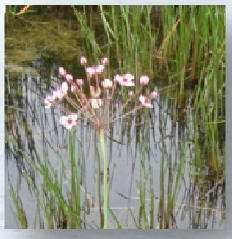
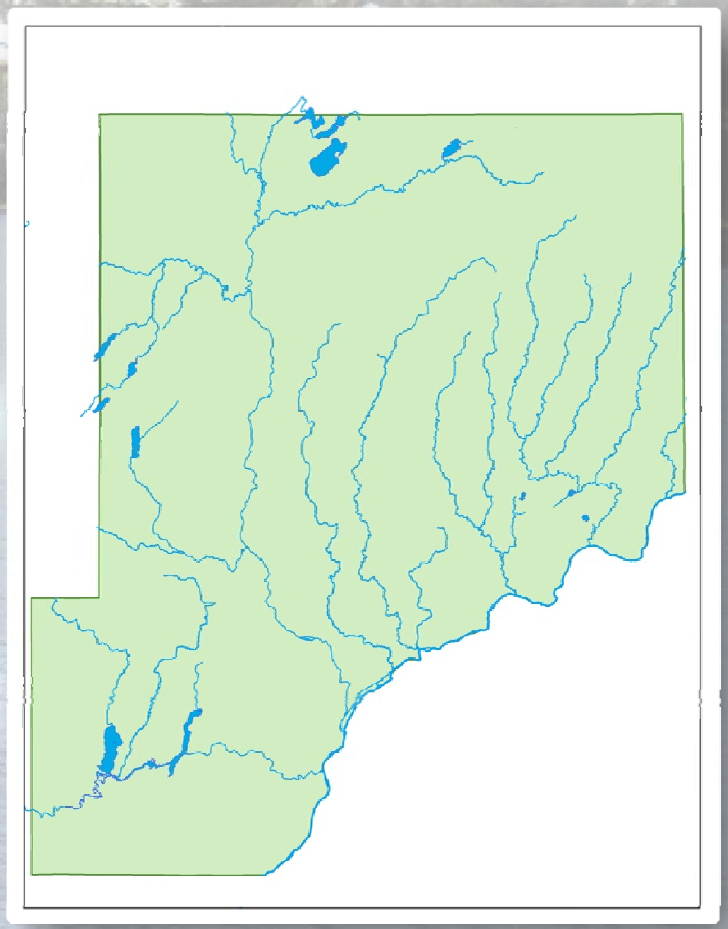
Pine County

AIS Prioritization

A planning tool developed for AIS risk management and prevention

2016





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Funded by: Pine County

Assessment Development: Moriya Rufer
RMB Environmental Laboratories
22796 County Highway 6
Detroit Lakes, MN 56501
218-846-1465
moriyar@rmbel.info
http://rmbel.info

Data Sources: Pine County Lake Associations
Pine County
Minnesota Department of Natural Resources
Minnesota Pollution Control Agency

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Introduction

Background

Aquatic Invasive Species (AIS) are aquatic plants and animals that are not native to Minnesota, and cause environmental changes to our waters, have negative economic consequences to our communities, or are harmful to human health. Minnesota's natural resources are threatened by a number of Aquatic Invasive Species such as Zebra mussels, Flowering rush, Eurasian watermilfoil and Asian carp. Invasive species are usually spread by humans.

Zebra mussels are particularly harmful because they spread so rapidly and there are currently no effective treatment options. They attach to hard surfaces such as boats, docks, boat lifts, aquatic plants, and water intake pipes, and can clog pipes, cut feet, and damage boats. Zebra mussels have a large economic impact to water treatment facilities, lakeshore owners, lake recreators, and the tourism industry.

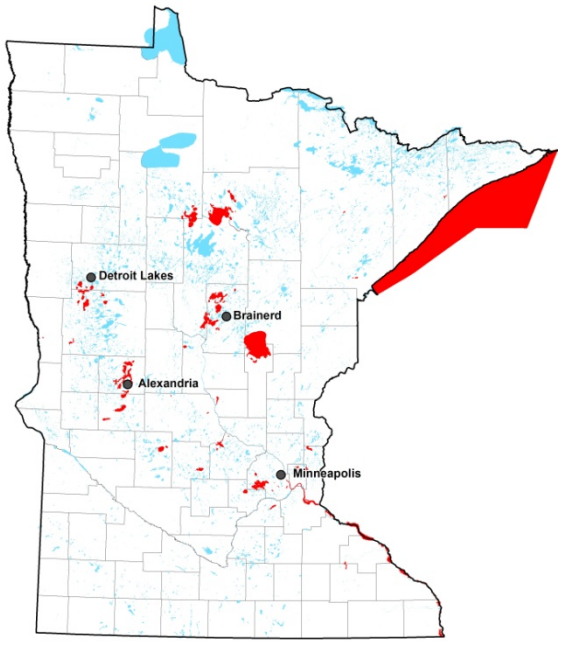


Figure 1. Minnesota Lakes infested by Zebra mussels, 2015.

Zebra mussels also affect the aquatic ecosystem by filtering out microscopic plankton from the water, and therefore removing the food source for other aquatic organisms. This has implications up the food chain, such as affecting fish populations.

As of the end of 2015 Zebra mussels have been found in approximately 94 lakes in Minnesota, and the DNR has included an additional 106 water bodies on their infested waters list because they are connected to a lake infested with Zebra mussels (MNDNR 2015) (Figure 1). The infestations are clustered around areas with high traffic lakes such as Brainerd, Alexandria, Detroit Lakes and Minneapolis. This pattern of spread is consistent with what has been seen in Michigan, another state with Zebra mussel infested lakes (Johnson *et al.* 2006).

In order to slow or stop the spread of Zebra mussels in Minnesota, a concentrated effort is required. Ideally, unlimited resources would be available to protect all lakes, but in reality budgets are always limited. Therefore, prioritizing lakes due to their risk of infestation is helpful in creating and implementing an AIS management plan.

Project Goals

Highest risk time of year
+
Highest risk lakes
=
When/where to focus AIS prevention

The goals of this project were to assess the risk of Zebra mussel infestation in Pine County in order to prioritize funding and efforts to prevent the further spread of Zebra mussels. Thirteen lakes were selected by Pine County for this prioritization document. Lakes were chosen based on size, public accesses and use.

Vectors of spread were evaluated for each lake such as connectivity to other water bodies and public use. In addition, the suitability of each water body to Zebra mussel establishment was evaluated considering

water chemistry, substrate, dissolved oxygen and temperature. A report card was developed for each water body showing the available data and assigned risk category.

These risk ratings can be used in AIS management plans to prioritize lakes for specific prevention measures. A summary table using the assessments to form management recommendations is provided (Table 13). This table can used to guide the most efficient use of AIS funds in the most effective way possible.

Setting

Watersheds

A basin is the area of land drained by a river or lake and its tributaries. Minnesota has 4 divides. All water in Minnesota eventually flows into 1 of 4 rivers. The divides are made of 8 major drainage basins (Figure 2). Each drainage basin is made up of smaller units called watersheds, which correspond to the drainage of a tributary or lake system.

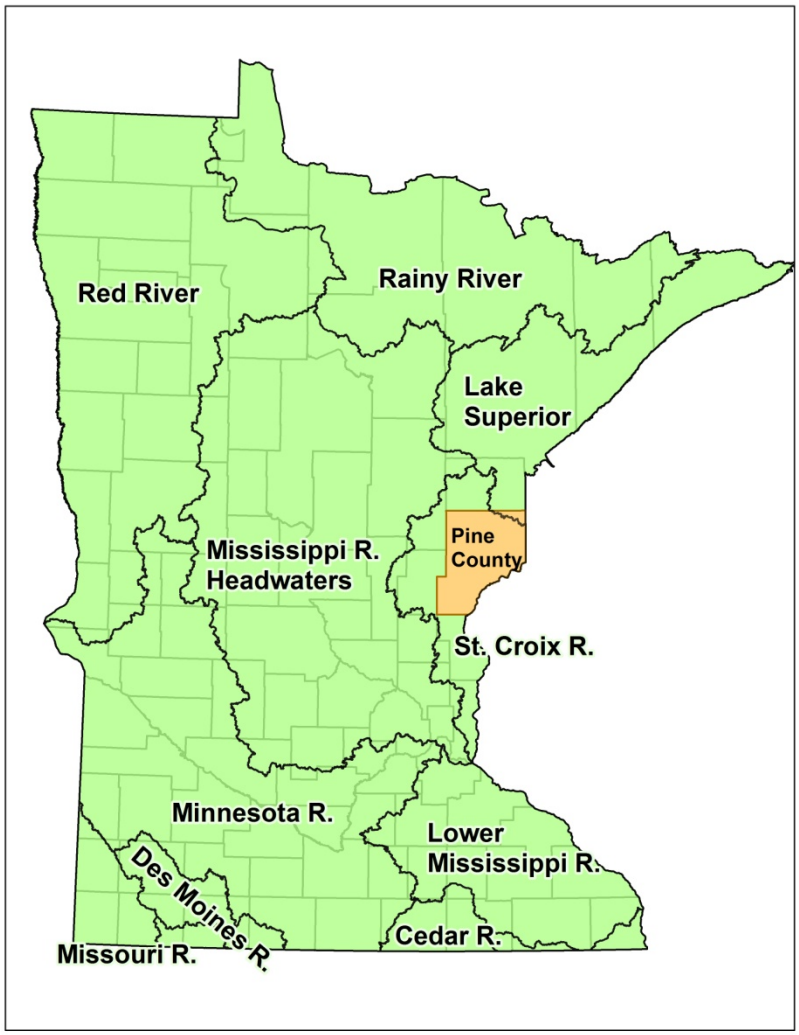


Figure 2. Minnesota showing all major drainage basins and Pine County.

Watersheds are categorized as major or minor. A minor watershed is the smallest category of watershed. A group of minor watersheds that eventually flows into a common stream, such as the Pine River, forms a major watershed. A group of major watersheds that flow into a common river, such as the Mississippi River, form a basin. A group of basins that flow into a common river form a divide.

