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A White Paper on the status and needs of walleye aquaculture in the North Central Region

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Abstract

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Disciplines

Aquaculture and Fisheries

Comments

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

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for the

North Central Regional Aquaculture Center

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INTRODUCTION AND JUSTIFICATION OF THE DOCUMENT

Walleye has been recognized as a species with substantial aquaculture potential in the National Aquaculture Plan of 1983 (Joint Subcommittee on Aquaculture 1983). NCRAC's Industry Advisory Council and the Technical Committee, have also identified walleye one of the most promising species for aquaculture in the North Central Region (NCR) since the first joint meeting, May 1988.

The potential for establishing successful aquaculture enterprises for walleye, as with any other new species, follows certain sequential steps, the first of which is to develop awareness by consumers (name recognition) and the second is to increase availability of the product (Engle 1998). Consumer awareness of walleye is less of a problem than for most prospective species. The popularity of walleye as a sport fish provides it with instant name-recognition by a substantial portion of potential consumers. Walleye are native to a substantial portion of North America and because they are among the most sought after sport fishes, they have been stocked far outside their original distribution. Walleye are now found in 32% of the freshwater habitat in North America and targeted as a sport fish in 34 states, seven provinces, and one territory (Fenton et al. 1996). In 1996, the 35.2 million U.S. residents 16 years old and older who fished had expenditures of $37.8 billion, up from $27.6 billion in 1991 (USDI 1997). About 11% of anglers fishing in freshwaters other than the Great Lakes fished for walleye and sauger, and 36% of anglers in the Great Lakes fished for walleye and sauger. In Canada, “The walleye is probably the most economically valuable species in Canada’s inland waters” (Scott and Crossman 1973).

The popularity of walleye as a sport fish contributes to market potential across all life stages. Walleye can be sold as fry, small and larger fingerlings, and as adult fish for stocking purposes, marketed to other walleye producers, and raised to a size sufficient for the food-fish market.

The palatability of walleye seems well established, which has contributed to their presence in food-fish markets for more than 150 years. Walleye were once a substantial part of the commercial fisheries of the Great Lakes, especially in Lake Erie, the Mississippi River, and from many of the numerous glacial lakes of the U.S. and Canada. Walleye harvest from Lake Erie was as much as 23.8 million lb (10.8 million kg) in 1956 (NOAA 1984).

A 1991 survey of marketing channels for fish and seafood products within the NCR indicated that walleye ranks first among a group of fish species with the most marketing potential (Hushak et al. 1992). Besides retail groceries and chain restaurants—it has been on the menu of some national franchise chains such as Red Lobster—walleye also has favorable name recognition in locally-owned, upscale, white-tablecloth restaurants, which implies potential for niche markets in the Upper Great Lakes states (Riepe 1999a). Given these facts and limited commercial supply, the retail price of walleye fillets is always more than cultured catfish or deboned trout, and usually slightly more than cultured Atlantic salmon.

After name recognition, the second priority for market development is to increase the availability of the product. A Minnesota producer of fingerling walleyes may think the market for fingerlings needs expansion, but the supply of food-fish is primarily of wild-caught fish from Canada, and those sources seem to be in the decline.

To enhance walleye culture opportunities in the NCR, NCRAC-sponsored research has been organized in work groups, functioning in a collaborative way to resolve critical constraints including biological and technological. Typically, university researchers led work groups with collaboration of state and federal agencies, and private producers. The first NCRAC-sponsored project was initiated May 1, 1989 and they have continued to the present. The first walleye work group involved faculty from Southern Illinois University-Carbondale, the University of Notre Dame, Iowa State University, the University of Minnesota at St. Paul, and the University of Wisconsin-Madison, and collaboration from several state agencies (Iowa Department of Natural Resources, Kansas Department of Fish and Game, Minnesota Department of Natural Resources, Ohio Department of Natural Resources, Wisconsin Department of Natural Resources) and the U.S. Fish and Wildlife Service Garrison Dam and Valley City National Fish hatcheries. The first NCRAC sponsored research focused on (1) characterization of the natural reproductive cycle and procedures for manipulating reproduction and inducing spawning in walleye brood stock; (2) fertilization strategies and zooplankton seeding for pond production of fingerlings; and (3) understanding of and control for the problem of non-inflation of the gas bladder of intensively cultured fry. Subsequent projects have been concerned with out-of-season spawning, stocking density for pond culture, methods for pond harvest, genetics, stock evaluation, hybrid walleye, production of food-size walleye, and production of all female walleye.

CURRENT STATUS OF THE INDUSTRY

MARKETING

It is important to recognize that markets exist for all life stages of walleye, and that the focus for marketing research should not be limited to only that of food-fish. There are commercial markets for eyed eggs and newly hatched fry, and both summer and fall fingerlings for stocking both public and private waters. Commercial food-fish markets have been present for more than 100 years, but to date, culture of walleye to food-size in the U.S. is nearly non-existent, and walleye in the marketplace (i.e., restaurants and grocery stores) is of wild-caught, nearly all imported from Canada. In a 1991 survey, retail, wholesale, and other firms that make up the marketing channels for fish and seafood products within the 12-state NCR indicated that sales of walleye were about 6.5% of sales of all freshwater species and that walleye were first among a group of fish species with the most marketing potential (Hushak et al. 1992).

<u>Supply</u>

Information on walleye production by commercial aquaculture—sources, volume, and value of—are very limited. The Minnesota Department of Agriculture has published surveys of commercial production of fingerlings in that state (MDA 1993), but about all we know of the supply of food-size walleye is from inferences about Canadian imports. With the exception of limited data by Hushak (1993), NCRAC-funded studies have not described supply-side facts, they have described markets for food-size walleye (Hushak et al. 1992; Riepe 1998, 1999a, 1999b).

Fry and fingerlings for stocking. There is a substantial body of information on production of walleye by state, federal, and provincial agencies, which propagate and stock walleye fry and fingerlings to introduce the species, enhance recruitment, and to provide fish where recruitment does not occur. By 1900, the U.S. Bureau of Fisheries, the forerunner of the U.S. Fish and Wildlife Service, stocked

368.2 million “pike perch” (formerly, a common colloquial name for walleye) (USCFF 1900). In 1948, hatcheries of 44 states and the U.S. Fish and Wildlife Service, listed the distribution of about 1.16 billion fry and 4 million fingerlings (Tunison et al. 1949).

In 1983, about 1 billion fry and more than 9 million pond-cultured fingerlings were stocked by state and provincial agencies (Conover 1986). Between 1986 and 1991, thirty-two state, federal, and provincial agencies reported stocking walleye and 29 agencies operated fingerling stocking programs (Fenton et al. 1996). In the NCR, the Minnesota DNR has stocked more than 250 million fry and as many as 5.6 million fingerlings in a single year (Lilenthal 1996). In 1990, the Michigan DNR stocked over 5.7 million fingerlings into state waters (Gustafson 1996).

