SWMP-14 H. Christmas Lake

Zebra Mussels Found in Lake Ossawinamakee, 2009 (photo by Steve McComas)

Christmas Lake Habitat Suitability Assessment for Invasive Zebra Mussels

Prepared for the Christmas Lake Association

Prepared by Steve McComas and Jo Stuckert,
Blue Water Science, St. Paul, MN

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(prepared by Steve McComas, Blue Water Science, 2011)

Summary

Christmas Lake Status: Not currently found in Christmas Lake as of August 2010.

Nearby Occurrences: Upper and Lower Prior Lakes (Scott County), Lake Minnetonka (Hennepin), Lake Mille Lacs (Cass County), St. Croix River (Washington County), Alexandria Lakes (Douglas County).

Overview: If zebra mussels are introduced into Christmas Lake, they have the potential to grow to water depths of 40 feet. However, their growth could be limited by the food supply. The amount of algae in a lake is an indicator of a potential food source. Christmas Lake has a low algae concentration and this should limit zebra mussel growth. The long term potential growth of zebra mussels is considered to be light to moderate with a fluctuating population dependent on the algae concentration which will be impacted by zebra mussel filtering and feeding dynamics. Even though the zebra mussel population may fluctuate over time, the zebra mussel shells will accumulate and produce nuisance conditions in swimming areas.

Zebra mussels may influence bottom algal conditions in lakes. (Left) Low to moderate zebra mussel density seems to lead to low to moderate filamentous algal growth. (Right) High density of zebra mussels may lead to high density of benthic filamentous algal growth. Christmas Lake is predicted to exhibit a combination of low to moderate growth of zebra mussels if zebra mussels become established.

Zebra Mussel Growth Potential in Christmas Lake Based on Water Quality

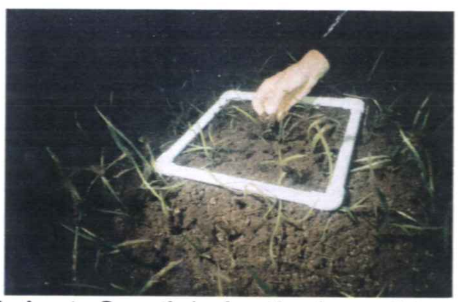
The water column assessment is used to determine if the water column environment is conducive to zebra mussel survivability and reproductive success in Christmas Lake. The suitability criteria are derived from a variety of sources. For Christmas Lake, the most recent reference by Mackie and Claudi (2010) has been used for suitability criteria for Christmas Lake (Table S-1).

Table S-1. Range of water column zebra mussel suitability criteria for lakes.

		Low Potential for Adult Survival	Low Potential for Larval Development	Moderate (survivable, but will not flourish)	High (favorable for optimal growth)
Calcium (mg/l)	Mackie and Claudi 2010	<8	8 - 15	15 - 30	>30
Dissolved oxygen (mg/l)	Mackie and Claudi 2010	<3	3 - 7	7 - 8	>8
Temperature (C)	Mackie and Claudi 2010	<10 or >32	26 - 32	10 - 20	20 - 26
pH	Mackie and Claudi 2010	<7.0 or >9.5	7.0 - 7.8 or 9.0 - 9.5	7.8 - 8.2 or 8.8 - 9.0	8.2 - 8.8
Potassium (mg/l)	(Bartell et al 2007)	>100	>50 (prevents settlement)	40 - 50	<40
Hardness (mg/l)	Mackie and Claudi 2010	<30	30 - 35	55 - 100	100 - 280
Alkalinity (as mg $CaCO_3$/l)	Mackie and Claudi 2010	<30	30 - 55	55 - 100	100 - 280
Conductivity (umhos)	Mackie and Claudi 2010	<30	30 - 60	60 - 110	>110
Secchi depth (m)	Mackie and Claudi 2010	<1 or >8	1 - 2 or 6 - 8	4 - 6	2 - 4
Chlorophyll a (ug/l)(food source)	Mackie and Claudi 2010	<2.5 or >25	2.0 - 2.5 or 20 - 25	8 - 20	2.5 - 8
Total phosphorus (ppb)	Mackie and Claudi 2010	<5 or >50	5 - 10 or 35 - 50	10 - 25	25 - 35

Examples of Zebra Mussel Growth Conditions

Light Growth (low potential for growth)
Weakly colonized on plants or hard substrates with factors limiting growth to a single season and then a zebra mussel die-off at the end of the year. Low impact to lake ecology and recreation.



Moderate Growth (suboptimal growth)
In soft sediments, found in clumps, with zebra mussels attached to each. Can colonize aquatic plants as well. Moderate impact to lake ecology, with increase in benthic filamentous algae and adverse impact on fish spawning success. Moderate impact to recreational swimming and boats will have to be serviced annually.

Heavy Growth (optimal growth)
Found at high densities when water column conditions are suitable on hard substrates such as rocks and submerged structures such as tree limbs, docks, and pipes. Impacts can be significant. Impacts to lake ecology include increase in benthic algae growth and a decline in fish spawning habitat and lower fry survival. Swimming areas with hard substrates will contain sharp edges of the mussels and produce an inconvenience to swimmers. Boats will have to be serviced annually.

Zebra Mussel Growth Potential Based on Water Quality

The water column has several parameters that are suitable for optimal growth (Table S-2). However, a lack of dissolved oxygen below 24 feet will limit the depth of zebra mussel colonization. Also, the good water clarity and moderate chlorophyll concentrations indicate food could limit zebra mussel growth in Christmas Lake and keep it from optimal growth conditions although zebra mussels are predicted to sustain long-term moderate growth.

Table S-2. Water column zebra mussel suitability criteria and Christmas Lake water column conditions. Suitability Conditions are mixed but chlorophyll appears to be the limiting factor for zebra mussel growth.

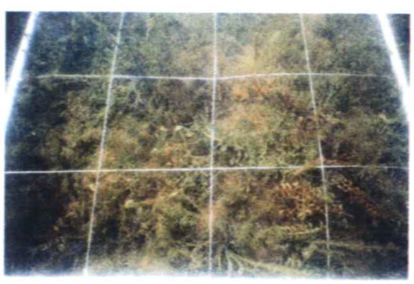
		Little Potential for Adult Survival	Little Potential for Larval Development	Moderate (survivable, but will not flourish)	High (favorable for optimal growth)
Calcium (mg/l)	Christmas Lake			28.7	
	Mackie and Claudi 2010	<8	8 - 15	15 - 30	>30
Dissolved oxygen (mg/l)	Christmas Lake	>15 m (depth)	15-10m (depth)	10-9m (depth)	9 - 0m (depth)
	Mackie and Claudi 2010	<3 mg/l	3 - 7 mg/l	7 - 8 mg/l	>8 mg/l
Temperature (°C)	Christmas Lake		16-11 m (depth)	10 - 5m (depth)	7 - 0m (June-August)
	Mackie and Claudi 2010	<10 or >32°C	26 - 32°C	10 - 20°C	20 - 26°C
pH	Christmas Lake			8.19	
	Mackie and Claudi 2010	<7.0 or >9.5	7.0 - 7.8 or 9.0 - 9.5	7.8 - 8.2 or 8.8 - 9.0	8.2 - 8.8
Potassium (mg/l)	Christmas Lake				3.87
	(Bartell et al 2007)	>100	>50 (prevents settlement)	40 - 50	<40
Hardness (mg/l)	Christmas Lake				133
	Mackie and Claudi 2010	<30	30 - 35	55 - 100	100 - 280
Alkalinity (as mg $CaCO_3$/l)	Christmas Lake				123
	Mackie and Claudi 2010	<30	30 - 55	55 - 100	100 - 280
Conductivity (umhos)	Christmas Lake				355
	Mackie and Claudi 2010	<30	30 - 60	60 - 110	>110
Secchi depth (m)	Christmas Lake		6.28		
	Mackie and Claudi 2010	<1 or >8	1 - 2 or 6 - 8	4 - 6	2 - 4
Chlorophyll a (ug/l)(food source)	Christmas Lake	1.8			
	Mackie and Claudi 2010	<2.5 or >25	2.0 - 2.5 or 20 - 25	8 - 20	2.5 - 8
Total phosphorus (ppb)	Christmas Lake			11.7	
	Mackie and Claudi 2010	<5 or >50	5 - 10 or 35 - 50	10 - 25	25 - 35