The St. Croix River's headwaters are at St. Croix Lake near Solon Springs, Wisconsin, from where it flows west and south over 160 miles until it joins the Mississippi River at Prescott, Wisconsin. Approximately 80% (129 miles) of the St. Croix River forms part of the boundary between Wisconsin and Minnesota. The upper 20% of the river is entirely within Wisconsin. The watershed covers approximately 7,760 square miles and extends from near Mille Lacs Lake in Minnesota on the west to near Cable, Wisconsin, on the east. Approximately 46% of the watershed is located in Minnesota (MPCA).

Pine County

Pine County contains five major watersheds: Nemadji River Watershed, Kettle River Watershed, Upper St. Croix River Watershed, Snake River Watershed, and Lower St. Croix River Watershed (Figure 3). Watersheds are important to consider in aquatic invasive species (AIS) planning because AIS can spread downstream. An infestation in a large chain of lakes, such as along the Mississippi River, can have implications for spread throughout the rest of the Mississippi River Basin.

Figure 3. Pine County with its lakes and rivers.

History of AIS in Pine County

Plants

Curly-leaf pondweed is a common invasive plant in Minnesota (Figure 4). It is unknown when it was first established; however, it was most likely introduced to the state by accident in the early 1900s when common carp were intentionally brought to Minnesota. Curly-leaf pondweed has been in Minnesota so long that many people do not realize that it is a non-native species (DNR).

Eurasian watermilfoil is an invasive plant that is more prevalent in the Twin Cities Metro Area than in northern Minnesota (Figure 4). Sturgeon, Pokegama and Cross Lakes in Pine County are infested with Eurasian watermilfoil (Figure 6). Eurasian watermilfoil is able to be managed with aquatic herbicides, but it can be expensive.

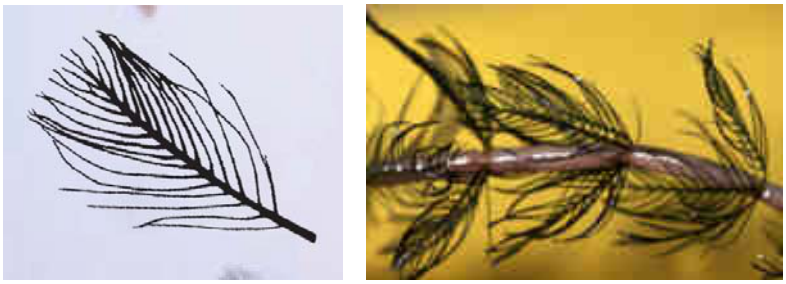


Figure 4. Eurasian watermilfoil, MN DNR.

Zebra mussels

Zebra mussel adults were first documented in Lake Mille Lacs in 2005 (Figure 7). Since 2005, Zebra mussel populations in Mille Lacs grew exponentially until 2013-2014, when they appear to have leveled off.

There are no documented Zebra mussel infestations in Pine County as of April 2016, which means that they have not spread out east of Mille Lacs in the 10 years that it's been infested.

Figure 5. Zebra mussels, USFWS.

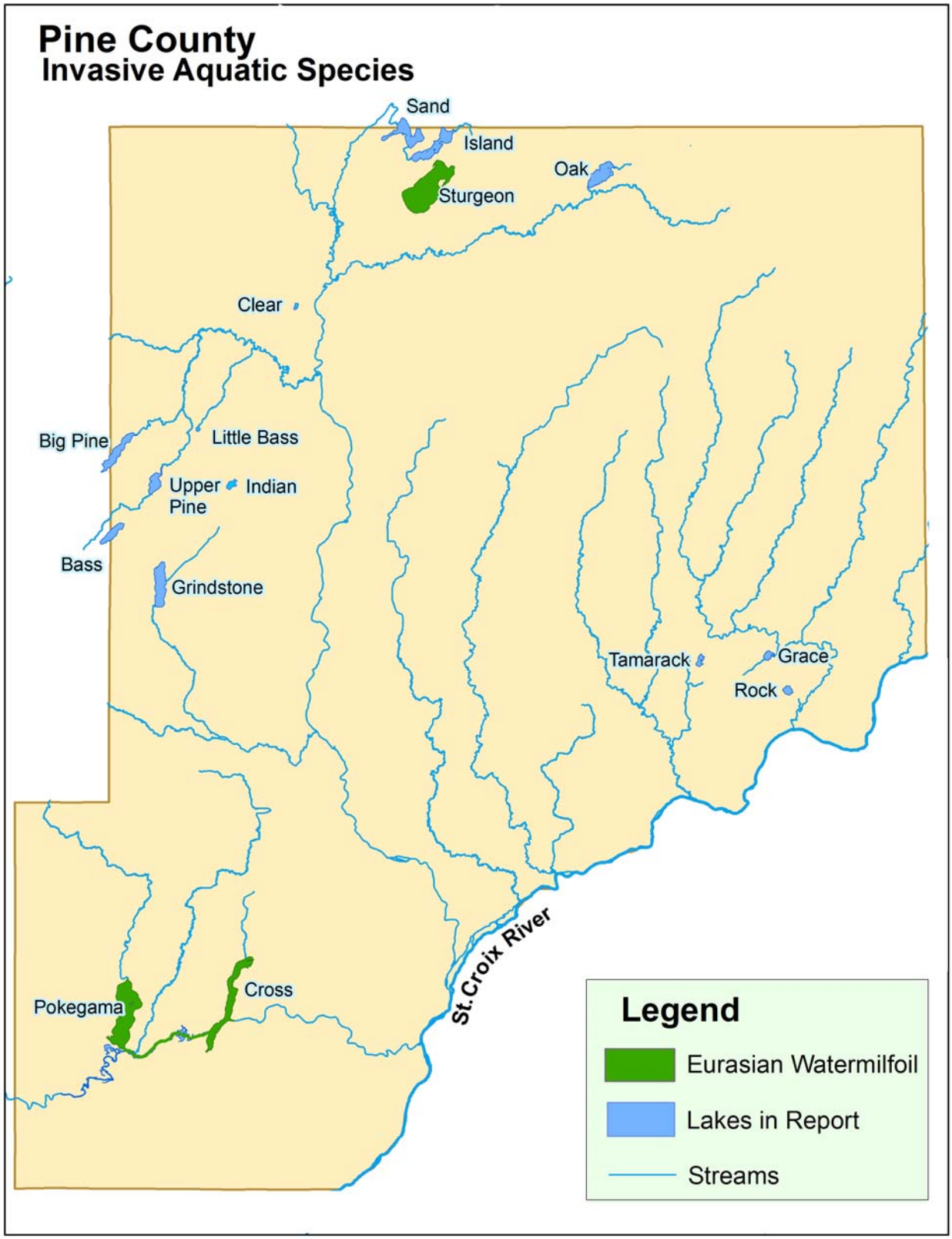


Figure 6. Aquatic species infestations in Pine County.

Zebra Mussel Risk Assessment

Lake Methods

The selected lakes in Pine County have water chemistry, temperature, and dissolved oxygen data available (Table 1). These data were collected by Pine County, Lake Associations, Minnesota Pollution Control Agency, Minnesota Department of Natural Resources and were used in the Zebra mussel risk assessment for lakes.

Table 1. Major lakes in Pine County.

Lake Name	Lake ID
Bass	58013700
Big Pine	58013800
Cross	58011900
Grace	58002900
Grindstone	58012300
Island	58006200
Oak	58004800
Pokegama	58014200
Rock	58000700
Sand	58008100
Sturgeon	58006700
Tamarack	58002400
Upper Pine	58013000

Water Connectivity

One of the highest risks to a water body becoming infested with Zebra mussels is if a nearby upstream lake is infested (Horvath 1996). Infested lakes can serve as a source of Zebra mussel veligers for downstream water bodies and adjacent lakes; however the inter-lake distance must be fairly close for the spread to be possible. Various studies have suggested a downstream veliger dispersal of 1-18 km (0.6-11 miles) in small streams (Lucy *et al.* 2005; Horvath *et al.*1996). In this assessment, lakes that have an infested lake already identified less than 20 km (12 mi) upstream are at a high risk of infestation since the Zebra mussels could spread downstream (Table 2). Lakes that are in a chain have a moderate risk because if any upstream lakes get infested with Zebra mussels (<20 km), they could spread downstream. Headwaters lakes have a very low risk of infestation through water connectivity.

In addition to stream connections, adjacent water bodies have the potential to infest each other via boats going from one lake to another, regardless if the lakes are connected or not.

Table 2. Water connectivity and the related risk of Zebra mussel infestation.

Water Connectivity Category	Risk of infestation
Headwaters lake	Low risk
Chain of lakes	Moderate risk
Upstream infested lake	High risk

Public Use

Boats and water related equipment have been shown to be one of the largest vectors in the spread of Zebra mussels (Johnson *et al.* 2001). Public use can be measured by some surrogate statistics. First, the number of public accesses and related parking spots are known on each lake. The more public accesses

on the lake, the more potential boats can use the lake. Secondly, the number of resorts and hotels on the lake are documented. The hotels and resorts on the lake attract local and regional visitors, increasing the risk of infestation. Thirdly, the number of fishing tournaments and special events on lakes is documented through a permitting process. Fishing tournaments and special events draw visitors to the lakes. And finally, the homeowners on the lake own an average of one dock/boat lift/boat per property. The purchase of an infested boat lift or other water related equipment has been the source of several documented new infestations in Minnesota. This use relationship coupled with transport of boats and water equipment from lake to lake, increases the probability of infestation. "Destination lakes" for popular fish species like walleyes and muskies along with popular recreation waters for boating and swimming are at increased risk for infestation.

Public access inspections data was reviewed for each lake, but difficulty in standardizing data across lakes challenges the reliability of these data to be used as part of public use data for the final risk assessment.

The numbers used represent boating units per summer. For parcels, an average of one boat per parcel was used in the calculation. For fishing tournaments, the total boats participating in the tournament was used.

