Treatment options for the eradication of limited-scale zebra mussel infestations at various water temperatures

Introduction

Zebra mussels (*Dreissena polymorpha*) are small bivalve molluscs native to eastern Europe and are an invasive and notorious ecosystem-altering species in North America (Mackie and Claudi 2010, Benson 2018). Their high fecundity and free-swimming larval life stage allow for rapid dispersion (Birnbaum 2011, Benson 2018). As of May 2018, the Minnesota Department of Natural Resources listed 335 waterbodies in the state as infested due to either confirmed zebra mussel presence or connection to a waterbody with a confirmed presence (http://www.dnr.state.mn.us/invasives/ais/infested.html, accessed May 22, 2018).

Zebra mussels pose both an ecological and economical threat to invaded areas including Minnesota's waters. They have the potential to establish massive populations that attach to hard surfaces and foul raw water conveyance systems in water treatment and power generating plants (De Leon 2008), cause declines in native freshwater mussel and fish populations (Lucy et al. 2014) and restructure aquatic food webs (Higgins and Vander Zanden 2010). Zebra mussels' sharp shells cut swimmer's feet, they may encrust boat motors or hulls, and they may promote noxious algae blooms, negatively impacting recreation. In North America, they cause economic harm that has been conservatively reported in the tens of millions of dollars per year (Mackie & Claudi 2010).

Few zebra mussel eradications have been attempted in open-water environments. Several rapid response treatments to eradicate zebra mussels in Minnesota have been unsuccessful (Christmas Lake, Lake Independence, Lake Irene, Lake Minnewashta, and Ruth Lake). These unsuccessful attempts may have been due to chemical applications that were not appropriately timed, dosed, or mixed or due to errors in estimating the extent of the infestation.

These attempts may have failed for several reasons, including: 1) the dose of the molluscicides were insufficient to kill all the zebra mussels because of errors in estimating the toxicity of the molluscicides, 2) the molluscicide concentrations within the treatment area varied and some zebra mussels survived, and 3) the spatial extent of the zebra mussel infestation was not accurately defined, resulting in treatment areas that did not contain the entire zebra mussel population.

In the Midwest, including Minnesota, new zebra mussel infestations are often observed in late summer to autumn, when settled veligers have had time to increase in size and when recreational equipment is being removed from the water. During this time, water temperatures, which have been shown to influence the sensitivity of zebra mussels to toxicants (Costa 2008), can vary greatly. Having a greater understanding of the influence of water temperature on the sensitivity of zebra mussels to toxicants will help resource managers select the optimal toxicant, concentration, and exposure duration.

This document includes temperature-specific data about four molluscicides in order to inform the selection of an effective molluscicide and the proper dose that will induce 100% zebra mussel mortality.

Audience for this treatment guide

This guide is ideal for natural resource managers and agencies, watershed districts, lakeshore associations, aquatic invasive species consultants or other entities that are planning or associated with zebra mussel monitoring or with the extirpation of *newly established and localized zebra mussel populations*, particularly in a bay or small body of water. These guidelines and recommendations were developed for use by natural resource managers in Minnesota; however, the results are transferable to natural resource managers that have infested waters that have similar characteristics. These guidelines and recommendations are not a guarantee for zebra mussel eradication, as each circumstance is unique, and pros and cons must be weighed individually. Prior to planning or conducting any treatment, contact and obtain necessary permits from all relevant local, state, tribal, and federal agencies.

Considerations before treatment

Several steps must be taken prior to treatment. Treatment officials should engage with the public, establish the treatment area, select the right product, and obtain the appropriate permits.

1. Public engagement

Public water resources typically have high use, value, and visibility and, generally, a large number of stakeholders. Communication with relevant stakeholders and dissemination of information early in the decision-making process are critical for gaining support for an extirpation treatment. Additionally, there are often legal requirements to notify riparian landowners and to post the treated areas of public waters. Stakeholder group engagement can aid in the dissemination of information to riparian landowners and for gaining support for an extirpation treatment.

