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Fish Culture in Wetlands:
A Review of the Science and Recommendations for Licensing Criteria

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Executive Summary

A Wetland Values Technical Committee was convened by the Minnesota Department of Natural Resources (MnDNR) to 1) review the existing status of technical knowledge regarding fish rearing in natural wetlands and shallow lakes and maintaining values for waterfowl and other aquatic life, and 2) to propose options for regulatory criteria that DNR should consider when licensing a wetland for fish rearing. Below are the key findings of the Wetland Values Technical Committee, based on a review of previous and on-going studies and the professional expertise of the committee members.

- Wetlands and shallow lakes may occur in one of two trophic states, one characterized by clear water and an abundance of rooted aquatic plants, the other characterized by turbid water due to high algae (phytoplankton) populations and few rooted aquatic plants. Basins in either of these states tend to be stable, but can and do switch states in response to perturbations.
- The factors that induce shifts and stabilize a basin in one trophic state or another are not completely understood, but involve both abiotic factors such as nutrient levels, basin morphology and wind, and biotic factors such as the plants and animals that inhabit the basin.
- Nearly all wetland functions and values, including wildlife habitat, are favored by wetlands in the clear-water state.
- Many factors other than potential impacts due to fish culture are responsible for degraded wetland functions and values, particularly in the agricultural regions of the state. These include historic wetland loss, increased connectivity and altered hydrology, accelerated sedimentation and nutrient inputs, climatic factors, and non-native/invasive species.
- Planktivorous fish, such as fathead minnows and benthivorous fish, such as white sucker, black bullhead, and carp have a clear association with basins in a turbid condition, although the relationship is not purely predictive.
- Background nutrient concentrations in the water appear to be a factor in whether or not fish introductions will cause a basin to switch to a turbid state.
- Benthivorous fish may be more responsible for shifting basins to a turbid condition, while planktivorous fish may be more responsible for maintaining them in that condition.
- White suckers behave as both benthivores and planktivores; however, the role of white suckers in influencing basin trophic state has not been specifically studied.
- The effect of walleye introduction in a basin depends significantly on pre-existing fish populations.
- Walleye fry (up to about 2.4 inches) eat primarily zooplankton; larger fry are piscivorous. When fish prey are not present, larger walleye fry will feed on macroinvertebrates as well as zooplankton, with potential adverse effects on food webs and trophic condition.
- Walleye fry introduced into basins having fathead minnows may suppress the minnow population by predation on fathead minnow fry, with positive consequences on basin trophic condition. Carryover walleye (1+ year) appear to enhance suppression of the minnow population by predation on adult minnows.
- Basins used for rearing walleye that do not winterkill may develop a recreational fishery if public access is available, and the resulting human disturbance can adversely affect migrating waterfowl.
- Aeration that enhances the overwinter survival of planktivorous and benthivorous fish populations increases the risk that a basin will shift to or be maintained in a turbid state.
- Application of fertilizer to increase fish yield increases the risk that a basin will shift to or be maintained in a turbid state.
- Supplemental feeding of walleye with fathead minnows can have adverse effects on a basin if the basin did not previously support a fathead minnow population. Supplemental feeding of walleye with forage fish can also result in the unintentional introduction of carp and black bullhead, which can have severe adverse impacts.
- Criteria to be evaluated for licensing basins should include: status of pre-existing fish populations, basin trophic condition and nutrient concentrations, connectivity to other waters, and the number of basins used for aquaculture within the watershed.
- The Wetland Values Technical Committee recommends that the public and private sectors be held to the same standards for maintaining the functions and values of wetlands and shallow lakes used for rearing fish.

1. Introduction

The Minnesota Department of Natural Resources (MnDNR) is responsible for licensing waters of the state for commercial fish rearing (see Minn. Statutes 17.4984). In 2005, 2,008 basins comprising 43,020 acres were licensed for fish rearing (Figure 1). In addition, the MnDNR uses approximately 650 basins for walleye rearing, with 300-350 being actively used each year. These figures do not include basins from which bait fish are trapped for commercial purposes.

The potential for conflict between the use of wetlands/shallow lakes for raising fish and maintaining habitat for other species, particularly waterfowl, has been recognized for many years (see Bouffard and Hanson 1997 and Minnesota DNR 2003 for reviews). Several factors recently converged to heighten the concern. Among these are the accelerated walleye stocking program by the MnDNR, which has generated an increased demand for fish-rearing basins, and declining harvests by duck hunters, which many attribute to poor wetland habitat quality. Another contributing factor is the high degree of overlap in the state between the best remaining waterfowl habitat and concentrated aquaculture activity (Figures 1 and 2).

During the 2005 legislative session, a bill (H.F. 1819) was introduced that would have required applicants for fish farming licenses to submit a management plan for each licensed body of water that, ". . . is designed to ensure that the ecological value for that water for waterfowl and other native aquatic wildlife will be maintained or restored." Furthermore, the legislation would have required the MnDNR

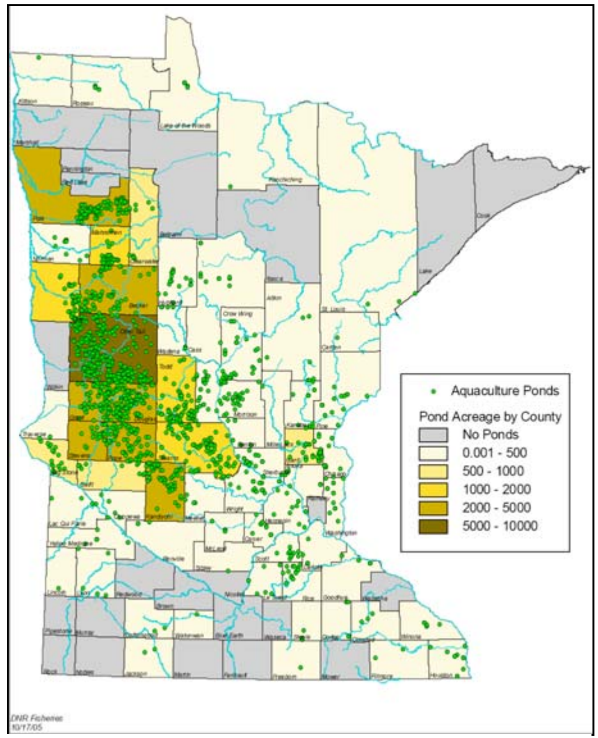

Figure 1. Distribution of licensed aquaculture ponds in 2005.

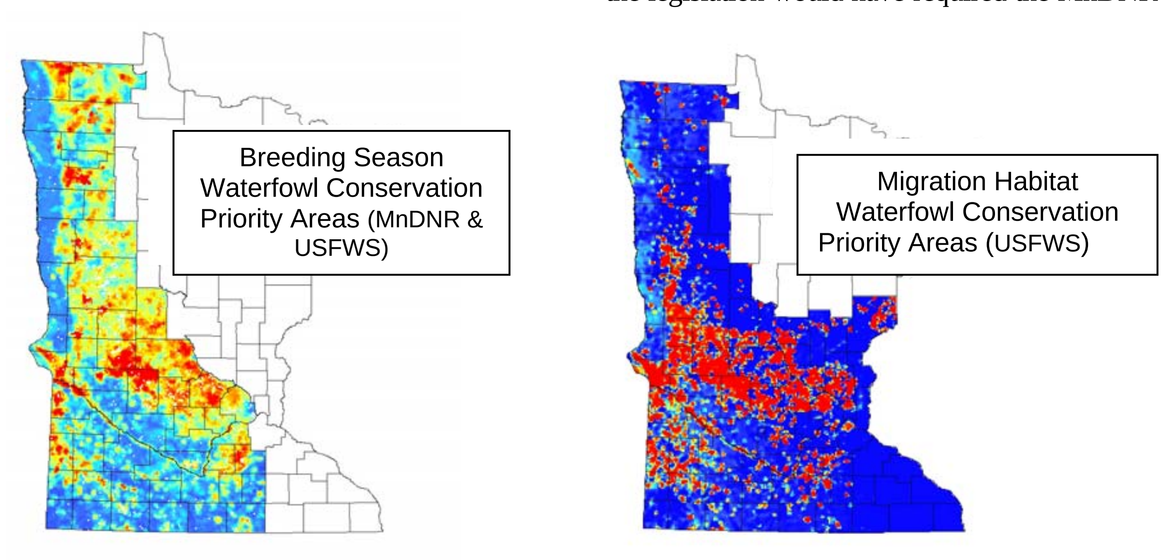

Figure 2. Priority conservation areas for waterfowl breeding and migration in Minnesota.

to, ". . . determine that the implementation of the management plan will ensure that the ecological value of the water will be maintained or restored." The bill did not pass, partly because the MnDNR maintained that no objective, measurable criteria exists for assessing ecological values of wetlands relative to licensing for fish culture. Nonetheless, the controversy persists and future legislative interest is likely.

Anticipating renewed legislative discussion, the MnDNR convened a Wetland Values Technical Group comprising technical experts in wetland ecology and fish culture from state and federal agencies and academia (Appendix 1). The Technical Group was assigned to:

1) Briefly summarize the existing status of technical knowledge regarding fish rearing and maintaining values of wetlands for waterfowl and other aquatic life;
2) Develop proposed guiding principles and/or definitions for the phrase "maintaining and restoring wetland values" as used in this context;
3) Propose options for regulatory criteria that MnDNR should consider when licensing a wetland for fish rearing. The criteria should contain enough objective detail that they could be articulated in the form of a rule or law. In connection with the criteria, address how licensing decisions or monitoring might be influenced by proposed physical, chemical, or biological manipulations associated with the activity being applied for (e.g., mix of fish species in the wetland; addition of nutrients; use of aeration; etc.);
4) Focus on what is currently feasible in terms of criteria; if there are things that would be desirable with more data or resources, please list gaps or barriers in data, information, or resources that prevent their use at this time;
5) Recommend pre- and post-licensing assessments that would be needed to address the criteria, make licensing decisions, and monitor wetland conditions; include proposed schedules, time requirements, and potential costs for those assessments;
6) Address the desirability for generally providing consistent criteria for private and public fish culture in wetlands.