For access parking and resort units, the numbers were multiplied by 15 weeks of summer between Memorial Day and Labor Day for an estimated total summer use. This number is likely underestimated, but the ratings still come out the same either way, showing that the calculations are very robust (Tables 3-4). In weighting the resorts and accesses by the 15 weeks of summer, they are weighted appropriately compared to the resident parcels.

Table 3. Public use rating calculations.

Lake	Parcels*	Access Parking*	Resort Units*	Total*	Risk
Pokegama	452	330	3,765	4,547	High
Sturgeon	321	330	3,480	4,131	High
Oak	67	210	3,120	3,397	High
Sand	293	135	765	1,193	Moderate
Big Pine	168	165	510	843	Moderate
Cross	509	150	0	659	Moderate
Island	234	240	0	474	Low
Grindstone	122	165	30	317	Low
Bass	108	135	0	243	Low
Upper Pine	59	135	0	194	Low
Tamarack	30	105	0	135	Low
Rock	2	0	120	122	Low
Grace	2	45	0	47	Low
Indian	9	0	0	9	Low
Clear	8	0	0	8	Low
Little Bass	5	0	0	5	Low

**All numbers are the total number of boats for the 15 weeks of summer.*

Table 4. Use ratings and assigned risk for Zebra mussel infestation.

	Low Risk	Moderate Risk	High Risk
Total Boat Units (the sum of public access parking spaces, resort units, lake parcels and special events)	0-500	501-2,000	2,000+

Water Chemistry

Available water quality data was compiled and analyzed for each major lake in Pine County. The average was calculated for each available parameter. The values were then compared to the ranges in Table 5 to determine the potential for Zebra mussels to establish and reproduce in the water body. Calcium was considered first, based on its importance in shell formation (Mackie & Schloesser 1996); however calcium data were not available for all water bodies. Next, alkalinity, hardness and pH were considered (Mackie & Claudi 2010; Hincks & Mackie 1997). Lastly, Secchi depth, chlorophyll a and total phosphorus were considered, although they are not sufficient parameters alone to assess risk (Mackie & Claudi 2010).

Total phosphorus and chlorophyll a are useful or determining the lake's trophic state, which does affect suitability for Zebra mussels. Zebra mussels thrive best in mesotrophic lakes (Karatayev et al. 1998, Nelepa 1992). Eutrophic lakes have a lower suitability due to too much phosphorus and chlorophyll a, and usually softer substrates.

Table 5. Water column Zebra mussel suitability criteria (Mackie and Claudi 2010).

	Risk		
Parameter	**Low Little Potential for Larval Development**	**Moderate (survivable, but will not flourish)**	**High (favorable for optimal growth)**
Calcium (mg/l)	8-15	15-30	>30
pH	7.0-7.8 or 9.0-9.5	7.8-8.2 or 8.8-9.0	8.2-8.8
Hardness (mg/L)	30-35	55-100	100-280
Alkalinity (mg/L)	30-55	55-100	100-280
Specific Conductance (umhos)	30-60	60-110	>110
Secchi depth (m)	1-2 or 6-8	4-6	2-4
Chlorophyll a (ug/L)	2.0-2.5 or 20-25	8-20	2.5-8
Total Phosphorus	5-10 or 35-50	10-25	25-35

Substrate Suitability

One of the reasons Zebra mussels are such a nuisance is that they attach to hard substrates via their byssal threads. Zebra mussels prefer a hard substrate for attachment although they will attach to plants as well (Karatayev et al. 1998). In lakes, they have been documented to colonize on rocks, docks, boatlifts and water intake pipes. Lakes with mainly soft substrate and not many man-made structures may not be as supportive to Zebra mussel colonization. Plants have just moderate suitability because in Minnesota they die off at the end of each summer, meaning the Zebra mussels that are attached to them must crawl to other substrates or die off during winter (Karatayev et al. 1998). Comments are made for each water body, its dominant substrate, and its likelihood to support Zebra mussels. The substrate types were determined by the MNDNR (Table 6).

Table 6. Substrate descriptions and their suitability to Zebra mussel survival.

Substrate (MNDNR)	**Description**	**Suitability to Zebra mussels**
Muck	Decomposed organic material	Low
Marl	Calcareous material	Low
Silt	Fine material with little grittiness	Low
Sand	Diameter less than 1/8 inch	Low
Submerged macrophytes	Underwater rooted plants	Moderate
Gravel	Diameter 1/8 to 3 inches	High
Rubble	Diameter 3 to 10 inches	High
Boulder	Diameter over 10 inches	High

Temperature

Zebra mussels begin reproduction when water temperature is above 12 C, but ideal reproduction temperature occurs above 17-18 C (McMahon 1996). The upper thermal limit for North American Zebra mussels occurs somewhere around 30 C (McMahon 1996) The optimal temperature range for zebra mussel spawning in North America is estimated to between 18-26 C.

In Minnesota, lakes are usually ice-covered on average from November to March. During the ice-covered season, it is assumed that the water temperature is too cold for Zebra mussel spawning. However, the Zebra mussels do over-winter at the bottom of the lake (Mackie *et al.* 1989).

In summer, Minnesota lakes rarely exceed 30 C (86 F); therefore, it is likely that the Zebra mussels reproduce all summer once the water temperature reaches 17-18 C. This occurrence has been documented in Pelican Lake, where Zebra mussel veligers were first found at 18 C in 2012 and 19 C in 2013 (Rufer 2015).

The maximum temperature was reported for each lake and the risk was assigned based on if the lake exceeded 32 C in mid-summer or not (Table 7). The lake's mixing regime and period of hypolimnetic anoxia were also noted as research has found that few Zebra mussel veligers occur below the thermocline in temperate lakes (Mackie *et al.* 1989).

Table 7. Temperature values and their impact on Zebra mussel survival.

Survival Potential	Temperature Range	Risk Rating
Prevent zebra mussel establishment	> 32 C	Low
Little impact on mussel survival	8 – 31 C	High

Infestation Risk Rating

The two main vectors of spread for Zebra mussels are lake connectivity and public use. The risks from these two categories were combined for an overall risk of infestation rating for each lake. A scoring system was used to weight each of these two categories, which resulted in three overall risk categories (Table 8).

Table 8. Combined infestation risk rating using public use and connectivity.

	Public Use Total Boat Units	Connectivity	Combined Risk Rating
Low Risk	0-500	0 = Headwaters Lake	0-750
Moderate Risk	501-2,000	500 = Chain of Lakes	750-3,000
High Risk	2,000+	1,000 = Infested or Infested lake upstream	3,000+

Zebra mussel Suitability Rating

The two main factors for zebra mussels thriving in a lake are suitable water chemistry and suitable substrate. The risks from these two categories were combined for an overall suitability rating for each lake. This suitability rating can be interpreted as the probability that Zebra mussels will thrive in the lake. A scoring system was used to weight each of these two categories, which resulted in three overall risk categories (Table 9).

Table 9. Combined Zebra mussel suitability rating using water chemistry and substrate.

	Water Quality	Substrate	Combined Risk Rating
Low Risk	0 = The majority of averages in green category.	0 = Sand, Silt, Muck	0 - Low
Moderate Risk	500 = The majority of averages in yellow category.	500=Submerged macrophytes	1000 - Moderate
High Risk	1,000 = The majority of averages in red category.	1,000 = Rocks, Gravel, Rubble	2000 - High

River Science

Unlike lakes, rivers are not usually ideal habitat for Zebra mussels. Studies have shown that the turbulence in streams and rivers causes high Zebra mussel veliger mortality and assists in preventing the veligers from settling on hard substrates (Horvath & Lamberti 1999). Without an infested lake upstream continually supplying the stream with Zebra mussel veligers, the stream is unlikely to sustain a large population on its own. Although streams can be pathways for downstream infestations, the probability of Zebra mussel veliger survival decreases with distance downstream (Horvath & Lamberti 1999; Horvath *et al.* 1996).

For small streams, even the presence of an infested lake upstream supplying veligers will probably not allow the stream to support populations of Zebra mussel adults. Strayer (1991) found that in streams <10 meters wide (33 feet) there were no stable adult Zebra mussel populations. Zebra mussel adults seem to only survive in the largest rivers (>100 m wide) or large pools and stagnant backwaters.

Turbulence & Flow

Studies show that turbulence or shear may be the limiting factor for Zebra mussel survival in streams and rivers (Horvath & Lamberti 1999). Although specific flow rates are not determined, it appears that in streams and rivers, zebra mussels are only self-sustaining behind dams and stagnant backwaters. Therefore, for the purposes of this risk assessment, any stream sites are considered to have low risk due to the flow in the river, even if there is no flow data available.

Downstream Dispersal

Zebra mussel veliger abundance has been shown to decrease with distance in streams. Veligers have been found 10-18 km (6-11 miles) downstream of an infested lake in stream systems (Horvath *et al*.,1996). In heavily vegetated wetland stream systems, the dispersal distance has been found to be about 1 km (0.6 mile), which is much lower. There are a few possible factors affecting Zebra mussel veliger survival in wetlands streams, including aquatic vegetation, low water velocity, unsuitable water characteristics, limited substrate availability, and/or increased predation pressure (Bodamer & Brossenbroek 2008). These results show that protecting aquatic vegetation from removal, limiting stream dredging, and installing wetlands could help as a barrier for spreading Zebra mussels downstream.

The small streams in Pine County have some submerged vegetation, usually lined with emergent vegetation, has sandy/rocky substrate and mostly clear water. Taking into account the literature and the condition and habitat of the river, for the purposes of this risk assessment, 32 km (20 mi) is considered the longest a veliger could theoretically travel. This distance of 32 km is very conservative, but until further research is conducted a better estimate is not available.