Suitability for Growth Based on Substrate Characteristics: The majority of the Christmas Lake bottom conditions to depths where zebra mussels will live will provide a substrate for colonization. However most of the lake bottom of Christmas Lake is composed of sand and muck and is not optimal for the densest type of zebra mussel colonization. An estimated 160 ac of lake bottom consist of substrate conditions that could support zebra mussel growth, but conditions are considered to be suboptimal (Table S-3). An additional estimated 1-2 acres of substrate which includes gravel and rock are rated as optimal for growth. The vertical substrate component could offer additional area for zebra mussel colonization, with less than 1 acre of surface area considered optimal for growth and 97 acres of aquatic vegetation offering suboptimal substrate conditions.

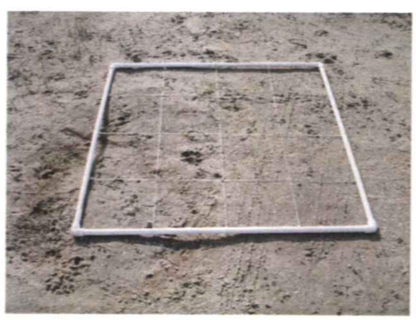
Table S-3. Christmas Lake substrate suitability characteristics.

	Not Suitable	Suboptimal	Optimal for Growth
Horizontal Substrate Assessment (colonization on lake bottom including muck, sand, gravel, rock, etc.)			
0 - 30 feet deep	0 ac (0%)	115 ac (44%)	2 ac (1%)
30 - 40 feet deep	0 ac (0%)	45 ac (17%)	0 ac (0%)
Greater than 40 feet deep	105 ac (39%)	0 ac (0%)	0 ac (0%)
Horizontal Subtotal (ac)	105 ac	160 ac	2 ac
Vertical Substrate Assessment (colonization on upright structure, like plants, boat lifts, etc.)			
Aquatic plant coverage	0 ac	97 ac	0 ac
Boat lifts and docks	0 ac	0 ac	<1 ac
Vertical Subtotal (ac)	0 ac	97 ac	<1 ac

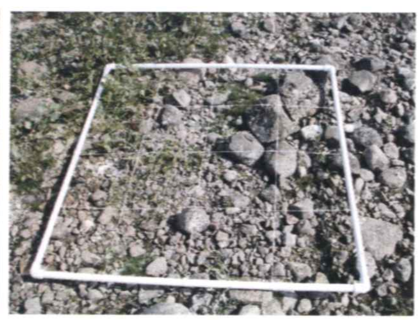
Examples of Substrate Conditions



Plant dominated substrate: Sub-optimal, but survivable



Sand: Suboptimal, but survivable.



