harvey 2003). The sum of the value of imported tilapia and salmon in 2002 (\$174 and \$818 million, respectively) was \$992 million, which was greater than the \$978 million for all of U.S. aquaculture production in 1998. Of course, the value in 2002 of all domestic and imported fish products were far less than the \$3.4 billion value of imported wild-caught and farm-raised shrimp.

Environmental Concerns

The growth of aquaculture has not been without environmental impacts and critics, and at the extreme, there have been boycotts of net pen reared salmon. The publication by the Environmental Defense Fund of *Murky Waters: Environmental Effects of Aquaculture in the United States* (Goldburg and Triplett, 1997) was not the first, but it made a significant public impact. The report identified environmental problems caused by aquaculture, stating that aquaculture operations are a significant source of chemical (antibiotics) and biological pollutants (pathogens) and nutrient wastes. The report also considered aquaculture as a contributor to the “fishmeal dilemma,” a major source for non-indigenous fish introductions (fish escapement), and noted the lethal control of predatory birds and marine mammals. Shrimp aquaculture has often been singled out for causing ecological and socioeconomic problems from destruction of mangrove forests and displacement of subsistence fishers.

Net pen culture of salmonids—i.e., farm-raised salmon in contrast to wild, hook-and-line or gill netted salmon—has been characterized as a fish feedlot that results in buildup of wastes around the net pens destroying benthos and a contributing to algal blooms. Fish escapement from net pens are considered potential threat to native salmon on both coasts, but special concern has been expressed about the impact of cultured Atlantic salmon on efforts to maintain and restore small stocks of native Atlantic salmon on the east coast. Salmonid culture, in net pens and raceway systems are also condemned for overuse of marine fish for fishmeal and oils for use in fish feeds. Fishmeal use in aquaculture feeds is said to consume more protein than it produces and to encourage excess harvest of pelagic marine fish (anchovy, menhaden, capelin, herring, and sardine), fish that are used by other organisms in the food web (Naylor et al. 1998).

Aquacultural effluents contain dissolved and suspended solids that have biochemical oxygen demand (BOD) and nutrients phosphorus (P) and nitrogen (N) that are derived from fish excretion, feces, and uneaten feed. Nutrients are the cause of eutrophication. The literature concerning aquaculture effluents shows great variability in reported waste loading and their environmental effects. This variability is a reflection of the 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.

The major focus of effluent issues has been on nitrogen compounds in marine environments that have caused hypoxia problems in the Gulf and eutrophication problems in freshwater from

phosphorus compounds. All commercial animal production systems, including aquaculture, generate wastes, generally expressed as kg/day per 1,000 kg live weight for BOD, solids (TSS), nitrogen (TKN), and total phosphorus (TP). Although the production of these specific wastes in fish culture is usually much less than that for beef cattle, dairy cows, poultry, or swine (Chen et al. 1993), the volume of water used per unit production (m^3/kg production) pond and raceway systems is 10 to 100 times greater (Hargreaves et al. 2002). On the other hand, freshwater use in recycle aquaculture systems (RAS) are typically less than 5% of total system volume per day, but RAS produce a concentrated waste.

Already, limitations on water supply and environment issues may constrain continued growth of certain segments of the aquaculture industry in the U.S. and Canada. The catfish industry, however, is in jeopardy due to drawdown of the once abundant groundwater resources in the Delta region (Tucker 1996) and expansion of the Idaho trout industry is challenged to meet a 40% reduction in phosphorus discharges (Goldberg and Triplett 1997). The image of aquaculture and its future may be in jeopardy unless it deals effectively with environmental issues.

Dilute, but large effluent volumes are discharged from traditional raceway systems used for salmonids (single pass and serial reuse), but they add up to high total daily loads (Westers 2000). Because of the high volume, effluents from raceway culture are extremely difficult to treat (Negroni 2000). Recycle aquaculture systems (RAS) use far less water, frequently less than 5% of system volume per day, and the effluent is concentrated.

Recently, in response to accusations and evidence of environmental pollution from aquaculture, both Canadian and U.S. environmental agencies have developed timelines for performance-based standards (effluent limitation guidelines) for aquaculture waste management. Eutrophication and related problems from fish hatchery effluents have been noted in freshwaters in both the U.S. and Europe, and in marine habitats affected by net pen culture (EPA 1974; Cowey and Cho 1991; Foy and Rosell 1991; Ketola 1991a; Ketola et al. 1991; Lall 1991; Ketola and Harland 1993; Ketola and Richmond 1994). In the North Central Region (NCR), environmental issues related to aquaculture effluents have already resulted in a mandated closure of a large salmonid net pen enterprise in Minnesota by the state Pollution Control Agency (Axler et al. 1998). Lawsuits by a homeowner association alleged that the phosphorus discharge from the Platte River Fish Hatchery, Beulah, Michigan caused eutrophication of their lake. Eutrophication issues from phosphorus are widely cited justification for reducing phosphorus content of fish feeds (Ketola 1991b; Ketola et al. 1991; Ketola and Harland 1993; Ketola and Richmond 1994). Similar concerns have been raised nearly everywhere salmonids are cultured (Cowey and Cho 1991; Foy and Rosell 1991; Persson 1991).