The production and sale of fry and fingerling walleye by private culturists is also well established but poorly documented. Most commercially produced walleye fry and fingerlings are marketed to lake associations and angler groups for walleye stock enhancement in private lakes, but some commercial producers also sell fish to public agencies (e.g., municipal and county lakes) as well. Noting the huge number of fingerlings produced by state agencies, and the clamor by angler groups for more stocking, some private culturists and state aquaculture associations have petitioned the state agency to purchase some of the walleye that are needed for stocking. A 1992 survey of a portion of the commercial aquaculture producers in Minnesota indicated that they sold 600,000 fingerlings for $328,000, or $0.54/fingerling (Gunderson et al. 1996). A 1991 survey of fish producers/growers in 11 of the 12 states of the NCR indicated that walleye were produced in 7 of 11 states, by 16.4% of the producers that responded to that survey, and that walleye ranked fourth in gross sales of the top 12 species or species groups (Hushak 1993).

However, my experience and deductive reasoning indicates that seasonally, availability of fingerlings is very limited. Typically, small fingerlings are available in June, large fingerlings in October, although a few producers over winter large fingerlings for sale the following spring. I do not know of any private producers that are spawning walleye out-of-season and few producers that effectively habituate walleye to formulated feed to produce “feed-trained fingerlings.” Moreover, to some producers, a “feed-trained fingerling” is a fingerling from a pond where the producer threw in feed, with no knowledge of whether the fish ate it. I know of no research that verifies that pond-reared walleye have ever been habituated to formulated feed while unconstrained (i.e., not in cages or pens) in ponds.

Food-size fish. About 68% of the supply of fresh food-size walleye purchased by restaurants in the NCR is from seafood wholesalers and 18% from food service distributors, whereas 65% of frozen walleye are from food service distributors and 22% from seafood wholesalers (Riepe 1999a). With the exception for a small tribal harvest in Minnesota, Wisconsin, and Michigan, the overwhelming majority of walleye in the food-fish market are derived from commercial harvest of wild-stock fish from the Canadian shore of Lake Erie, and smaller lakes of western Ontario and the Canadian Prairie Provinces. There is no licensed commercial harvest of walleye from the U.S. portion of the Great Lakes or the Mississippi River. Currently, the majority of Canadian-caught walleye are exported to the U.S. with the assistance of the Freshwater Fish Marketing Corporation (FFMC). It consolidates the collection and processing of fish, and serves as a single-desk agent for promoting markets and export of fish. Between 1990 and 1994, The FFMC handled 6.6–24.0 million lb of fish (3.0–10.9 million kg) annually, of which, the majority was marketed in the United States. However, several startups for food fish production have occurred in the NCR: a single-pass, tank culture system in a greenhouse by

Aquaculture Inc., Rolla, Missouri (NCRAC 1990) and a private cage culture enterprise in Iowa (Stevens 1996). Also, feasibility studies on cage-culture of walleye have been reported in Iowa (Bushman 1996) and Minnesota (Mittlemark and Kapuscinski 1993), but slow growth from short growing seasons indicated that it would require three years to reach a food size.

According to the evidence available at this time, production of walleye as a food fish is very limited. However, in late 1999, in Iowa, a recycle facility with state-of-the-art technology was under construction. It is designed to produce 100,000 lb (45,360 kg) per annum of food-size walleye.

Demand

Fry and fingerlings for stocking. Commercial production of fry and fingerlings for sport fish enhancement, as distinct from production by state, provincial and federal agencies, has been and continues to be the major form of walleye culture. Potential demand for commercially produced walleye fry and fingerlings for stocking purposes has not been researched, but, as noted above, production of fry and fingerlings by state and federal agencies is huge, and production by private producers would grow substantially if they become providers for even a minor portion of what state agencies are stocking. Research is needed on the constraints to this market opportunity.

Gunderson et al. (1996) stated that Minnesota producers of fingerling fish are able to produce more fingerling fish than the existing market can bear in most years. However, because nearly all of current production of fingerling walleyes is from ponds, producers are unable to hold fingerlings for more than a few days. Thus, nearly all producers are seasonal harvesters, and walleye fingerlings generally are available for only short intervals in early summer and late fall. There is a market for and a major serious deficiency in supply of feed-trained walleye and hybrid walleye for culturists who may wish to grow food-size walleye. A similar problem seems to occur with yellow perch.

Food-size fish. The price per pound of walleye as a food fish is among the highest of freshwater fish. In July 1996, the average price paid in the NCR for frozen, skin-on walleye fillets was $6.03 by restaurants and $5.54 by wholesalers (Riepe 1998). Wholesalers paid $2.21 for fresh whole walleye.

U.S. consumers of fish spent about two-thirds of their seafood dollars in foodservice outlets, primarily restaurants (Riepe 1999a). Riepe (1999a) conducted a mail questionnaire survey of a representative sample of restaurant managers in the fall of 1996 and winter of 1997 in the NCR. In response to the question to list the top five best selling species in their restaurants, the response was 75% shrimp, 50% cod, 28% salmon, 21% pollock, 19% (tie) catfish and scallops, 17% tuna, 14% orange roughy, 13% (tie) lobster, yellow perch and walleye, 12% crab, 10% (tie) lake whitefish and halibut. However, among restaurants having a high percentage of seafood sales, the percentage rank was shrimp 74%, salmon 36%, cod 34%, scallops 27%, walleye 25%, lobster 25%, yellow perch 21%, and lake whitefish 20%. Of this list, salmon is mostly netpen reared from marine sources, thus, walleye is first rank among freshwater fishes that have aquaculture potential in the NCR. In the 1996/97-restaurant survey, Riepe (1998) found that walleye, yellow perch, and lake whitefish are the best-selling species among NCR restaurants that are already serving some walleye. Thirty-one percent of these restaurants reported walleye as the best seller whereas 21% reported yellow perch and 13%

reported lake whitefish as the best selling species. Presumably, nearly all of these species were wild captured by commercial fisheries from the Great Lakes or imported from Canada.

Riepe (1998) described findings of a mail survey of retail and wholesale firms in the food industry regarding markets (i.e., demand) for food-size walleye. Firms in the food industry in her survey include restaurants, supermarkets, seafood wholesalers, seafood retailers, foodservice distributors, grocery wholesalers, and fish brokers. The following represent items gleaned from her report that speak directly to issues related to supply (although quotes are not used, most items are direct quotes or slightly paraphrased from her report):

- Market penetration is substantial, but less than 100%: only 41% of restaurants (establishments that are not part of a chain and not primarily serving pizza), 71% of supermarkets, 52% of wholesalers, and 68% of seafood retailers sold walleye in 1996.
- The origin of most walleye is from wild sources; e.g., less than 10% of wholesalers and 9% of restaurants reported purchasing farm-raised walleye, but 41% of restaurants and nearly 75% of wholesalers expressed interest in purchasing farm-raised walleye.
- There is a cyclical pattern in availability of walleye supplies.
- On average, wholesalers reported that walleye purchases could increase 50% with aquaculture.
- Wild-caught walleye is reasonably well accepted around the NCR, which should ease the entrance of farm-raised products.
- The market views frozen skin-on fillets (87% of sales) as an acceptable walleye product form, however, opportunities exist for selling fresh whole walleye as well.
- Weekly deliveries of product are highly preferred.

BIOLOGY AND AQUACULTURE TECHNOLOGY

Biology

A substantial scientific literature exists on the physiology, growth, genetics, behavior, ecology, and management of walleye (Scott and Crossman 1973; Collette et al. 1977; Kendall 1978; Colby et al. 1979; Becker 1983; Craig 1987; Carlander 1997). A bibliography of biological data through 1988 lists a total of 3,116 references to all aspects of walleye and sauger life histories (Ebbers et al. 1988). Although this database is useful to researchers focusing on aquacultural technology of walleye, the relevant items are incorporated into efforts by aquacultural researchers to overcome critical biological constraints to walleye culture. For example, the science of reproductive biology and endocrinology are applied for induced out-of-season spawning (e.g., Malison et al. 1994; Malison and Held 1996).