Gravel, cobble, rock: Optimal for growth

Map of Substrate Suitability for Christmas Lake

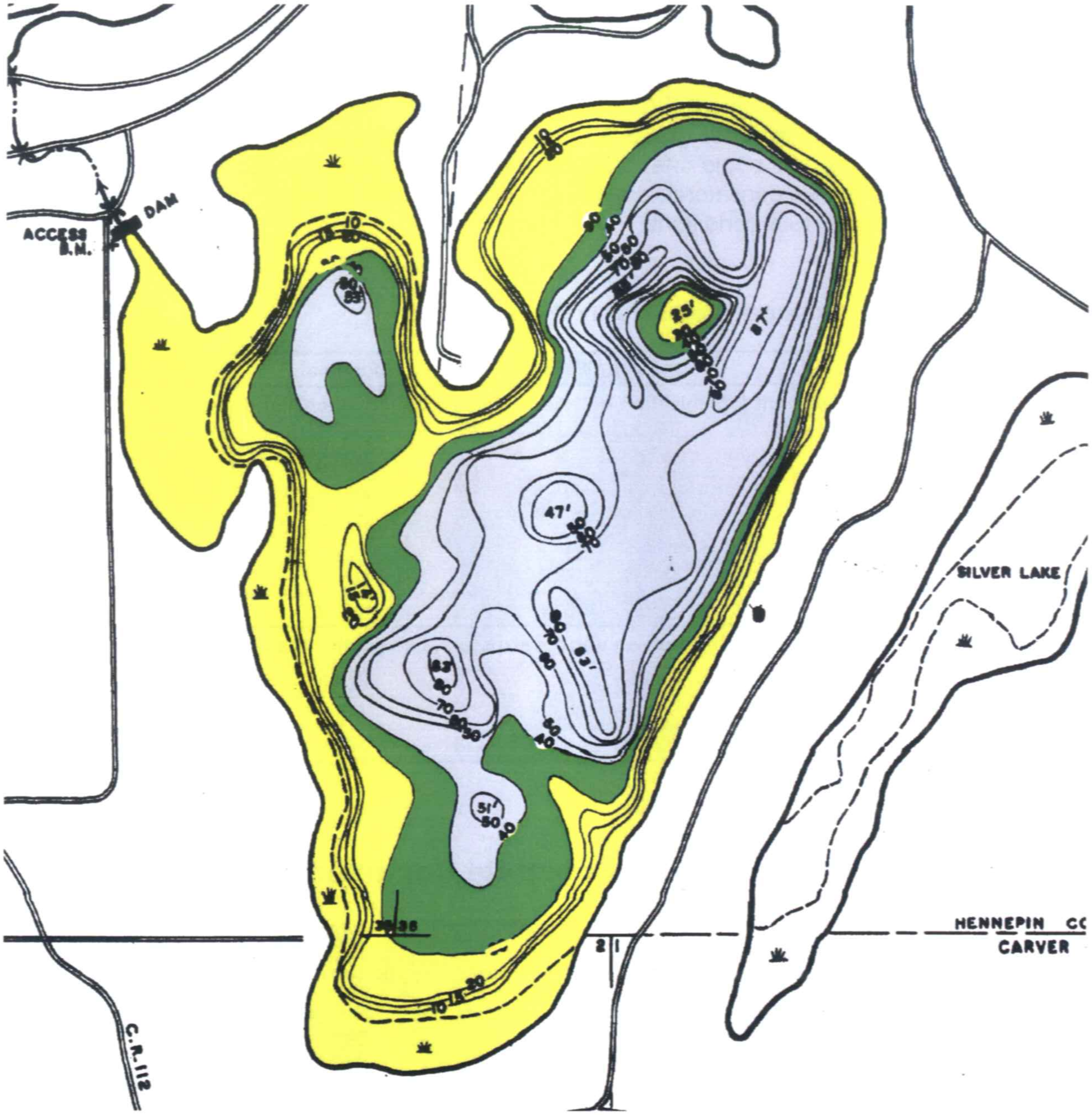


Figure A. Substrate suitability map for Christmas Lake. Yellow and green shading indicates suboptimal bottom composition for zebra mussel growth consisting of sand and muck conditions. Yellow shading represents dissolved oxygen conditions where growth is moderate and green shading represents conditions where growth is expected to be light. The blue shading represents water depths greater than 40 feet deep where no zebra mussel growth is expected.

Summary of Substrate Suitability Characteristics

Acreage of potential zebra mussel high density and high biomass (optimal growth): 2 acres
Acreage of suboptimal conditions (survivable): 160 acres (bottom substrate) + 97 acres (aquatic plants) = 257 acres
Acreage of conditions not suitable for growth: 105 acres

Potential for Zebra Mussel Colonization in Christmas Lake

If zebra mussels invade Christmas Lake, there is an estimated 162 acres of bottom area that could be colonized. Within the 162 acres, there are about 2 acres of optimal substrate habitat. In addition, there is about 97 acres of aquatic plants that could be colonized as well. There is the potential for fairly widespread zebra mussel colonization at low to moderate densities in Christmas Lake.

Limiting Factors: Due to the low chlorophyll concentrations which are an indicator of algal abundance, it appears zebra mussels in Christmas Lake will be food limited and this may limit their overall abundance. Also, because there is very little oxygen below 40 feet of water depth, zebra mussels are not expected to be found deeper than 40 feet.

Potential Impacts of a Zebra Mussel Invasion into Christmas Lake

- Water clarity should increase. Aquatic plant growth may increase because of the improved water clarity.
- Zebra mussel shells convert sandy substrate to shell gravel. Swimming areas will be impacted.
- Soft sediments will support clumps of mussels. The high density of clumps of mussels will excrete high nutrient waste products and likely produce filamentous algae on the lake bottom covering many acres.
- Fish spawning habitat will be covered with filamentous algae. Mussels will filter the water column and reduce the amount of edible algae. Zooplankton will decline and will impact the survival of young fish.
- Boats, docks, and lifts will have to be scraped annually. Boat servicing will be critical to avoid operating problems.
- Aquatic plants are not expected to be impacted, at least not initially. Growth of zebra mussels are expected to be food limited not space limited, so the likelihood of zebra mussels colonizing aquatic plants may be minor. However, if food is available, zebra mussels could colonize aquatic plants and this could adversely impact aquatic plant community structure.

Recommended Management Option: Because there is the potential for significant zebra mussel colonization in Christmas Lake, the recommended management option for Christmas Lake is Level 4 (out of 5 levels) - aggressive prevention and rapid response, with moderate aggressive control.

Table S-4. Levels of action to consider for zebra mussel prevention, rapid response, and control in Christmas Lake. The recommended level of action is Level 4 (shown in blue shading).

	Prevention	Rapid Response	Control
Level 1	Use existing programs.	No rapid response.	Monitor only.
Level 2	Employ additional prevention programs.	No rapid response.	Monitor only.
Level 3	Employ additional prevention programs.	Conduct assessment	Small-scale control demonstrations.
Level 4	Employ additional prevention programs and work at a state level.	Conduct an enhanced assessment	Small-scale annual control in selected areas.
Level 5	Boat and trailer sterilization and then inspection.	Conduct assessments for the next 5 to 10 years	Eradication by lake drawdown if colonization is significantly changing the lake.

Zebra mussel filtering activities will remove open-water algae from the lake and metabolic activities will discharge waste products to the bottom. Filamentous algae will develop from these nutrient sources. This has occurred in Lake Ossawinnanakee. At this time, the long term effects in Minnesota lakes is unknown. (photo by Steve McComas)

Zebra Mussel Management Plan Summary

Prevention - First Line of Defense. Employ the shield and containment strategy. For the "shield" strategy add additional inspection hours at the Christmas Lake boat landings (apply for MnDNR grants). Try to "shield" Christmas Lake from zebra mussels. Send out news releases at mussel spawning time (early to mid summer) to alert folks to be extra careful about transporting water from one lake to the next. Apply for MnDNR grants to improve signage at the landings. For the "containment" strategy encourage the MnDNR to increase inspections at major potential sources of zebra mussel exports, such as boats leaving Mille Lacs and Prior Lake. The idea is to contain the zebra mussel in infested systems and prevent new introductions to uninfested lakes and rivers.

Rapid Response - Second Line of Defense.

Scouting: Send a questionnaire to all lake residents asking them to inspect their boat lifts and docks on a routine basis. Have them contact the Christmas Lake Association if they see anything unusual.

Inventory: If zebra mussels are spotted and there are less than 10 growth centers documented after a thorough survey, then treat up to 1,600 m^2 per colonized area. If colonization sites exceed 10 growth centers, then go to the next line of defense, the control program.

Rapid Response Treatment: Use a tarp to cover an area of zebra mussel colonization. Inject either potassium chloride or chlorine under the tarp to kill the zebra mussels. Leave the tarp in place up to a month and then remove it from the lake.

Control Program - Third Line of Defense. If the Rapid Response effort is not successful, then a control program is the next line of defense. A high priority control area is mussel removal at swimming beaches. Zebra mussels will colonize in clumps of mussels about the size of tennis balls on top of sandy sediments. These mussels can be harvested. The next priority areas for control are at the two public boat landings. The next priority area for control after boat landings is spawning habitat around the lake.

On soft sediments, zebra mussels grow on top of other zebra mussel shells forming clumps of zebra mussels. These can be harvested. (Photo by Steve McComas)

Introduction

Zebra mussels have been in Minnesota since 1989 when they were first observed in the Duluth/Superior Harbor. Zebra mussels were first found in a Minnesota inland lake in 2000 in Lake Zumbro, Olmsted County. By the end of 2010, zebra mussels were reported in about a dozen or more lakes in Minnesota.

The rate of zebra mussel infestation in Minnesota lakes is low but could increase over the next few decades based on experiences in other states. The rate of expansion will be largely dependent on the adequacy of prevention programs and prevention efforts by individuals. Prevention is the first line of defense. However, if zebra mussels should get into a lake, an important question is what will zebra mussels do in that particular lake? Zebra mussels don't take over every lake they invade, but in some lakes they will cause significant problems.