The diverse nature of the U.S. aquaculture industry will require an equally diverse array of strategies to deal effectively with environmental issues. The 1998 Census of Aquaculture indicates that U.S. fish production comes from a variety of cultural systems: 63% from ponds for catfish and minnows; 14% from flow through raceways for salmonids; 7% from closed/recycle systems for a variety of fish, but mainly hybrid striped bass and tilapia; 3% from cages and net pens (1% for salmon; and others (12%). Most farms use groundwater (47.8%) or on-farm surface water (36.1%) sources for water supply. Aquaculture systems also represent various degrees of intensification (kg/unit of culture space), production (kg/yr), and concentration of waste components (solids, phosphorus, nitrogen) in their effluents. The diversity of aquaculture systems also results in a considerable diversity in waste characteristics. Engineering strategies to

reduce nutrients in effluent and removal of suspended and dissolved solids will be different for catfish ponds, salmonid raceways, and recycle systems.

The recent concern over aquaculture waste in the U.S. is not really new. More than 25 years ago, the EPA sponsored studies to gather information on pollution from trout hatcheries (Hinshaw 1973) and intensive culture of catfish (Summerfelt and Yin 1974). These and other studies placed aquaculture low on the priority list and for this and other reasons—to focus resources on other industries that EPA regarded as higher priorities for the regulation of toxic pollutants—specific effluent guidelines for aquaculture were not developed (Keup 1989). Thus, in 1977, EPA policy was to rely on various provisions of the Clean Water Act to regulate the discharge of wastes from concentrated aquatic animal production facilities (CAAPF) under the general National Pollution Discharge Effluent System (NPDES) permit for point source pollutants. Under the Code of Federal Regulations, concentrated aquatic animal production facilities are considered point sources requiring NPDES permits for discharges into waters of the United States. EPA's guidance, however, was insufficient for many state-permitting efforts; it reflected neither the growth in the industry, nor the significant technological advances that have been made.

EPA's effort to develop pollutant controls in the form of nationally applicable discharge standards (known as effluent limitations guidelines and standards) for commercial and public aquatic animal production facilities were announced in the Federal Register Notice, September 14, 2000. This was required by a consent decree from an action filed against EPA on October 30, 1989 by the Natural Resources Defense Council, Inc., and Public Citizen, Inc in which they alleged, among other things, that EPA had failed to comply with CWA section 304(m) of the Clean Water Act. The action by EPA is the result of a settlement of that action in a consent decree entered on January 31, 1992. The consent decree established a schedule by which EPA is to propose and take final action for eleven point source categories identified by name in the decree.

The decree also established deadlines for EPA to complete studies of aquaculture. The last date for EPA action under the decree, as modified, is June 2004. The decree also required EPA to establish Effluent Guidelines. Several effluent guidelines are currently underway to help address siltation and nutrient problems, and, to a lesser extent, pathogens. In the proposed plan, EPA announced efforts that were initiated in late 1999 to develop new or revised regulations for aquatic animal production (i.e., aquaculture). (EPA had originally used the term Aquaculture to describe this industry. However, EPA has since recognized that the term Aquatic Animal Production better reflects the operations that EPA expects will be subject to the forthcoming effluent guidelines.) EPA is discussing the tasks and information necessary to develop an aquatic animal production rule with the Joint Subcommittee on Aquaculture's (JSA's) Aquaculture Effluents Task Force, which consists of representatives from trade associations, academia, federal and state agencies, professional societies, and non-governmental organizations. EPA has said that it will provide a number of opportunities for further involvement before developing the effluent guideline regulation.

EPA is planning release of final regulations by June 2004. In most cases, the EPA will delegate the job of enforcing the regulations to state pollution control (environmental quality) agencies. Based on what state agencies already require, effluents will need to be monitored and regulations may specify treatment technologies that are needed to bring the effluents into compliance with EPA effluent standards.

Whether aquaculture reaches its growth potential depends on how well producers are able to ameliorate these many issues with best management practices (BMPs) that reduce nutrient, chemical, and biological pollution. In part, these problems are growing pains of a relatively new and rapidly growing industry for which technology and management methods are being developed (Boyd 1999). The goal of this conference is to review the issues and provide science-based information that will help define the regulations and BMPs for fish farms with a focus on ponds, raceways and recycle systems. Net pen culture and cage culture are not considered because net pens are mainly used in marine environments and cage culture is a minor culture system. Good environmental stewardship requires that aquaculture effluents not have negative impact on the environment.

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