Water Quality

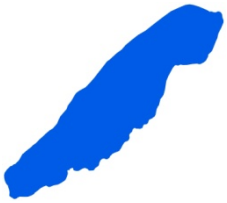
The water chemistry ranges from Mackie and Claudi 2010 (Table 5) can be applied to streams; however, more applicable water quality parameters to streams are turbidity and total suspended solids. Turbidity has been shown to limit Zebra mussel survival. Although acute exposures to high turbidity can negatively affect a Zebra mussel population, they are able to compensate for some high exposure (McMahon 1996). Chronic high turbidity has a greater negative effect on Zebra mussel survival, as it inhibits their filtering ability (McMahon 1996, Karatayev *et al.* 1998). Mackie and Claudi (2010) suggest upper limits for Zebra mussel survival for total suspended solids at 96 mg/L and turbidity at 80 NTU, if the turbidity is caused mainly from sediment suspension. The combination of high temperature and high turbidity seem to be most stressful to Zebra mussels (Alexander 1994).

Lake Risk Assessment Summary: Bass Lake (58-0137-00)

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: Southwest of Finlayson
Surface Area: 228 acres
Percent Littoral: 62.9%
Max Depth: 20 feet
Inlet: None



Summary

Bass Lake has no upstream lakes and low public use, resulting in a low infestation risk rating. Water chemistry shows that it is a soft water lake and substrates are soft, which could be unsuitable to Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (108)	243	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (135)		
Substrate Suitability (mean abundance, DNR)		Muck, Detritus	70%, 70%	Low

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	NA	>30
pH*		7.8	8	8.2-8.8
Alkalinity*	mg/L	15.4	5	100-280
Specific Conductance *	uS/cm	28.5	4	>110
Secchi Depth	ft	8.5	17	6.56-13.12
Chlorophyll a	ug/L	7.1	20	2.5-8
Total Phosphorus	ug/L	18.2	12	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

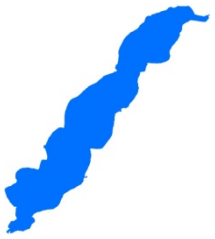
	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	26 (30)	>32 C	High
Dissolved oxygen	8.1 (30)	<7 mg/L	High

Lake Risk Assessment Summary: Big Pine Lake

Infestation Risk Rating: Moderate
1. Connectivity: Low Risk
2. Public Use: Moderate Risk

Suitability Risk Rating: High
1. Water Chemistry: High Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Kettle River
Location: West of Finlayson
Surface Area: 398.9 acres
Percent Littoral: 26.6%
Max Depth: 22 feet
Inlet: stream from Pine Lake,
1 headwater stream



Summary

Big Pine Lake has moderate public use and no upstream lakes, resulting in a moderate infestation risk rating. If Zebra mussels were introduced into Big Pine Lake they would likely thrive due to suitable water chemistry and substrate.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (168)	843	Moderate
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (675)		
Substrate Suitability (% frequency, DNR)		Sand, Gravel, Rubble	80%, 50%, 20%	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	42	1	>30
pH*		8.2	14	8.2-8.8
Alkalinity*	mg/L	80.6	11	100-280
Specific Conductance *	uS/cm	158.7	16	>110
Secchi Depth	ft	5.4	205	6.56-13.12
Chlorophyll a	ug/L	16.4	11	2.5-8
Total Phosphorus	ug/L	31.9	11	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	25.8 (32)	>32 C	High
Dissolved oxygen	7.2 (65)	<7 mg/L	High

Lake Risk Assessment Summary: Clear Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: North of Rutledge
Surface Area: 26.3 acres
Percent Littoral: NA
Max Depth: 39 feet
Inlet: None

Summary

Clear Lake has low public use and no upstream lakes, resulting in a low infestation risk rating. The water chemistry and substrate in Clear Lake is likely unsuitable to Zebra mussels. It is a soft water lake.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwater	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (8)	8	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (0)		
Substrate Suitability (mean abundance, DNR)		Sand, Muck	100%, 100%	Low

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	5.3	1	>30
pH*		5.9	2	8.2-8.8
Alkalinity*	mg/L	2.8	2	100-280
Specific Conductance *	uS/cm	27	1	>110
Secchi Depth	ft	NA	0	6.56-13.12
Chlorophyll a	ug/L	NA	0	2.5-8
Total Phosphorus	ug/L	57	1	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

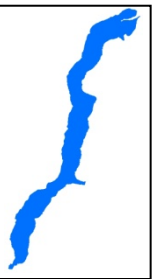
	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	NA	>32 C	NA
Dissolved oxygen	NA	<7 mg/L	NA

Lake Risk Assessment Summary: Cross Lake

Infestation Risk Rating: Moderate
1. Connectivity: Moderate Risk
2. Public Use: Moderate Risk

Suitability Risk Rating: High
1. Water Chemistry: High Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Snake River
Location: East of Pine City
Surface Area: 924.9 acres
Percent Littoral: 25.8%
Max Depth: 32 feet
Inlet: snake river, 4 headwater streams



Summary

Cross Lake has numerous upstream lakes and moderate public use, which results in a moderate infestation risk rating. If Zebra mussels were introduced to Cross Lake they would likely thrive due to suitable water chemistry and substrates.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	15 upstream Lakes	Moderate
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (509)	659	Moderate
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (150)		
Substrate Suitability (mean abundance, DNR)		Sand, Gravel, Boulder	77, 22, 18.9	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA		>30
pH*		8.0	91	8.2-8.8
Alkalinity*	mg/L	91	4	100-280
Specific Conductance *	uS/cm	201.8	91	>110
Secchi Depth	ft	3.4	38	6.56-13.12
Chlorophyll a	ug/L	18.4	29	2.5-8
Total Phosphorus	ug/L	76.6	29	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

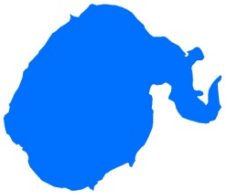
	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	28.2 (385)	>32 C	High
Dissolved oxygen	8.0 (29)	<7 mg/L	High

Lake Risk Assessment Summary: Grace Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Moderate
1. Water Chemistry: Moderate Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Upper St.Croix R.
Location: East of Hinkley
Surface Area: 53.4 acres
Percent Littoral: 100%
Max Depth: 10 feet
Inlet: 1 headwater stream



Summary

Grace Lake has no upstream lakes and low public use, which results in a low infestation risk rating. The water chemistry has moderate suitability and the substrate has low suitability, which results in a moderate suitability risk rating for Zebra mussel establishment.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (2)	47	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (45)		
Substrate Suitability (mean abundance, DNR)		Muck, Detritus, Sand	75, 17, 13	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	29	1	>30
pH*		8.6	1	8.2-8.8
Alkalinity*	mg/L	41	1	100-280
Specific Conductance *	uS/cm	80	1	>110
Secchi Depth	ft	NA		6.56-13.12
Chlorophyll a	ug/L	NA		2.5-8
Total Phosphorus	ug/L	NA		25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	22 (1)	>32 C	High
Dissolved oxygen	NA	<7 mg/L	NA

Lake Risk Assessment Summary: Grindstone Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: High
1. Water Chemistry: High Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Kettle River
Location: West of Sandstone
Surface Area: 528.2 acres
Percent Littoral: 10.3%
Max Depth: 153 feet
Inlet: stream from Miller Lake,
4 headwater streams

Summary

Grindstone Lake has only one upstream lake and low public use, resulting in a low infestation risk rating. If Zebra mussels were introduced to Grindstone Lake it would likely do well due to suitable substrate and water chemistry.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (122)	317	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (195)		
Substrate Suitability (mean abundance, DNR)		Sand, Gravel, Rubble	83, 50, 50	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	0	>30
pH*		8.0	4	8.2-8.8
Alkalinity*	mg/L	47.3	3	100-280
Specific Conductance *	uS/cm	125.4	10	>110
Secchi Depth	ft	12	186	6.56-13.12
Chlorophyll a	ug/L	3.1	8	2.5-8
Total Phosphorus	ug/L	12.8	8	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	23.9 (24)	>32 C	High
Dissolved oxygen	9.4 (43)	<7 mg/L	High

Lake Risk Assessment Summary: Indian Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: South of Finlayson
Surface Area: 76.5 acres
Percent Littoral: 100%
Max Depth: 15 feet
Inlet: 1 stream from Unnamed (Jacobson) Lake

Summary

Indian Lake has only one upstream lake and low public use, resulting in a low infestation risk rating. The water chemistry data show that the lake has soft water, and the substrates are soft, which is likely unsuitable to Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lake	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (9)	9	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (0)		
Substrate Suitability (mean abundance, DNR)		Sand, Detritus, Muck	48, 20, 15	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	6.3	1	>30
pH*		6.5	2	8.2-8.8
Alkalinity*	mg/L	6.9	2	100-280
Specific Conductance *	uS/cm	33	1	>110
Secchi Depth	ft	3.6	8	6.56-13.12
Chlorophyll a	ug/L	NA	0	2.5-8
Total Phosphorus	ug/L	NA	0	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	NA	>32 C	NA
Dissolved oxygen	NA	<7 mg/L	NA

Lake Risk Assessment Summary: Island Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Moderate
1. Water Chemistry: Moderate Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Kettle River
Location: Northeast of Sturgeon Lake
Surface Area: 536.2 acres
Percent Littoral: 34%
Max Depth: 40.9 feet
Inlet: stream from Echo Lake,
2 headwater streams

Summary

Island Lake has only one upstream lake and low public use, resulting in a low infestation risk rating. The pH and Alkalinity show that the lake is slightly soft water, which is less suitable to Zebra mussels. That is why this lake has a moderate suitability rating.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (234)	474	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (240)		
Substrate Suitability (mean abundance, DNR)		Sand, Gravel	48, 20	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA		>30
pH*		7.9	23	8.2-8.8
Alkalinity*	mg/L	33.9	12	100-280
Specific Conductance *	uS/cm	77	22	>110
Secchi Depth	ft	6.7	100	6.56-13.12
Chlorophyll a	ug/L	9.6	7	2.5-8
Total Phosphorus	ug/L	28.1	7	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	25.1 (49)	>32 C	High
Dissolved oxygen	8.4 (13)	<7 mg/L	High