Currently, zebra mussels have not been found in Christmas Lake. The objective of this assessment is to determine the potential habitat suitability for zebra mussel growth if they do invade Christmas Lake. If the overall growth potential is slight because of poor habitat suitability, then rapid response and control programs are not a high priority. However, if the habitat suitability is optimal for heavy zebra mussel growth, then extra provisions should be taken for prevention programs, as well as for rapid response and control programs.

This assessment bases habitat suitability on three areas: 1. Water column suitability, 2. Substrate suitability, and 3. Natural biological control suitability.

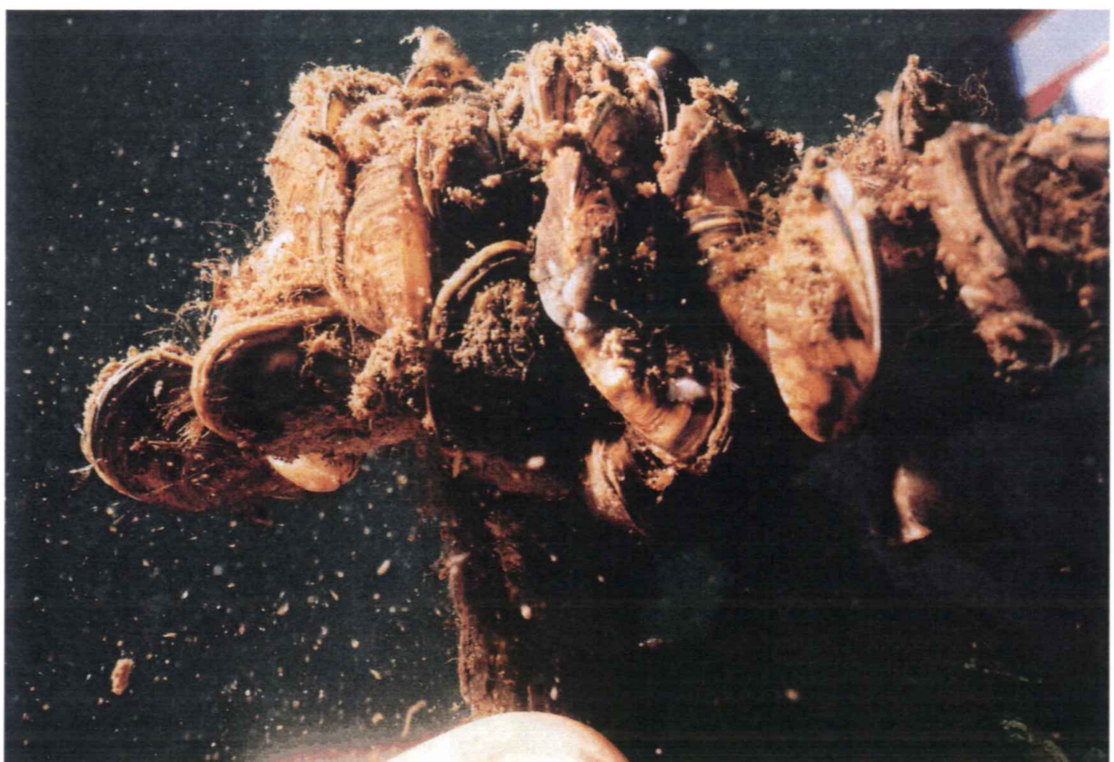


Figure 1. Zebra mussels in Lake Ossawinnamakee, summer of 2009. (Photo by Steve McComas).

Methods

Three types of assessments were conducted to evaluate the suitability of zebra mussels to grow in Christmas Lake.

Water Column Suitability: In order to assess the suitability of water column conditions to zebra mussel growth, a range of concentrations for several key water column parameters have been identified by researchers. Literature values were selected from a variety of reports and three growth categories (unsuitable, suboptimal, and optimal) were defined based on water column values.

Substrate Suitability: The substrate composition was estimated. Soft sediments (sand and muck) are considered to be suboptimal for growth whereas hard surfaces, as found with rock and cobble, are considered to be optimal for growth.

Natural Biological Control Potential: Research studies have found several types of predators will eat zebra mussels. Using this information as a guide, MnDNR fishery records and observations of waterfowl on Christmas Lake were used to evaluate the potential for natural biological control of zebra mussels.

Results

Zebra Mussel Background Information

Spawning temperature: 14° to 20°C (summer to fall in Minnesota)

Life span: 2 - 3 years in climates like Minnesota (temperate)

Growth rate: 0.5 mm/day (25 mm or 1 inch per year)

Preferred particle size for feeding: 0.001 to 0.05 mm

Filtration rates: 16.2 ml/mg/hr (range 4.0 - 40.7)
adults filter 1 liter/day (Ohio Sea Grant, 1994)
(Filtration decreases when chl a decreases from 7 to 2 ug/l)

Zebra Mussel Biomass: 1,500g dry mass/m^2 on rock surfaces

Typical Zebra Mussel Density:
Sand, silt, clay (sub optimal): 3,000/m^2 (Chakraborti et al 2002)
Gravel-cobble (near optimal): 10,000/m^2 (Chakraborti et al 2002)

>20,000 zm/m^2 for Lake Pepin (USACOE 2003)

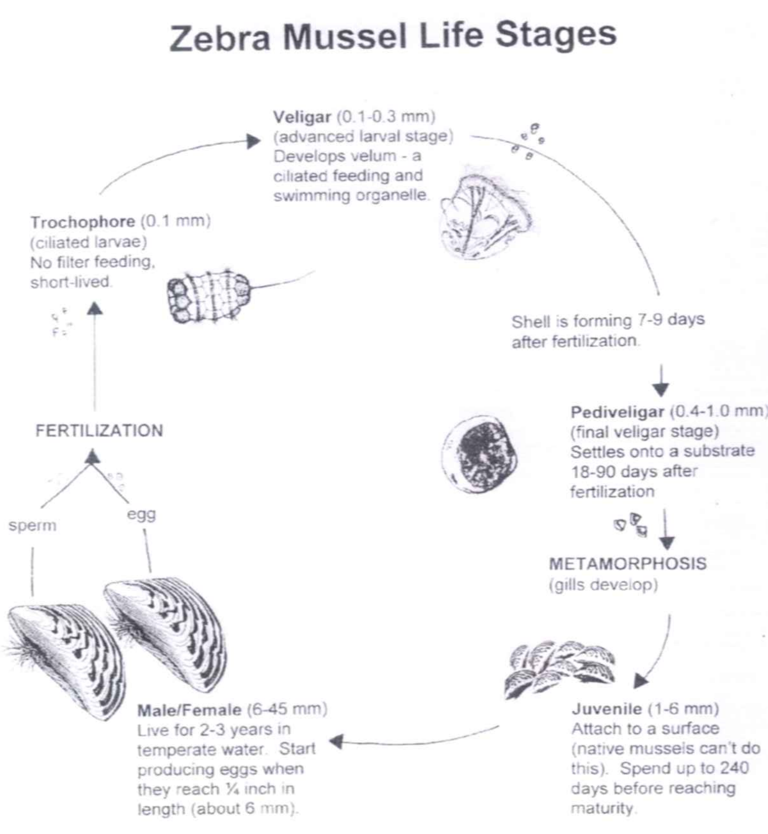


Figure 2. Zebra mussel life cycle. Male and female gametes must come together to produce larvae. (Source: McComas 2003)

Zebra Mussel - Water Column Suitability Criteria

The water column assessment is used to determine if the water column environment is conducive to zebra mussel survivability and reproductive success in Christmas Lake. The suitability criteria are derived from a variety of sources (Table 1). For Christmas Lake, the most recent reference by Mackie and Claudi (2010) is used for suitability criteria for Christmas Lake.

