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

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TABLE OF CONTENTS

INTRODUCTION AND JUSTIFICATION OF THE DOCUMENT

Baitfish grown in many states in the North Central Region (NCR) contribute significantly to aquaculture in the region. Each year priority research areas are identified by the North Central Regional Aquaculture Center (NCRAC) Industry Advisory Council and presented in consultation with the Technical Committee to the NCRAC Board of Directors. Concern has emanated from among the various NCRAC constituencies that network plans could potentially lose focus over time and not always address the most critical factors limiting the economical and sustainable production of important species in the region. After discussions were held among members of the various committees and the Board at its 1999 annual meeting, it was decided that a white paper should be developed on baitfish. The Board directed that the paper not be an exhaustive literature review, but rather a working document that clearly defines the current status of baitfish aquaculture, critical factors limiting its economical and sustainable commercial production, and recommendations concerning the research that should be considered in future work plans. It is recognized that this will be a "living document" in that priorities may change based on new developments, new problems encountered, or other externalities. Industry participation and peer reviews are critical components of the process.

CURRENT STATUS OF BAITFISH AQUACULTURE

BAITFISH PRODUCTION IN THE NCR

Baitfish production in the NCR is an important component of the aquaculture industry, yet it is extremely diverse in market demand, type of production, and species sold. The amount of baitfish produced varies greatly from state to state within the NCR. Current and accurate estimates of production and value of baitfish in the U.S. and the NCR are not available. The lack of accurate production estimates is the result of inconsistencies in reporting, different methods of reporting (i.e., gallons, dozens, pounds), use of different common names for the same species across the region, and difficulty in separating cultured baitfish from wild harvested baitfish.

Separating wild harvest of baitfish from aquaculture can be difficult. Baitfish that were "hatched in a hatchery or otherwise nurtured beyond simple collection and distribution" has been used to distinguish between cultured baitfish and wild harvested baitfish. Therefore, white suckers (*Catostomus commersoni*) that are hatched from the gametes of wild caught adults and released into natural ponds to fend for themselves until they are harvested are generally considered a cultured baitfish. Suckers harvested from lakes and rivers not stocked with sucker fry are considered to be wild harvested baitfish. However, wild caught suckers that are stocked into ponds and overwintered with the use of aeration and some feeding may be reported as cultured baitfish. Fathead minnows (*Pimephales promelas*) are harvested from many natural ponds leased from landowners in northern NCR states with almost no attempts to nurture them except to keep other fish species out of the pond or hold and possibly feed wild harvested fatheads in aerated ponds. These fish are, however, sometimes reported as cultured (Minnesota Aquaculture Report 1996; U.S. Department of Agriculture 2000). Similarly, golden shiners (*Notemigonus crysoleucas*) may be introduced to a natural pond but not nurtured beyond simple collection and distribution, yet they may be reported as cultured because the pond was dedicated to golden shiner production. Hence, no standard method for distinguishing between wild harvested and cultured baitfish exists.

Another difficulty in accurately calculating baitfish production is in determining which species are being reported on industry surveys. For example, in different areas of the NCR the term "chub" can refer to fathead minnows, creek chubs (*Semotilus atromaculatus*), hornyhead chubs (*Nocomis biguttatus*), finescale dace (*Phoxinus neogaeus*), or white suckers. Similarly, the term "shiner" can refer to the spottail shiner (*Notropis hudsonius*), common shiner (*Luxilus cornutis*), emerald shiner (*N. atherinoides*), river shiner (*N. blennius*), sand shiner (*N. stramineus*), golden shiner, or other cyprinids. Across the NCR, fathead minnows are known as fatheads, tuffy minnows, blackhead minnows, chubs, blacks, rosy reds, crappie minnows, and just plain "minnows."

Some estimates of baitfish production have been made. For example, it was reported that cultured baitfish ranked third in sales for the U.S. aquaculture industry (Mittelmark et al. 1993). More recent information (1996) indicates that the baitfish industry ($56 million) in the U.S. is the fourth largest aquaculture industry based on dollar sales behind catfish ($417 million), salmon ($82 million), and trout ($72 million) (S. Weber, Lonoke Agricultural Center, Lonoke, Arkansas, personal communication). In 1991, conservative estimates of reported annual sales of wild harvested and cultured baitfish indicate that this industry was worth in excess of $367 million to just nine U.S. states (Arkansas, Colorado, Kansas, Minnesota, Nebraska, Ohio, Vermont, West Virginia, and Wyoming) and $29 million to one Canadian province (Ontario). The combined U.S. and Canadian industry, therefore, is estimated to be worth at least $1 billion annually (Litvak and Mandrak 1993).

The 1998 Census of Aquaculture (U.S. Department of Agriculture 2000) reported that the value of cultured baitfish in the U.S. was $37.5 million, which ranked fourth behind catfish ($450 million), salmon ($103.9 million), and trout ($72.5 million). Of U.S. cultured baitfish, golden shiners led sales ($18.1 million), followed by feeder goldfish (*Carassius auratus*) ($9.3 million), fathead minnows ($7.4 million), and other baitfish ($2.7 million). The NCR ($6.4 million) was second only to the Southern Region ($27.1 million) in cultured baitfish production. Within the NCR, Wisconsin led cultured baitfish sales ($2.5 million), followed by Minnesota and Missouri ($0.82 million), Ohio ($0.54 million), and Illinois ($0.31 million). For the 1998 Census of Aquaculture (U.S. Department of Agriculture 2000), an aquaculture farm was defined as any commercial or noncommercial place from which $1,000 or more of aquaculture products were sold or normally would have been sold during the census year. They did not, however, define aquaculture products. As a result, there appear to be discrepancies in baitfish production reported in this survey, compared to other surveys. In addition, the 1998 Census of Aquaculture includes feeder goldfish as a component of baitfish. Some goldfish enter the baitfish market, but a large part of the production is used for feeding aquarium and pond fish and do not constitute baitfish production.

Hushak (1993) reported that baitfish sales ($1.89 million) ranked third behind salmonids ($6.18 million) and catfish ($2.59 million) in the NCR. Minnesota reported the highest gross sales ($1.42 million), followed by Missouri ($0.31 million), and Wisconsin ($0.14 million). The combined gross sales of the seven other NCR states surveyed by Hushak (1993) were only $27,000. In 1996, the Minnesota Department of Agriculture estimated that 56 growers reported sales of 160,000 gal (1.3 million lb; 589,680 kg) of bait worth $1.7 million (Minnesota Aquaculture Report 1996). Meronek et al. (1997a) estimated that the total value (wholesale plus retail) of baitfish sales resulting from both wild harvest and aquaculture in the six states they

surveyed (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) was $162 million. They were not able to separate estimates of wild harvested baitfish from cultured baitfish.