Lake Risk Assessment Summary: Little Bass Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: West of Finlayson
Surface Area: 19.4 acres
Percent Littoral: NA
Max Depth: 26 feet
Inlet:None

Summary

Little Bass Lake has no upstream lakes and low public use, resulting in a low infestation risk rating. The water chemistry shows that it is a soft water lake, and the substrates are soft, which is less suitable to Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (5)	5	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (0)		
Substrate Suitability (mean abundance, DNR)		Detritus, Sand, Muck	55, 28, 15	Low

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	4.0	15	>30
pH*		6.3	23	8.2-8.8
Alkalinity*	mg/L	4.3	20	100-280
Specific Conductance *	uS/cm	22.7	13	>110
Secchi Depth	ft	NA	0	6.56-13.12
Chlorophyll a	ug/L	NA	0	2.5-8
Total Phosphorus	ug/L	NA	0	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	27 (14)	>32 C	High
Dissolved oxygen	8.8 (6)	<7 mg/L	High

Lake Risk Assessment Summary: Oak Lake

Infestation Risk Rating: High
1. Connectivity: Low Risk
2. Public Use: High Risk

Suitability Risk Rating: Moderate
1. Water Chemistry: High Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: North of Kerrick
Surface Area: 454.8 acres
Percent Littoral: 91.8%
Max Depth: 18 feet
Inlet: stream from Little Oak Lake,
1 headwater stream

Summary

Oak Lake has only one upstream lake, but a high public use rating, resulting in a high overall infestation risk rating. The existing water chemistry data shows a likely high suitability to Zebra mussels, but the substrates are soft, which are less suitable. Getting calcium, alkalinity and specific conductance data will help show if the lake is a soft water lake or a hard water lake.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (67)	3,397	High
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (3,330)		
Substrate Suitability (mean abundance, DNR)		Sand, Silt, Detritus	70, 25, 23	Low

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	0	>30
pH*		NA	0	8.2-8.8
Alkalinity*	mg/L	NA	0	100-280
Specific Conductance *	uS/cm	NA	0	>110
Secchi Depth	ft	4.6	45	6.56-13.12
Chlorophyll a	ug/L	18.3	10	2.5-8
Total Phosphorus	ug/L	32.2	10	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	26.1 (3)	>32 C	High
Dissolved oxygen	NA	<7 mg/L	NA

Lake Risk Assessment Summary: Pokegama Lake

Infestation Risk Rating: High
1. Connectivity: Low Risk
2. Public Use: High Risk

Suitability Risk Rating: High
1. Water Chemistry: High Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Snake River
Location: West of Pine City
Surface Area: 1,515.5 acres
Percent Littoral: 27 %
Max Depth: 23 feet
Inlet: pokegama creek, 3 headwater streams

Summary

Pokegama Lake has no upstream lakes, but a very high public use rating. This results in a high infestation risk rating. If Zebra mussels were introduced into Pokegama they would likely survive, although the phosphorus and chlorophyll a may be too high for optimal growth.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (452)	4,547	High
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (4,095)		
Substrate Suitability (mean abundance, DNR)		Sand, Rubble, Gravel	46, 23, 22	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	0	>30
pH*		NA	0	8.2-8.8
Alkalinity*	mg/L	100	1	100-280
Specific Conductance *	uS/cm	NA	0	>110
Secchi Depth	ft	3.1	150	6.56-13.12
Chlorophyll a	ug/L	39.7	24	2.5-8
Total Phosphorus	ug/L	98.8	23	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	30 (332)	>32 C	High
Dissolved oxygen	8.6 (146)	<7 mg/L	High

Lake Risk Assessment Summary: Rock Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Upper St.Croix R.
Location: East of Hinkley
Surface Area: 79.3 acres
Percent Littoral: 76.7 %
Max Depth: 10 feet
Inlet: None

Summary

Rock Lake has no upstream lakes and a low public use rating, which result in a low infestation risk rating. The water chemistry indicates that Rock Lake is a soft water lake, which is not suitable for Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (2)	122	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (120)		
Substrate Suitability (mean abundance, DNR)		Sand, Detritus, Rubble, Boulder	47, 32, 27, 25	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	2.9	1	>30
pH*		6	1	8.2-8.8
Alkalinity*	mg/L	1.5	1	100-280
Specific Conductance *	uS/cm	17	1	>110
Secchi Depth	ft	2.1	39	6.56-13.12
Chlorophyll a	ug/L	40.7	10	2.5-8
Total Phosphorus	ug/L	217.6	10	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	22 (1)	>32 C	High
Dissolved oxygen	NA	<7 mg/L	NA

Lake Risk Assessment Summary: Sand Lake

Infestation Risk Rating: Moderate
1. Connectivity: Low Risk
2. Public Use: Moderate Risk

Suitability Risk Rating: Moderate
1. Water Chemistry: Moderate Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Kettle River
Location: Northeast of Sturgeon Lake
Surface Area: 516.2 acres
Percent Littoral: 39.6 %
Max Depth: 40 feet
Inlet: 4 headwater streams

Summary

Sand Lake has no upstream lakes and a moderate public use rating, which results in a moderate infestation risk rating. The water chemistry indicates the lake could have soft water, which is less suitable for Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (293)	1,193	Moderate
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (900)		
Substrate Suitability (mean abundance, DNR)		Sand, Gravel	81, 21	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	0	>30
pH*		8.0	11	8.2-8.8
Alkalinity*	mg/L	23.5	6	100-280
Specific Conductance *	uS/cm	74.3	11	>110
Secchi Depth	ft	8.7	27	6.56-13.12
Chlorophyll a	ug/L	4.3	7	2.5-8
Total Phosphorus	ug/L	17	7	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	25.4 (20)	>32 C	High
Dissolved oxygen	8.8 (6)	<7 mg/L	High

Lake Risk Assessment Summary: Sturgeon Lake

Infestation Risk Rating: High
1. Connectivity: Low Risk
2. Public Use: High Risk

Suitability Risk Rating: High
1. Water Chemistry: High Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Kettle River
Location: East of Sturgeon Lake
Surface Area: 1,705.9 acres
Percent Littoral: 42.6%
Max Depth: 40 feet
Inlet: stream from Johnson Lake

Summary

Sturgeon Lake has only one upstream lake, but a high public use rating. This results in a high overall risk rating. If Zebra mussels were introduced to Sturgeon Lake they would likely thrive due to suitable substrate and water chemistry.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (321)	4,131	High
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (3,810)		
Substrate Suitability (mean abundance, DNR)		Sand, Rubble	82, 8	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	23	1	>30
pH*		7.9	26	8.2-8.8
Alkalinity*	mg/L	37.6	16	100-280
Specific Conductance *	uS/cm	60.6	24	>110
Secchi Depth	ft	14.6	61	6.56-13.12
Chlorophyll a	ug/L	2.5	7	2.5-8
Total Phosphorus	ug/L	17.1	7	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	24.3 (39)	>32 C	High
Dissolved oxygen	8.2 (137)	<7 mg/L	High

Lake Risk Assessment Summary: Tamarack Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Low
1. Water Chemistry: Low Risk
2. Substrate: High Risk

Characteristics
Major Watershed: Upper St.Croix R.
Location: East of Hinkley
Surface Area: 70.5 acres
Percent Littoral: 61.3%
Max Depth: 46.6 feet
Inlet: None

Summary

Tamarack Lake has no upstream lakes and low public use, which results in a low overall infestation risk rating. Water chemistry shows that Tamarack Lake has soft water, which is unsuitable to Zebra mussels.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Headwaters	0 upstream Lakes	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (30)	135	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (105)		
Substrate Suitability (mean abundance, DNR)		Sand, Silt, Detritus, Rubble	53, 38, 20, 10	High

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	5.4	10	>30
pH*		6.9	61	8.2-8.8
Alkalinity*	mg/L	7.8	16	100-280
Specific Conductance *	uS/cm	19.7	55	>110
Secchi Depth	ft	17	113	6.56-13.12
Chlorophyll a	ug/L	NA	0	2.5-8
Total Phosphorus	ug/L	NA	0	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	27.5 (76)	>32 C	High
Dissolved oxygen	7.1 (343)	<7 mg/L	High

Lake Risk Assessment Summary: Upper Pine Lake

Infestation Risk Rating: Low
1. Connectivity: Low Risk
2. Public Use: Low Risk

Suitability Risk Rating: Moderate
1. Water Chemistry: Moderate Risk
2. Substrate: Low Risk

Characteristics
Major Watershed: Kettle River
Location: West of Finlayson
Surface Area: 210 acres
Percent Littoral: 100%
Max Depth: 15 feet
Inlet: Little Pine Creek

Summary

Upper Pine Lake has only one upstream lake and low public use, which result in a low overall infestation risk rating. The water chemistry is moderately suitable for Zebra mussels. pH, alkalinity and calcium would help determine whether it is a soft or hard water lake.

Attribute		Description	Number	Infestation Risk
Water Connectivity		Chain of Lakes	1 upstream Lake	Low
Public Use	Resident Watercraft/Boat Lift Impact	Number of parcels (59)	194	Low
	Non-resident Watercraft Impact	Total number of resort units, public access parking spots and special events for summer (135)		
Substrate Suitability (mean abundance, DNR)		Sand, Muck, Detritus	39, 33, 13	Low

Water Chemistry Risk

Parameter	Unit	Average	Sample Size	Suitable Range
Calcium*	Mg/L	NA	0	>30
pH*		NA	0	8.2-8.8
Alkalinity*	mg/L	NA	0	100-280
Specific Conductance *	uS/cm	66.4	1	>110
Secchi Depth	ft	4.9	66	6.56-13.12
Chlorophyll a	ug/L	5.2	14	2.5-8
Total Phosphorus	ug/L	26.7	14	25-35

**primary parameters for zebra mussel Suitability*

Seasonal Temperature and Dissolved Oxygen Risk

	Description	Lethal Limit	Suitability Rating
Summer maximum temperature	23.6 (1)	>32 C	High
Dissolved oxygen	NA	<7 mg/L	NA

Results and Discussion

Results

The lakes in Pine County resulted in differing infestation and suitability risk ratings (Table 10). In general terms, the headwaters lakes came out with the lowest infestation risk ratings because they have no water bodies upstream. Of the selected lakes assessed in this report, the headwaters lakes that also had low public use include Bass, Clear, Grace, Grindstone, Indian, Island, Little Bass, Rock, and Tamarack.. Lakes that had moderate infestation risk ratings had the combination of moderate public use and being in the middle of a chain of lakes (Table 10, Figure 8).