The Technical Group met four times from October 2005 through May 2006 to address the aforementioned tasks. The remainder of this report represents the findings and recommendations of the Technical Group.

Notes on terminology: This report focuses on shallow basins, generally less than 6.6 feet deep. The term "wetland," as used in this report encompasses all such basins, including very shallow basins that routinely dry out late in the growing season. The term "shallow lake" is generally used here to refer to a subset of wetlands that in most years contain water year-round. See Section 2 for additional information on the characteristics of wetlands and shallow lakes. Also, unless otherwise noted, the term "aquaculture" refers here to fish rearing conducted by both the public and private sector, and does not include other species such as leeches or the harvest of naturally occurring minnow populations for baitfish.

2. Wetland and shallow lake ecology

There are a number of references available on wetland and shallow lake ecology, including Good et al. (1978), Mitsch and Gosselink (2000), Scheffer (1998), Van Der Valk (1989), and Weller (1994). This chapter provides a brief overview of aspects of wetland and shallow lake ecology that are pertinent to issues associated with fish culture.

2.1. Physical characteristics

A fundamental aspect of wetlands and shallow lakes that distinguishes these ecosystems from other lakes is the fact that they are shallow, typically less than 6.6 feet deep. This characteristic has important ecological consequences:

- The shallow water does not inherently limit light penetration, so rooted aquatic plants (macrophytes) can grow throughout the basin. Extensive aquatic macrophyte communities in wetlands and shallow lakes are a key component of high quality wildlife habitat and are also important for a number of other wetland functions. In addition to serving directly as a food source for some wildlife species, the aquatic plants provide food and substrate for aquatic invertebrates, which are in turn consumed by waterfowl and other wildlife. These plants also sustain water clarity in shallow lakes and wetlands through a variety of mechanisms including protecting sediments from re-suspension by wave action.
- Unlike deeper lakes, shallow lakes and wetlands do not thermally stratify – the water column generally remains mixed from top to bottom (polymictic). Nutrients such as phosphorus and nitrogen can be easily translocated from sediments to the entire water column. On large shallow lake basins, wind can cause frequent resuspension of bottom sediments and associated nutrients.
- Shallow basins are subject to relatively frequent catastrophic perturbations such as winterkill or desiccation during drought. Winterkill, when the water column either freezes entirely during winter or becomes anoxic, eliminates or drastically reduces fish populations, which in turn affects populations of aquatic invertebrates. Desiccation similarly eliminates or reduces fish populations and also oxidizes and consolidates bottom sediments, stimulating aquatic plant germination and production once the water returns.

While the characteristics above are typical of all shallow lakes and wetlands, there are additional factors that are characteristic of basins in Minnesota that are used or can potentially be used for aquaculture:

- Many of the shallow basins in Minnesota that are candidates for aquaculture use are generally isolated from other water bodies and streams (however, see section 2.3.2). This lack of surface water connection plays an important role in recolonization by fish and their subsequent effects on the aquatic food web.
- Most of the basins used for aquaculture in Minnesota occur in areas of the state having relatively high availability of nutrients such as phosphorus and nitrogen (Heiskary and Wilson 1989; Moyle 1954). As a result, primary productivity is high, with few inherent limits on plant growth in these basins. The only question is whether the plant growth occurs primarily as algae or as macrophytes, which is further addressed in the next section.

2.2. Alternative stable states model

Observations in Europe and North America indicate that shallow lakes may exist in one of two trophic states: a clear-water, macrophyte (rooted aquatic plant) dominated state, or a turbid water state characterized by high phytoplankton (algae) populations and minimal macrophytes (Figures 3 and 4) (Moss et al. 1996; Scheffer 1998). Basins in either of these states tend to be stable, but can and do switch states in response to perturbations

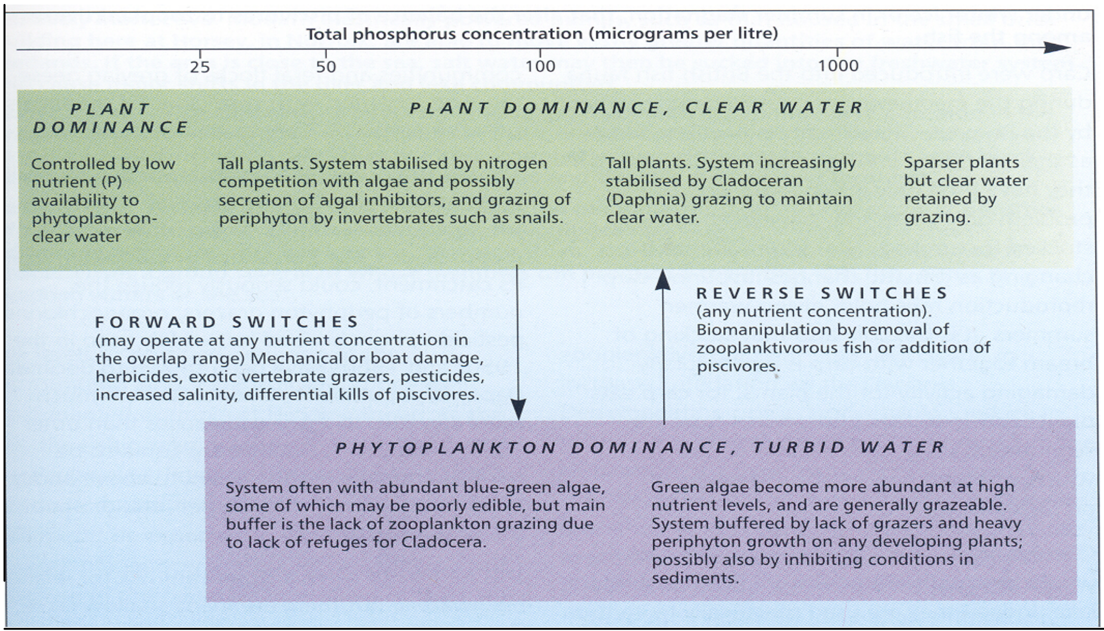

Figure 3. Representation of the alternative stable states model for dominance by aquatic plants or phytoplankton in shallow lakes. Reproduced with permission from Moss et al. 1996.

(Scheffer et al. 2001). The factors that induce shifts and stabilize a basin in one state or another are not completely understood, but involve both abiotic factors such as nutrient levels, basin morphology and wind, and biotic factors such as the plants and animals that inhabit the basin (Moss et al. 1996; Scheffer 1998; Zimmer et al. 2003a).

Several studies, including many in Minnesota, suggest that fish are an important influence on a basin's trophic state (see Bouffard and Hanson 1997 for a review, as well as Hanson et al. 2005; Zimmer et al. 2000, 2001a, 2003b). In particular, there is considerable evidence that high populations of planktivorous fish, such as fathead minnows *Pimephales promelas* and benthivorous fish, such as carp *Cyprinus carpio* and bullheads *Ictalurus spp.* may play a role in shifting basins from the clear-water trophic state to the turbid state or stabilizing basins in the turbid state (Hanson and Butler 1994; Parkos et al. 2003; Zimmer et al. 2001a, 2001b, 2002). In the case of benthivorous fish, the shift may result from the physical destruction of aquatic macrophytes, initiating a chain of events that culminates in the turbid, algae-dominated state and by transferring nutrients from bottom sediments into the water column through excretion (Lamarra 1974; Parkos et al. 2003). Planktivorous fish are thought to mediate the shift from clear-water to the turbid state by selective feeding on zooplankton grazers and the subsequent release of phytoplankton populations. Current, ongoing research suggests that benthivorous fish may be more responsible for *inducing* a shift to the turbid state, while planktivores act to *stabilize* basins in that state (Hanson, M., personal communication, 2006). Preliminary results from this study also suggests that ambient nutrient concentrations, particularly phosphorus, are an important factor in determining the probability that a basin will shift trophic states as a result of fish population dynamics.

Figure 4. Two shallow lakes illustrating the clear-water (top) and turbid (bottom) trophic states. Photo courtesy of Brian Herwig, MnDNR.

Shifts to the turbid state can sometimes be reversed by eliminating or reducing high populations of benthivorous and planktivorous fish. This may occur naturally through winter-kill or drought, or artificially by treatment with piscicides (Hansel-Welch et al. 2003; Hanson and Butler 1994) or, in the case of planktivores, by stocking predatory fish such as walleye *Sander vitreus* (Figure 5) (Herwig et al. 2004; Lathrop et al. 2002; Reed and Parsons 1999). Biomanipulation is the term used for managing basins by manipulating fish communities (Angeler et al. 2003; Perrow et al. 1997).

