A WHITE PAPER
ON THE STATUS AND NEEDS OF
SALMONID AQUACULTURE
IN THE NORTH CENTRAL REGION

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INTRODUCTION AND JUSTIFICATION OF THE DOCUMENT

Salmonids are grown in many states in the North Central Region (NCR) with a major emphasis on rainbow trout production. The North Central Regional Aquaculture Center (NCRAC) Industry Advisory Council (IAC) designated salmonids as a high priority area and research on salmonids has been supported by NCRAC since 1990. Recently concern was raised over the long-term focus of NCRAC funded research and extension activities and at the June 1999 NCRAC Board of Directors (Board) meeting, it was decided that additional white papers should be developed to help strengthen various focus areas. As a result, the Board determined that one of these white papers should be on salmonids. This white paper reviews the current status of the salmonid industry, addresses critical limiting factors and research/outreach needs, and gives recommendations for future research/extension priorities. It should be viewed as a "living document" and updated periodically as new developments occur.

CURRENT STATUS OF THE INDUSTRY

PRODUCTION FACILITIES AND CULTURE METHODS USED FOR RAISING TROUT

The salmonids have been one of the most studied fish in the U.S. and there is a vast amount of information available on their culture. In fact, many of the trout species have been domesticated over time and now fish farmers have various strains available (Kincaid 1981). Also, much is known about the optimum water quality conditions needed for their culture. Salmonid temperature requirements range from 33–70°F with the optimum range for rainbow trout being 50–60°F (Piper et al. 1982). Water temperature used for raising trout in the NCR is 45.0–57.9°F with an average of 51.1°F. The colder water temperature averages are 48.4°F in Wisconsin, 50.0°F in Michigan, and 50.7°F in Minnesota, while the warmer water temperature averages are 57.9°F in Missouri, 57.6°F in Ohio, and 54.0°F in Nebraska (Brown 1994). Some trout producers in the region have reported growing trout outside the water temperature ranges reported here, especially when temperature extremes can occur during the summer and winter months.

Salmonids require large amounts of high quality water with a minimum dissolved oxygen concentration of 5 mg/L. Thus, a source of high volumes of good quality water usually dictates where larger salmonid aquaculture facilities are located. If high volumes of water are not available, trout producers must pump additional water to make up for the shortfall and add oxygen via aerators and/or oxygen gas injection. A wide range of water sources are used for growing trout which include springs, streams, and wells. The average flow rate for sources used by small trout producers in the NCR is 383 gpm, medium trout producers 1,958 gpm, and large trout producers 3,833 gpm (Brown 1994). It should be noted here that not all trout producers with these water sources fall within this criteria. Some trout producers who have low flow rates actually have learned to fully optimize the water resources they do have to increase production and could be economically classified as large trout producers. To supplement water supplies, 38% of all trout producers in the NCR pumped at least part of their water and 19% pumped all of the water used. All of the large producers in the NCR reported that they did not pump any significant amount of water (Brown 1994).

Trout production facilities usually consist of indoor rearing facilities and outdoor raceways and ponds. The indoor rearing facilities are usually used for producing trout from the fertilized egg stage to fingerlings. Trout farmers who have brood stock can produce their own fertilized eggs or purchase them from commercial trout egg producers. After trout eggs are fertilized, they are placed in some type of flow through incubator and not disturbed until the eye spot appears in the eggs. After hatching, the sac fry are raised indoors in shallow troughs and they contain a large yolk sac, which provides nutrition for three to six weeks depending on the water temperature. When most of the yolk sac is absorbed, they begin the swim-up fry stage about 20–30 days posthatch and swim to the water surface to begin feeding. It is at this time that the fry are fed some type of artificial starter diet up to seven times daily, usually by way of an automatic feeder. They are moved outdoors to production raceways and ponds when they reach the fingerling stage which is about 3 in. In the NCR, facilities used to grow trout vary more than those for other species with 44% of the trout growers using ponds, 29% raceways, 23% tanks, 3% cages, and 1% other means of confinement (Hushak 1993). Ponds are also constructed as settling basins for effluent treatment from production facilities. A good overview of trout culture has been given by Cain and Garling (1993).

As trout grow, various size feeds are used containing specific protein percentages. Producers in Michigan, Minnesota, and Missouri report average growth rates of 0.5 in/month and grow out takes a minimum of 14–18 months to produce a 1.25 lb fish (Brown 1994). The overall food conversion efficiency ranged between 1.2–2.

TROUT INDUSTRY ECONOMICS

The data on the trout industry economics which follows, unless otherwise cited, was compiled from annual reports issued by the U.S. Department of Agriculture's National Agriculture Statistics Service (NASS) for 15 representative states in 1994 to 1996 and 18 representative states in 1997 and 1998 (NASS 1995-1998). During this time period Michigan, Missouri, and Wisconsin represented the NCR. In future reporting, three more states will be added to the 18 states currently in the U.S. program with Minnesota being an addition from the NCR.

Total Trout Sales

The total value of all U.S. trout sales increased from $65 million in 1994 to $77 million in 1999. In terms of overall sales in 1999, food size fish accounted for 84%, stockers 7%, fingerlings 2%, and eggs 6%. Idaho accounted for 39% of the dollar value at a national level in 1998, followed by North Carolina and California. In the NCR, only Wisconsin followed this upward trend in trout sales. Wisconsin trout sales climbed from $1.3 million in 1994 to $2.6 million in 1998. The other two large trout producing states in the NCR, Michigan and Missouri, have not followed this upward trend in trout sales. Michigan dropped from $2.3 million in 1994 to $1.4 million in trout sales in 1998 and during this time frame, the number of operations decreased from 57 to 42. Missouri trout sales stayed level from 1995 to 1998 and ranged from $1.95 million to $2 million. Missouri produced its trout at approximately a dozen operations from 1994 to 1998 compared to Wisconsin which had 80 registered operations during this time period. Wisconsin, Missouri, and Michigan ranked fifth, eleventh, and thirteenth, respectively, in 1998 value of total trout sales in the United States.