Meronek et al. (1997b) reported in their survey of six NCR states that fathead minnows were sold in the highest volume (2.4 million lb; 1.09 million kg) followed by lake shiners (spottail, emerald, and sand shiners) (0.8 million lb; 0.36 million kg), white suckers (0.6 million lb; 0.27 million kg), golden shiners (0.3 million lb; 0.14 million kg), and chubs (0.2 million lb; 0.09 million kg). The sales volume of other species such as central mudminnows (*Umbra limi*) (14,000 lb; 6,350 kg), river shiners (77,000 lb; 34,927 kg), rosy red variety of fathead minnows (7,500 lb; 3,402 kg), dace (11,000 lb; 4,990 kg), and mixed species (6,000 lb; 2,722 kg) were much lower. They estimated that over 4.4 million lb (2.00 million kg) of baitfish were sold in the six states. According to their survey, Minnesota led in the sale of fathead minnows, white suckers, and chubs. Michigan had the highest sales of lake shiners and Illinois had the highest sales of golden shiners (see Table 2 in Meronek et al. 1997b).

BAITFISH MARKET DEMAND

The three primary baitfish species cultured in the NCR are the fathead minnow (including the rosy red variation), the white sucker, and the golden shiner. Goldfish, hornyhead chubs, creek chubs, central mudminnows, green sunfish (*Lepomis cyanellus*), and dace (*Phoxinus eos, P. neogaeus*, and/or *Margariscus margarita*) are also cultured in the NCR, but are more limited in production and distribution. The demand for baitfish in the NCR far exceeds the supply from within the region. To meet the demand, cultured fatheads (including the rosy red variation), golden shiners, and goldfish from Arkansas are imported into the NCR. Still, significant shortages of a variety of species (including the three primary NCR aquacultured species) were reported by bait dealers (Meronek et al. 1997b). Baitfish reported in short supply during various times of the year were large fathead minnows, lake shiners (primarily emerald, spottail, and sand shiners), white suckers, golden shiners, chubs (hornyhead and creek), dace (finescale and pearl), and goldfish. The information regarding baitfish shortages below comes from a survey of six NCR states (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) conducted by Meronek (1994) and also reported by Meronek et al. (1997b).

The shortage of fathead minnows in the six states surveyed by Meronek (1994) occurs in March and April when lakes containing fathead minnows are still ice-covered. Some wholesalers seine their holding ponds underneath the ice or purchase fathead minnows from southern states. At times, the shortages are size-related with not enough large fathead minnows available. The November to March shortage in South Dakota suggests those dealers rely heavily on bait that they harvest from the wild and do not harvest bait from under the ice.

White suckers were mainly in short supply in Minnesota from May to August. In Michigan, shortages occurred throughout the summer, but were greatest in December and January. A small percentage of Wisconsin and Illinois bait retailers experienced white sucker supply shortages from March to September.

The peak of golden shiner shortages occurred in August. Of the six states surveyed, Minnesota reported the largest shortage, probably due to baitfish import restrictions. Shortages through most of the year in Minnesota, Michigan, and Wisconsin probably result from the popularity of golden shiners. Shortages of golden shiners in summer also reflect transportation

problems; many wholesale dealers stop hauling golden shiners from Arkansas because of high mortality rates associated with handling golden shiners during periods of warm water (greater than 75°F; 24°C).

Demand exceeded availability for other species occasionally cultured in the NCR. Dace were in short supply from June to August primarily for bait dealers in Michigan and Minnesota. The finescale dace and pearl dace were probably the two dace species that constituted most of the reported shortage. These species are sold together under the name rainbow chubs. The northern redbelly dace was probably not part of the shortage reported for dace.

The rosy red minnow is a cultured red variation of the fathead minnow available from aquaculturists primarily in Arkansas, although some rosy reds are produced in portions of the NCR. Rosy reds were reported in short supply at various times of the year in Illinois, Michigan, and Minnesota.

Illinois and Wisconsin bait dealers reported shortages for central mudminnows from July to September. A few Minnesota bait dealers reported a shortage of central mudminnows throughout the year. Because central mudminnows have a limited wild harvest, retailers in the NCR did not commonly sell them. However, some efforts have been made to culture this baitfish based on its local demand.

Seasonal shortages of emerald shiners occur frequently in late spring and autumn along Lake Erie. This is caused sometimes by population size fluctuations and other times by erratic distribution of emerald shiners. The shortages cause periodic demands for imported golden shiners, and less frequently, for imported fathead minnows for fishing on Lake Erie (F. Snyder, Ohio Sea Grant, Port Clinton, personal communication).

Appropriately sized and colored goldfish were reported in short supply during June to August in Ohio. The market demand is for 3–5 in (76–127 mm) brightly colored goldfish, however, goldfish during June to August are smaller and darker in color (T. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication).

Meronek (1994) asked bait retailers and wholesalers if demand for bait or availability of baitfish was changing. While responses varied by state and for the two groups (retailers and wholesalers), about 50% of both groups felt that demand was constant. The other 50% were fairly evenly split between demand increasing and demand decreasing. When asked about changes in availability, retailers and wholesalers did not agree as closely. A majority (60%) of retailers felt that availability was constant while nearly half (47%) of the wholesalers felt that availability was declining. Those wholesalers who had the opinion that baitfish availability was declining were greatest in the states of Michigan (72%) and South Dakota (67%).

BAITFISH PRICES

Prices of baitfish vary by species, time of year, state, and production method (wild harvest versus culture). Of the three main species cultured in the NCR, golden shiners generally command the highest price, followed by white suckers, and fathead minnows. The wholesale price for golden shiners in Minnesota in 1992 was reported at $3.20/lb ($7.05/kg) (Minnesota Aquaculture Report 1993). The 1999 pond-side price of farm-raised Arkansas golden shiners

was $3.25/lb ($7.16/kg), but the wholesale price reported in Kansas City and southwest Ohio was $7.00/lb ($15.43/kg) (J. Keller, Keller's Bait and Fish Farm, Buckner, Missouri and M. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication).

Wholesale prices of white suckers in the 1992 Minnesota survey averaged $1.25/lb ($2.75/kg) but sometimes exceeded $2.50/lb ($5.51/kg). The price of white suckers in Wisconsin was also reported to average about $1.25/lb ($2.75/kg) with increases to $2.25–$2.50/lb ($4.96–$5.51/kg) when demand was high and supply was down (D. Gollon, Jr., Gollon Bait and Fish Farm, Dodgeville, Wisconsin, personal communication). The wholesale price paid by baitfish retail outlets in states where white suckers are not produced is around $5.50–$6.00/lb ($12.13–$13.23/kg) (A. Kirchner, Curtis Fisheries, Martinsville, Indiana and T. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication).