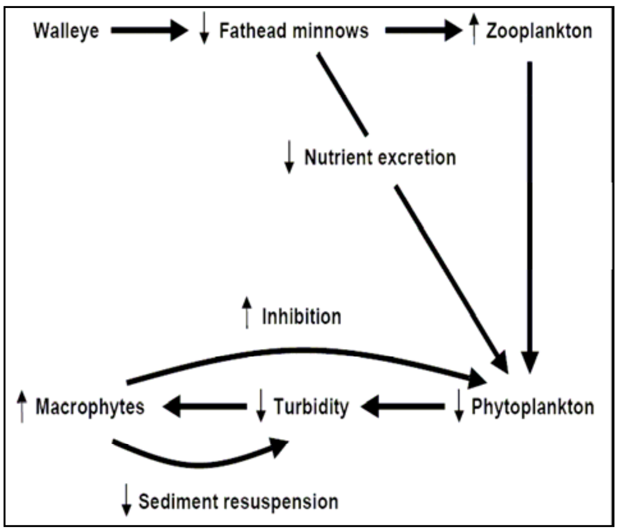

Figure 5. Predicted interactions resulting from biomanipulation involving the addition of walleye to turbid wetlands (from Herwig et al., 2004).

2.3 Alterations and disturbance factors (other than fish culture)

A variety of human-induced factors have greatly affected the ecology of Minnesota's wetlands and shallow lakes, particularly in the agricultural regions of the state. Physical, chemical and biological processes have been disrupted, diminishing the wetlands' functions and values (see Chapter 3). Some of these factors are discussed below.

2.3.1. Historic wetland loss. It's estimated that Minnesota has lost approximately one-half of the wetland acreage that existed prior to European settlement (Anderson and Craig 1984). The loss is concentrated in the southern and western agricultural regions of the state, where some counties retain less than one percent of their presettlement wetlands (Figure 6) (Anderson and Craig 1984). This area generally corresponds to the prairie pothole region of Minnesota, a critical area for continental waterfowl production.

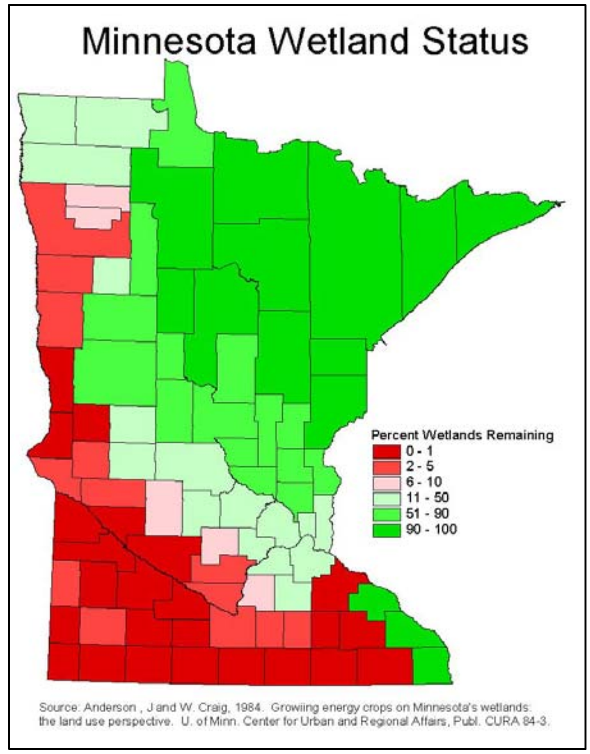

Figure 6. Minnesota wetland status

Most of the wetland loss is due to artificial drainage to enhance agricultural productivity, but urbanization and transportation have had important impacts as well. Temporary and seasonal wetlands have been most heavily affected, but a surprising number of large, shallow lake basins have also been drained. A study conducted in central and northeast Minnesota to estimate common loon populations found that 10 percent of basins between 150 and 499 acres that were inventoried using 1930s to 1950s aerial photography (Minnesota Conservation Department 1968) had been either partially or completely drained by 1989 (Strong and Baker 1991).

There are both direct and indirect ecological impacts associated with this wetland loss. The outright loss of wetland habitat is directly reflected in reduced populations of many wildlife species. In areas where wetland loss is significant, even the remaining wetlands have diminished habitat value. In the prairie pothole region of the state, waterfowl, wading birds, amphibians and other wetland-dependent species evolved in a landscape characterized by a dynamic mosaic of grassland and wetlands of various sizes and types. The diversity of wetlands ensured that the habitat requirements for wildlife were met on a seasonal/annual basis, and through wet and dry climatic cycles. Grassland breeding waterfowl in particular require a variety of wetland types for optimal breeding success. The disproportionate loss of temporary and seasonal wetlands has reduced the diversity of available habitats, thus compromising the habitat value of the remaining wetlands.

2.3.2. Increased connectivity and altered hydrology. The drainage of Minnesota's wetlands was accomplished through the construction and installation of thousands of miles of open drainage ditches and underground tile lines. Whereas many wetlands in the pre-settlement landscape were isolated or only intermittently connected, wetlands today are often connected to each other and to watercourses by ditches and/or tile lines. This increased connectivity has altered the dynamics of fish colonization of the remaining wetlands and shallow lakes. Prior to the widespread use of artificial drainage systems, wetlands and shallow lakes supported dynamic populations of native fish, characterized by periodic colonization and elimination/reduction through winterkill or drought. Because many of the basins were hydrologically isolated in most years, fish were not usually able to immediately recolonize. Today, many of the remaining basins are connected via ditches and/or tiles, allowing nearly immediate recolonization by large numbers of fish following extirpation events. In addition, the fish colonizing these basins today often include non-native species, common carp being of particular concern (see Section 2.3.5).

The enhanced drainage system has also radically altered the natural water regime of many wetlands. Tile lines and ditches that discharge to wetlands and shallow lakes alter the timing, frequency and duration of inundation of the basins. Periodic drawdown and desiccation is important for maintaining wetland productivity and stimulating the germination of some wetland plants (see Kantrud et al. 1989). The discharge from ditches and tiles often maintains artificially high water levels, thereby reducing wetland productivity and adversely affecting plant populations. Swan Lake, a well-known shallow lake in Nicollet County, has approximately 80 tile outlets discharging into the lake.

2.3.3. Nutrient inputs and sedimentation. Agricultural and urban runoff often contains elevated concentrations of nitrogen and phosphorus as well as sediment. In wetland and shallow lakes, elevated nutrient levels are factors in shifting and maintaining basins in a turbid, algae-dominated state (see Section 2.2). Water- and airborne sediment also adversely affects wetlands. Gleason et al. (2003) found that as little as 0.2 inches of sediment in wetlands caused a 91.7% reduction in seedling emergence and a 99.7% reduction in invertebrate emergence.

2.3.4. Climatic factors. Johnson et al. (2005) found that temperatures throughout the prairie pothole region became warmer throughout the 20th century, and that the eastern part of the region (including Minnesota) became wetter (see also Hanson et al. 2005). The resulting combination of long-term high water levels in wetlands and mild winters has important ecological implications. First, the basins experience less frequent drawdowns that are important for maintaining productivity and stimulating growth of emergent aquatic plants. Second, fish populations are maintained at high levels because of the lack of desiccation and winter kill. Considering the changing climatic conditions, Johnson et al. (2005) postulates that the eastern portion of the prairie pothole region will become more important for breeding waterfowl. Therefore, sound management of Minnesota's wetlands and shallow lakes may become even more important in the future.

2.3.5. Invasive/non-native species. One of the most serious disturbance factors for wetlands and shallow lakes has been the invasion by common carp. Common carp were originally stocked in some Minnesota waters in the late 1800s and have since spread throughout much of the southern half of the state (Phillips et al. 1982). Carp feed primarily by suctioning bottom sediments. Nutrients that are normally sequestered in these sediments are excreted and suspended into the water column where they become available to promote growth of phytoplankton. In addition, their feeding action may uproot aquatic macrophytes, leading to elimination of aquatic plant beds (Crivelli 1983). As a result, wetlands and shallow lakes that support common carp populations are maintained in a turbid state, with high nutrient levels and few rooted aquatic plants (see Parkos et al. 2003).

3. Wetland functions and values

A central theme in the proposed aquaculture legislation and in the assignment to the Technical Group is "maintaining wetland values" as it relates to fish culture in wetlands. The term "wetland values" may have different meanings to different people. This section explains how the Technical Group addressed this concept in its analysis.

3.1. Functions vs. values

The reason that federal and state laws and programs exist to protect and restore wetlands is that they provide services and products that are useful to society (Greeson et al. 1978; Hubbard 1988; Mitsch and Gosselink 2000; Sather and Smith 1984). Examples in state statute include: maintaining and improving water quality, protecting shorelines, recharging groundwater, flood- and stormwater retention, public recreation and education, commercial uses (including aquaculture), fish, wildlife and native plant habitat, and low flow augmentation of streams (Minn. Stat. 103B.3355).

These characteristics are often referred to collectively as "functions and values." However, there are important distinctions between functions and values, particularly as they relate to establishing measurable criteria for licensing wetlands for fish culture. Wetland functions are physical, chemical or biological processes or attributes of a wetland, independent of any utility to human society. Certain wetland functions often translate into services or products that are useful to people, i.e., wetland values. For example, the ability of a wetland to capture, store and slowly release a certain amount of runoff is a wetland function. The fact that this may help prevent flooding of downstream cities or farms is a wetland value. An important distinction is that wetland functions can generally be objectively measured, while measuring wetland values can be problematic. In the foregoing example, the amount of water that a wetland is capable of storing can be straightforwardly measured in acre-feet. Measuring its value in protecting against flooding is more complicated, depending in part upon downstream land uses and their economic values.

In recommending criteria for licensing wetlands for fish culture, the Technical Group thought it important to understand the distinction between functions and values and, to the extent practical, to limit the analysis to wetland *functions* that can be objectively measured. However, certain wetland *values* were also included in the group's analysis because they are relevant to the issue at hand, and specifically mentioned in state statute.