Table 1. Water column suitability criteria (collected from various sources).

		Little Potential for Adult Survival	Little Potential for Larval Development	Moderate (survivable, but will not flourish)	High (favorable for optimal growth)
Calcium (mg/l)	Whittier 2008	<12	12 - 20	20 - 28	>28
	Mackie and Claudi 2010	<8	8 - 15	15 - 30	>30
Dissolved oxygen (mg/l)	Cohen and Weinstein 2001	<4	--	4 - 8	8 - 12
	Mackie and Claudi 2010	<3	3 - 7	7 - 8	>8
Temperature	Kozlowski et al 2002	<10 or > 32°C	--	31 - 32	15 - 31
	Mackie and Claudi 2010	<10 or >32	26 - 32	10 - 20	20 - 26
pH	Kozlowski et al 2002 and Doll 1997	<6.8 or >9.5	--	6.8 - 7.4 or 8.7 - 9.5	7.4 - 8.7
	Mackie and Claudi 2010	<7.0 or >9.5	7.0 - 7.8 or 9.0 - 9.5	7.8 - 8.2 or 8.8 - 9.0	8.2 - 8.8
Potassium (mg/l) (Bartell et al 2007)		>100	>50 (prevents settlement)	40 - 50	<40
Magnesium (mg/l) (Rancharan et al 1992)		<3	--		
Hardness (mg/l)	Sorba and Williamson 1997	<25	25 - 45	45 - 90	>90
	Mackie and Claudi 2010	<30	30 - 35	55 - 100	100 - 280
Alkalinity (as mg $CaCO_3$/l)	Hincks and Mackie 1997	<17	17 - 40	40 - 60	>60
	Mackie and Claudi 2010	<30	30 - 55	55 - 100	100 - 280
Conductivity (umhos)	Sorba and Williamson 1997	<22	22 - 36	37 - 82	>83
	Mackie and Claudi 2010	<30	30 - 60	60 - 110	>110
Secchi depth (m)	Sorba and Williamson 1997	<0.1 or >2.5	0.1 - 0.2 or 2.0 - 2.5	0.2 - 0.4	0.4 - 2.0
	Mackie and Claudi 2010	<1 or >8	1 - 2 or 6 - 8	4 - 6	2 - 4
Chlorophyll a (ug/l)(food source)	Bartell et al 2007, Strayer and Malcom 2005	<4	--	4-8	>10
	Mackie and Claudi 2010	<2.5 or >25	2.0 - 2.5 or 20 - 25	8 - 20	2.5 - 8
Total phosphorus Mackie and Claudi 2010		<5 or >50	5 - 10 or 35 - 50	10 - 25	25 - 35

Christmas Lake Water Column Suitability Conditions

Water column conditions for several parameters in Christmas Lake indicate there are conditions for optimal growth (Table 2). However, a lack of dissolved oxygen below 40 feet will limit the depth of zebra mussel colonization and zebra mussels should not be found in water deeper than 40 feet. The good water clarity indicates a possible low algal condition which could indicate a lack of food available to zebra mussels which could limit their growth and prevent optimal growth conditions.

Table 2. Water column zebra mussel suitability criteria and Christmas Lake water column conditions.

		Little Potential for Adult Survival	Little Potential for Larval Development	Moderate (survivable, but will not flourish)	High (favorable for optimal growth)
Calcium (mg/l)	Christmas Lake			28.7	
	Mackie and Claudi 2010	<8	8 - 15	15 - 30	>30
Dissolved oxygen (mg/l)	Christmas Lake	>15 m	15-10m	10-9m	0-9 m
	Mackie and Claudi 2010	<3	3 - 7	7 - 8	>8
Temperature (°C)	Christmas Lake		16-11 m	5-10m (depth)	0-7m (June-August)
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Potassium (mg/l)	Christmas Lake				3.87
	(Bartell et al 2007)	>100	>50 (prevents settlement)	40 - 50	<40
Hardness (mg/l)	Christmas Lake				133
	Mackie and Claudi 2010	<30	30 - 35	55 - 100	100 - 280
Alkalinity (as mg $CaCO_3$/l)	Christmas Lake				123
	Mackie and Claudi 2010	<30	30 - 55	55 - 100	100 - 280
Conductivity (umhos)	Christmas Lake				355
	Mackie and Claudi 2010	<30	30 - 60	60 - 110	>110
Secchi depth (m)	Christmas Lake		6.28		
	Mackie and Claudi 2010	<1 or >8	1 - 2 or 6 - 8	4 - 6	2 - 4
Chlorophyll a (ug/l)(food source)	Christmas Lake	1.8			
	Mackie and Claudi 2010	<2.5 or >25	2.0 - 2.5 or 20 - 25	8 - 20	2.5 - 8
Total phosphorus (ppb)	Christmas Lake			11.7	
	Mackie and Claudi 2010	<5 or >50	5 - 10 or 35 - 50	10 - 25	25 - 35

Christmas Lake Substrate Suitability Conditions

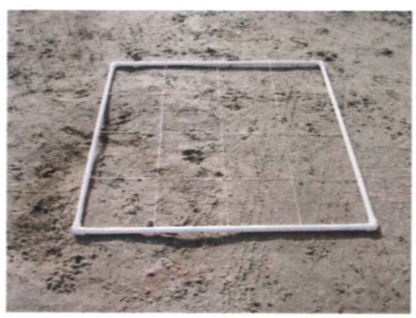
The majority of the Christmas Lake bottom conditions to depths where zebra mussels will live will provide a substrate for colonization. However most of the lake bottom of Christmas Lake is composed of sand and muck and is not optimal for the densest type of zebra mussel colonization. An estimated 160 ac of lake bottom consist of substrate conditions that could support zebra mussel growth, but conditions are considered to be suboptimal (Table S-3). An additional estimated 1-2 acres of substrate which includes gravel and rock are rated as optimal for growth. The vertical substrate component could offer additional area for zebra mussel colonization, with less than 1 acre of surface area considered optimal for growth and 97 acres of aquatic vegetation offering suboptimal substrate conditions.

Table 3. Christmas Lake substrate suitability characteristics.