Biological characteristics of fish that are important for a decision on their suitability for aquaculture include: (1) desirable reproductive traits; (2) suitable growth rate; (3) acceptance of formulated feed (e.g., commercial diets); (4) tolerance of crowding and other hatchery conditions; (5) disease resistance; and (6) palatability (Summerfelt 1981). As described below, walleye has suitable basic biological attributes that make them an excellent candidate species for aquaculture. Desirable biological attributes, and name recognition as a highly desirable food and game fish, indicate a strong potential for aquaculture.

The current status of aquacultural technology of walleye has been thoroughly described in the Walleye Culture Manual (Summerfelt 1996a), therefore, the following commentary provides only a selective summary of that information and an update on promising new technologies.

Walleye are commercially cultured in many parts of the Midwest, including Ohio, Michigan, Illinois, Wisconsin, Minnesota, Iowa, and Nebraska for production is of eggs, fry, and pond-raised fingerlings for stocking. Hushak (1993) reported that 16.4% of 286 respondents to his survey were raising walleye. Commercial pond production of fingerling walleyes has been especially strong in Minnesota and to a lesser extent elsewhere. Excellent prices have bolstered commercial walleye production of fingerling walleyes to the point where production of fingerlings in Minnesota may exceed demand in some years. Market opportunities for fingerlings need research.

Reproductive traits. It is easy to strip both eggs and milt from reproductively ripe walleye. Public hatcheries have spawned, incubated, and hatched walleye for more than 100 years. The Manual of Fish-Culture published by the U.S. Commission of Fish and Fisheries in 1900 has a chapter on “The Pike Perch or Wall-Eyed Pike” (USCFF 1900) that describes spawning and spawn-taking, use of “swamp muck” to prevent adhesion of eggs, egg-incubation, transportation of eggs, description of cannibalism (including some excellent photographs of cannibalism), and prey selectivity by first feeding fry when lake water containing zooplankton was used for the water supply. There was no mention, however, of pond culture of fingerlings or any attempts at intensive culture of either fry or fingerling walleye.

Since 1900, techniques for spawning, incubation, and hatching of fry improved and substantially expanded. The Walleye Culture Manual includes case histories on brood stock collection, spawning, and egg incubation procedures in Colorado, Michigan, Minnesota, Pennsylvania, and two tribal operations in Wisconsin. Female walleyes have been stripped of as many as 300,000 eggs, although the number varies with size of the female, ranging from 121,252–194,004 lb (55,000–88,000/kg) (Harvey and Hood 1996). Walleye eggs are easily incubated in conventional hatchery containers (McDonald jars), and the number of days for incubation can be regulated by controlling the temperature; the incubation period can be extended to 42 days. Experimental methods to induce out-of-season spawning in walleye (Malison et al. 1994; Malison and Held 1996) have been used each year by the Iowa Department of Natural Resources (A. Moore, Iowa Department of Natural Resources, Moravia, personal communication). Further research to phase-shift the season to obtain eggs and fry several times each year would be a desirable adjunct to year-around culture in recycle systems.

Growth. Growth rate determines how long it will take any fish to reach a market size. Because fish are ectothermal, meaning that their metabolism and growth rates are affected by environmental temperature, when cultured in ponds and cages at ambient environmental temperatures at sites in the northern portion of the NCR, the growing season may be too short to grow walleye to the minimum food-size (1.25 lb; 567 g) until their third summer. Minimum temperature for growth is not as well defined, but growth rate (mm/day) at 68°F (20°C) was 3.75 fold greater than at 62.6°F (17.0°C) (Siegwarth and Summerfelt 1990). Huh et al. (1976) reported a similar temperature effect. They reported that walleye growth at 64.4°F (18.0°C) was one-third that of walleye reared at 71.6°F (22.0°C). It would seem that the growing season for walleye in ponds and lakes could be defined as the number of days where ambient water temperature is greater than 59°F (15°C), and growth will be very slow at temperatures of less than 68°F (20°C).

There is no agreement on an optimum temperature for growth of fingerling walleye; values of 71.6°F (22.0°C) (Smith and Koenst 1975) to 78.8°F (26.0°C) have been reported (Hokansen and Koenst 1986). Hokansen and Koenst (1986) found that optimal temperature was higher (78.8°F; 26.0°C) at low (5 lux) light intensity. Considering both temperature and light, Cai and Summerfelt (1992) estimated from regression analysis that the optimal temperature for metabolism of juvenile walleye was 77.5°F (25.3°C) at 45 lux. Summerfelt and Summerfelt (1996) estimated a range for maximum growth rate of advanced juvenile fish to be from 73.4–75.0°F (23.0–23.9°C). At an average temperature of 73.4°F (23.0°C), 1.25 lb (567 g) walleye have been produced in 410–480 days (14–16 months) from hatch (Summerfelt and Summerfelt 1996). Lack of agreement may be related to size of the experimental fish, feed quality and feeding rates, cultural conditions (e.g., light, density, stress factors), and genetic differences in the stock.

Acceptance of formulated feed. In intensive culture, first feeding walleye fry readily accept formulated feed (Summerfelt 1996c). Success in habituating small (1.4–2.4 in; 35–60 mm) pond-reared fingerlings to manufactured feed has been as high as 90% of the initial stock (Nagel 1996b). Once walleye are habituated to formulated feed, they do well on many but not all commercial feeds used for trout, salmon, and hybrid striped bass (Stettner et al. 1992; Bristow 1996).

Life stage diets have been developed for fry (starter diets), for habituating fingerlings to formulated feed (conversion diets), and grower diets (Barrows and Lellis 1996). The most common starter diet is the Kyowa B-series feed (Biokyowa, Inc., Chesterfield, Missouri), but a Barrows (F. T. Barrows, U.S. Fish and Wildlife Service, Fish Technology Center, Bozeman, Montana) has had long-term studies on a starter diet. The 1999 version of the Barrows starter diet showed higher feed acceptance, but slightly slower growth and higher rate of deformities than the Kyowa diet B-series diet (A. Moore, Iowa Department of Natural Resources, Moravia, personal communication). Czesney et al. (1999) found that walleye fed *Artemia* enriched with a combination of cod liver oil and n-3 HUFA concentrate grew faster than those fed 100% n-3 HUFA enriched *Artemia*. Kolkovski et al. (In press) found no relationship between HUFA enrichment and larval survival. They did find that that survival of larval walleye to day 40 post hatch was significantly higher for larvae fed cod liver oil and vitamin C (ascorbly-6 palmitate) enriched *Artemia*.

The most recent formulation of Barrows walleye grower diet (WG-9901), produced a fingerling in 150 days that is 0.6 in (15 mm) longer than the WG-9206 grower diet, but further testing will continue in 2000 before a decision is made on whether the WG-9901 will replace the WG-9206 formulation (A. Moore, Iowa Department of Natural Resources, Moravia, personal communication). Of course, there will be a continuing need to study feed formulations to determine the formulation and feeding rates that supports maximum fish growth at the least cost (Hardy 1997). Kolkovski et al. (2000) found that a commercial trout starter diet coated with liquid krill hydrolystate increased ingestion rates and growth of fingerling walleye compared to the starter diet without the kill hydrolystate. The increased ingestion rate can be considered to serve as feed attractants that enhance food search and ingestion by the fish. They did not consider the krill to be a growth stimulant.