3.2. Functions and values considered in this review

Although H.F. 1819 and the subsequent assignment to the Wetland Values Technical Group focused on maintaining "ecological" values, particularly related to waterfowl and other aquatic wildlife, the Technical Group thought it appropriate to undertake a broader analysis of wetland functions and values relative to fish culture. Although the potential conflict between fish culture and waterfowl habitat has generated the most attention, the Technical Group desired to foster a broader, more holistic view of wetlands rather than focus solely on waterfowl habitat.

Wetland functions and values can be categorized, labeled, split and combined in innumerable ways. For the purposes of this report, functions and values were analyzed as identified in the Minnesota Routine Assessment Method for Evaluating Wetland Functions (MnRAM) ver. 3 (Minnesota Board of Water and Soil Resources 2004). MnRAM is a widely used function and value assessment method developed specifically for use in Minnesota. In addition, the functions and values addressed in MnRAM and described below are expressly identified in state statutes.

3.2.1. Wildlife habitat. Wetlands provide habitat for numerous species of wildlife, including many species that are dependent on wetlands for all or part of their life cycle. Examples include waterfowl, wading birds, shorebirds, songbirds, amphibians, reptiles, and mammals such as muskrat *Ondrata zibethica* and beaver *Castor canadensis.*

3.2.2 Fish habitat. A number of species of fish may inhabit wetlands and shallow lakes, depending on depth and permanence of inundation. In the more shallow basins, the only species that typically persist are those that are tolerant of low dissolved oxygen, such as the fathead minnow, brook stickleback *Culaea inconstans*, central mudminnow *Umbra limi*, black bullhead *Ictalurus melas*, common carp, and northern pike *Esox lucius* (Peterka 1989). Deeper basins may support populations of largemouth bass *Micropterus salmoides*, sunfish *Lepomis spp.*, crappie *Pomoxis spp.* and walleye. However, natural fish populations in wetlands and shallow lakes are dynamic and temporal. They are often limited and sometimes eliminated by winterkill, or by declining water levels late in the growing season. Fish populations are also greatly influenced by the degree of connectivity with other waters. Connected basins can rapidly become recolonized by fish following drawdowns or winterkill.

3.2.3 Native plant diversity/ integrity. This function is a measure of the extent to which a wetland supports the full diversity of plant species that would normally be expected for a particular type of wetland. In addition to obvious biodiversity values, this function is directly related to several other functions, including wildlife habitat and water quality maintenance.

3.2.4. Water quality. The quality of water flowing out of a wetland is often of higher quality than the water flowing in. Pollutants can be removed from the water by physical (e.g., sedimentation), chemical (e.g., denitrification) and biological (e.g., nutrient uptake by plants) processes.

3.2.5. Water storage/retention. Depending on the physical characteristics of the basin and antecedent water levels, wetlands may capture and store runoff, which is then released slowly or lost to evapotranspiration.

3.2.6. Groundwater interaction. Wetlands may interact with groundwater in various ways. Some wetlands recharge shallow aquifers by allowing runoff to percolate slowly into the soil. Other wetlands are sites of groundwater discharge. Some wetlands do both, depending on hydrologic conditions.

3.2.7. Stream flow maintenance. By capturing runoff and releasing it slowly, either directly to streams or via shallow groundwater flow, wetlands can help maintain base flows in streams, which is important for sustaining habitat quality.

3.2.8. Shoreline protection. Emergent vegetation in wetlands provides a physical buffer to prevent wave action from eroding shorelines.

3.2.9 Recreation. Wetlands support many forms of recreation, including hunting, trapping, angling, and wildlife watching.

3.2.10. Commercial products. A variety of commercial products can be obtained from wetlands. Examples include wild rice, plant seeds and stock for aquatic gardening and wetland restorations, furbearers, minnows and leeches for bait, and game fish used for stocking lakes and streams.

3.3. Maintaining wetland functions and values

One of the assignments to the Wetland Values Technical Group was to develop guiding principles and/or definitions for the phrase, "maintaining and restoring wetland values." Natural, undisturbed wetlands generally provide a suite of functions and values, although not all wetlands perform all functions (and related values) equally. Wetlands can be manipulated or managed to enhance their capacity for certain functions. However, this may result in a decline in other functions and values. For example, the capacity of a wetland to store runoff can be maximized by extreme manipulation of water levels. However, the resulting water level fluctuations have severe adverse impacts on wildlife habitat. Chapter 4 provides an analysis of various aspects of fish culture on other wetland functions and values.

In many respects, the issues surrounding aquaculture in natural wetlands are similar to those facing the forest products industry, i.e., how to derive commercial products from natural communities without unacceptably compromising other values. The 1995 Minnesota Sustainable Forest Resources Act adopted the concept of *sustainability* to guide forest management in the state. Sustainability is defined in Minnesota Statutes as, "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (M.S. 89A.01, Subd. 13). The Wetland Values Technical Group considered the phrase "maintaining and restoring wetland values" to be analogous to the concept of sustainability. Therefore, the recommended licensing criteria in Chapter 5 are consistent with the following guiding principles of sustainability:

- Conservation of biological diversity (defined in M.S. 89A.01 as, "the variety and abundance of species, their genetic composition, and the communities and landscapes in which they occur, including the ecological structures, functions, and processes occurring at all of these levels.");
- Maintenance and restoration of natural productive capacity;
- Maintenance and restoration of long-term multiple socio-economic benefits to meet the needs of society.

Associated with these principles are issues of scale and scarcity. The functions and values provided by a particular wetland are partly dependent on landscape scale factors such as surrounding land use and the presence/absence and characteristics of nearby wetlands. Some areas of Minnesota have lost more than 90 percent of their pre-settlement wetland acreage (Anderson and Craig 1984). The relative scarcity of wetlands in these landscapes influences the functional profile of the remaining wetlands and must be considered in resource management decisions.

4. Ecological effects of fish culture in wetlands and effects on wetland functions and values

As discussed in Section 2.2, there is considerable evidence that fish play a role in determining the ecological characteristics of a basin, including inducing and stabilizing shifts between turbid and clear-water trophic states. The types of fish culture practiced in Minnesota are described below, with discussion of their observed and potential ecological effects. An analysis of the effects of fish culture on specific wetland functions and values (see Section 3.2) is provided in Table 1. The alternate stable states model was used as the basis for the analysis. For each of the functions and values, the group first evaluated whether the function/value was improved or degraded by shifts to one or the other trophic state. As might be expected, nearly all of the functions/values improve when wetlands exist in the clear-water, macrophyte-dominated state. Subsequently, the group considered how the various aquaculture practices might drive a basin toward one or the other trophic state, or otherwise influence specific functions and values. It's important to note that the effect of aquaculture practices on certain functions and values depends heavily on the pre-existing condition of

Table 1. Analysis of the effect of fish rearing practices on wetland functions and values. Key: + = positive effect, - = negative effect, N = no effect, ? = unknown effect, FHM = fathead minnow.

Wetland Functions and Values	Aquacultural Practices							Incidental carp/bullhead introduction
	Fish Introductions				Fertilizing[2]	Aeration[3]	Rotenone	
	Walleye[1]		White Sucker	FHM				
	w/ FHM	Fishless						
Wildlife Habitat	+	-	-	-	-	-	+ / -	-
Fish Habitat[4]	+		-	-	-	+	+ / -	-
Native Plant Diversity	+	?	-	-	-	-	+	-
Water Quality	+	?	-	-	-	-	+	-
Water Storage and Retention	+ / N	N	- / N	- / N	-	N	N	-
Groundwater Quantity Interaction	N	N	N	N	N	N	N	N
Stream Flow Mainte-nance	N	N	N	N	N	N	-	N
Shoreline Protection	+ / N	N	-	-	-	-	+	-
Recreation								
	+ / N	+	N	N	-	+	+ / -	-
Fishing Hunting	+	-	-	-	-	-	+	-
Trapping	+	-	-	-	-	-	+	-
Wildlife Obs.	+	-	-	-	-	-	+	-
Boating[5]	- / N	N	+	+	+	+	-	+
Commercial Products								
	+	+	+	+	+	+		?
Fish products	?	?	-	-	-	-	+	-
Leeches	+	N	-	-	-	-	+	-
Plant products Wild rice	+	N	-	-	-	-	+	-
Turtle harvest	+	N	-	-	-	-	+	-

[1] The analysis for walleye introductions assumes that walleye predation on fathead minnows is likely to either help maintain the basin in a clear-water state or create conditions for a shift back to the clear-water state. In fishless basins, the analysis is based on walleye predation on aquatic invertebrates.
[2] Fertilizing basins can cause shifts to the turbid state or prevent restoration of basins back to the clear-water state.
[3] Aeration is assumed to maintain populations of benthivorous and/or planktivorous fish that are responsible for shifting or maintaining basins in the turbid state.
[4] Assumes that clear-water, macrophyte dominated state favors diverse, native fish populations
[5] Assumes that boating is preferred in basins in the turbid state that lack dense growth of aquatic plants.

the basin. Many wetlands and shallow lakes are already in poor condition due to other factors (See Section 2.3). In such cases, aquacultural practices may have limited additional effect, although they may hinder restoration efforts.

4.1. Walleye and other game fish

For walleye and other game fish, wetlands are used as rearing ponds to grow the fish to a size suitable for stocking in other lakes. Walleye fry are introduced into wetlands in the spring, where they grow throughout the summer and are then captured in autumn as fingerlings for stocking. The advantage of using wetlands for raising game fish is that the basins are highly productive, and typically lack larger predatory fish that prey on fry and fingerlings. A few basins (about three for the MnDNR, unknown for private licensees) are used to raise/maintain broodstock. In those instances, the basins are managed to promote overwinter survival. In 2006, 1,288 basins, comprising 43,159 acres were used in Minnesota for walleye rearing (Appendix 2. Aquaculture Statistics).