Across the NCR, the wholesale prices of fathead minnows vary considerably. For example, in 1999 an Illinois fish producer sold fathead minnows for $4.50/lb ($9.92/kg), but sold them for stocking into ponds for forage. He couldn't compete with the wholesale price for wild harvested fatheads (from Minnesota or Wisconsin) sold as baitfish (G. Opel, Opel's Fish Hatchery, Worden, Illinois, personal communication). In Ohio, the wholesale price of wild caught fathead minnows (from Minnesota or Wisconsin) was $5.00–$6.00/lb ($11.02–$13.23/kg) (M. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication). Even though cultured fathead minnows from Arkansas, called tuffies, are considered hardier and are free of other fish, e.g., sticklebacks (*Pungitius pungitius*) and bullheads (*Ameiurus* spp.), most bait shops in Ohio prefer the cheaper wild fathead minnows. Pond-side price of farm-raised fathead minnows in Arkansas was $2.75/lb ($6.06/kg) in 1998. A wholesale price for South Dakota wild harvested fathead minnows as low as $0.50/lb ($1.10/kg) was reported in 1999 (D. Schmeisser, Centre Fisheries, Sauk Centre, Minnesota, personal communication). Fathead minnow wholesale prices averaged $0.62/lb ($1.37/kg) in Minnesota in 1992 (Minnesota Aquaculture Report 1993).

Because of high local demand, wholesale prices higher than $10.00/lb ($22.05/kg) have been reported for some baitfish species that are not generally cultured in the NCR. Hornyhead chubs (known to the bait industry as redtail chubs), tadpole madtoms (*Noturus gyrinus*, known as willow cats along the Mississippi River), central mudminnows, and creek chubs are examples of these locally high value baitfish. Wholesale price for goldfish (generally used for catfish trotline bait), which primarily come from Arkansas, Louisiana, and Missouri, is about $7.00/lb ($15.43/kg) in the NCR. Pond-side in Arkansas, goldfish sold for $3.00/lb ($6.61/kg) in 1998.

The retail price per pound of baitfish can be difficult to estimate because baitfish are sold by the dozen and often more than a dozen are given to the customer. For example, three dozen fathead minnows were purchased from bait shops around Minnesota. The actual number of fish in 35 purchases (of three dozen each) averaged nearly 12 dozen and ranged from 6 to 26 dozen (unpublished data). The retail price of small fathead minnows (740/lb; 336/kg), therefore, is estimated at $23.00/lb ($50.71/kg) based on a per dozen cost of $1.50. The actual number of baitfish received approaches the number purchased for baitfish that are larger and more expensive than fathead minnows. Because of the high demand for hornyhead chubs in areas of Minnesota, retail outlets usually only give customers the number they order. Therefore, an estimate of the retail price of medium sized hornyhead chubs (57/lb; 26/kg) is $28.50/lb ($62.83/kg) based on a per dozen cost of $6.00. The retail price for 4–6 in (102–152 mm) hornynosed chub (probably *Nocomis biguttatus* or *Semotilus atromaculatus*) in Ohio was

reported to be $12.00 per dozen (M. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication). (For information on the number of fish per pound by species and size, see Table 1 in Meronek et al. 1997b.)

GENERALIZED BAITFISH CULTURE TECHNIQUES USED IN THE NCR

White Suckers

Suckers rarely spawn in ponds and must be stocked as eggs or most often as fry. Sucker fry can be obtained by stripping ripe fish during the spring spawning runs that occur in most streams between mid-April and the end of June and then hatching the eggs. The stripping of eggs and milt from suckers is fairly simple (Dobie 1972) and follows standard procedures. Similar to walleye (*Stizostedion vitreum*) eggs, the fertilized eggs are adhesive and must be placed into a slurry of bentonite clay to prevent them from sticking together and clumping (Malison and Held 1996). Eggs are incubated in jars receiving a flow of water that gently agitates the eggs. When the water flow is properly regulated, dead eggs will flow to the surface and be carried out of the jar while the live eggs remain in the lower portion of the jar. The entire mass of eggs is kept in motion by a slow, gentle rolling action produced by the water coming in at the bottom of the jar. Ponds can be used as a source of water, which can be piped to the hatching unit. Eggs will hatch in 10–15 days at water temperatures of 50–60°F (10–16°C). When fry hatch, they swim up and flow out of the hatching jar. They collect in tanks were they can be scooped out with a fine meshed screen and their volume measured. There are approximately 85,000 fry/qt (80,440 fry/L). The sucker fry are placed in plastic bags with water and oxygen and transported to the pond or lake for stocking. Between 40,000 and 100,000 fry are stocked per acre (16,188–40,470/ha). Fry growth and survival will depend on the fertility of the pond, the availability of suitable food, the absence of competing fish, and the maintenance of suitable oxygen levels throughout the summer. Depending on the rate of stocking and fertility of the pond, the suckers may reach market size by July or August. Suckers can be trapped at certain times of the year, but most ponds are harvested by seining with nets of 0.25-in (6.4-mm) mesh. Suckers that reach market size in the fall are held over winter and marketed in the spring. Suckers that don't reach market size during their first growing season are usually held over winter for additional growth in the spring so that they can be sold in June and early July. Because suckers are typically raised in ponds and lakes that winterkill, they must be removed and marketed before winter, the pond/lake must be aerated, or they must be moved to an aerated over-wintering pond.

Fathead Minnows

Fathead minnows are primarily a product of winterkill lakes, prospering when there is little competition or predation from other fish species. Wisconsin, South Dakota, and especially Minnesota have many shallow lakes that produce the bulk of the fathead minnows in the NCR. Many winterkill lakes are simply harvested and do not constitute culture; other producers attempt some forms of management that could be considered culture. Fathead minnow culture in the northern NCR generally involves managing them through selective harvest, occasionally aerating, and preventing competing species from becoming established.

Where fathead minnows, including the rosy red color variation, are cultured rather than simply harvested, adult and juveniles are stocked in April or May at a rate of 500–5,000/acre (202–2,024/ha). A ratio of 60% adults to 40% juveniles is recommended because most adults die after spawning and the juveniles will provide spawning later in the season (Dobie et al.

1956). Males and females are stocked in approximately equal numbers, but a 5:1 female:male ratio has been recommended to increase production (Flickinger 1971). Spawning begins in May and continues throughout the summer. The eggs are attached to the underside of rocks, boards, and plant leaves where the male guards them. Spawning substrate may be added to the pond if there are insufficient spawning sites. Several females may use the same nest site. The eggs hatch in 4–6 days. Fathead minnows hatched in the spring will reach saleable size by August or September. The larger minnows can be removed and marketed during the summer. Because many of the young-of-the-year will not reach market size by fall, they must be held over winter, in some cases with the use of aeration, and reared to saleable size the following year. Fathead minnows in the NCR are typically not fed formulated feeds, but some producers fertilize ponds to increase production or simply use ponds that receive added fertilization via agriculture runoff. Ponds are seined or trapped multiple times each year and saleable size minnows removed. Fatheads have a short two-year life span. The harvest of yearlings, therefore, is as complete as possible to prevent losses. Removing yearlings also increases the growth of the remaining small minnows of the current year's hatch. More intensive (but less common) pond culture can be found in the southern NCR where fathead minnows and rosy reds are fed formulated feed and raised at higher densities.