Lakes with high infestation risk ratings include Oak, Pokegama and Sturgeon (Figure 8). These lakes have a very high public use, especially Pokegama and Sturgeon (Figure 6). Pokegama Lake has the highest total of resort units, public accesses, and property owners of any lakes in the county (Table 3). Public use risks come from both lake visitors via boats and lake property owners via boats, boat lifts, docks and other water-related equipment.

About half of the lakes in Pine County resulted in a high Zebra mussel suitability rating (Figure 9). The lakes in northwest and north central Minnesota are considered hardwater lakes from glacial deposits of calcium carbonate (limestone) (Wetzel 2001). Water chemistry data show that six of the lakes evaluated in this report are soft water lakes, which are likely unsuitable to Zebra mussels: Bass, Clear,Indian, Little Bass, Rock, and Tamarack. In the lakes with moderate suitability, there wasn't always enough data to determine if the lake was soft or hard water: Oak, Island, Upper Pine, and Sand. Testing calcium in these lakes would help further determine the suitability of the lake to Zebra mussels.

The limiting factor that resulted in some lakes receiving a moderate or low suitability rating was substrate. Zebra mussels are not able to attach silt, muck, and sand directly. In areas with these substrates, the Zebra mussels will attach to plants, native mussels, and pieces of wood or stones (Karatayev et al. 1998). They will also attach to each other in clumps. Therefore, lakes that have predominantly silt, muck and sand have a low substrate suitability rating. In addition, in lakes that tend to be more eutrophic, Zebra mussels have a low suitability. Zebra mussels do not thrive in eutrophic lakes like they do in mesotrophic lakes (Karatayev et al. 1998, Nelepa 1992).

The rivers, such as the Kettle and Snake Rivers, are pathways for the spread of Zebra mussels downstream. Zebra mussel establishment in streams is limited by turbulence and flow, therefore the river itself is likely not a major source of zebra mussels. If lakes in a chain are less than a mile apart, Zebra mussels from an infested lake are likely to move downstream and infest downstream lakes.

Table 10. Summary of risk ratings and prioritized recommendations taking into account the risk.

Lake Name	Lake ID	Public Use Risk	Infestation Risk	Suitability Risk	AIS Program Prioritized Recommendations
Bass	58-0137-00	Low	Low	Low	1. Education
Big Pine	58-0138-00	Moderate	Moderate	High	1. Education
Clear	58-0104-00	Low	Low	Low	1. Education
Cross	58-0119-00	Moderate	Moderate	High	1. Education
Grace	58-0029-00	Low	Low	Moderate	1. Education
Grindstone	58-0123-00	Low	Low	High	1. Education
Indian	58-0132-00	Low	Low	Low	1. Education
Island	58-0062-00	Low	Low	Moderate	1. Education
Little Bass	58-0127-00	Low	Low	Low	1. Education
Oak	58-0048-00	High	High	Moderate	1. Public Access Inspections 2. Education 3. Early Detection Monitoring
Pokegama	58-0142-00	High	High	High	1. Public Access Inspections 2. Education 3. Early Detection Monitoring
Rock	58-0007-00	Low	Low	Low	1. Education
Sand	58-0081-00	Moderate	Moderate	Moderate	1. Education
Sturgeon	58-0067-00	High	High	High	1. Public Access Inspections 2. Education 3. Early Detection Monitoring
Tamarack	58-0024-00	Low	Low	Low	1. Education
Upper Pine	58-0130-00	Low	Low	Moderate	1. Education

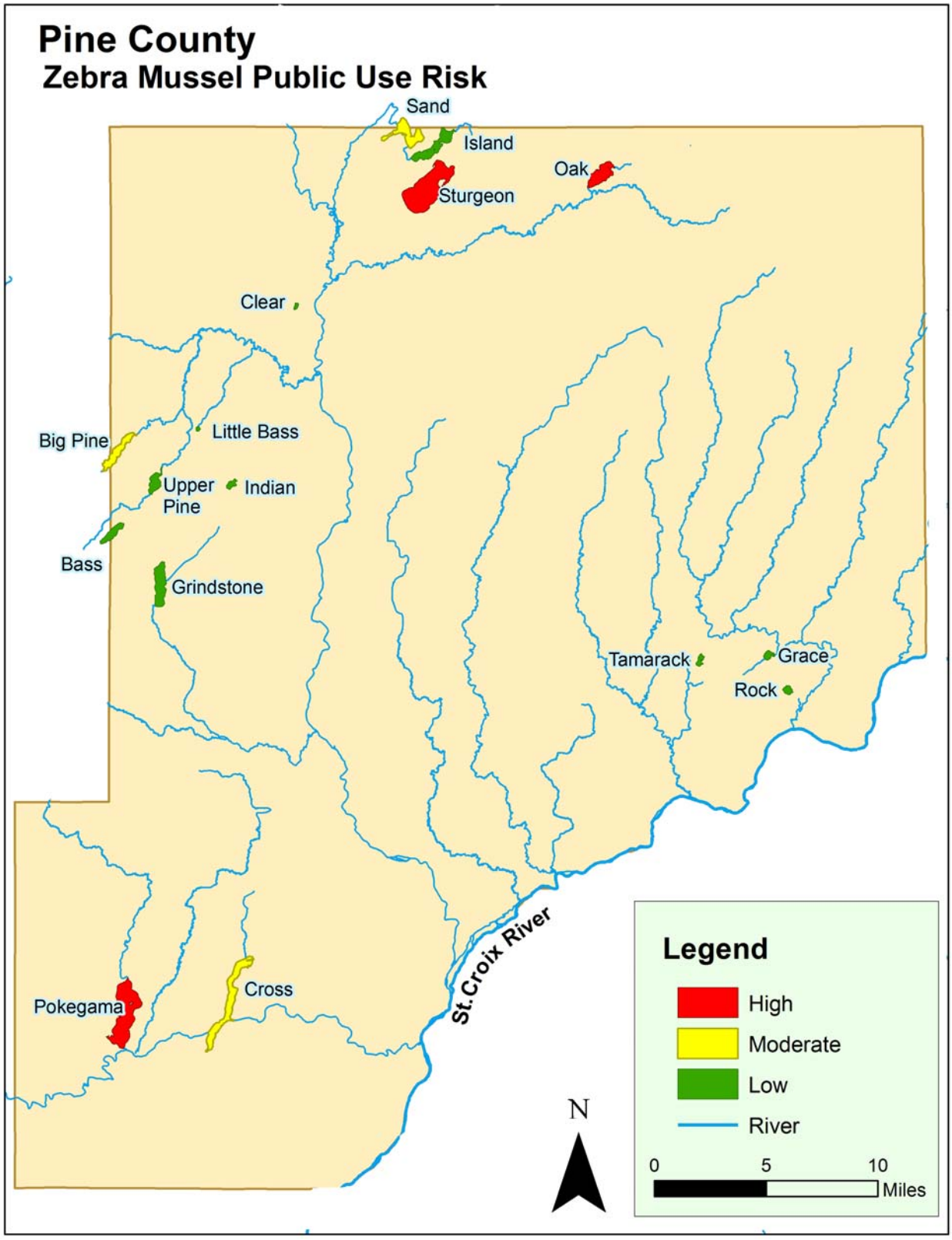


Figure 7. Public use risk rating for lakes in Pine County.