Some of the ecological effects of walleye rearing in wetlands arise from the direct presence of the fish; other effects are related to various practices associated with walleye rearing. One of the main concerns is the potential for walleye to directly compete with waterfowl, and perhaps amphibians (see Semlitsch 2000) for aquatic invertebrate foods. Invertebrate food sources are critical for waterfowl during migration (e.g., Anteau and Afton 2004), breeding (Swanson et al. 1979), and for duckling growth and survival (Cox et al. 1998). Walleye reared in wetlands consume zooplankton until they reach a certain size, at which time they begin to prey on fish (Walker and Applegate 1976). As prey fish become less abundant, walleye fingerlings turn to invertebrate food sources (Walker and Applegate 1976). In a Minnesota study, Reed and Parsons (1999) analyzed the effects of introduced walleye fry/fingerlings in three wetlands, two of which had pre-existing fathead minnow populations, and compared the results to three basins without walleye. They found that the introduced walleye consumed aquatic macroinvertebrates throughout the summer and into the fall, indicating dietary overlap between walleye and waterfowl. However, the walleye had no apparent effect on overall invertebrate populations in the two wetlands having fathead minnow populations. In the treatment wetland that was otherwise fishless, an observed decline in inverterbrate populations may have been related to heavier walleye predation due to a lack of fish prey. Consequently, the authors recommended that walleye production in fishless basins be discouraged.

The preference of walleye for fish prey offers a potential management tool for wetlands in a turbid, algae-dominated state mediated by existing planktivorous fish populations, such as fathead minnows (see Section 2.2). Herwig et al. (2004) evaluated the use of walleye as a biomanipulation tool to suppress fathead minnow populations in Minnesota wetlands. They found that walleye fry were effective in reducing fathead minnow populations and observed subsequent increases in water clarity, aquatic invertebrates and submerged aquatic vegetation (Figure 5). Similar results were observed in a South Dakota study (Walker and Applegate 1976). However, the long-term effectiveness of biomanipulation using walleye is not known. Herwig et al. (2004) suggested that walleye fry stocking may need to be continued, perhaps every other year to control fathead minnow populations in a basin, and that biomanipulation may not be successful in basins where fish can readily immigrate from other sources. Landscape scale factors may also be important. Biomanipulation success in Herwig et al.'s (2004) study was positively correlated with the amount of grassland in the watershed (Reed 2006). Herwig et al. (2004) recommend that as many walleye fingerlings as possible be removed each fall to minimize walleye predation on invertebrates, and they echo Reed and Parsons' (1999) recommendation that walleye not be stocked into fishless basins.

A number of management actions associated with walleye production in wetlands have the potential for adverse impacts. To boost production, licensees commonly stock walleye rearing ponds with fathead minnows to supplement natural food sources. Fathead minnows and other planktivorous fish have a well-documented role in stabilizing and maintaining basins in the turbid, algae-dominated state (see Sections 2.2 and 4.3). Artificially maintaining high fathead minnow populations through stocking contributes to perpetually degraded wetland conditions. The practice of supplemental feeding with minnows can also introduce other unwanted fish species such as black bullhead and common carp into the wetland. These benthivorous fish, carp in particular, can quickly turn a high quality wetland into a turbid, algae-dominated basin and can be very difficult to eliminate (Crivelli 1983; Parkos et al. 2003). The MnDNR does no supplemental feeding for its walleye rearing operations.

Walleye fry may be supplementally fed with zooplankton collected from other basins. See Section 4.2 for a discussion on this aspect of supplemental feeding.

Another common practice associated with walleye rearing is fertilizing basins with organic (soybean meal or alfalfa) and inorganic fertilizers. These nitrogen sources promote algae growth, which in turn increases populations of zooplankton that walleye feed on. The elevated nutrient concentrations and enhanced algae growth raise the risk of shifting a basin into a turbid, algae-dominated trophic state.

In general, survival of walleye in rearing ponds through the winter is undesirable because carryover fish will prey on fry stocked the following spring. Therefore, fish culturists attempt to remove all of the walleye in the fall and do not attempt to prevent winterkill. In some cases, rotenone is applied to a basin to help ensure that that there are no carryover fish. Rotenone is toxic to all fish and also affects aquatic invertebrates, tadpoles, and juvenile salamanders (Chandler and Marking 1982; Schnick 1974). MnDNR Fisheries is currently conducting a study of the effects of rotenone use in walleye rearing ponds (Roy Johannes, personal communication). The study is evaluating the effects on water quality, aquatic vertebrates, aquatic macroinvertebrates and zooplankton, and aquatic plants and includes monitoring waterfowl use of the treated basins. Preliminary observations are that rotenone use has at least short-term positive effects on basin trophic condition, most likely due to suppression of planktivorous and benthivorous fish populations. Longer-term effects, including potential impacts on populations of non-target aquatic organisms will be reported upon completion of the study in 2008.

As described above, overwinter survival of walleyes in rearing ponds is generally undesirable. However, when the objective is to raise walleye to a larger size or to maintain broodstock, basins are usually aerated in winter to protect against winter-kill. This practice eliminates the natural dynamics of periodic expansion and contraction/elimination of fish populations in wetlands. In the absence of a fish prey base, artificially maintained walleye populations raise the likelihood of competition with waterfowl for invertebrate foods (Herwig et al. 2004; Reed and Parsons 1999). In basins with fathead minnow populations, carryover walleye may be important in suppressing the minnow population and improving the success of biomanipulation efforts (Herwig et al. 2004 and personal communication). However, it should be noted that aeration to carry over walleye also ensures that fathead minnow populations are not eliminated due to winterkill. Aeration also promotes survival of other fish species such as common carp and black bullhead, which are implicated in inducing basin shifts to the turbid, algae-dominated state (see Section 2.2). Basins that exhibit frequent winter carryover of walleye (or other game fish) may develop a recreational fishery if access is available. The human disturbance associated with angling can adversely affect the value of a basin for waterfowl, particularly during migration.

When walleye fingerlings are being harvested from rearing ponds, copper sulfate, an irritant to fish, is sometimes applied to the basin to assist in driving the fish into the nets. Copper sulfate can be toxic to other aquatic organisms, particularly in water with low concentrations of dissolved minerals (i.e., “soft” water) (Eisler 1998). A review conducted by the MnDNR on the long-term impacts of copper sulfate application concluded that its use does not likely pose a problem in most of the hard water lakes in western Minnesota used for walleye rearing, but that little was known about the impacts of copper accumulation in soft water lakes (Jacobson 1990). In an update to that review, Jacobson (2003) recommended that due to the cost of testing and the uncertainty of setting a safe sediment concentration, it would be reasonable to discontinue the use of copper sulfate to harvest walleye.

Copper sulfate is a well-known algicide, thus a side effect of its use in harvesting fish can be a temporary reduction in algae populations in the basin. However, *Chara*, a macroalga, is a benefical algae for shallow lakes and wetlands as it stabilizes the clear-water state mainly by absorbing nutrients and protecting bottom sediments from resuspension (Blindow 1992; Blindow et al. 2000; Vermaat et al. 2000). *Chara* control is a labeled use of many copper sulfate algaecides. Therefore copper sulfate used to increase walleye harvest may potentially have negative trophic effects on the shallow lake or wetland if the copper causes a loss or reduction of *Chara* in the basin.

4.2. White sucker

White suckers *Catostomus commersoni* are raised for baitfish purposes. In Minnesota, 1,283 basins comprising 32,782 acres were licensed for raising suckers in 2006, which is more licensed acreage than for any other fish species. White suckers are purchased from the MnDNR as eggs in the spring, hatched in hatchery facilities, and the fry stocked in wetlands in early May. Licensees must have 1.5 acres of water licensed in order to purchase 1 quart of sucker eggs. Each quart contains approximately 45,000 eggs. Suckers are raised to various sizes: some are harvested in the first fall following stocking as 4"- 6" fish, some are held over in aerated ponds and harvested throughout the winter and spring as 7"- 9" fish, and some are grown into the following summer and harvested in the 9"-11" range.

The effects of sucker introduction in wetlands have not been as well studied as walleye and fathead minnows. White suckers are omnivorous, feeding on a variety of aquatic invertebrates, zooplankton and algae (Chen and Harvey 1995; Dobie 1968, 1972; Eder and Carlson 1977). In a study of white suckers in Minnesota rearing ponds, zooplankton and chironomid larvae comprised the bulk of the diet (Dobie 1972). As planktivores, it's thought that suckers may have effects similar to fathead minnows in suppressing zooplankton populations, thus stabilizing shifts in the trophic state of basins to turbid, algae-dominated conditions (see Section 2.2). When invertebrate populations are low, suckers shift to consuming detritus and algae (Ahlgren 1990), which has the effect of recirculating nutrients into the water column, thereby perpetuating algal growth and maintaining turbid conditions (as described by Zimmer et al. 2006 for fathead minnows).

In order to raise suckers to larger sizes, basins are often aerated to prevent winterkill. High spring populations of planktivorous fish may increase the potential for a shift in trophic state to a turbid condition (as described in Section 2.2) because the bloom in phytoplankton populations occurs before the seasonal growth of aquatic macrophytes gets started. Also, as described in the previous section on walleye, aeration maintains artificially high fish populations in wetlands, including non-target species such as carp and bullheads, when present.

As with walleye, basins used for rearing white suckers may be fertilized with organic and inorganic fertilizer to promote algae growth, which in turn increases populations of zooplankton that suckers feed on. If overapplied, the elevated nutrient concentrations and enhanced algae growth raise the risk of shifting a basin into a turbid, algae-dominated trophic state.