Golden Shiners and Goldfish

Golden shiners are both wild harvested and cultured in the NCR while goldfish are only cultured. Culture of golden shiners and goldfish in the southern part of the NCR is limited but is similar to the method of culturing golden shiners and goldfish in Arkansas. Typically, the egg transfer method is used for both golden shiners and goldfish, but free spawning and fry transfer methods may be employed (Giudice et al. 1983). In the egg transfer method for both golden shiners and goldfish, spawning mats are placed in brood ponds where fish lay eggs on them. The mats containing fertilized eggs are transferred to nursery ponds where the eggs hatch and young are fed formulated feed. The growing season is shorter in the NCR (120–150 days) than in Arkansas (180 days), consequently the size attained by golden shiners and goldfish over a single growing season is less. Growth of golden shiners to market size in the northern part of the NCR nearly always takes more than one growing season. Where cultured in the northern part of the NCR, golden shiner brood stock are placed in ponds by the first of May. They are stocked at rates of 200–3,000 adults/acre (81–1,214 adults/ha) (Dobie 1948; Dobie et al. 1956; Forney 1957) or as high as 4,000–8,000 adults/acre (1,619–3,238 adults/ha) for intensive culture where fry removal is planned (Dobie et al. 1956). Spawning usually begins in May when water temperatures reach 68–70°F (20–21°C) and continues into August. The slightly adhesive eggs are attached to filamentous algae or other aquatic plants. Mats of straw or other substances may be submerged along shorelines to provide useable spawning sites in ponds without suitable vegetation. After the eggs hatch, the fry feed on naturally occurring zooplankton. Formulated feeds are typically not provided to golden shiners in the northern NCR, although some producers have experimented with feeding and fertilizing ponds. Management consists primarily of making sure that no competing fish enter the pond and selectively harvesting the golden shiners as they reach market size. Ponds may be treated with oil to kill predatory insects (Dobie 1972) and aeration may be used to prevent losses during summer and/or winter.

Mittelmark et al. (1993) investigated the potential profitability of golden shiner culture in Minnesota. They were able to grow fish to a marketable size — 3.4 in (86 mm) — by November of the first year, but yields were low; only 128 lb/acre (143 kg/ha) were harvested. An economic analysis by Mittelmark et al. (1993) found that the break-even price for raising golden shiners in

10, 0.5 acre (0.2 ha) ponds was $1.20/lb ($2.65/kg). Pounds et al. (1991) found that the break-even price for raising golden shiners in Arkansas ranged from $2.33–$2.90/lb ($5.14–$6.39/kg) in ponds that ranged from 5–20 acres (2–8 ha) and total farm sizes that ranged from 160–640 acres (65–259 ha) of ponds.

Chubs

Although neither hornyhead nor creek chubs are currently cultured to any significant degree, their value in the bait market may create economically viable culture opportunities in the NCR. A brief overview of their culture is presented here because of historically successful production of creek chubs and because of current efforts to develop hornyhead chub culture. Creek chubs have been cultured in the past in Ohio and Michigan. The culture techniques for producing creek chubs have been described by Langlois (1941), Washburn (1945), and Dobie et al. (1956). Although creek chubs are stream spawners and will not spawn in ponds, the fry can still be stocked into ponds and grown to market size. The fry are obtained by either injecting mature creek chubs with carp pituitary (Ball and Bacon 1954; Dobie et al. 1956) and hatching the fertilized eggs in hatching jars or by creating an artificial stream and allowing stocked brood fish to spawn naturally (Dobie et al. 1956). Artificial streams designed for creek and hornyhead chub spawning must take into account the environmental conditions affecting their breeding habits, such as currents, pools, hiding places, water temperature, and bottom substrate. Both creek and hornyhead chubs build nests with small stones, so the appropriate sized nest building material must be provided in the artificial streams. Studies in Michigan found that about 800 fry can be expected from every female creek chub placed in the artificial stream (Dobie et al. 1956). Ohio studies found that for each female creek chub stocked into the artificial stream approximately 400 saleable fish were produced (Dobie et al. 1956). Fry stocked into ponds feed on natural foods and readily accept formulated fish feeds. The production of saleable creek chubs per acre of water varies considerably. Records from an Ohio hatchery for the years 1949–1952 show that the annual production of saleable creek chubs ranged from 500–3,000 lb/acre (560–3,362 kg/ha) (Dobie et al. 1956). Similar pond production studies have not been conducted for the hornyhead chub.

Researchers have brought young-of-the-year hornyhead chubs that were reared in ponds into indoor recirculation aquaculture facilities in the fall and grown them to market size by the following spring (P. Tucker, unpublished data). Hornyhead chubs appear to adapt well to pond and indoor aquaculture production. Young-of-the-year hornyhead chubs that were brought indoors from ponds where they received no feeding could be trained to formulated feed almost immediately. The economic viability of culturing creek and hornyhead chubs has yet to be documented, but given past (creek chubs) and current (hornyhead chubs) successes, their high market value, and the lack of competition from growers outside the region, they may prove to be worthwhile species to raise.

CRITICAL LIMITING FACTORS AND RESEARCH/OUTREACH NEEDS

GENERAL OBSERVATIONS

Factors limiting the economic viability of baitfish culture in the NCR include extreme variability in climate, limited water and land resources (some areas), restrictive regulations, variable market demands across the region, and other factors described below. Many existing

baitfish producers believe that research and extension activities focused on baitfish will not benefit the industry. There is a general feeling that baitfish aquaculture cannot compete with wild harvest and southern aquaculture (see below). There is also concern that new baitfish aquaculture research might be disruptive to the existing producers in this highly competitive industry. Yet, many of these same producers feel that baitfish aquaculture in the NCR will eventually be needed to supply the market demands.

This future need for baitfish aquaculture was identified because of increasing restrictions imposed on the wild harvest of baitfish. For example, wild baitfish producers experience problems accessing traditional harvest areas because of user conflicts and private land ownership. The spread of exotic species and subsequent regulations limiting baitfish harvest in infested areas, designed to prevent further spread of the invading species, have reduced wild baitfish production. As exotic species continue to spread, their impact on harvesting baitfish from the wild may increase.

Draining and tiling of agricultural land is a serious threat to the tremendous resource that exists in winterkill lakes, especially in Minnesota. Because of recent high water, many tiling projects have been constructed to drain or reduce the size of important baitfish production lakes and ponds. Creating drainage connections to other surface waters allows baitfish to be lost in overflow and allows competing species to enter the lakes from downstream sources. Once bullheads (*Ameiurus* spp.), sunfish (*Lepomis* spp.), carp (*Cyprinus carpio*), and other species enter these lakes, baitfish production declines dramatically. Walleye fingerling producers compete for the shallow winterkill lakes that are large baitfish producers. No baitfish are produced when lakes are used for walleye fingerling production. Another concern expressed by baitfish producers is that agricultural pesticide and herbicide runoff causes declines in wild baitfish populations.