Tolerance to hatchery conditions. Walleye used in aquaculture today are usually progeny of wild stock, or they are progeny of captive stock that are unselected. These walleye are skittish and more easily stressed by overhead movement and hatchery activities than a domesticated aquaculture species such as rainbow trout. Some types of cultural technology can reduce the stressful behavioral responses of walleye in hatchery tanks. When overhead light intensity is low (<20 lux), or in-tank lighting is used, or turbid water culture is employed, progeny of wild-stock walleye are tolerant of high-density culture, and they are surprisingly tolerant of low oxygen and high temperatures. A domestic brood stock will probably be better adapted to hatchery conditions. Hybrid walleye (cross between female walleye and male sauger) are very docile and they lack the skittish problem of walleye (Siegwarth and Summerfelt 1992; Siegwarth and Summerfelt 1993).

Disease. Walleye are susceptible to commonplace external protozoan parasites (*Ichthyopthirius multifilis* and *Trichodina* spp.) that are found on cultured fish (Marcino 1996). They are "very susceptible" to infestations by ich (*Ichthyopthirius multifilis)* and highly susceptible to columnaris disease (Marcino 1996). The latter is closely related to mechanical injuries from harvest and handling at temperatures favorable to the bacterium (Hussain and Summerfelt 1991; Horner 1996). To date, no viral infections have been found to cause epizootic mortality in walleye, but adult walleye are susceptible to certain viral diseases of the integument: lymphocystis; epidermal hyperplasia; and dermal sarcoma, a type of skin tumor (McAllister 1996; Bowser et al. 1997; Getchell et al. 1998).

Suitability as a food fish. Walleyes have white meat and a light delicate flavor. They are described as one of the "best eating of all freshwater fishes" (Carmichael et al. 1991), and "one of the most delicious of fresh-water fishes" (Cameron and Jones 1983). Skinless fillets from tank-cultured walleye had protein contents of 20.4–20.6%, and a fat content of 0.1–0.4%, values which place them in the low fat and high protein category of food fishes (Yager and Summerfelt 1996). Surveys in 1990 and 1992 of retail, wholesale, and other firms that comprise the traditional marketing channel for fish and seafood products within the Midwest indicated that walleye had high marketing potential as a food fish (Hushak et al. 1992; Hushak 1993). Riepe (1998) found that walleye is one of the top four best selling species for both seafood wholesalers and retailers.

Fillet yield for processed walleye is similar to channel catfish and 10% higher than tilapia. Two 4-oz (113.4-g) portions can be obtained from a 1.25-lb (567-g) fish (Yager and Summerfelt 1996), a size that can be produced in 16–18 months in intensive culture. The organoleptic qualities—those characteristics (aroma, flavor, and texture) that are evaluated by one's senses—of fillets from intensively cultured walleye were found to be as good as that of wild-caught walleye purchased from a market (Yager and Summerfelt 1996).

<u>Aquacultural Technology</u>

The status of walleye culture has been reviewed by Nickum (1978; 1986), Nickum and Stickney (1993), and presented in detail in the Walleye Culture Manual (Summerfelt 1996a). Highlights are given here to clarify cultural systems and their potential.

Cultural systems. Several types of culture systems are used for walleye:

- Pond culture in drainable and undrainable ponds

- Tandem pond to tank culture
- Pond to tank to pond culture
- Cage culture
- Intensive (tank) culture in flow-through and recycle systems

Pond culture in drainable and undrainable ponds. Most walleyes are raised from fry to fingerlings in drainable (Summerfelt et al. 1996) and undrainable ponds (Kinnunen 1996), commonly called extensive culture. State, federal, and provincial agencies typically raise walleye fingerlings in drainable ponds, but most commercial culture in Minnesota, the largest commercial source of walleye fingerlings, are raised in undrainable ponds. Walleyes harvested from ponds 30–50 days after stocking, which is mid-June to early July (total length of 1.25–3.0 in; 32–76 mm), are called "summer fingerlings," or "phase I fingerlings." Fish raised to the end of the growing season (September and October) are called "fall fingerlings" or "phase II fingerlings." In undrainable ponds, fry may be stocked at low initial stock density with the intention of obtaining a single fall harvest, or they may be stocked at a heavier initial stocking density when the plan is to reduce the density in midseason by a partial harvest of phase I fingerlings, and with continued growth of the remaining fish to fall. For grow out to phase II fingerling, substantial quantities of minnows are required (Jorgensen 1996; Raisanen 1996).

Pond culture of phase I and phase II fingerlings has been a viable commercial enterprise for many years at many locations in the Midwest, especially Minnesota. Presently, the entire crop of fingerlings is marketed to individuals, angler groups, lake associations, and public agencies for stocking (Kinnunen 1996). In a 1991 survey of fish producers in the 12 states of the NCR, 16.4% of the 295 respondents reported that they were raising walleye; walleye represented 8% of total gross sales for the region, and ranked fourth of 61 cultured species (Hushak 1993). In the Midwest, where commercial walleye culture is concentrated, about16% of fish farmers responding to a survey were raising walleye; walleye represented 7.9% of US $13.9 million in total gross sales for respondents to the survey (Hushak 1993). In 1992 in Minnesota, over 600,000 walleye fingerlings valued at $328,000 ($0.54/fish) were sold by private growers (MDA 1993).

Inorganic and organic fertilizers are added with the expectation that food webs will provide the right kind and size of zooplankton for first feeding walleye without causing an oxygen depletion, or excessive aquatic weeds. When zooplankton populations are lacking, fish may starve and cannibalism may occur (McIntyre et al. 1987). Insect predation also contributes to fry mortality. Even so, although pond culture is economically effective for the production of large numbers of phase I fingerlings, it may not be the choice for the production of large, phase II fingerlings (≥2.0 in; 50 mm) (Raisanen 1996).

Considerable research on pond fertilization strategies has been published since the Walleye Culture Manual was published (Tice et al. 1996; Soderberg et al. 1997; Soderberg et al. 2000). The findings of these studies corroborate that of early studies by Culver (1991) that demonstrate that frequent applications of liquid nitrogen and phosphorus fertilizers are a less expensive alternative to use of organic fertilizers.

Tandem pond to tank culture. Because it is difficult to raise large numbers of walleye to sizes >3.9 in (100 mm) in ponds without the addition of forage fishes, many public hatcheries raise phase II fingerling by the tandem pond-tank culture method (i.e., extensive-intensive) (Kuipers and Summerfelt

1994; Malison and Held 1996; Nagel 1996b). In this process, pond-raised phase I fingerlings (1.5–2.6 in; 38–65 mm) are transferred to indoor culture tanks and habituated to formulated feed, then raised to 4.9–7.9 in (125–200 mm). Once walleye are habituated to formulated feed, rearing can continue to food-size. A variety of factors have been studied, including stocking density, temperature, light, diet, and feeding frequency (Nickum 1986; Kuipers and Summerfelt 1994; Bristow 1996; Flowers 1996; Malison and Held 1996; Nagel 1996b). In tandem pond-tank culture, substantial mortality typically occurs in the pond (McIntyre et al. 1987), and secondly in the intensive culture system during the first 21-days when fish are habituated to formulated feed (Kuipers and Summerfelt 1994).