The first North Central Regional Aquaculture Industry Situation and Outlook Report indicated that the most common species cultured in the NCR in 1990 was salmonids, which accounted for 44% of gross sales by species in the NCR at $6.2 million (Hushak 1993). At that time Missouri led the way in gross sales of salmonids in the NCR, followed by Wisconsin. This report indicated that the largest percentage of trout producers were from Wisconsin, Michigan, and Minnesota while Illinois and North Dakota were the only states within the NCR that did not have any trout producers. Currently, Illinois has a small but growing number of rainbow trout producers and haulers (L. Swann, Purdue University, West Lafayette, Indiana, personal communication), while Kansas does not have any trout production (C. Lee, Kansas State University, Manhattan, personal communication).

In 1991, gross sales from small trout producers in the NCR averaged $20,000, medium producers $108,000, and large producers $331,000. Total annual output for small trout producers in the NCR averaged 6.9 thousand pounds, medium producers 61 thousand pounds, and large producers 161 thousand pounds (Brown 1994).

Food-size Trout Sales

Food-size trout are grown commercially for food and usually range from 0.75–1 lb and over 12 in total length. U.S. food-size trout sales had a low of $52.7 million in 1994 and a high of $65 million in 1999. Over this same period a low of 52.1 million lb of food-size trout was produced in 1994 and a high of 60.3 million lb in 1999. At a national level a low of $1.01/lb was paid for food-size trout in 1994 and a high of $1.09 in 1995. The major outlet for food-size trout sales in the U.S. was to processors which ranged from 59 to 68% of total live weight sales. The next largest outlet for food-size trout was fee/recreational fishing operations which ranged from 17 to 23% of total live weight sales. The overall trend between 1991 to 1998 was a decrease in the amount by food-size trout processed and an increase of food size sold to fee/recreational markets.

Idaho continues to be the leader in food-size trout production in the U.S. and in 1999 it accounted for 76% of production by weight and 57% of dollar value at a national level. In 1999, North Carolina and California ranked second and third, respectively, in national production by weight and dollar value of food-size trout. Wisconsin, Missouri, and Michigan ranked eighth, ninth, and eleventh, respectively, in 1998 production of food-size trout by weight in the United States. Wisconsin, Missouri, and Michigan ranked seventh, tenth, and eleventh, respectively, in 1998 value of food-size trout sales in the United States.

In the NCR Michigan food-size trout sales dropped from $1.42 million in 1994 to $0.86 million in 1999 while Wisconsin food-size trout sales increased from $0.82 million in 1994 to $1.25 million in 1999. During this same time period, Missouri food-size trout sales had a low of $0.96 million in 1998 and a high of $1.71 million in 1996. From 1994 to 1999, Michigan food-size trout production dropped from 610,000 lb to 352,000 lb while Wisconsin production increased from 283,000 lb to 368,000 lb. Missouri food-size trout production had a low of 570,000 lb in 1994 and a high of 728,000 lb in 1996. The NCR trout producing states received a much higher price for food-size trout than the national average. From 1994 to 1999 Michigan food-size trout prices ranged from $2.22–$2.44/lb, Missouri ranged from $2.11–$2.34/lb, and Wisconsin ranged from $2.78–$3.39/lb. Depending on the year, 35–50% of the value sold of food-size trout in Michigan was going to fee/recreational fishing operations, 11–20% to live haulers, 12–18% to restaurant and retail facilities, and 5–23% to other producers. In Missouri 49–59% of the value sold of food-size trout went to fee/recreational fishing operations and 13–19% to other producers. Wisconsin moved 33–55% of the value sold of food-size trout to restaurant and retail facilities and 12–22% to fee/recreational fishing operations.

Hushak et al. (1993) found that trout was one of the four freshwater species that were most frequently sold in the NCR as trout was handled by 67% of wholesalers, specialty retailers, and grocery retailers in the region. Product forms sold include fresh, frozen, and live. All grocery retailers, along with most of the other respondents, mainly sell a fresh product. Only 14% of supermarket managers responding to a NCR seafood marketing survey listed trout as one of their best selling species (Riepe 1999b).

<u>Stocker Trout Sales</u>

Stocker trout are usually 6–12 in total length and weigh <0.75 lb. In the years 1994 to 1999, U.S. stocker trout sales had a low of $5.63 million in 1999 and a high of $12.5 million in 1997. During this same period, a low of 2.23 million lb of stocker trout was produced in 1999 and a high of 3.48 million lb was produced in 1996. At a national level a low of $2.13/lb was paid for stocker trout in 1996 and a high of $2.54 in 1997. The major outlet for stocker trout sales in the U.S. was to fee/recreational fishing operations which ranged from 41 to 49% of total live weight sales, followed by 11 to 34% of sales to the government, and 16 to 25% to other producers. Recent increases in the sales and value of stocker trout contributed considerably to the overall value of the trout industry relative to the early 1990s.

In 1999, Pennsylvania ranked number one in stocker trout production in the U.S. and accounted for 17% of production by weight and 22% of dollar value at a national level while Washington was second in stocker trout production and dollar value. Wisconsin and Michigan ranked fifth and ninth, respectively, in production of stocker trout by weight in the United States. Wisconsin and Michigan ranked fifth and eighth, respectively, in value of stocker trout sales in the United States.