Some management agencies have applied harvest restrictions on important baitfish production areas in response to increasing concern regarding the environmental impacts of harvesting baitfish from winterkill lakes. Concern has also been expressed that intense wild harvest of baitfish from natural waters may reduce the available forage for game fish populations. Therefore, increased scrutiny from environmental groups may further limit the use of natural winterkill lakes or other public waters for baitfish production.

Most bait retailers in the NCR consider cultured bait hardier than wild harvested bait, although there are some exceptions; for example some bait retailers in northern Wisconsin advertise that they have “wild” baitfish because anglers there prefer them over cultured baitfish (B. Gollon, Gollon Brothers, Stevens Point, Wisconsin, personal communication). The higher mortalities experienced in wild baitfish may be a result of poor condition, disease, parasites, or poor handling practices. Wild baitfish are purchased by many retailers instead of cultured baitfish because of their lower prices. However, if wild baitfish production declines, then wild baitfish prices will increase. If prices for wild and cultured baitfish begin to equalize, preference may switch to cultured baitfish.

Many baitfish species, e.g., hornyhead chub, creek chub, finescale dace, central mudminnows, and tadpole madtoms that may offer aquaculture opportunities are only in demand in limited geographic areas. Research efforts have not been directed at culturing some of these species due to the lack of a strong statewide or regional interest. Generally, demand is localized

because wild harvest cannot support distribution beyond the local area. If, however, culture techniques were developed for the species and resulted in increased production that would allow distribution beyond the local area, the market demand may expand as well. Unfortunately, it is difficult to predict potential demand in areas where the baitfish is not currently available. Retailers are often reluctant to sell new baitfish species without some guarantee of their continued and consistent availability. Consequently, little research effort has or will be focused on these species unless industry representatives, outside the current geographic area where these high-value baitfish are sold, support the research efforts.

Some species that are not readily found in the wild baitfish market could offer aquaculture and baitfish marketing opportunities. One species is the spotfin shiner (*Cyprinella spiloptera*). Its culture potential has been identified by Scott and Crossman (1973), Gale and Gale (1977), and Snyder (1993), although Phillips et al. (1982) question its value as a bait minnow. Snyder (1993) reports that spotfin shiner's shape, coloration, and hardiness could make them preferable to fathead minnows and golden shiners in some NCR baitfish markets. Spotfin shiners are fractional spawners (periodically mature eggs) that deposit eggs in crevices (Gale and Gale 1977). This spawning characteristic was used to collect fertilized eggs in multiple plate spawning devices from wild spotfin shiners. The spawning devices were then transferred to a pond for hatching and grow out (Snyder 1993) similar to the egg transfer method used for golden shiner and goldfish culture. Spotfin shiners attained a maximum length of 3.2 in (81 mm) in a 110-day growing season (Snyder 1993).

Other species that have been suggested by Dobie et al. (1956) as potential baitfish culture species include the pearl dace, river chub (*Nocomis micropogon*), blacknose dace (*Rhinichthys atratulus*), longnose dace (*R. cataractae*), finescale dace, northern redbelly dace, southern redbelly dace (*Phoxinus erythrogaster*), common shiner, brassy minnow (*Hybognathus hankinsoni*), bluntnose minnow (*Pimephales notatus*), and central stoneroller (*Campostoma anomalum*).

The baitfish species that producers across the NCR most consistently requested aquaculture research for was the golden shiner. Even though many cultured golden shiners are brought into the region from Arkansas, the shortages that still exist warrant examining ways to increase golden shiner production in the region. The main obstacles to local production seem to be that the growing season is not long enough or that golden shiner fry are not available early enough in the year to reach market size in one growing season in outdoor ponds (see *PRODUCTION TECHNOLOGY,* Golden Shiners below for more detail).

The long-term future of using live fish for bait was questioned during the course of interviewing people for this paper. Apparently in Europe, because of strong animal rights sentiments, the use of live fish for angling has been eliminated or severely restricted in some areas. The impact of the animal rights movement on the future of baitfish aquaculture in the U.S. is not predictable, but it could present problems for fish farmers in the future.

COMPETITION

A critical limiting factor frequently mentioned for baitfish aquaculture in the NCR was competition. Competition came from wild harvested baitfish, baitfish aquaculture outside the region, and other forms of aquaculture within the region. Because of the competitiveness of the

baitfish industry, many industry representatives felt that these various forms of competition would impede or preclude the expansion of successful baitfish aquaculture in the region.

There is a general agreement among baitfish producers that, for many species of baitfish in the NCR, competition from wild harvest would prohibit viable baitfish aquaculture. The costs associated with wild harvest are relatively small in comparison to the costs of culturing baitfish. For example, lake shiners (emerald, spottail, and sand shiners) account for the second highest volume of sales in the six NCR states surveyed by Meronek et al. (1997a), but they are not considered a good candidate for aquaculture because of prices that fluctuate greatly with supply and the spawning biology of these species do not appear to offer reasonable prospects for successful pond culture. Wholesale prices can vary from a low of $0.65/lb ($1.43/kg) when supplies are high to a high of around $4.00/lb ($8.82/kg) when supplies are scarce (F. Snyder, Ohio Sea Grant, Port Clinton, personal communication). Even the culture of white suckers in Michigan is not considered by industry representatives as economically viable as it is in Minnesota and Wisconsin because of the greater availability of wild harvested white suckers there (R. Weidenhamer, Michigan Bait, Alanson, personal communication). Certainly the high production of relatively inexpensive wild harvested fathead minnows in the northern part of the NCR reduces the viability of applying more intensive (and expensive) aquaculture technology to fathead minnow production throughout the region. The costs of production are not likely to be recovered unless inexpensive methods can be applied to manage natural fathead minnow lakes in the northern part of the NCR or specialty products, like the rosy red variation of the fathead minnow (which command a higher price), can be produced.

Competition also arises from farm-raised baitfish produced outside the NCR. Arkansas is a national leader in baitfish aquaculture and annually produces approximately 80% of all farm-raised baitfish in the United States. In 1998, Arkansas had baitfish sales worth about $37.9 million from 27,820 acres (11,259 ha) of water (Collins and Stone 1999). That year they produced 6.5 million lb (2.95 million kg) of golden shiners, 3.0 million lb (1.36 million kg) of goldfish, 1.6 million lb (0.73 million kg) of fathead minnows, and nearly 0.5 million lb (0.23 million kg) of rosy reds. Average production for golden shiners, fathead minnows, and rosy reds was reported at 350 lb/acre (392 kg/ha). Production of goldfish was approximately 790 lb/acre (885 kg/ha), more than twice that for the other species. The pond-side prices reported for 1998 were $3.25/lb ($7.16/kg) for golden shiners, $3.00/lb ($6.61/kg) for goldfish, $2.75/lb ($6.06/kg) for fathead minnows, and $7.00/lb (15.43/kg) for rosy reds. Not all of Arkansas' production went into the baitfish market. Some goldfish and rosy reds were sold as food (feeders) for other aquarium or pond fish.