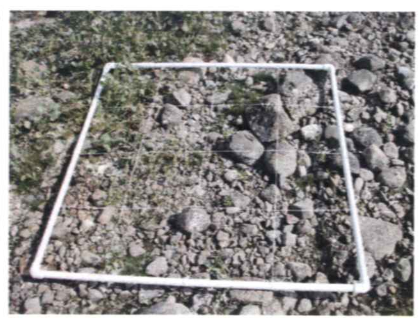
	Not Suitable	Suboptimal	Optimal for Growth
Horizontal Substrate Assessment (colonization on lake bottom including muck, sand, gravel, rock, etc.)			
0 - 30 feet deep	0 ac (0%)	115 ac (44%)	2 ac (1%)
30 - 40 feet deep	0 ac (0%)	45 ac (17%)	0 ac (0%)
Greater than 40 feet deep	105 ac (39%)	0 ac (0%)	0 ac (0%)
Horizontal Subtotal (ac)	105 ac	160 ac	2 ac
Vertical Substrate Assessment (colonization on upright structure, like plants, boat lifts, etc.)			
Aquatic plant coverage	0 ac	97 ac	0 ac
Boat lifts and docks	0 ac	0 ac	<1 ac
Vertical Subtotal (ac)	0 ac	97 ac	<1 ac

Examples of Substrate Conditions

Plant dominated substrate: Sub-optimal, but survivable



Sand: Suboptimal, but survivable.



Gravel, cobble, rock: Optimal for growth

Details of Substrate Suitability Assessment: Examples of substrate conditions are shown in Figures 3-5. Based on general observations a map was constructed of the suitability of lake bottom conditions (the substrate) to support either optimal or suboptimal growth (Figure 6). From other studies, and from observations by McComas (unpublished), it is clear that zebra mussels will grow on muck and sand sediments. This is considered to be suboptimal substrate. Hard surfaces represent the best substrate for growth and is considered optimal. Hard substrate conditions represent less than 2 acres in Christmas Lake.

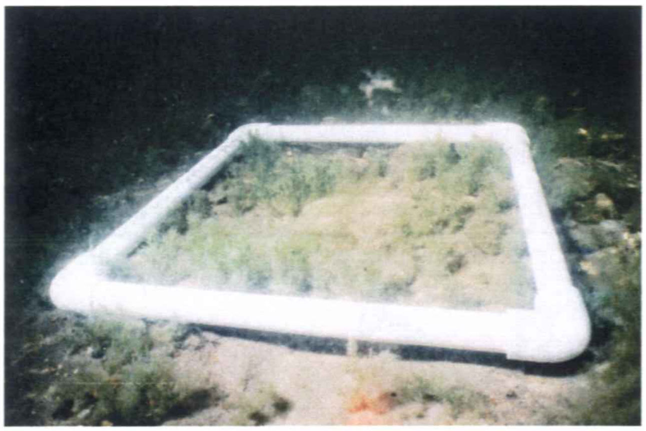


Figure 3. Rocky areas in Christmas Lake present an optimal substrate for zebra mussel growth (picture is from Christmas Lake).

Figure 4. Sandy and silty-sand sediments are the dominant type of bottom substrate in Christmas Lake. This substrate is suboptimal for growth (quadrats are 1 meter^2).

Figure 5. Low lying aquatic plants, like chara, do not offer as good of a surface for zebra mussel attachment compared to broadleaf plants.

Map of Substrate Suitability for Christmas Lake: The majority of the bottom substrate in Christmas Lake is composed of soft sediments, consisting of sand and silt in shallow water and muck in deeper water. Zebra mussels will grow on soft sediments but it is not an optimal substrate for growth.

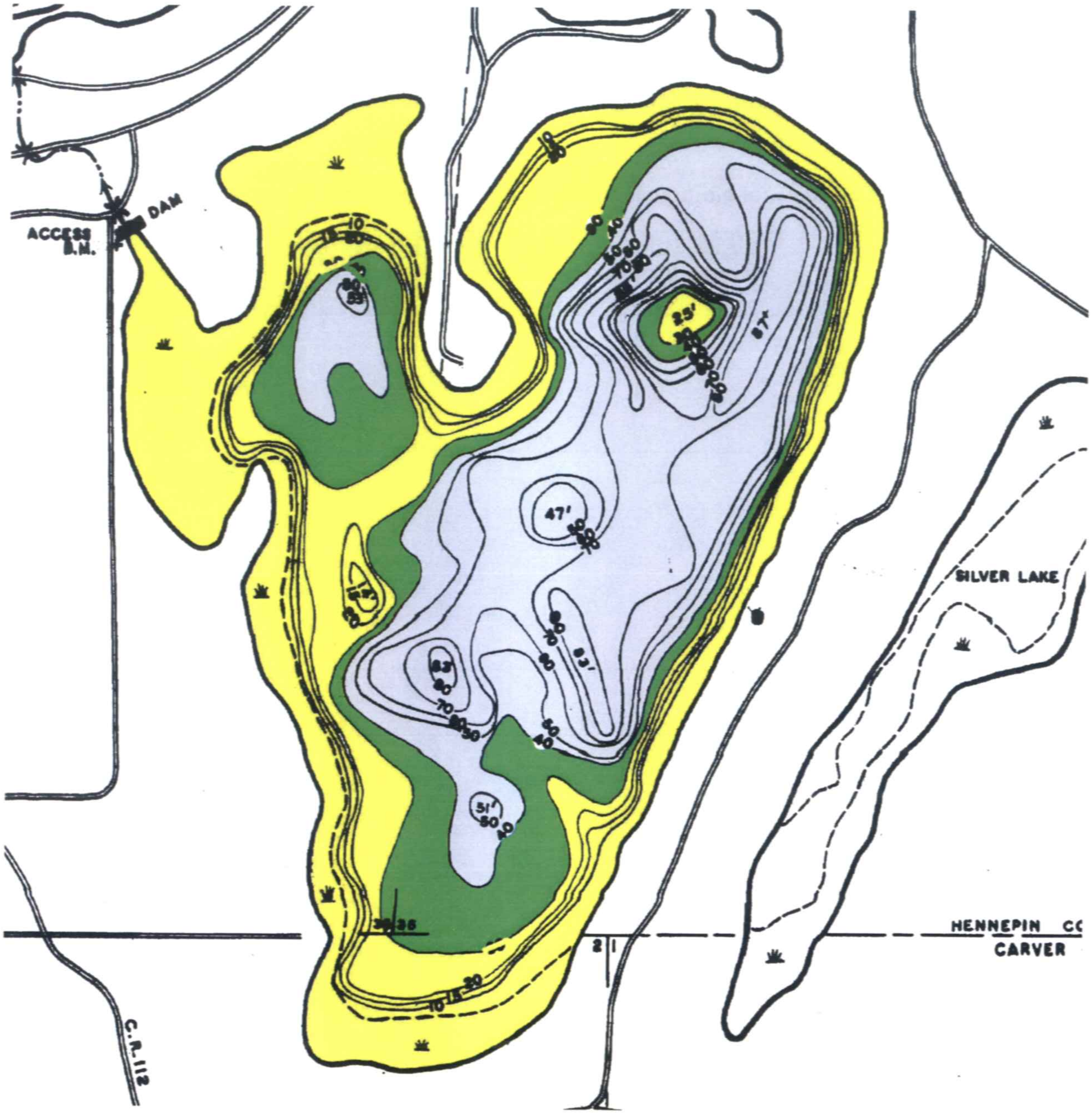


Figure 6. Substrate suitability map for Christmas Lake. Yellow and green shading indicates suboptimal bottom composition for zebra mussel growth consisting of sand and muck conditions. Yellow shading represents dissolved oxygen conditions where growth is moderate and green shading represents conditions where growth is expected to be light. The blue shading represents water depths greater than 40 feet deep where no zebra mussel growth is expected.