In the NCR, Michigan stocker trout sales ranged from a low of $160,000 in 1997 to a high of $670,000 in 1994. Missouri stocker trout sales had a low of $316,000 in 1996 and a high of $521,000 in 1997. In Wisconsin, stocker trout sales had a low of $189,000 in 1998 and a high of $399,000 in 1999. Stocker trout production in the years 1994 to 1999 ranged from 65,000–300,000 lb in Michigan, 183,000–320,000 lb in Missouri, and 67,000–164,000 lb in Wisconsin. During this time period stocker trout prices varied from $2.13–$2.77/lb in Michigan, $1.61–$1.84/lb in Missouri, and $2.34–$2.82/lb in Wisconsin. Stocker trout prices in Missouri were well below those of Michigan and Wisconsin and the national average. Live haulers, fee/recreational fishing operations, and other producers were all important outlets for stocker trout in Michigan, Missouri, and Wisconsin. In 1998, 46% by value of Missouri stocker trout went to government outlets, mainly at the local level.

<u>Trout Fingerling Purchases, Production, and Sales</u>

Fingerling trout usually are 1–6 in total length. Total U.S. trout fingerling sales from 1994 to 1999 had a high of $1.67 million in 1996 and a low of $890,000 in 1998 and during this time period a production low of 162,000 lb occurred in 1998 and a high of 288,000 lb in 1996. During this time frame fingerling prices ranged from $5.06–$6.67/lb.

In 1999, North Carolina ranked number one in fingerling trout production in the U.S. and accounted for 28% of production by weight and 18% of dollar value at the national level. Wisconsin and Michigan ranked third and fourth, respectively, in production of fingerling trout by weight. Michigan and Wisconsin ranked fourth and eighth, respectively, in value of fingerling trout sales in the United States in 1999.

In the NCR, trout fingerling sales in Michigan dropped from $225,000 in 1994 to $80,000 in 1999. Wisconsin trout fingerling sales fluctuated during this period with a high of $100,000 in 1995 and a low of $15,000 in 1997. During this reporting period, data for Missouri was only available in 1997 and trout fingerling sales were $62,000. Production of trout fingerlings in Michigan dropped from 32,000 lb in 1994 to 10,000 lb in 1999. During this time period Wisconsin trout fingerling production varied from 3,000–13,000 lb. Data for Missouri was only available in 1997 when trout fingerling production was 19,000 lb. From 1994 to 1999, the value of trout fingerlings was erratic and ranged from $3.85–$11.11/lb in Michigan and $2.14–$11.11/lb in Wisconsin. In Missouri trout fingerlings were $3.26/lb in 1997 as this was the only year reported.

Thirty-five percent of salmonid producers in the NCR indicated they purchased salmonid fingerlings in 1990 (Kinnunen 1991). Rainbow trout fingerling purchases accounted for 77% of all salmonid fingerlings purchased with 93% of these purchases made within the NCR. Half of the rainbow trout fingerlings purchased by producers in the NCR were registered strains, mainly Kamloop. Brook trout, brown trout, and coho salmon fingerlings accounted for the remaining 23% of fingerlings purchased in the NCR with all acquired in the region.

Sixty-five percent of those producing salmonids in the NCR in 1990 produced their own fingerlings (Kinnunen 1991). Of these, 25% indicated they produced them for their own use, 17% produced fingerlings for the sole purpose of selling them, and 58% produced them for both their own use and to sell them. Rainbow trout fingerling production accounted for 54% of all salmonid fingerling production, followed by coho and chinook salmon (26%), brook trout (10%), and brown trout (10%). Sixty-five percent of the rainbow trout fingerlings produced in the NCR were registered strains, mainly Kamloop and Donaldson.

Rainbow trout accounted for 79% of all salmonid fingerling sales in the NCR in 1990, and of these 98% were sold within the region. Rainbow trout fingerlings sold by producers from the region were mostly registered strains (73%) with the majority being Kamloop and Donaldson. Brook trout, brown trout, and coho and chinook salmon fingerlings accounted for 21% of the sales in 1990 with most being sold within the NCR (Kinnunen 1991).

Rainbow trout accounted for 77% of all fingerling purchases, 54% of fingerling production, and 79% of fingerling sales in the NCR in 1990, clearly demonstrating the importance of this species in the NCR (Kinnunen 1991).

Trout Egg Purchases, Production, and Sales

Total U.S. trout egg sales ranged from $4.72 million to $5.94 million from 1994 to 1999. The average value per one thousand eggs increased from $12.76 in 1994 to $15.83 in 1999. NASS did not report specific information on trout egg sales in the NCR.

A survey of salmonid producers in the NCR found that 41% of them purchased salmonid eggs in 1990 (Kinnunen 1991). Rainbow trout accounted for 67% of all salmonid eggs purchased followed by coho and chinook salmon at 29%. Other salmonids purchased included brook and brown trout. This survey revealed that the majority of rainbow trout eggs purchased were registered strains, with slightly over half of all the eggs purchased being of the Kamloop strain purchased from Washington. In 1990, 92% of the rainbow trout eggs were coming from outside the NCR, and the majority of these were from the western United States. Only 34% of coho and chinook salmon eggs came from outside the NCR.

Forty percent of those producing salmonids in the NCR in 1990 produced their own eggs (Kinnunen 1991). Of those producing their own salmonid eggs, 66% produced them for their own use while 34% used some of the eggs themselves and sold the rest. Rainbow trout egg production accounted for 68% of all salmonid egg production by producers in the NCR. Brook and brown trout accounted for 32% of egg production. Sixty-eight percent of the rainbow trout eggs produced in the NCR in 1990 were registered strains, mainly Kamloop and Donaldson.