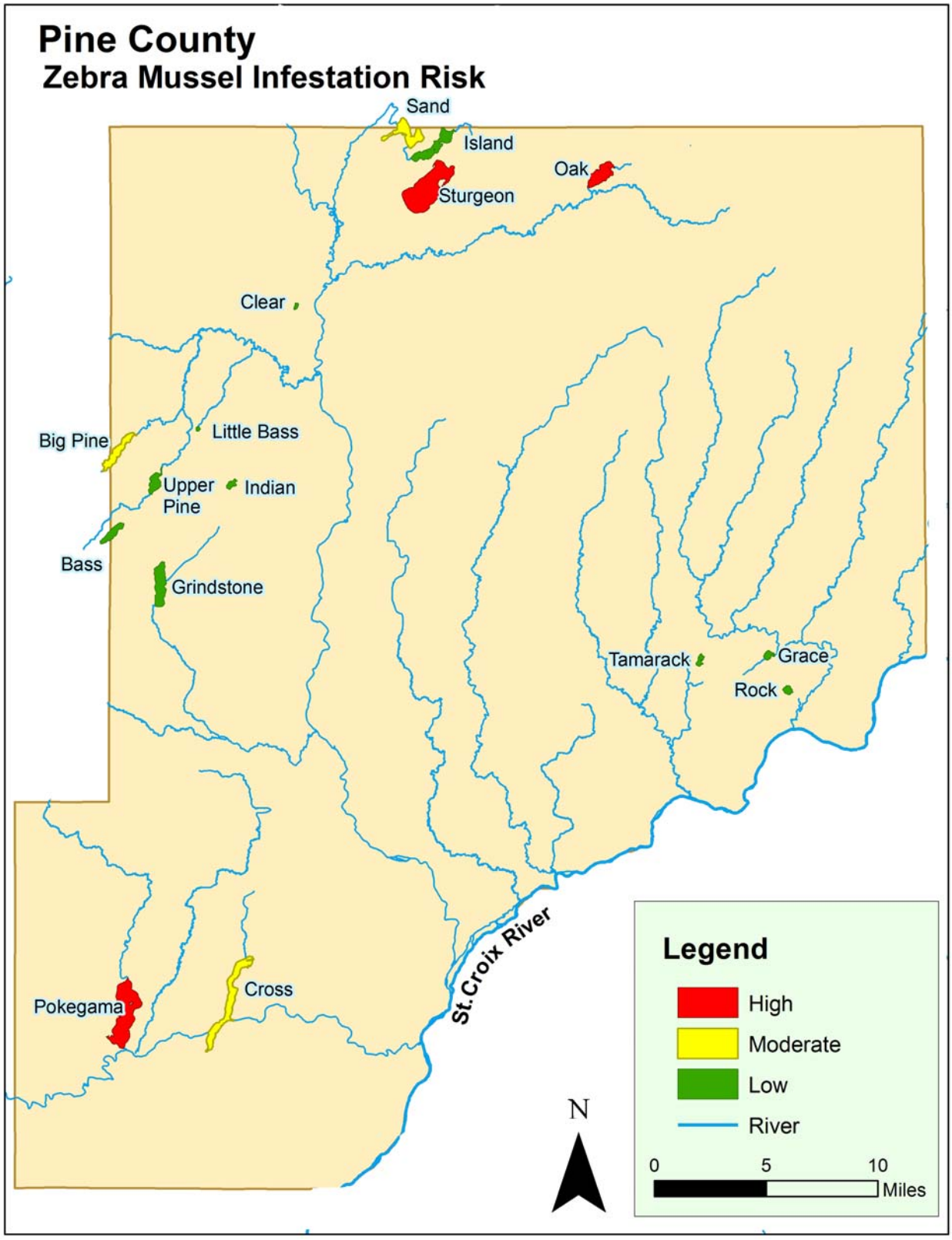


Figure 8. Overall Zebra mussel infestation risk rating in Pine County.

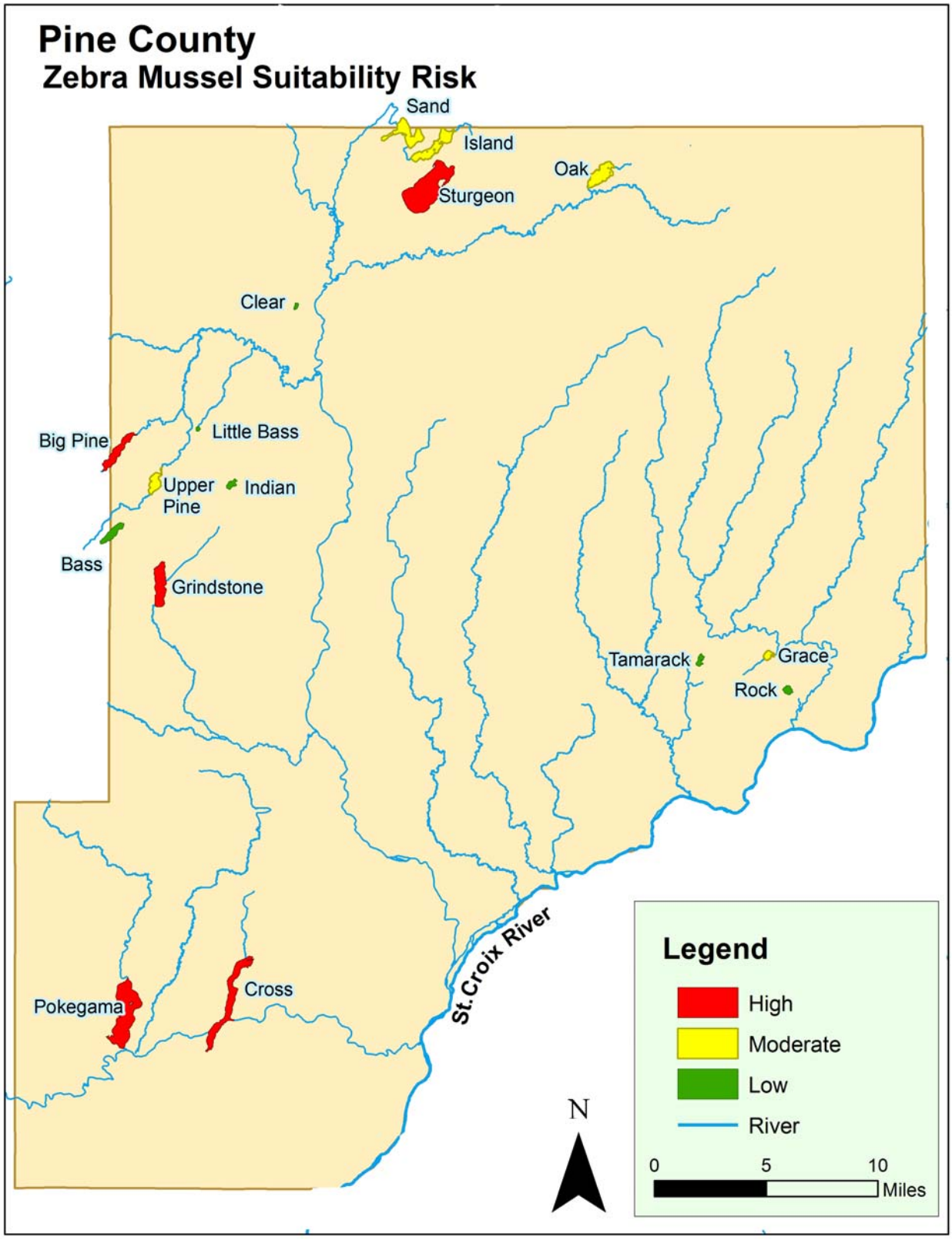


Figure 9. Overall Zebra mussel suitability risk rating in Pine County.

Data Gaps

This study identified some data gaps in Pine County. Calcium is the most important water chemistry parameter when evaluating Zebra mussel habitat suitability. Many lakes did not have any historical calcium data. It is recommended that this data be collected to assist with overall verification of water chemistry. The data gaps are indicated on the lake report cards. See the table below for a summary of parameters needed for each lake (Table 11).

Table 11. Summary of data gaps for water bodies in Pine County.

Lake Name	Lake ID	Parameters Needed
Bass	58-0137-00	Calcium
Big Pine	58-0138-00	None
Clear	58-0104-00	Secchi, Chlorophyll-a, Temp, Dissolved Oxygen
Cross	58-0119-00	Calcium
Grace	58-0029-00	Secchi, Chlorophyll-a, Total Phosphorous, Dissolved Oxygen
Grindstone	58-0123-00	Calcium
Indian	58-0132-00	Chlorophyll-a, Total Phosphorus, Temp, Dissolved Oxygen
		Calcium
Island	58-0062-00	Secchi, Chlorophyll-a, Total Phosphorus
Little Bass	58-0127-00	Calcium
Oak	58-0048-00	Calcium, pH, Alkalinity, Specific Conductance, Dissolved Oxygen
Pokegama	58-0142-00	Calcium, pH, Specific Conductance
Rock	58-0007-00	Dissolved Oxygen
Sand	58-0081-00	Calcium
Sturgeon	58-0067-00	None
Tamarack	58-0024-00	Chlorophyll-a, Total Phosphorus
Upper Pine	58-0130-00	Calcium, pH, Alkalinity, Dissolved Oxygen

Vectors of Spread – Infestation Routes

In order to have a watershed strategy for AIS program management, the vectors of spread for each lake needs to be determined. This risk assessment process also identifies the vectors of spread for the lakes in the watershed. For headwaters lakes there is no risk of infestation from upstream, so any new infestation would come from lake users (boats, boat lifts, docks, etc). For lakes in a river chain, both lake users and upstream lakes need to be considered as potential vectors of spread.

Zebra mussels can be transferred from infested waters through several different pathways. These pathways are highly dependent upon the time of year and the stage in the Zebra mussel life cycle. The risk pathway ratings for time of year are shown in Table 12.

1. Connectivity via a river or stream.
   An upstream infested lake is almost certain to infest downstream lakes if the stream distance between lakes is short enough.

2. Transfer of equipment from lake to lake.
   The transfer of a large breeding adult Zebra mussel population from one lake to another on an infested boat lift, dock, swim raft or other water-related equipment has a very high probability of infesting a lake.

3. Transfer of mussels hitchhiking on vegetation or mud on boat and trailers.
   The risk of hitchhiking mussels depends somewhat on the time of year. When vegetation dies off in the fall, the Zebra mussels fall off into the sediments. Therefore, Zebra mussels are only attached to plants from approximately June to September. Zebra mussels can't be transferred alone in mud because they do not thrive in soft substrates; they need to be attached to a hard surface.

4. Transfer of veligers or mussels from live wells, bilges, and any area of the boat that holds water.
   The risk of veliger transfer depends greatly on the time of year. In infested lakes in northwest Minnesota, it has been documented that Zebra mussel veligers are at peak concentrations in early July (Rufer 2015). *Therefore, July is the month of the year where veliger transfer from lake to lake has the highest risk for infestation. Research has shown that veligers are non-existent during the ice-covered season, so there is essentially no risk of veliger transfer in the winter* (Rufer 2015).

5. Transfer of juvenile mussels on boats not thoroughly cleaned after being tied up on infested waters for an extended period of time.
   The risk of mussel transfer on boats is highest in July through September, because that is when the mussels are reproducing and settling on new hard surfaces.

6. Transfer of veligers and juvenile mussels on swimwear, SCUBA equipment, waders or other gear used in water.
   The risk of veliger transfer on gear depends somewhat on the time of year. July and August would be the times of highest risk throughout the year. Overall, this pathway is considered to be very low risk potential because the amount of water transferred is so small.

Risk – Time of Year

The risk of Zebra mussel infestation varies by the time of year. Data sources show that in Minnesota, the time of year that has the highest concentration of Zebra mussel veligers matches up with the highest use time for the public (Figures 23-24, Pesch & Bussiere 2014, Rufer 2015). The implications of these data indicate that additional prevention measures should be implemented during July to prevent Zebra mussel spread.