A large portion of Arkansas' production was marketed as baitfish in the NCR. Only Minnesota prohibits the importation of live baitfish, yet Arkansas cultured golden shiners still found their way into the Minnesota marketplace. Arkansas baitfish producers have a longer growing season than producers do in the NCR; they have access to inexpensive, ideal land for pond construction; they have abundant water supplies; they have an established infrastructure for feeds, equipment, and technical advice; and they are continuing to develop the technology for efficient baitfish production. Arkansas baitfish producers are increasing the use of feeding, aeration, indoor hatching of eggs, indoor spawning, using smaller ponds, and reusing water (B. Collins, HKD-Stuttgart National Aquaculture Research Center, Stuttgart, Arkansas, personal communication). Many NCR baitfish industry representatives believe that attempting to duplicate or compete with the Arkansas baitfish production in the NCR will not be cost effective.

Competition with other forms of aquaculture also occurs in areas of the NCR. Private land owners lease the use of their ponds and lakes for aquaculture production; baitfish producers compete with private and public walleye fingerling producers for access to these water bodies. Lease prices have increased as walleye fingerling production has increased. As a result, the number of these water bodies available for baitfish production has declined and baitfish production has become less profitable.

BIRDS AND OTHER UNWANTED SPECIES

Birds are considered a form of competition that must be addressed before baitfish aquaculture can expand in the region. Bird depredation is by far the biggest concern among baitfish producers. Producers experience significant losses each year to Great Blue herons (*Ardea herodias*), double-crested cormorants (*Phalacrocorax auritus*), and American white pelicans (*Pelecanus erythrorhynchos*). One southern Missouri producer (P. Moore, Jones and Eaker Farms, Harviell, Missouri, personal communication) experienced most of the bird depredation during spring and fall migrations, but herons were a problem throughout most of the year. They suggested, however, that wintering cormorants and pelicans were a bigger problem in Arkansas. Missouri was north of the primary wintering grounds for those birds. Other southern NCR producers reported similar problems during migrations (G. Opel, Opel's Fish Hatchery, Worden, Illinois, personal communication). Bait producers in the northern NCR have to contend with cormorants, pelicans, and herons throughout the growing season as well as during spring and fall migrations because they are within the summer range of these birds. Birds were also considered a vector for fish diseases, which could threaten baitfish culture/production.

Another common problem for baitfish aquaculture was unwanted fish and crayfish becoming established in production ponds. In some cases, unintentional introductions become so abundant they are marketed, e.g., green sunfish marketed as catfish trotline bait in southern Missouri (P. Moore, Jones and Eaker Farms, Harviell, Missouri, personal communication) and crayfish infesting west central Missouri ponds were sold as fishing bait in Ohio (J. Keller, Keller's Bait and Fish Farm, Buckner, Missouri, personal communication). The invading species is invariably less valuable than the target species and probably competes for food and space thereby reducing production and interfering with harvest.

PRODUCTION TECHNOLOGY

<u>White Suckers</u>

Harvest of suckers (stocked as fry into natural ponds and lakes) is the primary source of cultured white suckers. The greatest shortage of market-sized white suckers occurs in June and July after most of the stock that was held over-winter becomes depleted. Production after July is supplied from ponds stocked in May with sucker fry.

Some of the many factors influencing growth, production, and survival of white suckers are light, stocking density, temperature, food consumption rate, energy densities of predator and prey, chemicals, the metabolic rate, and allometric effects of body size on metabolism (Hoar et al. 1979; Hewett and Johnson 1992; Hewett and Kraft 1993; Lucas and Johnstone 1993). The optimal temperature for white sucker larvae when actively feeding is 80°F (27°C) (McCormick et al. 1977), but the temperature in Minnesota wild rice paddies, where poly-culture of white suckers and paddy rice was studied, averaged only 68°F (20°C) for the time period between June

15 and August 31, 1993 (unpublished data). Obviously, temperature is an important factor controlling growth and survival of white suckers, but it is not something easily controlled by producers. White sucker producers are concerned with only those factors that they can control with the least effort and cost, e.g., stocking densities, fertilization, and protein level in food (Rosenberg and Kilambi 1975; Huner and Dupree 1984). Dobie (1972) concluded that variable survival of stocked fish may result in too many fish in years when survival is good in a pond; fish then grow slowly and do not reach a marketable size until late fall when the demand is lower.

A group of 14 natural ponds ranging in size from 5–135 acres (2–55 ha) were studied during the summer of 1994 for the purpose of determining which environmental variables affect growth of stocked white suckers, and which of those variables could be controlled by producers (P. Tucker, unpublished data). Results indicate that the factors important to growth were conductivity, relative abundance of other fishes in the pond, and wind accessing the pond. Conductivity, which is a measure of ionized salts in the water, was the water quality parameter that best described white sucker production. While white sucker production was higher in ponds that had higher conductivity, the exact cause of this positive relationship is not known. Baitfish producers have little control over conductivity, but they may be able to choose ponds open to the wind, remove trees to allow wind to reach the pond, or design new ponds in areas open to the wind. Wind helps with water circulation and oxygenation. Ponds that had fewer other fish species present had higher white sucker production. Fish farmers can exert some control over other species of fish present through piscicide treatments and fish passage barriers. Baitfish producers could assess these variables in prospective ponds and make management decisions accordingly. For example, the feasibility of reducing or eliminating other fishes in a pond or considering the orientation of the pond with prevailing winds may play a large part in determining the quality and quantity of production.

Inability to efficiently and effectively harvest suckers from large ponds has resulted in many suckers being wasted each year because they were not removed before they died over winter. Developing technology to increase harvest efficiency and effectiveness would benefit the industry. Another important limiting factor in the growth of white sucker culture is available culture waters. Most of the current culture is done in natural ponds, which are already under lease by fish farmers. If production is to expand, alternate culture methods, which may be more intensive, need to be explored.

Fathead Minnows

Availability of inexpensive wild harvested fathead minnows may be limiting their aquaculture in the NCR. Culture techniques for fathead minnows are well described and adaptable to the NCR, but the prices received for fathead minnows don't seem to justify the investment in more intensive culture development (however, see *ECONOMIC CONSIDERATIONS* below). A common problem reported for fathead minnows is that adults handled while in spawning condition or immediately thereafter experience high mortality rates during hauling and holding. Techniques to delay the spawning of fathead minnows so that non-spawning fatheads could be available during the time when wild harvested fathead minnows are spawning would benefit the industry (A. Kirchner, Curtis Fisheries, Martinsville, Indiana, personal communication). Another common problem is that the high fathead minnow reproductive rate frequently results in too many fish, which causes slow growth and stunting. Techniques to limit reproduction would be beneficial.