Rainbow trout accounted for 63% of all salmonid egg sales by producer in the NCR in 1990 and more than half of these sales were made to areas outside the NCR. Brook trout accounted for 29% of salmonid egg sales by producers in the NCR in 1990 and only 21% of these were sold outside the region (Kinnunen 1991).

Rainbow trout accounted for 67% of all the egg purchases, 68% of egg production, and 63% of egg sales in the NCR in 1990, clearly demonstrating the importance of this species in the NCR (Kinnunen 1991).

Losses of Trout

Total losses of all trout in the U.S. from 1995 to 1998 ranged from 27.4–39.1 million fish or 4.24–7.84 million lb. Of the total number lost, 71–84% was due to disease and 12–34% was due to predators. During this time period, the losses of trout in Michigan ranged from 178,000–423,000 (44,000–115,000 lb), in Missouri 195,000–231,000 (51,000–67,000 lb) , and in Wisconsin 176,000–273,000 (69,000–104,000 lb). The major cause of trout losses in the NCR was due to predators, which accounted for 18–65% of the losses in Michigan, 30–39% of the losses in Missouri, and 58–75% of the losses in Wisconsin. The next leading cause of trout losses was disease, with a low of 13% in Michigan and Wisconsin and a high of 38% in Missouri.

Costs for Trout Production

Fish feed is one of the most expensive feeds for commercial animal production. Variable costs represented 81% of total costs for trout production in the NCR in 1991 (Brown 1994). The main variable cost was feed, which was followed closely by labor, with feed costs accounting for 29% of total costs and 35% of all variable costs. Brown (1994) indicated that the higher cost of feed for NCR trout producers may be due to transport costs from out-of-state feed mills. Many of the mills used by trout producers in the NCR are located in Pennsylvania, Utah, and Canada. On average, hired labor accounted for 26% of total costs and 32% of variable costs of trout production in the NCR. In Idaho. feed costs are generally around 50% of variable costs, and this may be due to less pumping costs in Idaho compared to the NCR (G. Fornshell, University of Idaho Extension, Twin Falls, personal communication).

Investment costs for a trout production facility include the buildings, electrification, troughs and tanks, flow through egg incubators, automatic feeders, aerators, and plumbing. For 1991 the average investment made by NCR trout farmers was $82,000 for a small facility, $333,000 for a medium facility, and $500,000 for a large facility. Total costs, as well as variable and fixed costs, exhibit economies of scale for the three trout production scales. Taking into account total variable and fixed costs the average cost to raise a pound of trout was $3.07 for a small facility, $1.57 for a medium facility, and $1.39 for a large facility with an overall average cost of $1.53/lb (Brown 1994). Thus, the input cost per unit of output decreases with increases in output.

SALMON INDUSTRY ECONOMICS

The National Marine Fisheries Service Fisheries Statistics and Economics Division (1999) reports that U.S. aquaculture production of salmon increased from 23.9 million lb in 1992 to 39.7 million lb in 1997. During this time period the value of this salmon production varied from $61–$76 million. While salmon production increased, the value decreased from $3.14/lb in 1992 to $1.64/lb in 1997. According to the U.S. Department of Agriculture, U.S. farm-raised salmon production in 1998 is expected to increase only slightly from 1997. Maine and Washington are the largest producers of salmon in the United States.

A survey of salmonid producers in the NCR found that 41% purchased salmonid eggs in 1990 (Kinnunen 1991). Salmon accounted for 29% of all salmonid eggs purchased and of these 66% were chinook salmon eggs which were purchased from within the NCR (Michigan and Minnesota), while the others were coho and chinook salmon eggs purchased from outside the NCR.

Thirty-five percent of salmonid producers in the NCR indicated they purchased salmonid fingerlings in 1990 (Kinnunen 1991). Salmon fingerlings accounted for 4% of fingerlings purchased in the NCR with all acquired in the region. Sixty-five percent of those producing salmonids in the NCR in 1990 produced their own fingerlings and of this salmon accounted for 26% of the production, which consisted mostly of chinook salmon followed by coho salmon (Kinnunen 1991). Salmon accounted for 6.5% of all salmonid fingerling sales in the NCR in 1990, and of these all were coho and chinook salmon which were sold within the NCR in the states of Nebraska and Minnesota (Kinnunen 1991).

Salmon production in the NCR is small compared to trout production. Early attempts to develop salmon aquaculture in abandoned mine pits in northern Minnesota were stifled by the regulatory environment (Axler et al. 1996). Currently, Minnesota does not have any significant salmon production (R. Ji., Minnesota Department of Agriculture, St. Paul, personal communication). Nebraska is the only state within the NCR that has several producers who specialize in raising salmon. These producers raise coho salmon in tanks and raceways that are fed with pumped groundwater. No specific production numbers are available from these Nebraska salmon producers (R. Arends, Nebraska Department of Agriculture, Lincoln, personal communication). Future expansion of salmon production in the NCR does not look bright as foreign imports of salmon into the U.S. are very large with stiff competition from Canada and Chile, with additional growth in imports from European growers, mainly Norway and the United Kingdom. U.S. imports of Atlantic salmon in 1999 totaled 242 million lb and $629 million as reported by the Economic Research Service (2000) of the U.S. Department of Agriculture.