Pond to tank to pond culture. There are no published reports describing the habituation of walleye to formulated feed when they are at large in ponds. However, after phase I walleye fingerlings are habituated to feed in hatchery tanks, they have been restocked in ponds and raised on pelleted feed (Nagel 1996a).

Tandem pond to cage culture. Walleye have been cultured in cages placed in water-filled gravel and rock quarries, natural and artificial lakes, and farm ponds (Bergerhouse 1996). Although it is possible to rear walleye from fry to fingerlings in small mesh cages suspended in ponds (Brugge and McQueen 1991), more typically, cage culture is an alternate method for growing summer fingerlings to phase II fall fingerlings, however, temperature constraints to growth of walleye in cages are similar to that of pond culture. Cage culture of walleye may be appropriate for producing 5.9-in (15-cm) fingerlings for stocking lakes or as a “starter” size for commercial farms that grow walleye to food size.

Cage culture is more successful when starting with feed-trained fingerlings rather than it is when it is necessary to habituate pond-raised fingerlings to accept commercial feed (Harder and Summerfelt 1996). Survival during the process of habituating pond-reared walleye in cages has been poor; survival after stocking cages is usually much greater when fingerlings are first habituated to formulated feed before stocking. Thus, cage culture might require a pond-tank-cage sequence. Disease problems have been difficult to treat and grow out to food-size constrained by low environmental temperatures. In Iowa and Minnesota, walleye will not reach market-size as a food fish (1.25 lb; 567 g) until their third summer (Bushman 1996; Stevens 1996).

Intensive (tank) culture. Culture of first-feeding fry to fingerling walleyes in tanks or raceways with single-pass or recycle systems is referred to as intensive culture systems. Twenty years ago, the prospects for intensive culture of walleye fry seemed remote, because of nonfeeding, noninflation of the gas bladder, clinging behavior (larvae cling to tank surfaces), and the interrelationships among these problem areas. Overcoming these problems required a succession of successful problem solving of critical bottlenecks. Intensive fry culture is now a successful production technology to produce walleye fingerlings (Colesante 1996; Moodie and Mathias 1996; Moore 1996; Summerfelt 1996c).

Although no economic comparisons have been made of the cost of pond- versus tank-reared fingerlings, intuitively, intensive culture may be more expensive technology to produce a 2.0-in (50-mm) summer fingerling, but intensive culture is the only technology that can be used to raise fry produced by out-of-season (early) spawning. Fry produced by spawning fish in fall and winter months cannot be stocked in ponds anywhere in the NCR. Pond stocking begins in mid-April in western Nebraska

(Summerfelt et al. 1993), mid- to late April in Ohio (Culver 1996), late April-early May in lower Michigan (Gustafson 1996), early May-early June in North Dakota (Summerfelt et al. 1993), the third week of May in northern Michigan (Wright 1996), and late May-early June in Ontario (Flowers 1996).

Intensive culture has many factors in its favor. Intensive culture is not subjected to variable environmental conditions, temperature can be controlled to enhance growth and growing season lengthened, nuisance aquatic organisms are eliminated, and the quality and quantity of the feed is controlled. In spite of high stocking density, cannibalism may be less of a problem in intensive culture than pond culture because in intensive culture cannibalism is easier to monitor, and should it occur, the environment (temperature, light, turbidity) or feeding rates can be adjusted, and variability in fish size, which is a major cause of cannibalism, can be reduced by grading. In intensive culture, growth rates can be stepped up or slowed by temperature manipulation to meet production schedules for fish of different size.

Fingerlings started from out-of-season spawning and raised in intensive culture may find a special niche for commercial production of feed-trained fingerlings for cage culture and other intensive culture systems. Fingerlings from early spawned fish can be available in advance of young-of-the-year fingerlings produced from ponds or from extensive-intensive culture. Because of the difficulty in habituating pond-raised fingerlings to formulated feed, a commercial source of feed-trained fingerlings is critical for the successful cage culture of walleye to a fall (advanced) fingerling. Disease and cannibalism are less and survival is greater in cages stocked with feed-trained walleye fingerlings than in cages where pond-raised fingerlings had to be habituated to feed (Blazek 1996; Bushman 1996; Harder and Summerfelt 1996).

Walleye may be raised from hatch to food-size in high density, flowing water culture systems. The advantage of intensive culture of fry to fingerling size is that it "closes" the production cycle, in that all aspects of culture from holding brood stock, spawning, and culture to food size can be done indoors. Certainly, fry produced by advancing the spawning season (i.e., in January or February) must be raised indoors; they cannot be stocked in ponds when the ponds are still ice-covered, or at the onset of winter.

In intensive culture, a single interval of high mortality occurs during the critical period when fish switch from yolk-sac nutrition (endogenous feeding) to active feeding (exogenous feeding), which coincides with the interval of gas bladder inflation. The critical interval occurs before the fish reach 21-days post hatch; thereafter, with suitable feeds and appropriate husbandry, fingerlings may be raised to whatever target size is needed, or to the limits of the cultural system, which ever occurs first. In the tandem, pond-tank culture system, mortality occurs in the pond and in tanks during the two-three week interval when fingerlings are habituation to formulated feed.

Processing. Small fish processing facilities are located in many of the 12 states of the NCR. For at least the new producer of food fish, it would be helpful to have a list of processors, the species and size of fish that they purchase, seasonal changes, and the product forms that they market.

<u>Product characteristics</u>. Most walleye purchased by restaurants and wholesalers are of frozen fillets (Table 1). Mostly, walleye are marketed as skin-on fillets. A 4-oz (113.4-g) fillet might be the

smallest product that can be marketed. An 8–10 oz (227–284 g) fillet is the most common size for both restaurants and wholesalers (Table 1). The most common size for whole, fresh walleye is 2.0 lb (0.91 kg). Although Riepe (1998) pointed out that opportunities exist for selling different sizes of products, aquaculturists need to shop around to find buyers willing to accommodate their (i.e., the seller's) preferences regarding product forms and sizes. Restaurants purchase 75% of the walleye fillets they use as frozen product. They primarily purchase their walleye products from seafood wholesalers and food service distributors; seafood wholesalers play a larger role in providing fresh fillets.

Table 1. Fillet sizes (skin-on) and prices purchased by restaurants and wholesalers for fresh and frozen fillets as of July 1996 (all data from Riepe 1998).