Fish culturists may also provide supplemental food for suckers in the form of zooplankton collected from other basins. The amount of zooplankton introduced is probably not sufficient to have trophic level effects on the receiving basin, particularly since they are quickly consumed by the fish. On the other hand, there may be a potential for impacts on the basin from which the zooplankton were collected if it is fishless and zooplankton populations are reduced enough to allow release of the phytoplankton populations. This is purely speculative, as the effects of supplemental feeding have not been studied to our knowledge. This type of supplemental feeding also has the potential for introducing invasive species into previously unaffected basins.

4.3. Fathead and other minnows

Fathead minnows are a widespread, native fish in Minnesota wetlands and shallow lakes (Phillips et al. 1982). They are tolerant of low oxygen conditions and are extremely productive, spawning as many as seven times in a growing season (Herwig and Zimmer 2006, *in review*). Fathead minnows are commonly harvested and sold as baitfish. Much of the commercial market involves harvesting native populations. However, aquatic farm and private hatchery license holders may stock natural basins with fatheads where natural populations are low or nonexistent.

As a ubiquitous and abundant fish in wetlands and shallow lakes (Peterka 1989), fathead minnows have been the focus of numerous studies related to their implications for waterfowl management. Potential ecological effects include impacts on aquatic invertebrate communities and their role in influencing the trophic state of wetlands (Herwig and Zimmer 2006, *in review*; Zimmer et al 2006). In a study of Minnesota wetlands, Hanson and Riggs (1995) found that high densities of fathead minnows severely depressed the abundance, biomass and diversity of aquatic invertebrates compared to fishless wetlands. Other studies have confirmed that wetlands with fathead minnows have distinctly different invertebrate communities than fishless wetlands (Zimmer et al. 2000, 2001c).

Several studies have identified a link between high fathead minnow populations and turbid, algae-dominated conditions in wetlands (Hanson et al. 2005; Zimmer et al. 2001a, 2001b, 2002). One possible explanation is predation by fathead minnows on zooplankton and the subsequent release of phytoplankton populations (see Scheffer 1998). Another factor involves fathead consumption of detritus and subsequent excretion of nutrients into the water column in a form readily available for uptake by algae (Zimmer et al. 2006). However, the causal mechanisms responsible for producing trophic states are complex, and fathead minnows are not always associated with the turbid state (Zimmer et al. 2003a, 2003b). Ongoing research suggests that planktivorous fish such as fathead minnows may be more responsible for stabilizing basins in a turbid state, rather than inducing such shifts (M. Hanson and B. Herwig, personal communication). Another important factor may be ambient nutrient levels. Basins characterized by high nutrient concentrations may be more susceptible to shifts to the turbid state mediated and/or stabilized by fish.

Nonetheless, high populations of fathead minnows are clearly associated with adverse effects in wetlands. Under natural conditions, fathead minnow populations in wetlands are extremely dynamic. Their natural fecundity produces rapid population expansion, while periodic winterkill and drought causes significant contraction or elimination. In much of Minnesota, populations of fathead minnows (and other fish) are maintained at unnaturally high levels in wetlands due to a number of human factors, including the increased connectivity from drainage infrastructure, less frequent winterkill due to higher and more permanent water levels as a result of ditch and drain tile outlets into basins, intentional and unintentional stocking, and aeration. As discussed in Section 4.1, stocking basins with walleye fry offers a potential management tool for temporarily controlling fathead minnow populations and improving wetland condition.

Other minnow species such as golden shiners *Notemigonus crysoleucas* and northern redbelly dace *Phoxinus eos* are also harvested as baitfish from wetlands and shallow lakes. However, this generally involves only natural populations that are not artificially manipulated and is therefore not considered a fish culture activity.

4.4 Incidental introductions

A number of fish rearing practices may result in introducing incidental species into basins, either intentionally or accidentally. Benthivorous fish such as common carp and black bullheads have a clear role in eliminating aquatic macrophytes and shifting basins to a turbid trophic state, with severe adverse impacts on nearly all wetland functions and values. In addition to incidental introduction of unwanted fish, aquacultural practices may also result in introductions of invasive plant species such as Eurasian water milfoil *Myriophyllum spicatum*, curly-leaf pondweed *Potemogeton crispus*, and purple loosestrife *Lythrum salicaria*, all of which adversely affect wetland habitat and plant diversity functions. Other aquatic invasive species that are not as easily monitored are the zebra mussel *Dreissena polymorpha*, spiny water flea *Bythotrephes longimanus* and New Zealand mud snails *Potamopyrgus antipodarum*. They all could easily be unintentionally transported in water and all have negative impacts on habitat.

5. Recommended licensing criteria

Many factors play a role in determining the impact of aquaculture on wetlands and shallow lakes, including the composition and density of pre-existing fish populations, basin trophic state, background nutrient concentrations, basin morphology, and weather and climate patterns. To complicate matters, all of these factors are interrelated. Following are criteria to be considered in licensing basins for various fish species, with potential implications based on published studies and the expertise of the Wetland Values Technical Committee. These criteria are also summarized in Table 2.

5.1. Criteria for licensing basins for minnows and suckers

5.1.1. Status of pre-existing fish populations:

Fishless (no fish are detected in a spring survey and the basin is not connected to other waters) – Truly fishless basins are increasingly rare. If a basin is fishless and in a clear-water, macrophyte-dominated state, introducing planktivorous fish such as fathead minnows or benthivorous fish such as white suckers (which also act

Table 2. Summary of recommended aquaculture licensing criteria.

Criteria/Scenario	Introduction of Minnows or Suckers	Introduction of Game Fish
Fish Status		
Fishless	1. Clear-water state: Greatly increases the risk that the basin will switch to a turbid state. Will alter the aquatic invertebrate community. 2. Turbid state: Greatly reduces the chances of the basin recovering to a clear-water state. Will alter the aquatic invertebrate community.	Potential to alter aquatic invertebrate communities. Supplemental feeding by stocking the basin with fathead minnows increases the risk of significant adverse effects on basin trophic state. Incidental introduction of carp or black bullhead can have disastrous consequences for habitat quality.
Pre-existing populations of planktivores	1. Basin typically winterkills: Introduction of additional fish may result in trophic state or invertebrate population effects. 2. Basin does not typically winterkill and in turbid state: Introduction of additional fish may not have any significant ecological effects but may act to stabilize the basin in a turbid state.	Introducing walleye fry may suppress the minnow population with positive consequences for basin trophic condition.
Pre-existing populations of benthivores	Turbid state: May not cause any further degradation of the trophic condition, but may act to stabilize the basin in a turbid state, hindering or precluding restoration.	Walleye rearing would not be expected to have any beneficial effects, nor would it be likely to have any further adverse impacts on turbid trophic state. Walleye predation on aquatic macroinvertebrates may adversely affect aquatic food webs.
Pre-existing populations of game fish	Not likely to be used for rearing minnows and suckers due to predation by pre-existing game fish.	Not likely to be used for walleye rearing due to predation on walleye fry and fingerlings.
Basin Trophic Condition		
Clear-water state	Greatly increases the risk that the basin will switch to a turbid state especially if background nutrient concentrations are high.	If fish prey base is absent, may result in walleye predation on invertebrates and zooplankton, with potential adverse effects on habitat quality and trophic state. If pre-existing populations of planktivores are present, walleye rearing may act to sustain the clear-water state, particularly if background nutrient concentrations are high.
Turbid state	Unlikely to have further trophic level effects. Reduces the chance that the basin will recover to a clear-water condition and may also directly affect aquatic invertebrate numbers and composition.	Unlikely to incur significant adverse effects due to walleye introduction, and may be improved if planktivorous fish are a factor in the turbid trophic condition. If the fish prey base is eliminated, continued introduction of walleye will result in walleye predation on invertebrates and zooplankton, with potential adverse effects on habitat quality.
Connectivity with other waters		
	Increases potential for movement into other, previously fishless basins and for rapid recolonization of winterkilled basins, both of which can have adverse impacts.	Increases potential for movement into other, previously fishless basins and for rapid recolonization of winterkilled basins, both of which can have adverse impacts.
Landscape scale considerations		
No. of basins used for aquaculture within a watershed	Wetlands benefits provided at the landscape scale could be compromised if too many basins are used for aquaculture, although this threshold cannot be quantified.	

Table 2. Continued.

Aquaculture Practices	
Aeration	Aeration to promote winter carryover of white suckers increases the risk of a basin switching to a turbid trophic condition, or if already turbid, increases the likelihood of it remaining in that state. Aeration to promote winter carryover of walleye may help to suppress fathead minnow populations, if present, with positive implications for basin trophic condition. However, aeration also ensures that the fathead minnow population is not eliminated by winterkill. For basins that do not support minnow or other forage fish populations, carryover walleyes may adversely aquatic macroinvertebrate populations. If a recreational fishery develops, the human disturbance from angling during the waterfowl migration period may adversely affect use of the basin by waterfowl and hunting recreation. Aeration maintains populations of undesirable fish such as common carp and black bullheads, if present.
Supplemental feeding	Supplemental feeding by introducing zooplankton collected from other basins is unlikely to adversely affect the receiving basin, but the “donor” basin could be adversely affected if it’s in a clear-water state and the numbers of zooplankton collected reduces populations sufficiently to release phytoplankton populations, leading to a trophic shift. Supplemental feeding of walleyes with fathead minnows may be particularly harmful if the basin did not previously support fathead minnow populations. If fathead minnow populations are already present, supplemental feeding of walleyes may contribute to degraded wetland conditions by maintaining an artificially high fathead minnow population. Supplemental feeding with minnows can also introduce other unwanted fish species such as black bullheads and common carp into the wetland, which can have severe adverse impacts.
Fertilizing	Elevated nutrient concentrations and enhanced algae growth raise the risk of shifting a basin into a turbid, algae-dominated trophic state.
Copper Sulfate	Copper sulfate can be toxic to other aquatic organisms, particularly in water with low concentrations of dissolved minerals (i.e., “soft” water). It may also suppress populations of beneficial algae, Chara sp.
Rotenone	Rotenone use has been observed to have at least short-term positive effects on basin trophic condition, most likely due to suppression of planktivorous and benthivorous fish populations. However, rotenone is toxic to all fish and also affects aquatic invertebrates, tadpoles and juvenile salamanders. Longer-term effects of rotenone use in rearing walleye, including potential impacts on populations of non-target aquatic organisms is currently under investigation by the MnDNR, with completion of the study scheduled for 2008.

as planktivores) greatly increases the risk that the basin will switch to a turbid state. This risk is enhanced if the basin has high background nutrient concentrations (total phosphorus > 25-30 μg/L). Introducing suckers or minnows into a fishless basin already in a turbid state greatly reduces the chances of the basin recovering to a clear-water state. Introducing fathead minnows into a fishless basin is also likely to alter the aquatic invertebrate community, with adverse consequences for waterfowl and other wildlife. White suckers may have similar impacts based on their food habits, however, they have not been specifically studied in this regard.