Hushak et al. (1993) found that salmon was one of the four freshwater species that were most frequently sold in the NCR as it was handled by 66% of wholesalers, specialty retailers, and grocery retailers in the region. Product forms sold include fresh, frozen, and live. All grocery retailers, along with most of the other respondents, sell mainly fresh products. At the time of this survey 15% of those not selling cultured salmon indicated that they would like to sell the product if it were available to them. Forty-five percent of supermarket managers, responding to a NCR seafood marketing survey, listed salmon as one of their best selling species (Riepe 1999b). Twenty-eight percent of the restaurants in the NCR listed salmon as one of their best selling species (Riepe 1999a).

SALMONID DISEASES AND AQUACULTURE DRUG APPROVAL

Six of the states within the NCR boarder the Great Lakes and they include Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. Fish disease control in the Great Lakes basin has been the responsibility of fisheries management agencies. The Fish Health Committee of the Great Lakes Fishery Commission, which does not seek fish disease control authority, has developed a model program to unify and coordinate fish disease control efforts in the Great Lakes basin (Hnath 1985). In recent years some states have moved aquaculture licensing into their departments of agriculture and licensed veterinarians employed by the state agriculture departments as state animal health officers have assumed more of the fish health responsibility.

A list of disease agents covered by the Great Lakes fish disease control policy and model program include emergency and restricted diseases. The emergency diseases are those which have not been detected within the waters of the Great Lakes basin and include viral hemorrhagic septicemia virus (VHS), infectious hematopoietic necrosis virus (IHN), ceratomyxosis, and proliferative kidney disease agent (PKD). The restricted diseases are those diseases currently present within the Great Lakes basin, but whose geographic range is limited and include whirling disease, infectious pancreatic necrosis virus (IPN), bacterial kidney disease (BKD), furunculosis, and enteric redmouth disease (ERM). The policy of the Great Lakes Fishery Commission is to encourage each agency to prevent the importation, into the Great Lakes basin, of fish infected with emergency diseases and to prevent the transfer, within the Great Lakes basin, of fish infected with restricted diseases (Hnath 1985).

Whirling disease has been present in the environment for many years in a few isolated areas in Michigan. Ohio has had whirling disease in the past, but no recent cases have been documented. Michigan’s Department of Agriculture and Department of Natural Resources, and Michigan’s aquaculture industry have been working together on a cooperative program to monitor commercial fish production facilities for the organism that causes whirling disease. It is hoped that these efforts will help reduce the incidence and spread of the parasite.

The second leading cause of trout losses in the NCR has been attributed to disease. Salmonid producers in the NCR have thus far avoided any introductions of virulent disease agents, such as IHN, which has caused problems in the Idaho trout industry. Trout producers in the NCR must remain vigilant on only importing certified disease free salmonid eggs and fish into the region to avoid any future catastrophic losses.

To help combat disease problems when they do occur it will be important that salmonid producers have access to effective therapeutants. Currently there are three major therapeutants of significant importance to salmonid producers which are awaiting aquaculture drug approval in the U.S. and they include chloramine-t, florfenicol, and hydrogen peroxide (R. Schnick, National Aquaculture New Animal Drug Application (NADA) Coordinator, Michigan State University, East Lansing, personal communication). Chloramine-t, which is an external microbicide, is used to prevent and control bacterial gill disease in salmonids. Florfenicol is an oral antibacterial agent used to treat furunculosis in salmonids. Hydrogen peroxide is an external microbicide used to treat fungal infections on salmonids and their eggs. Additional studies are needed with this compound to test it effectiveness in controlling external bacteria, bacterial gill disease, and parasites.

CRITICAL LIMITING FACTORS AND RESEARCH/OUTREACH NEEDS

A major limiting factor which will hinder future growth of salmonid aquaculture in the NCR, based on current technology in use, is an adequate water supply at the proper temperature and quantity. Environmental regulations will prevent the use of additional surface waters and thus fish farmers will have to better utilize the current water resources which are available to them. In addition, environmental regulations will become more stringent when it comes to addressing the water quality of discharges from flow-through aquaculture systems. With limited water resources in many parts of the NCR, it will be necessary to capitalize on production scenarios which can help support the viability of a regional salmonid industry. Salmonid producers will be required to run very efficient operations to make a profit. Production costs will always be higher in the NCR and value-added products aimed at targeted markets are needed to make salmonid production more profitable. Thus, the following scenarios for increasing production efficiency and sales of salmonids in the NCR have been developed to best deal with the critical limiting factors facing the industry.

SCENARIOS FOR INCREASING PRODUCTION EFFICIENCY AND SALES OF SALMONIDS IN THE NCR

Increasing Rearing Densities and Use of Recirculation Technology

The lack of an adequate supply of high quality flowing water in many parts of the NCR will preclude future expansion of the traditional methods of salmonid culture. Environmental regulations will also prevent the further use of additional surface water supplies in the region. Thus alternative methods must be explored to utilize the water sources which are available. Research has shown that rainbow trout can be produced at much higher rearing densities than traditionally recommended. Presently no wide scale use of pure oxygen supplementation is being used by salmonid producers within the NCR. By using pure oxygen supplementation, rainbow trout can be produced in cylindrical tanks at as high a rearing density as in raceways, but at a significantly lower water turnover rate than is normally used in the latter (NCRAC 1997). This should help trout farmers who are constrained by water limitations and rearing space. Kebus et al. (1992) found that rainbow trout held at 49.6–53.4°F without oxygen supplementation can be raised at a high density without impairing their growth or causing chronic stress if high water quality is maintained. In contrast, Procarione et al. (1999) found that at relatively high loading rates without oxygen supplementation, rainbow trout reared at high densities at 59°F exhibited decreased growth and feed conversion efficiency. High rearing density may have negative impacts on the growth of rainbow trout only under certain conditions such as the loading rate or water temperature being above a critical level. Additionally, this study found that high rearing density itself was probably not a chronic stressor in rainbow trout because fish reared at high densities did not experience changes in physiological measures that would normally be expected under stressful conditions.