Christmas Lake Natural Biological Control Potential

Predation appears to be a controlling factor in the native range of zebra mussels in Eastern Europe. In the United States and perhaps, Minnesota, predation pressure from several types of predators could keep zebra mussel numbers under control. In Minnesota lakes, diving ducks and several fish species are the best candidates for exerting predation pressure on zebra mussels. A review of the MnDNR fish survey from 2007 indicates fish predation from the best candidate species of mussel-eating fish would be minimal due to the low pumpkinseed sunfish and freshwater drum population in Christmas Lake.

Also the diving duck population is low and predation pressure is expected to be minimal. The natural biological potential for zebra mussel control in Christmas Lake is minimal.

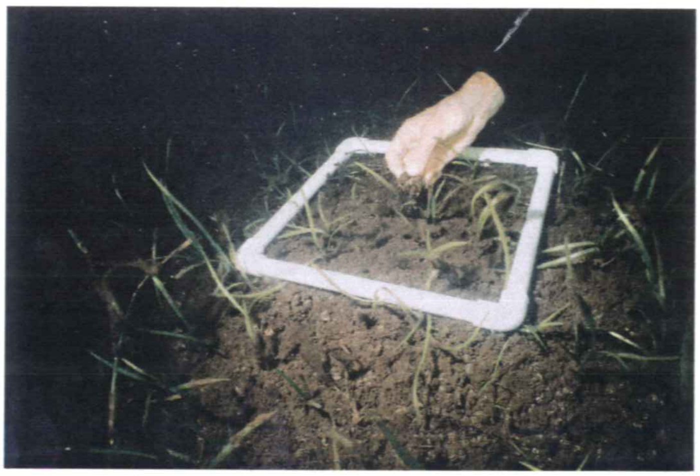
Table 5. Christmas Lake natural biological control potential (predators, parasites, diseases).

	Heavy Pressure (severely limits mussel abundance)	Moderate Pressure	Minimal Pressure (does not limit mussel abundance)
Biological Assessment			
Diving ducks (some stage for short periods, but permanent residents are few in numbers)	--	--	minimal predation pressure
Fish community predators	--	--	minimal predation pressure
Pumpkinseed (MnDNR fish survey: 2007)			2.2 fish/trapnet 0.5 fish/gillnet
Freshwater drum (MnDNR fish survey: 2007)			no drum sampled
Parasites	--	--	no known parasites
Diseases	--	--	no known diseases

Definitions of Growth Categories of Zebra Mussels for Christmas Lake

Light Growth (suboptimal growth)

Weakly colonized on plants or hard substrates with factors limiting growth to a single season and then die-off. Low impact to lake ecology and recreation.



Moderate Growth (suboptimal growth)

Found on soft sediments and aquatic plants. Moderate impact to lake ecology, with increase in benthic filamentous algae and adverse impact on fish spawning success. Moderate impact to recreational swimming and boats will have to be serviced annually.

Heavy Growth (optimal growth)

Found on hard substrates such as rocks and submerged structures such as tree limbs, docks, and pipes. Impacts can be significant. Impacts to lake ecology includes increase in benthic algae growth and a decline in fish spawning habitat and lower fry survival. Swimming areas with hard substrates will contain sharp edges and an inconvenience to swimmers. Boats will have to be serviced annually.

Potential Growth of Zebra Mussels in Christmas Lake

Acreage of potential zebra mussel high density and high biomass (optimal growth): 2 acres

Acreage of suboptimal conditions (survivable): 160 acres (bottom substrate) + 97 acres (aquatic plants) = 257 acres

Acreage of conditions not suitable for growth: 105 acres

Potential for Zebra Mussel Colonization in Christmas Lake

If zebra mussels invade Christmas Lake, there is an estimated 162 acres of bottom area that could be colonized. Within the 162 acres, there are about 2 acres of optimal substrate habitat. In addition, there is about 97 acres of aquatic plants that could be colonized as well. There is the potential for fairly widespread zebra mussel colonization at low to moderate densities in Christmas Lake.

Limiting Factors: Due to the low chlorophyll concentrations which are an indicator of algal abundance, it appears zebra mussels in Christmas Lake will be food limited and this may limit their overall abundance. Also, because there is very little oxygen below 40 feet of water depth, zebra mussels are not expected to be found deeper than 40 feet.

Figure 7. Shallow water substrate conditions in some parts of Christmas Lake. This type of substrate is optimal for growth.

Impacts of Zebra Mussels on Christmas Lake

- Water clarity should increase. Aquatic plant growth may increase because of the improved water clarity.

- Zebra mussel shells convert sandy substrate to shell gravel. Swimming areas will be impacted.

- Soft sediments will support clumps of mussels. The high density of clumps of mussels will excrete high nutrient waste products and likely produce filamentous algae on the lake bottom covering many acres.

- Fish spawning habitat will be covered with filamentous algae. Mussels will filter the water column and reduce the amount of edible algae. Zooplankton will decline and will impact the survival of young fish.

- Boats, docks, and lifts will have to be scraped annually. Boat servicing will be critical to avoid operating problems.

- Aquatic plants are not expected to be impacted, at least not initially. Growth of zebra mussels are expected to be food limited not space limited, so the likelihood of zebra mussels colonizing aquatic plants may be minor. However, if food is available, zebra mussels could colonize aquatic plants and this could adversely impact aquatic plant community structure.

Management Plan Summary

Because there is the potential for significant zebra mussel colonization in Christmas Lake, the recommended management option for Christmas Lake is Level 4 (out of 5 levels) - aggressive prevention and rapid response, with moderate aggressive control.

Table 5. Levels of action to consider for zebra mussel prevention, rapid response, and control in Christmas Lake. The recommended level of action is Level 4 (shown in blue shading).

	Prevention	Rapid Response	Control
Level 1	Use existing programs.	No rapid response.	Monitor only.
Level 2	Employ additional prevention programs.	No rapid response.	Monitor only.
Level 3	Employ additional prevention programs.	Conduct assessment	Small-scale control demonstrations.
Level 4	Employ additional prevention programs and work at a state level.	Conduct an enhanced assessment	Small-scale annual control in selected areas.
Level 5	Boat and trailer sterilization and then inspection.	Conduct assessments for the next 5 to 10 years	Eradication by lake drawdown if colonization is significantly changing the lake.