	Restaurants[1]		Wholesalers	
Product Form	Percent of firms	Price paid[5]	Percent of firms[6]	Price paid[7]
Fresh fillets	25[2]	$5.94	28.9	$5.27
4–6 oz (113.4–170.1 g)	5[3]	NA	12	NA
6–8 oz (170.1–226.8 g)	24[3]	$4.67	17	NA
8–10 oz (226.8–283.5 g)	33[3]	$6.60	29	$5.83
10–12 oz (283.5–340.2 g)	24[3]	$6.80	17	NA
Other	14[3]	NA	25	NA
Frozen fillets	75[2]	$5.82	51.8	$5.54
4–6 oz (113.4–170.1 g)	20[4]	$6.00	9	NA
6–8 oz (170.1–226.8 g)	11[4]	NA	33	$5.68
8–10 oz (226.8–283.5 g)	27[4]	$6.20	46	$5.71
10–12 oz (283.5–340.2 g)	26[4]	$6.30	7	NA
Other	16[4]	NA	5	$5.03
Fresh, whole/round	NA	NA	19.3	$2.21
1.5 lb (0.68 kg)	NA	NA	19	NA
2 lb (0.91 kg)	NA	NA	62	NA
≥ 3 lb (1.36 kg)	NA	NA	19	NA

[1]Data (percent of firms selling fresh or frozen skin-on walleye fillets) on restaurants from Table 10 (Riepe 1998).
[2]Percent of 80 restaurants that reported use of walleye fillets (Table 10, Riepe 1998).
[3]Percent of 21 restaurants that reported most frequently purchased sizes of fresh walleye fillets (Table 9, Riepe 1998).
[4]Percent of 66 restaurants that reported most frequently purchased sizes of frozen walleye fillets (Table 9, Riepe 1998).
[5]From Table 10, Riepe 1998.
[6]From Table 14, Riepe 1998.
[7]From Table 15, Riepe 1998.

Obviously, market size is of considerable importance for aquaculture because the smaller the market size, the less time it takes to raise a fish, which means the shorter the turnover time (i.e., residence time) of the stock in the culture system. The minimum size for the current market seems to be a 4-oz (113.4-g) fillet. With a 45% dress-out yield, a fish that will yield two 4-oz (113.4-g) fillets would be at least 1.1 lb (500 g); and a dress-out yield of 40% would require a fish of 1.25 lb (567 g) to yield two 4-oz (113.4-g) fillets. At present, only a small percentage of walleye are purchased by restaurants in the 4-oz (113.4-g) fillet size. If walleye can be marketed in a smaller portion size as a product called "pan-sized walleye," or "petite walleye," ("little walleye"), the time required to grow walleye from hatch to market size can be reduced. Fish size in Riepe's (1998) study may be as much a reflection of the size available to the market, as well as comparative prices for fish of different sizes.

The definition of a minimum food-size walleye (10 in; 25.4 cm minimum) used in objectives 1a and 1b of the current NCRAC project is much smaller than would be needed to produce the size of fillets that are purchased by restaurants and wholesalers (Table 1). The minimum size for the current market seems to be a 4-oz (113.4-g) fillet. The 4–6 oz (113.4–170.1 g) fresh fillet size is purchased by only 5% of the restaurants and 12% of the wholesalers. A 10-in (25.4-cm) walleye will weigh about 0.3 lb (136.1 g) and even a 35 cm (about 14-in) walleye, the maximum size they plan to raise, would weigh only 0.8 lb (0.4 kg). If walleyes 10–14-in (25.4–35.6-cm) are to become the production goal, then market testing will be required to determine the acceptability of such a small fillet.

Live-dressed weight relationships of walleye and hybrid walleye have been reported by Summerfelt et al. (1996). The yield of skin-on fillets was 44.4% and 44.5% for males and 41.0 and 39.3% for females of the 1987 and 1988 cohorts, respectively, of walleye from Spirit Lake, Iowa. Rock Lake walleye and hybrid walleye had slightly lower yields. Differences in head weight account for the gender differences in yield of skin-on fillets, the head weight of males is less than head weight of female fish from Spirit Lake, Iowa. One of the surprising findings was that fish size (length or weight) did not account for more than 10% of the variability in fillet yield, however, the largest fish in that analysis was less than 1.1 lb (500 g).

Economics and Business Planning. Economic feasibility is an essential component of a business plan. Information desired for a business plan includes demand, production potential (supply), system costs, production costs, processing costs, markets, and financing (Garling 1992). O'Rourke (1996) described analytical methods to evaluate the potential economic viability of a current or planned walleye aquaculture enterprise. In the example given by O'Rourke for a fingerling production facility, a market price of $0.72 for a 6-in (15.2-cm) fingerling walleye gave a calculated net profit with a discount rate of 15%.

CRITICAL LIMITING FACTORS AND RESEARCH AND OUTREACH NEEDS

MARKETING RESEARCH

Marketing plans are needed for all life stage of walleye — eggs, fry, fingerlings and food-size fish. At this time, the larger portion of all commercial walleye producers market their product for sportfish enhancement, which are sold as fingerlings to lake owners, lake associations, angler/sportsman clubs, city and county parks, and some state agencies. There is a lack of information on these market outlets. Research is needed to define the current and potential size of this market, location, preference as to fish size, season, elasticity of price, and constraints to growth. However, the major constraint for this market is regulatory issues related to stocking hatchery-produced fish, which is a major issue in fisheries management. Genetics and fisheries personnel are very concerned that offspring of hatchery produced fish will mate with wild stock and that the introgression of hatchery produced fish will "jeopardize the long-term sustainability of walleye populations" (Kapuscinski et al. 1996).

Another market for fry and fingerling fish is for the aquaculture industry. Not all producers of fingerlings have facilities or interest in spawning and incubating eggs and few producers have learned to habituate pond-reared fingerlings to formulated feed. "Feed trained" fingerlings could be sold to other producers who might grow out walleye in cages or tank culture. Fewer still are producers who can intensively (i.e., tank culture) culture walleye fry to fingerlings.

A specialty market might exist for small fingerlings for pet trade, and a market for subadult and adult fish for the numerous public and private aquaria.

NCRAC has supported research on marketing seafood to restaurants (Riepe 1999a) and supermarkets (Riepe 1999b). Supermarkets (grocery stores with $2 million or more in annual sales) account for about one-third of consumer expenditures on seafood, and foodservice outlets (primarily restaurants) accounted for most of the other two-thirds. "Understanding the flow of seafood products through marketing channels is important for understanding where and how to market aquaculture products" (Riepe 1999b). Based on the percent of firm type that sold walleye in 1996, marketing efforts could begin with seafood wholesalers and retailers as 98% of these wholesalers and 95% of the seafood retailers marketed fresh and/or frozen fish. Only 16% of grocery wholesalers and 40% of foodservice distributors marketed fresh and/or frozen fish.

However, the problem at this point is not market and market demand but a lack of commercially produced food-size fish. Riepe (1996b) suggests "that farm-raised walleye marketing efforts would be most likely to meet with success in Minnesota and Michigan, followed by Wisconsin and Ohio, and trailed by Illinois and Indiana." Obviously, all of these states have a Great Lakes border, but comparable marketing effort may achieve similar success in the other states of the NCR.

BIOLOGICAL AND TECHNOLOGICAL RESEARCH

Development of Domesticated Brood Stock, Genetic Selection, and Use of Hybrids

There is a major need to utilize traditional methods (not genetic engineering) of genetic selection for shortening the time to produce a market size fish (i.e., to improve growth rates) for stock that is to be grown to food-size in the farm environment. Poultry production is highly efficient, with a five- or six-week period to grow a chick to market-size broiler. Eighty percent of the increase in growth rates of broiler chickens is attributed to genetic gains, only 20% to improved nutrition (Hardy 1997). The role of nutrition is "…to formulate feeds that exploit the growth potential of the fish and achieve maximum return for the fish farmer" (Hardy 1997).