Golden Shiners

Baitfish producers across the NCR have identified limiting factors related to production technology. Of greatest interest was aquaculture technology for golden shiner production. It generally takes two growing seasons to obtain golden shiners of market size in the NCR. This increased culture time increases the risk of losing production to severe summer or winter conditions and exposes fish to a longer period of bird depredation. The problem occurs because golden shiners do not spawn until the water temperature has reached 68–70°F (20–21°C). By the time they spawn and the eggs hatch, much of the growing season has passed. If golden shiner fry were available earlier, they might be able to be grown to market size within one season. Cost-effective techniques for early season production of golden shiner fry could benefit NCR baitfish aquaculturists. Stone et al. (1998) reported that indoor tank spawning and hatching of golden shiners is possible and allows fish to be spawned early or late in the season. Other advantages include less labor required to run a hatchery than to move spawning mats, egg survival is better and fewer brood stock are needed, and known numbers of fry can be stocked into prepared ponds. They provided recommendations for the methods of tank-spawning golden shiners, but warn that this is a new technology that needs additional research.

Other production strategies suggested include a combined pond and indoor culture production scheme. In this scheme, pond reared golden shiners would be brought indoors in the fall and grown to market size by the following spring. Efforts to culture golden shiners in indoor recirculation systems have been unsuccessful so far. Continuous low-level mortality has proven to be a significant problem. Overcoming this problem could benefit golden shiner aquaculture in the NCR. Golden shiners also have relatively high mortality when handled during warm water periods. As described earlier, wholesale prices for golden shiners range from $3.25/lb (pond-side) to $7.00/lb (final wholesale) ($7.16–$15.43/kg). This price is higher than for food-fish currently being cultured in recirculation systems and would appear to offer an economically viable aquaculture opportunity.

Culture of High Value Species

The development of culture technologies for baitfish species that have a high demand in a limited geographic area, as detailed above, could benefit NCR aquaculture producers. These species command high prices because of limited wild harvests and high angler demand. If aquaculture made these species more broadly available, market opportunities may expand beyond their current geographic distribution. The development of culture techniques will also help relieve the intense harvest pressure on natural populations of these high value species and be an environmentally sound approach to satisfying the market demand. Species that fall within this category include hornyhead chubs, creek chubs, tadpole madtoms, finescale dace, and central mudminnows. These hardy species appear to lend themselves to aquaculture development, but each has its own aquaculture challenges. Research needs include examining the broader market potential for each of these locally popular species, identifying and solving their individual aquaculture challenges, and assessing the economic viability of their culture. Some of these high value species are cannibalistic, so culture technology that separates brood fish from young fish would be an important consideration. In some species, like the hornyhead chub and the creek chub, the male grows larger and faster than the female. Therefore, the use of methyl testosterone to create all male populations should be investigated. Feeds for these high value species will also need to be developed for appropriate life stages and production systems. When assessing aquaculture technologies for new species, it will be important to look across the

whole NCR to find the resources (land, water, climate, energy costs) that are most advantageous for viable aquaculture.

Improved Production Technology

Even though baitfish have been cultured for a long time, there is still a need to apply current culture technologies on NCR baitfish aquaculture problems. Even in Arkansas, where baitfish aquaculture is a large, economically important industry, many recent advances in culture technology have not been implemented on the fish farms (S. Weber, Lonoke Agricultural Center, Lonoke, Arkansas, personal communication). The average production of golden shiners and fathead minnows in Arkansas is reported at 350 lb/acre (392 kg/ha). In the NCR, many natural ponds are leased and, increasingly, ponds are being constructed for baitfish production. Research directed at determining how best to manage these ponds could increase production and profits. Examination of feeds, feeding regimes, fertilization, aeration, aquatic plant control, nuisance fish control, and other management options need to be examined. In addition, no efforts at genetic selection, selective breeding, or hybridization have been applied to baitfish aquaculture. Hybrids have become important to food-fish production (sunshine bass — *Morone chrysops* × *M. saxatilis*) and to sport fish stocking programs (splake — *Salvelinus fontinalis* × *S. namaycush*, saugeye — *Stizostedion canadense* × *S. vitreum*, tiger musky — *Esox lucius* × *E. masquinongy*, and sunshine bass), but have not been used for baitfish production. The characteristics of hybrids that make them desirable for food-fish production and stocking programs could also make them desirable for baitfish aquaculture. Hybrids of the northern redbelly and the finescale dace are almost exclusively female and are the result of clonal reproduction (Dawley et al. 1987). This unique hybrid characteristic or the hybrid vigor resulting from other crosses might present economically viable and environmentally friendly culture opportunities. Hybrids that are sterile would be especially desirable because they would not establish naturally reproducing populations in the wild.

REGULATIONS

Meronek et al. (1995) presented a summary of bait regulations in the twelve states of the NCR. They concluded that the variation in regulations among states confuses anglers, hinders the bait industry, and reduces the credibility of management agencies. Examples they gave of regulations hampering the bait industry include those in which dealers are allowed to ship across some state lines legally but not others, or in which dealers' seines and minnow traps are legal in some states but not in others. In addition, differences among states in license requirements, definitions of bait, transportation regulations, gear restrictions, and inspection and records requirements were found to hinder the bait industry, increase its costs, and foster violations. Meronek et al. (1995) suggest that "a number of benefits would result if management agencies, in consultation with responsible members of the bait industry, reviewed their regulations concerning the bait industry and established new ones, modified existing regulations, or deleted unnecessary regulations to attempt to achieve more uniformity among states consistent with protection and wise use of aquatic resources."

Examples of regulations of interest to baitfish fish farmers include the following: (1) no cultured or wild harvested baitfish can be transported out of Kansas, (2) no live wild harvested baitfish can be exported from Michigan, (3) white suckers cannot be used for bait in North Dakota, (4) no baitfish can be imported into Minnesota for sale. However, some permits have been issued to allow Minnesota fish farmers to bring golden shiners into the state for grow out

and subsequent sale in states other than Minnesota and to bring fathead minnows into the state to feed other cultured fish. The Minnesota baitfish importation ban and the Michigan baitfish exportation ban have both been accused of interfering with interstate commerce. Minnesota's import restrictions may result in legal challenges from other states or reciprocal baitfish importation bans on Minnesota baitfish. Iowa, Minnesota, and South Dakota require proper aeration for transporting baitfish. In South Dakota, a loss of more than one quart of baitfish for every 50 gal of water (0.95 L/189 L) was considered a violation of the aeration regulation.

Some of the culture and harvest methods that are reported in this paper might not be legal for all states in the NCR. Check with state management agencies for current regulations prior to developing plans for baitfish culture or wild harvest.