In the NCR it would be interesting to include an analysis of pounds of trout produced per unit of water. This would provide some additional measure of the efficiency of production and the extent to which production might be increased. In Idaho trout are produced from 10,000 lb/cfs/yr up to nearly 30,000 lb/cfs/yr with the higher stocking densities requiring greater management intensity (R. MacMillan, Clear Springs Foods, Inc., Buhl, Idaho, personal communication).

As water recirculation technology develops further, it will be wise for salmonid producers to explore this option to fully optimize water resources. Although recirculation technology has not been adapted to any great extent by salmonid producers in the NCR, some progress in this area is occurring in Ohio. There are currently about a dozen trout producers in Ohio who use pole barns for trout production using recirculation systems (D. Smith, Freshwater Farms of Ohio, Inc., Urbana, personal communication). These systems consist of indoor raceways or conical tanks which make it easier to maintain water temperature control throughout the year. The densities of trout produced in these systems range from 0.5 lb/gal in the raceways to 1 lb/gal in the conical tanks. Complete water turnover occurs in 3–4 h in the raceways and 1 h in the conical tanks. Average water replacement for these systems is about 1 gal/min and can run as high as 2–3 gal/min in the summer months. These systems require aeration, but no pure oxygen supplementation is being used in Ohio. One great benefit of utilizing recirculation technology is that the waste stream is better controlled, thus avoiding conflict with environmental regulations.

Development of Strains Best Suited for Environmental Conditions in the NCR

There may be a lack of information on strains which are best suited for production in the NCR. Kinnunen (1991) found that the Kamloop strain of rainbow trout was used by over half of the producers in the NCR using registered strains followed by the Donaldson strain. The ideal water temperature for optimum growth of the Kamloop strain of rainbow trout is 59°F. Yet most locations in the NCR have water temperatures that are either warmer or colder than 59°F. For those producing trout in the NCR, the average water temperature is 51.1°F (Brown 1994). Thus, most trout producers in the NCR have water that is below the optimum temperature for ideal growth of the Kamloop strain of rainbow trout.

On-going NCRAC studies will provide detailed information on the growth and stress responses of Kamloops and Donaldson strains of rainbow trout and Arctic charr reared under thermal conditions typically found in the NCR. Regional salmonid producers will be able to use this information to determine which of the three species/strains can be best utilized at their operation under their specific thermal conditions to maximize productivity and profitability (NCRAC 1999). Future research should also focus on developing new strains which are best suited for culture in the NCR.

The lack of large quantities of high quality water for salmonid aquaculture expansion in the NCR will require fish farmers to better utilize the existing water sources. This might include producing salmonids at higher densities and the use of recirculation systems, which could be an added stress on the fish. Thus it might be possible to genetically select faster growing fish based on how they respond to stress. Procarione et al. (1996) found that rainbow trout which have a fast return of cortisol concentration to a baseline following a stressor is a more important determinant of fish performance than the magnitude of the cortisol response. Rainbow trout with a low 3 h cortisol concentration following a stressor grew significantly faster than those with a high 3 h cortisol concentration. Further study is needed to determine whether low 3 h post-stress cortisol is a heritable trait and correlated with resistance to disease. With regards to disease resistance, rainbow trout selected for high peak post-stress cortisol concentrations had higher mortality rates than rainbow trout selected for low peak cortisol level following exposure to *Aeromonas*, but lower mortality rates following exposure to *Vibrio* (Fevolden et al. 1992). Still other research has shown that acute stress may actually stimulate primary defense mechanisms rather than suppress them in rainbow trout (Ruis and Bayne 1997). Thus, more research is needed to determine the affects of stress on disease resistance.

<u>Control of Sexual Maturation and Gender</u>

The control of sexual maturation and gender in rainbow trout for the purpose of increasing growth efficiency has been a common practice in other geographic areas for many years. Production by aquaculture producers in Europe of hybrids, sterile fish, or monosex populations through chromosome set manipulation has been shown to be highly profitable (Bye and Lincoln 1986). In Idaho, which is one of the leading trout producing states in the U.S., nearly all of the facilities use all-female diploid rainbow trout (R. MacMillan, Clear Springs Foods, Inc., Buhl, Idaho; G. Fornshell, University of Idaho Extension, Twin Falls, personal communication).

Salmonid producers who control sexual maturation and gender in their fish are quite limited in the NCR based on current interviews with producers and a previous survey by Kinnunen (1991). This survey showed that 64% of salmonid producers in the NCR who purchased eggs in 1990 were familiar with eggs that had undergone chromosome set manipulation but they never attempted to purchase any. Another 9% indicated that they were not familiar with this type of egg. Eighteen percent indicated that they attempted to purchase all-female rainbow trout eggs and, of these, 83% found them available. Six percent of those purchasing salmonid eggs tried to purchase all-female triploid rainbow trout eggs and none were successful finding them. Twelve percent attempted to purchase mixed-sex triploid rainbow trout with half of which found them available. Fifty percent of the salmonid producers in the NCR who produced eggs in 1990 indicated that they were familiar with chromosome set manipulation of eggs, but never attempted to produce them (Kinnunen 1991). Another 19% said they were not familiar with these types of eggs. Twelve percent of those producing salmonid eggs in the NCR in 1990 indicated having produced either all-female or mixed-sex triploid rainbow trout eggs. One producer in the region declared that he had produced tetraploid eggs but did not indicate which species of salmonid.