Gains from selection are accumulated over generations of selection, but it may not require many generations to obtain substantial improvement. Some examples are worth noting. In Norwegian Atlantic salmon breeding, growth increases have ranged from 14–30% gain per generation (Kinghorn 1983). A 60% improvement in weight at harvest, a period of eight months of saltwater rearing, was obtained after the first four generations of a high level of selection intensity in the Domsea coho salmon brood stock program (Meyers et al. 1999). NRCAC sponsored research has demonstrated high heritability values for walleye length- and weight-at-age (Kapuscinski et al. 1996). Summerfelt and Bristow (1994) created 12 pedigreed families of full-sib walleye from the Mississippi River stock. Hatchability differences ranged from 40 to 80%, and significant differences in fish size were observed among 42- and 84-day-old fingerlings of different families. Correlation among the factors indicated that cannibalism may be reduced by selective breeding and that selection for faster growth should not increase the incidence of cannibalism.

A captive-breeding program can benefit by selecting the founder stock from the best sources. A haphazard choice of founder stock may seriously limit the potential gains from the breeding program (Kapuscinski et al. 1996) that have been demonstrated to show superior performance characteristics. Molecular (genetic) markers (allozymes and mtDNA haplotypes) are widely used to estimate the percentage contributions of source populations to stock that is a mixture of sources (McParland et al. 1999). Although there is considerable variation in mtDNA haplotypes within and among walleye populations, there is recognition of genetically distinct stocks of walleye across the U.S. and Canada (Billington and Hebert 1991; Billington et al. 1990, 1992; Billington 1996). Studies on stock performance coupled with use of allozymes and mtDNA haplotypes may provide molecular fingerprint of desirable stocks.

Although genetic improvement through selective breeding may be highly desirable for production of food-size fish, there is considerable concern about the intentional release or escape of "hatchery fish." This concern also applies to stock transfers, which implies criticism of the sale and distribution of fry and fingerlings across state lines. Kapuscinski et al. (1996) warned of this concern, and recently Philipp et al. (2000), on behalf of the Genetics Section of the American Fisheries Society, has proposed that AFS adopt a position statement opposing the transfer of native stocks of aquatic organisms among North American waters by public agencies and the private sector. They contend that stock transfers (i.e., such as the sale and distribution of fish across the NCR) threaten the genetic integrity of local stocks, which have been acquired as a result of the evolutionary processes that lead to differentiation and adaptation. Culver (D. Culver, Ohio State University, Columbus, personal communication) expressed similar concern. He suggested that NCRAC's research should be conducted in a manner that will minimize impacts on the genetic diversity of native percid stocks, and that neither walleye nor hybrid walleye (saugeye) should be stocked in waters that have native walleye or sauger populations.

There is also concern over escapement of walleye from fish farms, especially when the walleye are developed from genetic selection for fast growth in aquaculture environments. Fish farms can only counter this issue by developing effective security systems to prevent escape and by use of sterile triploid fish. Because hybrid walleye show desirable characteristics for aquaculture (Siegwarth and Summerfelt 1990, 1992, 1993; Malison and Held 1996), NCRAC's current walleye project is focusing on field trials for the production of hybrid walleye. Unfortunately, adult hybrid walleye are fertile, and they may cross with native stocks of walleye or sauger (Fiss et al. 1997). For this reason, production of sterile, triploid hybrid walleye should receive further study to prevent the problem of hybrids contaminating parental stocks (Garcia-Abiado et al. 1999). If government regulators can be convinced that triploid hybrid walleye are sterile and if the triploids have similar growth rates to diploid hybrids, they may be used to overcome the opposition to stock transfers for stocking ponds and lakes, and the triploids may be useful in aquaculture as well because they can overcome concerns about escapement of fish from fish farms. The University of Wisconsin-Madison has undertaken research to evaluate growth of sterile triploid walleye in ponds and tanks with a recycle system (Weil 1999).

Walleye Culture in Recycle Systems

Even with genetic selection, the northern part NCR has a short growing season, which would slow growth walleye raised in ponds or cages. Stevens (1996), an early pioneer in cage culture of walleye and entrepreneur in the commercial production of food-size walleye, raised walleye to 1.5–2.0 lb (0.68–0.91 kg) in cages. However, because of the relatively short growing season for fish in southern Iowa where his culture site was located, the fish did not reach market size until the middle to latter part of the third year and the enterprise was not economically viable. Bushman (1996) concluded that because of the short growing season, cage culture of walleye in ponds in northeast Iowa would be unprofitable.

Therefore, a critical limiting factor in the NCR is experience with walleye culture in recycle systems, especially state-of-the-art recycle systems. Recycle culture systems offer the same advantages for walleye as any other species; that is, controlled water temperature, a 12-month growing season; low water requirements relative to production capabilities; a small volume of concentrated waste; and the ability to locate a facility close to major markets. In recycle culture, fish are stocked at high densities, raised on pelleted feeds, and there is an intentional effort to minimize the use of new water to $\leq$5% or less of total system volume per day. The effluent from the culture tanks can undergo several treatment processes before it is returned to the culture tank: clarification to remove solids; nitrification (biofiltration) to convert ammonia to nitrate; reaeration or reoxygenation; and disinfection by ozone (Summerfelt 1996d).

Recycle systems can be used to culture walleye anywhere in North America, because the volume of water used is typically $\leq$5% of the water requirements needed for a single-pass system. If water needs to be heated to obtain the desirable temperature for growth, it must be reused if it is to be economic. Hushak's (1993) survey of fish producers in the NCR indicated that 89% used ponds, but a surprising 14% used some form of recycle system to produce a variety of fishes. There are recycle culture facilities in the Midwest and elsewhere that raise food-size rainbow trout, tilapia, hybrid striped bass, and others. Moodie and Mathias (1996) reported on intensive culture of walleye in a recycle culture system at a site near Winnipeg, Canada. Summerfelt (1996d) provides design criteria for large-scale recycle system for walleye culture. Pond-raised, phase I fingerling walleyes 84-days old have been raised to 1.25 lb (567 g) in 14–16 months in 264.2-gal (1,000-L) in circular tanks in a recycle system at a temperature of 73.4°F (23°C) (Summerfelt and Summerfelt 1996).

Only two studies have reported grow out of walleye to food-size or near-food size. Summerfelt and Summerfelt (1996) described grow out of walleyes from 3.4 in (87 mm) long and 0.2 oz (5.0 g), to an average of 13.5 in (342.5 mm) and 12.1 oz (342 g) at 368 days post hatch. An extrapolation of their growth curve indicates that walleyes would be 1.25 lb (567 g) by 410 days (13.5 months) for the largest 20% of the population but 480 days (15.8 months) would be needed for the average fish to reach the same size. Siegwarth and Summerfelt (1993) described growth models for walleyes and walleye-sauger hybrids reared for 783 days post hatch in intensive culture. They found that before about 700 day for length and 625 day for weight, the hybrids grew faster, after which growth rates of walleyes exceeded those of hybrids.

Information is needed on optimal temperature, carrying capacity, tolerance to ammonia, nitrite, and carbon dioxide, and chemical variables that are typically high in recycle systems. Also, and of major concern, is disease problems in recycle system and effects of chemotherapeutics on the biofilter.