Pre-existing populations of planktivores – The effects of introducing minnows and/or suckers into basins that have pre-existing populations of these fish depends somewhat on the population dynamics of the basin. If the basin frequently winterkills, then the existing fish populations would typically be reduced to very low levels in the spring and the fish populations may not expand early enough in the growing season to have trophic state effects, or to compete with spring breeding waterfowl for aquatic invertebrates. Introducing fathead minnows or suckers for aquaculture into these basins will artificially boost population levels with potential trophic level effects and food web implications. If the basin does not typically winterkill and has persistent, high populations of planktivores and is already in a turbid trophic state, then introduction of additional fish may not have any significant ecological effects, but may act to stabilize the basin in a turbid state, hindering or precluding restoration

Pre-existing populations of benthivores – Basins with established, persistent populations of benthivores such as carp and black bullhead, and high background nutrient concentrations (total phosphorus > 25-30 μg/L) will typically be in a turbid trophic condition. Rearing minnows or suckers in these basins may not cause any further degradation of the trophic condition in these basins, but may act to stabilize the basin in a turbid state, hindering or precluding restoration. Introducing minnows or suckers into basins that contain populations of benthivores and are in a clear-water state raises the risk that the basin will switch to the turbid state.

Pre-existing populations of game fish – Basins having pre-existing populations of piscivorous game fish would not be preferred for rearing minnows and suckers because of predation on the fish being reared. However, the introduction of planktivorous or benthivorous fish could cause or maintain a switch to the turbid state if the game fish population is too low or of the wrong species to exert control on the planktivore/benthivore populations.

5.1.2. Basin trophic condition:

Clear-water state -- Introducing planktivorous fish such as fathead minnows or benthivorous fish such as white suckers (which also act as planktivores) greatly increases the risk that the basin will switch to a turbid state. This risk is enhanced if the basin has high background nutrient concentrations (total phosphorus > 25-30 μg/L). Thus, fertilizing the basin with organic fertilizers to enhance production increases the risk of a shift to turbid conditions. Basin aeration, which is often used for the culture of white suckers also enhances winter carryover of non-target species such as carp and black bullhead, which can severely degrade basin condition.

Turbid state – Introducing fathead minnows or white suckers into a basin that is already in a turbid state is unlikely to have further trophic level effects, but there is evidence that these fish serve to stabilize a basin in this turbid condition. Therefore, artificially sustaining high populations of these species greatly reduces the chance that the basin will recover to a clear-water condition and may also directly affect aquatic invertebrate numbers and composition, with potential adverse consequences for waterfowl and other wildlife.

5.1.3. Connectivity with other waters

Fish introduced into basins that may connect to other waters raises the potential for movement into other, previously fishless basins and for rapid recolonization of winterkilled basins, both of which can have adverse impacts.

5.1.4. Associated Practices

Aeration – Aerating basins to improve winter carryover results in higher spring populations of minnows and suckers than would normally occur if the basin was allowed to winterkill. Higher populations of these fish, particularly in spring increases the risk of a basin switching to a turbid trophic condition, or if already turbid, increases the likelihood of it remaining in that state.

Supplemental feeding: The effects of supplemental feeding of suckers by introducing zooplankton collected from other basins have not been studied. It's unlikely that the receiving basin would be affected, but the "donor" basin could be adversely affected if it's in a clear-water state and the numbers of zooplankton collected reduces populations sufficiently to release phytoplankton populations, leading to a trophic shift. Therefore, in developing license criteria, it may be more important to assess and regulate the collection of zooplankton in the "donor" basin.

Fertilizing: Elevated nutrient concentrations and enhanced algae growth raise the risk of shifting a basin into a turbid, algae-dominated trophic state.

5.2. Criteria for licensing basins for game fish (walleye, primarily)

5.2.1. Status of pre-existing fish populations:

Fishless (no fish are detected in a spring survey and the basin is not connected to other waters) – Truly fishless basins are increasingly rare. Rearing walleye in fishless basins has the potential to alter aquatic invertebrate communities, with adverse consequences for waterfowl and other wildlife. Supplemental feeding of walleye by stocking the basin with fathead minnows increases the risk of significant adverse effects on basin trophic state. Incidental introduction of carp or black bullhead can have disastrous consequences for habitat quality.

Pre-existing populations of planktivores – Introducing walleye fry into basins having prior established populations of fathead minnows may suppress the minnow population with positive consequences for basin trophic condition.

Pre-existing populations of benthivores – Although specific studies are lacking, walleye are not thought to have a significant effect on populations of benthivores such as carp or black bullhead. Assuming the basin is already in a degraded condition due to persistent populations of these species, walleye rearing would not be expected to have any beneficial effects, nor would it be likely to have any further adverse impacts on basin trophic state. However, walleye predation on aquatic macroinvertebrates may adversely affect aquatic food webs.

Pre-existing populations of game fish – Basins having pre-existing populations of piscivorous game fish would not be preferred for rearing walleye because of predation on walleye fry and fingerlings.

5.2.2. Basin trophic condition:

The role of walleye in influencing basin trophic condition is more related to interaction with other fish species, particularly fathead minnows.

Clear-water state -- Introducing walleye into a clear-water basin lacking a fish prey base will result in walleye predation on invertebrates and zooplankton, with potential adverse effects on habitat quality and trophic state. Rearing walleye in clear-water basins having pre-existing planktivore populations may sustain the clear-water state by continued suppression of the planktivores, particularly where background nutrient concentrations are high.

Turbid state -- Basins already in a turbid state are unlikely to incur significant adverse effects due to walleye introduction, and may be improved if planktivorous fish are a factor in the turbid trophic condition. If the fish prey base is eliminated, continued introduction of walleye will result in walleye predation on invertebrates and zooplankton, with potential adverse effects on habitat quality.

5.2.3. Connectivity with other waters

Fish introduced into basins that may connect to other waters raises the potential for movement into other, previously fishless basins, and for rapid recolonization of winterkilled basins, both of which can have adverse impacts. With game fish, there are additional considerations of ownership of the resource. In general, the Wetland Values Technical Committee recommends that public aquaculture be held to the same standards as private aquaculture for maintaining and restoring wetland values, but resource ownership is more of a policy issue and was not addressed by our committee.

5.2.4. Associated Practices

In addition to the criteria listed above, the following practices associated with aquaculture should be considered in basin licensing decisions.

Aeration: For basins supporting populations of fathead minnows, aeration to promote winter carryover of walleye (for maintaining broodstock or a recreational fishery) may help to suppress the minnow population, with positive implications for basin trophic condition. On the other hand, aeration also ensures that the fathead minnow population is not eliminated by winterkill. For basins that do not support minnow or other forage fish populations, carryover walleyes may adversely affect aquatic macroinvertebrate populations. If a recreational fishery develops, the human disturbance from angling during the waterfowl migration period may adversely affect use of the basin by waterfowl and hunting recreation. Aeration will also act to maintain populations of undesirable fish such as common carp and black bullheads, if present.

Supplemental feeding: As discussed in Section 4.3, there is an observed (but not necessarily predictive) relationship between the presence of fathead minnows in a basin and a turbid trophic state. Supplemental feeding of walleyes with fathead minnows may be particularly harmful if the basin did not previously support fathead minnow populations. Even though walleye may prey on aquatic invertebrates in the absence of fish prey, the food web and trophic state effects of walleye alone are less damaging than the impacts of persistent, high fathead minnow populations. If fathead minnow populations are already present, supplemental feeding of walleyes may contribute to degraded wetland conditions by maintaining an artificially high fathead minnow population. The practice of supplemental feeding with minnows can also introduce other unwanted fish species such as black bullheads and common carp into the wetland, which can have severe adverse impacts.

Fertilizing: See Section 5.1.4.

Copper sulfate: Copper sulfate can be toxic to other aquatic organisms, particularly in water with low concentrations of dissolved minerals (i.e., “soft” water). It may also suppress populations of *Chara spp,.* a beneficial algae.

5.3. Criteria that apply to licensing basins for all fish: Landscape scale considerations

In addition to considering basin-specific factors, the Wetland Values Committee recommends that licensing decisions also take into account the overall number of basins used for aquaculture within a particular area, such as a watershed. Considering the historical loss of wetlands in areas of the state where aquaculture is concentrated and the potential for adverse impacts resulting from aquaculture, it’s possible that the benefits that wetlands provide at the landscape scale could be compromised if too many basins are used for aquaculture. Current science is not sufficient to recommend a specific threshold, but this criterion should be considered in licensing basins.