Figure 8. Zebra mussel metabolic activities will gather algae and discharge waste products to the bottom. Filamentous algae will develop from these nutrient sources. This has occurred in Lake Ossawinnanakee. At this time, the long term effects in Minnesota lakes is unknown. (photo by Steve McComas)

Zebra Mussel Management Plan Summary

Prevention - First Line of Defense. Employ the shield and containment strategy. For the "Shield" strategy add additional inspection hours at the Christmas Lake boat landings. Try to "shield" Christmas Lake from zebra mussels. Send out news releases at mussel spawning time (early to mid summer) to alert folks to be extra careful about transporting water from one lake to the next. For the "Containment" strategy encourage the MnDNR to increase inspections at major potential sources of zebra mussel experts, such as boats leaving Mille Lacs and Prior Lake. The idea is to contain the zebra mussel in infested systems and prevent new introductions to uninfested lakes and rivers.

Rapid Response - Second Line of Defense.

Scouting: Send a questionnaire to all lake residents asking them to inspect their boat lifts and docks on a routine basis. Have them contact the Christmas Lake Association if they see anything unusual.

Inventory: If zebra mussels are spotted and there are less than 10 growth centers documented after a thorough survey, then treat up to 1,600 m^2 per colonized area. If colonization sites exceed 10 growth centers, then go to the next line of defense, the control program.

Rapid Response Treatment: Use a tarp to cover an area of zebra mussel colonization. Inject either potassium chloride or chlorine under the tarp to kill the zebra mussels. Leave the tarp in place up to a month and then remove it from the lake.

Control Program - Third Line of Defense. If the Rapid Response effort is not successful, then a control program is the next line of defense. A high priority control area is mussel removal at swimming beaches. Zebra mussels will colonize in clumps of mussels about the size of tennis balls on top of sandy sediments (Figure 11). These mussels can be harvested. The next priority areas for control are at the two public boat landings. The next priority area for control after boat landings is spawning habitat around the lake.

Figure 9. On soft sediments, zebra mussels grow on top of shells forming clumps of zebra mussels. These can be harvested. (Photo by Steve McComas)

Prevention Details - First Line of Defense

Prevention is the critical component for keeping Christmas Lake free of zebra mussels. How much effort should be expended for prevention. For Christmas Lake, because of the potential for a zebra mussel infestation to produce significant problems in the lake fairly aggressive prevention efforts should be implemented. This includes extra inspection hours at public accesses, additional signage (like what is shown in Figure 10), and the distribution of informational and educational materials pertaining to the prevention of zebra mussels invading Christmas Lake.

Prevention Example: Shield Strategy Used for Lakes Without Zebra Mussels

NRM 8.2.79B

NRM 8.2.79C

NRM 8.2.79A

Figure 10. Several prevention techniques are recommended for Christmas Lake including the installation of new signs (shown above) at the four main access points to Christmas Lake. These signs are available through a grant program from the MnDNR.

Prevention Example: Containment Strategy for Lakes with Zebra Mussels

Figure 11. Signage and a disposal area for aquatic plants and zebra mussels at the public access to Lake Ossawinnamakee, Crow Wing County, MN. In the bottom photo, zebra mussels were found attached to aquatic plants that were deposited in the disposal box in October 2009. It is hoped that 100% of zebra mussels were removed from outgoing boats and trailers before heading to another lake. Containment strategies in lakes with zebra mussels could be stronger. It is recommended that the Christmas Lake members write letters of support to the MnDNR to implement more aggressive containment methods including more inspection of boat and trailers leaving the lake.

Rapid Response Protocol Details - Second Line of Defense

Because of the potential adverse impacts that zebra mussels could deliver to Christmas Lake, an aggressive rapid response plan is recommended. Rapid response measures have been formulated for plants and animals in other states (NEANS 2003) as well as for Minnesota (MISAC 2009). However, successful eradication of a non-native species with a rapid response has been challenging with only a few examples of success. Rapid response action has been attempted for zebra mussels in Lake George, New York (Wimbush et al. 2009). Although it was considered a success, Lake George had water column concentrations that were unsuitable for growth with a calcium concentration of 11.0 mg/l (Frischer et al. 2005). Although zebra mussels might not have done very well in Lake George in the long run, their basic rapid response approach may be applicable to waters with suboptimal growth conditions like Christmas Lake.

Zebra mussels are different then other non-native invaders like Eurasian watermilfoil. Zebra mussels monecious and only spread through sexual reproduction with gametes of male and females combining in the open water to create veligers. There is likely some critical threshold density necessary for a zebra mussel population to become established and then flourish. Maybe a rapid response before zebra mussels become established could eliminate a pioneer zebra mussel invasion in a lake. Still, the odds of eradication of a new infestation of zebra mussels are considered to be low. Because there is not much experience with a rapid response approach for zebra mussels in Minnesota, the Christmas Lake protocol would be a pilot program.

For a rapid response for Christmas Lake, a five step program is proposed:

1. Monthly zebra mussel checks (July-September) should be conducted at 10 sites around the lake. This could be a volunteer program. If zebra mussels are detected than there is a need for an immediate intensive inventory and then a rapid response treatment.

2. After an initial discovery of zebra mussels in Christmas Lake, a thorough shoreline survey and inventory should be conducted. All zebra mussel locations should be marked with GPS coordinates and with buoys.

3. If the inventory finds ten locations or less, with any individual area not exceeding 1,600 m^2 (40 m x 40 m) a rapid response control project should be implemented.

4. The rapid response control action has two components and is more aggressive than a control program (described in the next section).
    a. For vertical surfaces - scrape zebra mussels off hard surfaces with scrapers.
    b. For horizontal surfaces - remove zebra mussels that can be removed by hand from bottom substrates followed by coverage with a tarp with KCL or chlorine injected underneath the tarp. The tarp is kept in place for one month and then is removed.

    This should be done for three consecutive years. If zebra mussels are still present after that time, the rapid response program should be re-evaluated.

    If any area exceeds 40 m x 40 m or if colonization areas exceed 20 sites in year 2 or year 3, rapid response should be abandoned and small-scale control should be considered.

5. Meetings should be held with the MnDNR as soon as is practical in 2010 (and prior to zebra mussel detection) to determine specific treatment methods and permit requirements. A permit system is needed for a turn-around of 2 to 3 days.

The lead agency for coordinating the rapid response would most likely be the Christmas Lake Association. The zebra mussel inventory and rapid response treatments would most likely be contracted out. Cost for an inventory is estimated at $3,000. Costs for a rapid response treatment are estimated at $1,000 per site.

Control Program - Third Line of Defense

If a rapid response program is unsuccessful, an established population of zebra mussels in Christmas Lake will be attached to hard surfaces, soft surfaces, or possibly aquatic plants. A high priority area to manage for zebra mussel removal will be swimming beaches. Because the swimming area is mostly sand, zebra mussels will likely attach to each other and form clumps ranging in length of about 2 inches to 6 inches long and one to two inches in diameter. Examples of zebra mussel clumps are shown in Figure 12. These clumps can be picked up by divers or with the aid of hand-operated harvesting machines. Zebra mussel harvesters are in the design phase with the first prototypes being available in 2010 (being developed by Blue Water Science, St. Paul, MN).

Figure 12. Zebra mussels will be found on soft sediments, but will be attached and growing on each other. In soft sediments zebra mussel clumps can be picked up and removed from the lake.

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