In the current walleye project, which started September 1, 1999, recycle systems are used in objective 1a to "Carry out commercial-scale field trials for rearing hybrid walleye fingerlings to food size (25.4 cm [10 in] minimum) in tanks." Hybrid walleye will be reared from fingerlings to food-size in recycle systems capable of maintaining a 77.0°F (25.0°C) water temperature in Ohio (Freshwater Farms of Ohio) and Wisconsin (University of Wisconsin-Madison).

Optimizing fish stocking and harvesting strategies can maximize production per unit system volume maintain the culture system at or near its biomass capacity — and also increase product value by providing uniformly sized fish for the market (Summerfelt et al. 1993; Hankins et al. 1995). There are three main methods for stocking and harvesting fish that can be used to accomplish these goals: batch culture (BC); concurrent batch stocking and harvesting (CBSH); and concurrent mixed-stocking and graded harvesting (CMSGH) (Summerfelt et al. 1993; Hankins et al. 1995). It is easier to understand these procedures if one visualizes a facility with many culture tanks, perhaps 12 or more. BC is the practice of stocking all tanks in the facility at the same time with fish of the same age. Because growth rate of fish in separate tanks is about the same, fish in all tanks are harvested when the average fish reaches market size. This results in a large harvest in a relatively short interval. The sub-market-size fish that are graded out during harvest may be placed in one or a few tanks and retained 1–2 months longer to raise them to market size. Then the process is repeated with another group of fish. The advantage of BC is that stocking and harvest are done infrequently, and feed types and sizes are similar for all tanks throughout the production cycle. In BC, the system's overall production is equal to the maximum biomass obtained at harvest, and it can be predicted by applying growth models which account for temperature, food, and size of fish (Ricker 1979; From and Rasmussen 1984; Hewett and Johnson 1987; Bjørndal 1988). However, in the course of a production cycle, average fish density is about half the carrying capacity, thus annual production from the facility is about half that which can be obtained using the other two strategies and it does not provide a steady supply of fish for the market (Summerfelt et al. 1993).

CBSH uses the production capacity more efficiently because it uses one or several tanks of a multiple tank facility for fish of different ages. It is like the BC system except that each batch of fish is cultured in one or a few of the total number of tanks in the culture system. It requires the availability of small fish year-around for restocking. CBSH procedure involves three steps: (1) one or several tanks within a facility that has many tanks are stocked with fish of similar size; (2) fish in each group of tanks are cultured independently of fish in the other tanks until the average size within a tank reaches market size; and (3) harvesting all fish in each tank when mean length reaches market size. Advantages of CBSH are continuous operation at or near the carrying capacity of the facility, and continuous stocking and harvest (Watten 1992). Disadvantages of CBSH are frequent stocking and harvest, and additional costs for keeping several feed sizes on hand at all times, and increased labor costs to inventory and culture several size groups at the same time. If a supply of fingerlings can be obtained year round, the CBSH strategy would probably be most effective method used to produce walleye.

The CMSGH procedure involves stocking and culture of fish of different sizes together in the same tank, which is the procedure used for rainbow trout at the Freshwater Institute's recycle facility, and continuous harvest of the market-sized fish by frequent grading. CMSGH would not be suitable for walleye because the larger cohorts of walleye would probably eat smaller, newly stocked fish. Frequent grading also places stress on the fish that can affect growth and incidence of disease.

Economic analysis of walleye culture in recycle systems for the production of fingerling walleyes is reported by Edon (1994) and Makowiecki (1995), however, these master's theses (Illinois State University) were not available for review.

<u>Disease Diagnosis, Prevention, and Treatment</u>

In all fish culture, disease claims a part of the stock each year, and a serious epizootic may claim a major part of the stock at a given time. Pond-reared fingerlings that are harvested after their food supply has sharply diminished (zooplankton "crashed") or that are harvested and roughly handled at high (i.e., $\geq$68°F; 20°C) water temperatures succumb quickly to columnaris disease when they are stocked in tanks or cages (Harding and Summerfelt 1993; Horner 1996). There is a general understanding that prevention is an essential component (Horner 1996), but a critical limiting factor is lack of infrastructure within the region that can provide growers with a prompt response for disease diagnosis and treatment. Walleye culture, as with that of other newly emerging species, lacks registered chemotherapeutants for bacterial diseases. Salt (NaCl) and temperature control has been used for columnaris disease, but walleye have been found to be unusually sensitive to hydrogen peroxide (Clayton and Summerfelt 1996).

<u>Regulatory Constraints</u>

A variety of laws affect water use, zoning of agricultural enterprises, environmental laws on pollution discharge or disposal, permits, and constraints by the fish and game agencies on the purchase, transport, and marketing of walleye are critical constraints. There are restrictions by EPA and FDA on use of drugs and treatment. Some regulations, such as use of chemotherapeutics, are uniformly applied throughout the NCR, but some regulations differ from state to state.

SUMMARY OF RESEARCH AND EXTENSION PRIORITIES

(Not in rank order)

MARKETING

- Fingerling Walleyes for Stocking
    - Develop lists of angler groups, sportsman's clubs, lake associations, and government agencies (city, county, and state) that purchase or potentially purchase walleye for stocking.
    - Develop marketing information on preferred sizes, numbers, prices, and seasonal demand of walleye sold for stocking.
    - Summarize regulations regarding interstate transfer of walleye and other fish used for stocking, and determine whether regulatory agencies (i.e., state fish and game agencies) will permit use of sterile walleye and hybrid walleye for stocking.

- Food-Size Walleye

- Do no further market studies for food-size walleye at this time. Riepe's (1998) report and the current marketing study provide sufficient marketing information for food-size walleye at this time.

BIOLOGY AND CULTURAL TECHNOLOGY

- Develop a research program for production and harvest strategies for raising walleye fingerlings in undrainable ponds.
- Inventory heated water resources (heated water effluents from steam-electric generating plants and alcohol production facilities) in the North Central Region.
- Prepare a white paper on the potentials and problems of heated water aquaculture for the North Central Region.
- Nutrition and diets
  - Evaluate krill hydrolysate (KH) coated feed for habituating pond-reared walleye to formulated feed.
  - Evaluate commercial diets using walleye grower (WG 9206) as reference diet for juvenile walleye.
- Genetic improvement
  - Research is needed to develop domesticated strains of walleye that have faster growth rates and that are better adapted for aquaculture. Commercial sources of genetically selected walleye are needed to shorten the culture interval between egg and market size fish.
  - Research is needed on methods to cryopreserve walleye sauger semen to produce interspecific hybrids and to evaluate geographically and genetically distinct stocks of walleye.
- Triploid walleye
  - Research is needed on the methods for production and evaluation of the growth and sterility of triploid walleye and hybrid walleye.
- Disease identification and control
  - NCRAC should sponsor a white paper on "Infectious diseases of walleye, their prevention and treatment," including EPA and FDA regulations on use of chemotherapeutants.
- Regulatory constraints
  - Sponsor a white paper on regulatory constraints that affect production, transport, and marketing of walleye.

EXTENSION

- Develop extension literature on disease diagnosis and treatment of walleye and hybrid walleye including up to date information on regulatory status of chemotherapeutants.
- Develop fact sheet from previously funded NCRAC research on procedures to habituate fingerlings to formulated feed in ponds.
- Conduct workshops on pond and intensive culture of fingerling walleye and intensive culture of food-size walleye.

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