During their early life stages, all-female diploid rainbow trout grew and survived the same as mixed-sex diploid, but declines in flesh quality and appearance due to sexual maturation occurred earlier in mixed-sex diploid than all-female diploid trout (NCRAC 1997). This research also showed that all-female diploid trout grew faster than mixed-sex diploids through grow out, but survival was similar. One concern regarding these research findings was that all-female diploid trout show reduced non-essential activity at culture temperatures above 54.5°F, when a range of 45.0–57.9°F is the water temperature used for raising trout in the NCR with an average of 51.1°F (Brown 1994). Thus the non-essential activity exhibited by the all-female diploid trout would not be much of an advantage in the NCR, except for states such as Missouri and Ohio. Fish with excessive non-essential activity will require more energy which may be a detriment to efficient feed conversion and growth.

A better alternative would be all-female triploid rainbow trout production which appears to be an especially strong option for farmers interested in producing a larger trout. Research has shown that all-female triploid rainbow trout are superior to mixed-sex diploids and all- female diploids during grow out through market size (NCRAC 1997). All-female triploid rainbow trout should not show declines in flesh quality and appearance which accompany sexual maturation in mixed-sex diploid and all-female diploid rainbow trout. Although all-female triploid rainbow trout show somewhat reduced survival through yolk-sac absorption, the production of all-female triploids via crosses of tetraploids with diploids may reduce or eliminate this problem. In Europe trout farms which are growing triploids to produce large table-fish have found their growth rate, feed conversion efficiency, and flesh quality acceptable. Controlled, blind taste trials have indicated a significant preference for sterile triploid trout when tested against diploids of similar size (Bye and Lincoln 1986).

Cost-effective all-female triploid and all-female diploid production in the NCR will require that salmonid producers develop brood stock for producing all-female diploid and all-female triploid fry. This will require production of sex-reversed gynogens for all-female production and tetraploid production for crosses with diploids to produce triploids (NCRAC 1997). Presently all-female diploid and triploid eggs are available for purchase in the western U.S. and this may be a more feasible alternative than producing them in the NCR.

Utilizing Diets Consisting of Regional Ingredients and Reducing Phosphorus Concentrations in Effluents

Fish feed is one of the most expensive feeds for commercial production. In 1991 feed costs accounted for 29% of total costs and 35% of all variable costs at trout production facilities in the NCR (Brown 1994). The major cost of fish feed is the highly priced fish meal ingredient which is subject to dramatic price fluctuations due to natural variations in the ocean fish source that supplies this protein. Thus replacement of fish meal protein with plant or other animal proteins of similar biological value is the most desired goal in culture of carnivorous fishes. To realize cost savings for salmonid producers, it becomes prudent to develop diets for rainbow trout that are free of fish meal and rely on feed ingredients common in the NCR. This will result in diets that are lower in cost, which will reduce overall production costs, and can be taken to local feed mills, thus reducing transportation costs.

Current research has shown that weight gain, feed intake, feed conversion efficiency, and specific growth rate of rainbow trout fed two formulations free of fish meal by utilization of plant proteins were not significantly different from fish fed a control diet (NCRAC 1999). However, both diets contained fish oil as the lipid source. Adelizi et al. (1998) observed favorable growth in rainbow trout fed diets that completely lacked fish meal but indicated that additional research was needed to improve the quality of diets high in agricultural byproducts before they are to be cost effective. A present concern regarding vegetable proteins as substitutes for fish meal is that they are expensive and not readily available unless you make them yourself (R. MacMillan, Clear Springs Foods, Inc., Buhl, Idaho, personal communication). Also research results suggest that a fish meal analog utilizing various animal meals could be used up to 20% as fish meal protein substitution in diets for juvenile rainbow trout without adverse effects on growth rate (NCRAC 2000). Other research has shown that fish meal can be entirely replaced by a mixture of plant proteins (25% extracted cottonseed meal and 25% soybean meal) and 50% animal by-product proteins without affecting growth rate and feed utilization of juvenile rainbow trout (Lee et al. Submitted). Additional research has demonstrated that traditional fish meal diet can be altered up to 100% with a mixture of animal by-products without affecting growth, reproduction efficiency, and fillet quality in rainbow trout (Dabrowski et al. 1998; Lesiow et al. Submitted).

Environmental regulators are becoming increasingly concerned with the waste discharge via effluent from aquaculture facilities. New changes in salmonid diet formulations which are being studied in the NCR should help decrease pollution due to leaching minerals/nutrients such as phosphorus and ammonia. Research has shown that pretreatment of plant feedstuffs with the enzyme phytase can help improve utilization of phosphorus and nitrogen in limited fish meal and all plant diets for rainbow trout (NCRAC 1999). Preliminary results indicate that the phytase-treated diet out performs the fish meal and the soybean meal untreated diet. This is the same trend observed by Cain and Garling (1995) who indicated that if cost effective phytase treatments of plant feedstuffs could be developed, phosphorus levels in trout feeds and phosphorus effluent concentrations from trout hatcheries could be significantly reduced. Rainbow trout fed the phytase-treated diets without phosphorus supplementation had excellent weight gain and feed conversion, and exhibited an 88% reduction in phosphorus discharge over fish fed a commercial diet. Brown (1993) found that phytase improved phosphorus absorption from soybean meal but it also resulted in greater leaching of phosphorus from fecal samples of rainbow trout. Other research has shown that a substantial reduction of phosphorus discharge from trout farms could be achieved without any additional cost by replacing ordinary grains with low-phytate mutant grains in low-ash fish feeds (WRAC 1998).