In Pesch and Busierre's (2014) survey of 2nd Homeowners in Central and West Central Minnesota, the highest use time of year was July, at an average of 16 days during that month (Figure 23, Pesch & Bussiere 2014). Rufer's monitoring of Zebra mussel veligers in Pelican Lake, a Zebra mussel infested lake in Otter Tail County, shows the peak density for Zebra mussels is in July (Figure 24, Rufer 2015).

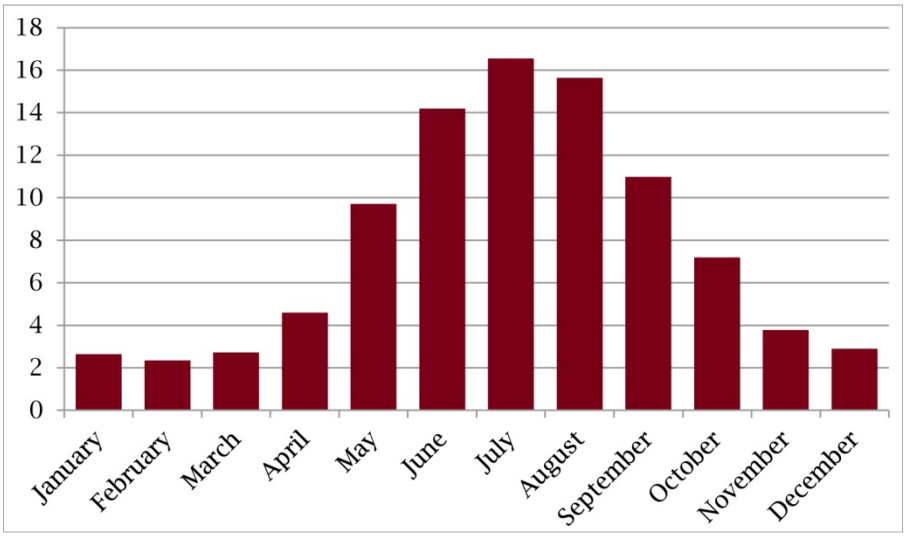


Figure 10. Average number of days occupied per month (n=552) from Pesch & Bussiere 2014.

The full report can be downloaded from this link:
http://www.extension.umn.edu/community/research/reports/docs/2014-2nd-Homeowners.pdf

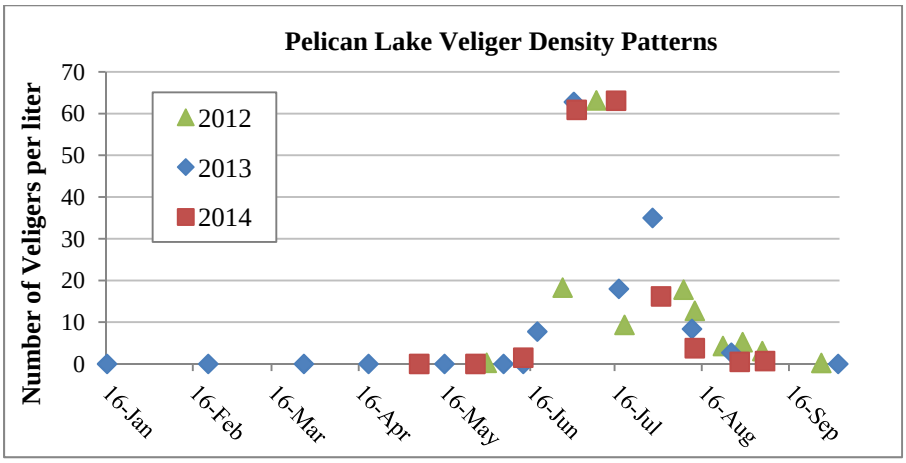


Figure 11. Veliger densities in Pelican Lake, 2012-2014 from Rufer 2015.

The full report can be downloaded from this link:
http://pgolid.org/wp-content/uploads/2014/01/PGOLID-Veliger-Report-2012-2014.pdf

Table 12. Summary of risk pathways depending on the time of year. The Zebra mussel life stage for the pathway is indicated in italics.

	Typical Minnesota Open Water Season							Typical Minnesota Ice-covered season				
Risk Pathway	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**
1. Connectivity via a river or stream.	insignificant	insignificant	Low *Veligers*	High *Veligers*	Moderate *Veligers*	Low *Veligers*	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
2. Transfer of equipment from lake to lake.	insignificant	insignificant	Moderate *Adults & juveniles*	High *Adults & juveniles*	High *Adults & juveniles*	Low *Adults & juveniles*	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
3. Transfer of mussels hitchhiking on vegetation or mud on boats, trailers and gear.	Low *Adults & juveniles*	Low *Adults & juveniles*	Moderate *Adults & juveniles*	High *Adults & juveniles*	High *Adults & juveniles*	Moderate *Adults & juveniles*	Low *Adults & juveniles*	insignificant	insignificant	insignificant	insignificant	insignificant
4. Transfer of veligers via water in boats (live wells, bilges, etc) and float planes.	insignificant	insignificant	Low *Veligers*	High *Veligers*	Moderate *Veligers*	Low *Veligers*	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant
5. Transfer of juvenile mussels on boats not thoroughly cleaned after being tied up on infested waters for an extended period of time.	insignificant	insignificant	Moderate *Adults & juveniles*	High *Adults & juveniles*	High *Adults & juveniles*	Moderate *Adults & juveniles*	Low *Adults & juveniles*	insignificant	insignificant	insignificant	insignificant	insignificant
6. Transfer of veligers and juvenile mussels on swimwear, SCUBA equipment, waders or other gear used in water.	insignificant	insignificant	Low *Veligers*	High *Veligers*	Moderate *Veligers*	Low *Veligers*	insignificant	insignificant	insignificant	insignificant	insignificant	insignificant

Sources: Zebra mussel veliger time-of-year risk was taken from Rufer 2015.
Zebra mussel adult and juvenile time-of-year risk was taken from Mackie & Claudi 201, Mackie 1996, McMahon 1996.

AIS Program Management Recommendations

In an ideal world, all Aquatic Invasive Species (AIS) prevention programs would be applied to all lakes. In reality, budgets are always limited, so prioritization of programs due to risk ratings is necessary. Due to the differing risk ratings, programs can be individualized to fit each lake's risk category (Table 13). Lakes with high public use ratings should be at the highest priority for boat inspections at public accesses. Lakes that are already infested should have boat-washing stations nearby for decontamination. All lakes should be targeted with a watershed-wide education program. Because the highest risk time of the summer and one of the highest tourism times of the summer intersect on 4th of July week, focus *additional* targeted education and outreach during this time of year. For monitoring, ideally all lakes would be monitored for adult Zebra mussels because if trained volunteers are used there is no monetary cost, but there is a large benefit.

The assessments in this report result combine the report cards with the risk of time of year (Table 12) in the following specific Aquatic Invasive Species Program Management Recommendations (Table 13). This portion of the report can be inserted directly into the county's AIS Plan, and guide the use of the county's AIS funds in the most efficient and effective way possible.

Table. 13. Framework for the watershed's AIS plan.

Activity	Target Lakes	Target Time of Year	Who	Cost	Narrative
Watercraft Inspections	Priority 1: • Oak • Pokegama • Sturgeon Priority 2: • Big Pine • Cross • Sand	Priority 1: July Priority 2: August Priority 3: June	County	TBD	This activity depends on available funding. If limited funding is available, focus inspections on the high risk public use lakes (Oak, Pokegama and Sturgeon) in July. If more funding is available, add in moderate public use risk lakes (Big Pine, Cross, Sand) in July. Next, add in August inspections.
Water Quality Monitoring	Priority 1: • Oak • Island • Upper Pine • Sand Priority 2: See Table 11 for data gaps.	May – September	Lake Associations	TBD	There were not enough data to determine if Oak, Island, Upper Pine, or Sand were hard water or soft water lakes. Testing calcium in these lakes this summer would be the first priority for determining Zebra mussel suitability. Monitor lakes for missing parameters shown in Table 11. Priority parameters for each lake would be Calcium, Alkalinity, pH and Specific Conductance as they have the most effect on Zebra mussel suitability.

Table 13 continued on the next page…

Table. 13 continued. Framework for the watershed's AIS plan.

Activity	Target Lakes	Target Time of Year	Who	Cost	Narrative
Early Detection Monitoring: *Zebra mussel veligers*	• Oak • Pokegama • Sturgeon	July	County or Lake Associations	$540	Collect plankton tow samples in high infestation risk lakes in early and late July for veliger analysis. Early detection allows for possible treatment.
Early Detection Monitoring: *Adult Zebra mussels*	Priority 1: • Oak • Pokegama • Sturgeon Priority 2: • Big Pine • Cross • Sand Priority 3: All lakes	Priority 1: September Priority 2: Every other week from late June to mid-September	Volunteers, Lake Associations	$0	a. In September, conduct a lake-wide inspection of docks and boat lifts as they are removed from the lake. b. Place a cinder block in 5-8 feet of water near the public access and any other heavily used areas of the lake, and have the volunteers check the block (pull it up or snorkel) every other week from late June to mid-September. Record results on the MN DNR's website: http://www.dnr.state.mn.us/volunteering/zebramussel_monitoring/report.html

Table 13 continued on the next page…

Table. 13 continued. Framework for the watershed's AIS plan.

Activity	Target Lakes	Target Time of Year	Who	Cost	Narrative
Monitoring: Invasive Plants	Priority 1: • Oak • Pokegama • Sturgeon Priority 2: • Big Pine • Cross • Sand	Mid to late June	County, Lake Associations, or private contractor	TBD	Conduct plant surveys to look for aquatic invasive plants. Mid to late June will catch Curly-leaf pondweed, Flowering rush, and Eurasian watermilfoil.
Education and Outreach	All	Priority 1: 4th of July week Priority 2: Memorial day to labor day Priority 3: Year round	County and watershed	TBD	Conduct a consistent watershed-wide education program to schools and the general public. In high tourism areas focus ***additional*** education around 4th of July since that is the highest risk time of the year for spread.

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