5.4. Licensing assessment needs

The licensing criteria above would require the following surveys and data for licensing new basins and in evaluating renewal of existing licenses:

- Fish surveys, to characterize existing fish populations.
- Secchi disk, total phosphorus, chlorophyll a, and possibly vegetation surveys to evaluate basin trophic condition.
- Survey of potential connections to other waters, including through ditches and tiles lines.

5.5. Public vs. private application

The Wetland Values Technical Committee recommends that the public and private sectors be held to the same standards for maintaining the functions and values of wetlands and shallow lakes used for rearing fish. The decision to license or use a basin for fish rearing should use the same criteria, with the possible exception of the criterion related to connectivity of the basin to other waters. Because fish reared by the MnDNR are a public resource, it may be acceptable for the MnDNR to use basins that are connected to other public waters, provided that it does not result in establishing fish populations in other, previously fishless basins and that the other criteria are met.

6. Research needs

The licensing criteria above represent a conservative approach aimed at maintaining wetland functions and values, based on current knowledge. Additional research on the following topics would be helpful in refining the criteria:

- Effects of long-term, annual use of wetlands for rearing walleye;
- Effects of white sucker rearing in wetlands;
- Impacts of aeration on wetland food webs and wetland water quality;
- Landscape level impacts of fish rearing; and
- Impacts of global warming on wetland quality and potential effects on aquaculture in Minnesota.

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Appendix 1. Aquaculture statistics for Minnesota

Private Ponds Licensing 2001- 2006

Year	Overall Waters Ponds	Overall Acres Acres	*Acres approved for Walleye	*Acres approved for White Sucker
2001	1,977	42,816	13,297	31,161
2002	1,958	42,862	13,998	31,478
2003	1,981	43,119	14,196	31,529
2004	2,050	45,574	16,815	32,833
2005	2,026	43,090	21,473	33,448
2006	2,008	42,625	21,446	32,782

Pond Acre Size	Overall Waters approved	Overall Acres approved	*Waters approved for Walleye	*Acres approved for Walleye	*Waters approved for White Sucker	*Acres approved for White Sucker
0-2.99	633	365	272	180	201	166
3.0-4.99	135	467	67	231	89	306
5.0-9.99	264	1,747	139	914	195	1,298
10.0-24.99	437	6,688	194	2937	359	5,490
25.0-49.99	295	10,290	144	4924	249	8,688
50.0-99.99	171	11,406	92	6117	135	8,942
100.0-149.99	47	5,479	26	2989	36	4,129
150-199.99	10	1,616	6	944	10	1,616
200.0-299.99	11	2,556	7	1557	8	1,847
300.0 -Plus	5	2,011	2	652	1	302
Total	**2,008**	**42,624**	**949**	**21446**	**1,283**	**32,782**

***A number of waterbodies have received approval for both walleye and white sucker and are listed twice.**

DNR Walleye Rearing Ponds*

Year	Number of Ponds	Number of Acres
2001	327	23,898
2002	329	21,091
2003	374	22,296
2004	347	24,919
2005	371	24,016
2006	339	21,713

***Includes ponds that were harvested but not stocked for that year**

Overall breakdown of ponds used for walleye rearing during 2001-2006

Pond Acre Size	Number of Ponds	Number of Acres
0-2.99	23	34
3.0-4.99	19	73
5.0-9.99	49	347
10.0-24.99	187	2,963
25.0-49.99	137	4,736
50.0-99.99	131	8,934
100.0-149.99	50	6,057
150-199.99	21	3,523
200.0-299.99	21	5,079
300.0 -Plus	16	6,497
Total	**654**	**38,242**

Aquaculture Information from 2005

Aquatic Farm/Private Hatchery

<u>Types of Licenses (2005)</u>
Aquatic Farm/Private Hatchery (sales greater than $200) - 88
Hobby licenses (sales less than $200) – 73
Aquarium Licenses (pet stores) – 7
Indoor system licenses – 10
Licenses that use wetlands for rearing – 143
Number of licenses that also has a minnow dealer license – 62

Licensed Ponds 2005
Total number of acres that are approved for walleye rearing: - 21,409 (includes artificial and natural ponds)
Total number of acres that are approved for white sucker – 33,447 (includes artificial and natural ponds)
Total number of acres for other species - 4,375 (includes artificial and natural ponds)

Total number of ponds approved for licensing - 2,008 for 43,020 acres

Minnow licenses in 2005
Retail stores (cannot trap) – 868
Minnow Dealers – 310 (62 also have an aquaculture license see above)
Exporting Minnow Dealers – 36 (22 also have an aquaculture license)

Aquaculture Reports for licensees that have a minnow dealer license (Minnesota sales only)

04 Minnow Report	Species	# Gallons*	# Pounds
Fathead minnow	FHM	123,828	
Golden shiner	GOS	16,915	
White sucker	WTS	68,705	
Northern dace	NRD	3,564	
Leech	LEC		120,873
Chub	CHB	1,050	
Other	OTH	648	
Totals		**214,710**	**120,873**

*There are eight pounds of fish for each gallon

2004 Minnow Dealer Reports (separate from aquaculture)

	Species	Total Gallons*	Total Pounds
Chubs	CHB	3,796	
Fathead minnows	FHM	96,390	
Golden shinners	GOS	16,352	
Leeches(pounds)	LEC		204,852
Northern redbelly dace	NRD	4,981	
Unidentified-other	Other	263	
White sucker	WTS	18,404	
Totals		**140,186**	**204,852**

*There are eight pounds of fish for each gallon

2004 Exporting Minnow Dealer Reports (Aquaculture and Minnow licenses combined)

	Species	Total Gallons*	Total Pounds
Fathead minnows	FHM	183,839	
Golden shinners	GOS	16,915	
Leeches(pounds)	LEC		102,886
White sucker	WTS	21,493	
Totals		**222,247**	**102,886**

*There are eight pounds of fish for each gallon

Game Fish sold in Minnesota during 2004

Game Fish Species	**Code**	**Sales Number**	**Pounds**
Brook trout	BKT	2,638	1,065
Bluegill sunfish	BLG	48,663	1,546
Black crappie	BLC	85,133	6,045
Brown trout	BNT	400	500
Hybrid sunfish	HSF	16,641	596
Largemouth bass	LMB	6,873	405
Muskellunge	MUE	22,798	87
Northern pike	NOP	6,203	579
Rainbow trout	RBT	68,014	26,411
Smallmouth bass	SMB	1,245	72
Tiger muskellunge	TME	4,867	1,251
Walleye	WAE	8,745,450	50,860
Yellow perch	YEP	82,654	1,289
Totals		**9,091,579**	**90,706**

Other Fish Species Sold in Minnesota in 2004

Other Fish Species	Code	Sales Number	Pounds
Alligator gar	ALG	20	1
Shortnose gar	SNG	11	1
Longnose gar	LNG	16	1
Black bullhead	BLB	261	102
Brown bullhead	BRB	519	6
Lake sturgeon	LKS	4,304	431
Koi-goldfish	KOI	0	0
Green sunfish	GSF	49	2
Red claw crayfish	RCC	500	1
Orangespotted sunfish	OSS	7	1
Pumpkinseed sunfish	PMK	100	2
Rock bass	RKB	14	1
Sauger	SAR	0	0
Tilapia	TIL	1,254,670	1,692,030
Total		**1,260,471**	**1,692,579**
Grand Total		**10,352,050**	**1,783,285**

Appendix 2. Comparison of aquaculture statutes and rules from Minnesota and surrounding states.

Questions	Minnesota	Iowa	Wisconsin	Michigan	North Dakota	South Dakota
1. Does your state permit use of public waters or wetlands for private aquaculture?	Yes with restrictions.	Yes with restrictions. Private aquaculture is not allowed in private or nonmeandered lakes and streams and ponds that may become stocked with fish from public waters or natural migration.	Yes with restrictions. New private aquaculture ponds are limited to shallow waters of the state called freeze out ponds. These are ponds that freeze out twice in 5 years and they must obtain a natural water body permit from DNR. Some ponds that existed prior to 1998 have been grandfathered with a natural water body permit.	No. Michigan does not allow the use of public waters for private aquaculture. MI does have specific wetland regulations and any development for aquaculture in a wetland area would have to meet specific criteria depending on the size of the wetland area.	Yes	Yes
2. What are current regulations for minnow harvest?	Licensee may take minnows (sperm, eggs or live fish) or sucker eggs from public waters	Licensed bait dealers may harvest unprotected species for hook and line fishing within the state. State may designate certain lakes and streams from which minnows may not be harvested.	License required to harvest bait fish if offered for sale in WI. Anglers with fishing license may harvest up to 600 minnows for personal sport fishing.	No information in statutes.	No information in statutes.	Public waters open to taking of bait with exceptions for listed basins and those within 100 feet of areas designated by GFPC as protected spawning beds, rearing ponds, or other areas protected as fish management areas.
3. What are licensing criteria for public waters?	1. Basins with continual connections to other waters are not licensed; however, connected waters isolated from other basins can be licensed. 2. Waters with intermittent connections require screening to prevent passage of aquatic life. 3. Basins with game fish of significant value may be denied licensing unless applicant can demonstrate exclusive riparian control or game fish are removed or sold to applicant.	No information in statutes.	New private aquaculture ponds are limited to shallow waters of the state called freeze out ponds. These are ponds that freeze out twice in 5 years and they must obtain a natural water body permit from DNR. Must lease or own land around pond so that there is no public access.	No information in statutes.	No information in statutes.	No information in statutes.