Riche and Brown (1996) determined that periodic feeding of phosphorus-deplete diets may function as a useful strategy in reducing overall phosphorus levels in effluents. This approach coupled with precisely formulated diets to meet, but not exceed, the dietary phosphorus requirement, appear to be positive approaches to reducing phosphorus in aquaculture effluents. Similar research has demonstrated that dietary phosphorus levels can be reduced for finishing rainbow trout without affecting weight gain or product quality and result in a significant reduction in phosphorus discharge (WRAC 1996). Also this research has shown that feeding a diet with reduced total phosphorus during the first year of brood stock production helps reduce the amount of phosphorus discharged compared to feeding a standard brood diet.

Feed companies can take two approaches when manufacturing diets to help reduce pollution due to leaching of phosphorus from fish waste. One approach is to use high quality fish meal with the bone removed. This type of diet is nutrient dense and results in a feed conversion efficiency which is under one to one and thus less feed has to be used which helps reduce the waste problem (C. Nelson, Silver Cup Feeds, Murray, Utah, personal communication). The other approach is to supplement diets with plant proteins that contain a minimum of 15–20% fish meal. It is true that lower-ash fish meals would produce a less-polluting effluent, unfortunately a premium price is paid for the lower-ash fish meals and it is not routinely available (R. MacMillan, Clear Springs Foods, Inc., Buhl, Idaho, personal communication).

<u>Marketing Trout to Regional Restaurants and the Food Service Industry</u>

Production costs will always be higher in the NCR because of added electrical costs for pumping water and aeration, and value-added products and marketing are needed to make salmonid production more profitable, especially as it relates to rainbow trout. Trout producers will be required to acquire marketing skills to help tap into new and emerging markets. Marketing trout to restaurants in the NCR appears to be an avenue to explore to help expand sales.

Prior marketing research has shown that both trout and salmon are widely accepted among wholesalers, specialty retailers, and grocery retailers in the NCR. Hushak et al. (1993) found that trout and salmon were among the four freshwater species that were most frequently sold in the NCR as they were handled by 66–67% of wholesalers, specialty retailers, and grocery retailers in the region. Product forms sold included fresh, frozen, and live. All grocery retailers, along with most of the other respondents, mainly sold a fresh product. Only 14% of supermarket managers responding to a NCR seafood marketing survey listed trout as one of their best selling species while 45% of them indicated salmon was their best selling species (Riepe 1999b). Low sales of trout at supermarkets may be related to inferior product quality. To increase sales to supermarkets it will be necessary to educate sales managers on the qualities of purchasing locally produced trout. Locally produced trout will be of higher quality as compared to Idaho trout which is shipped half way across the country. Many states have promotional programs that promote products produced within their own state and trout producers should capitalize on this avenue of marketing their products. Thus supermarkets in the NCR should be promoting locally grown trout for its freshness.

Recent marketing research has shown that 28% of the restaurants in the NCR listed salmon as one of their best selling species, while trout was not even listed (Riepe 1999a). This marketing research showed that salmon had wide popularity in both urban and rural restaurants as well with those having high and low seafood sales. Trout did not make the list of best selling species in any of these restaurants, which indicates that marketing efforts directed at this food establishment sector should be undertaken to help increase sales volumes. These marketing efforts directed at increasing trout sales to restaurants could be accomplished in two ways. First, the trout producers themselves could make contact with local restaurants in their area and encourage them to try their product. Or secondly, the trout producers could encourage wholesalers that purchase their finished product to explore restaurants as an outlet for trout products.

SUMMARY OF RESEARCH AND EXTENSION PRIORITIES

(Not in rank order)

ENVIRONMENTAL STRATEGIES

- Characterize the water quality of aquaculture discharges based on diet composition and feed utilization especially as it relates to recirculating systems and other new system designs.
- Develop methods for improving water quality discharges through improved system design. Such design might include removal of solids by technologies like side streaming waste out of double drain systems.
- Develop diets and feeding strategies that result in less nutrients being introduced into the environment without jeopardizing fish performance.
- Evaluate current environmental regulations for their appropriateness. Determine if aquaculture is treated similarly to other water users.
- Develop/improve predator control techniques.

GENETICS

- Identify or develop salmonid strains that are better suited for the different temperatures and production systems in the NCR.

- Develop new strains with advanced growth characteristics similar to what has happened in other agriculture meat producing segments.

ECONOMICS AND MARKETING

- Develop and extend the best marketing strategies.
- Improve trout markets to family style and white table cloth restaurants.
- Develop and improve value added products such as smoked fish.
- Improve strategies to deal with market price suppression by Idaho trout.
- Improve technical expertise for raising salmonids.
- Feeds made with regional ingredients and produced locally to hold the costs down.
- Better access to lower cost feeds.
- Better access to lower cost fingerlings.
- Better access to investment capital.
- Increase regional processing/marketing capabilities.
- Develop aquaculture programs within land grant universities which focus on developing skilled personnel who are employable in the private sector.

PRODUCTION FACILITIES

- Enhanced facility design and water management.
- Utilize GIS to document potential regional availability of water resources.
- Develop manuals on high density production under low flow conditions.
- Land grant universities should contribute more research on various types of aquaculture production facilities.

TRANSPORTATION METHODS

- Improve delivery methods for live salmonids which maintain water quality, reduce stress, and are economical to operate.

RISK ASSESSMENT

- Sound risk assessment and management of diseases and aquatic nuisance species introductions.

FISH DISEASES

- Development of approved therapeutants.
- Access to official fish health inspections.
- Develop sound cost effective industry driven disease management strategies.
- Better access to qualified aquaculture veterinary services.
- Develop uniform import regulations for salmonids among states.

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