BUSINESS MANAGEMENT

Many of the critical limiting factors for baitfish aquaculture relate to business management and marketing issues. Widely fluctuating prices are common to this industry. The price fluctuations are a result of annual cycles of production for both cultured and wild harvested species and angler preferences. When baitfish (like shiners or fathead minnows) are easily captured in the wild or when cultured species (like white suckers) all reach market size, the supply exceeds the demand. When this happens, producers with inadequate holding facilities, or with wild species that are not able to be held for long fear losing their product to mortality. They then drop their prices to ensure sales, which causes others to drop their prices, which, in turn, reduces the industry's economic viability. In addition, anglers have seasonal expectations for species, size, and quality that are frequently not met, again because of the annual cycles in production and availability. Historically, the industry takes what it can get, when it can get it, and dumps the baitfish on the market for whatever price is available to move as much product as possible. There are exceptions to this, but overall this appears wasteful and counter to good business management. The application of aquaculture management techniques such as feeding, fertilization, aeration, stocking density manipulation, indoor culture, and others could improve marketing and business management efforts. For some high value species, aquacultured bait could be given a brand name, which could increase the market and price for the baitfish. To date, no live baitfish at the retail level have been given a brand name.

ECONOMIC CONSIDERATIONS

It is often confusing to report wholesale prices of baitfish. Baitfish are sometimes sold wholesale many times before they reach the retail outlet. For example, a fathead minnow producer may sell to a larger wholesale distributor, who may sell to an interstate distributor (trucker), who then sells to a local wholesaler in another state, who may finally distribute the baitfish to a retail outlet. The wholesale price paid for baitfish increases with each step. In this document, we report baitfish prices that represent the price paid to the initial producer (pond-side price) and the price paid for the final wholesale transaction (price paid by the retailer). These two "wholesale" prices are significantly different. The final wholesale price is frequently more than double the price paid to the grower or trapper.

Many food-fish producers in the NCR market their product directly to retail outlets like restaurants or grocery stores because they cannot cover their cost of production by selling through the typical seafood distribution system. If baitfish aquaculture production was similarly

marketed directly to retail outlets, the economics of baitfish production would appear more viable. Prices paid by retail outlets for baitfish generally exceed food-fish prices and ranged from $4.00–$10.00/lb ($8.81–$22.05/kg). Even fathead minnows are frequently sold at $1.75/lb ($3.85/kg) to retailers in the NCR, which is a price above that paid for live tilapia. The pond-side prices paid for most baitfish species exceed pond-side food-fish prices. The problem becomes one of developing a cost-effective culture program that produces the right size and species of baitfish at the time of year and geographic location where they are in greatest demand. A direct comparison of baitfish prices to food-fish prices may not be warranted, however, if baitfish cannot be marketed on a continual basis as can food fish or if culture systems cannot annually produce as many pounds of baitfish as food fish. Another problem is being able to produce baitfish on a scale large enough that makes economic sense. A thorough understanding of the baitfish industry and the baitfish market is needed before attempting to enter into baitfish culture.

EXTENSION EDUCATION

One area where extension education can help the baitfish industry is in improving fish handling techniques to reduce baitfish mortality. According to Meronek (1994), mortality of baitfish was reported by 57% of retailers and by 50% of wholesalers. The most common reasons for baitfish mortality given by both baitfish retailers and wholesalers were temperature changes, handling and transportation, low dissolved oxygen, and tank crowding. Extension programs could help reduce baitfish mortality for both retailers and wholesalers by teaching proper fish handling, hauling, and holding techniques. One wholesaler who thought education would help bait producers and retailers (M. Fessel, Wholesale Bait Co., Inc., Hamilton, Ohio, personal communication) indicated that fact sheets alone would not change behavior.

Extension education can also help address business management and marketing problems for the baitfish industry. If baitfish aquaculture is to develop, potential investors will have to understand the effects of economies of scale, break even analyses, realistic fish yield information, price fluctuations, and market demands. Another problem is the independent nature and competitiveness of baitfish producers. While they are reluctant to work together, they may benefit from cooperatively working to solve problems of price fluctuations, baitfish shortages, and inconsistent or inappropriate regulations. Extension workshops or forums could provide opportunities for closer collaboration.

When new technologies specific to baitfish culture are developed, extension education will be needed to present this information to fish farmers and baitfish producers across the NCR.

SUMMARY OF RESEARCH AND EXTENSION PRIORITIES

(Not in rank order)

CULTURE TECHNIQUES FOR GOLDEN SHINER PRODUCTION IN THE NCR

- Develop early season fry production to extend growing season
- Examine combined pond and indoor culture system to get golden shiners to market sooner and during peak shortages
- Reduce the slow, continuous mortality of golden shiners in recirculation systems.

- Conduct genetic selection program to improve growth and hardiness

CULTURE POTENTIAL AND SPECIFIC CULTURE TECHNIQUES FOR HIGH VALUE BAITFISH SPECIES

- Hornyhead chubs
  - Develop cost-effective fry production techniques
  - Examine use of methyl testosterone for creating all male populations
- Creek chubs
- Finescale dace
- Central mudminnows
- Tadpole madtoms
- Spotfin shiners
  - Examine egg transfer production technology
- Examine use of hybrids for baitfish production
  - Examine the aquaculture advantages offered by the clonal reproductive strategy of the finescale dace × northern redbelly dace hybrid
- Develop sterile baitfish to reduce environmental concerns of introducing baitfish to new locations

POND CULTURE TECHNIQUES

- Vegetation control
- Feeds and feeding strategies for baitfish
- Fertilization techniques
- Control bird depredation
- Restricting over-reproduction of baitfish in ponds
- Maximizing pond production of baitfish
- Provide non-spawning fathead minnows during times when they spawn in the wild

EXTENSION

- Provide existing information to baitfish wholesalers and retailers regarding proper handling, transportation, and holding techniques to reduce baitfish mortality
  - Temperature acclimation
  - Use of salt
  - Proper water quality (ammonia, nitrite, pH, dissolved oxygen, etc.)
  - Parasites and disease treatments
  - Reducing stress
- Teach marketing and business management skills to baitfish producers, wholesalers, and retailers
- Teach bait harvesters how not to spread exotic species with baitfish and how to certify their baitfish as “exotics free”
- Facilitate forum or workshop to bring baitfish producers together to solve business management and marketing problems

BUSINESS MANAGEMENT

- Examine production costs and profitability for increased golden shiner aquaculture options in the NCR
- Examine broader NCR market potential for high value baitfish that are currently only available in limited geographic areas
- Examine production costs and profitability for new aquaculture opportunities with the high value species listed above
- Determine if brand-name baitfish command a higher price and increase market area

REGULATIONS

- Encourage development of more uniform state regulations across the NCR
- Conduct a forum to discuss baitfish and aquaculture regulations across the NCR
- Work with INAD/NADA coordinator to register drugs and hormones for use on baitfish

ENVIRONMENTAL ASSESSMENT

- Examine the tiling and draining of natural lakes and ponds to assess the impacts to aquaculture production and to assess environmental impacts to these unique ecosystems
- Examine the environmental impacts of increased baitfish aquaculture in the NCR
- Examine impacts of the spread of any cultured baitfish not currently widely marketed
- Assess environmental implication of any changes in the genetic makeup of baitfish

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