2. Establishing the treatment area

Before treatment can begin, it's crucial that the scope of the infestation is understood. An integrated sampling approach to determining the spatial extent of the infestation will provide the most reliable information. A sample scheme that integrates the use of plankton tows (at temperatures > 11°C) for identification of veligers and physical surveys using SCUBA divers, snorkeling, and/or wading may provide multiple detection techniques to define the spatial extent and reproductive status of a zebra mussel infestation.

If treating a bay or other small area within a lake, the area will need to be hydrologically isolated before treatment. For example, managers at Christmas Lake in Minnesota used a vinyl turbidity curtain to hydrologically separate the treated area (Lund et al 2017) and researchers at Lake Minnetonka in Minnesota used similar barriers (Figure 1) when treating veligers.

Figure 1: Floating vinyl curtain membrane used to contain treatment area

3. Selecting a product

This guide covers four molluscicides: Zequanox, EarthTec QZ, potassium chloride (potash) and Niclosamide. More information about each toxicant is below.

Product	How it works	Registration status	Potential pros	Potential cons
Zequanox®	Killed-cell bacteria that causes death by necrosis of the digestive system after ingestion as food particles	Registered by U.S. EPA as molluscicide for zebra and quagga mussel control	Few reported impacts to non-target species	As currently formulated and as tested under our laboratory conditions, Zequanox is not able to consistently achieve complete zebra mussel mortality
EarthTec QZ®	Copper-based molluscicide that interferes with cellular respiration and ciliary activity of gill tissues	Registered by U.S. EPA as molluscicide for zebra and quagga mussel control	Should be considered for urgent treatments because permitting requirements are easier	Copper could be harmful to non-target species and copper will accumulate in the sediment over time with repeated applications
Potassium chloride (potash)	Potassium interferes with the epithelial cell function by impairing cell volume regulation and vacuolation	Not registered by U.S. EPA as a molluscicide; has a history of being used in zebra mussel treatment efforts	Non-mollusk species appear unaffected at concentrations effective for zebra mussels at temperatures equal to or greater than 12°C with exposure durations ranging from 96 to 336 hours	Not recommended at temperatures less than 12°C
Niclosamide	Niclosamide interferes with cellular respiration	Not registered by U.S. EPA as a molluscicide; however it is registered to kill sea lamprey. Products containing Niclosamide are also used for snail control in tropical areas	Toxic at low doses and over a wider range of temperatures	Would likely cause substantial non-target animal mortality at the minimum lethal concentrations required to induce 100% mortality

4. Getting your permits

Permit requirements vary by state and municipality. In Minnesota, the Department of Natural Resources has the authority to permit pilot projects to kill zebra mussels in public waters. Zequanox and copper products are EPA-registered for use in controlling zebra mussels in open waters; however, additional state or local registrations and/or permits will likely be required. Niclosamide is EPA-registered for use as an aquatic pesticide; therefore, it would potentially qualify for a Section 24(c) Special Local Needs permit from the State. Potassium chloride (potash) is not EPA-registered for use in aquatic systems; therefore, a Section 18 emergency exemption or an experiment use permit would be required.

Aquatic pesticide applications must be completed by a licensed applicator. State specific permit requirements vary depending on what molluscicide is used, how and where the molluscicide is applied, and the non-target species composition. It is the responsibility of the applicator to assure that all appropriate permits and licenses are acquired prior to application.

Temperature and duration table for each product

Minimum lethal dose of toxicants required to induce 100% zebra mussel mortality at specific water temperatures are listed below. Note that the exposure duration for Zequanox differs from durations for the other three toxicants.

Notes:
> indicates that observed mortality was >90% and <100% at the specific concentration
NE indicates that the treatment was deemed not effective; observed mortality was ≤ 90%.
* indicates a nominal concentration

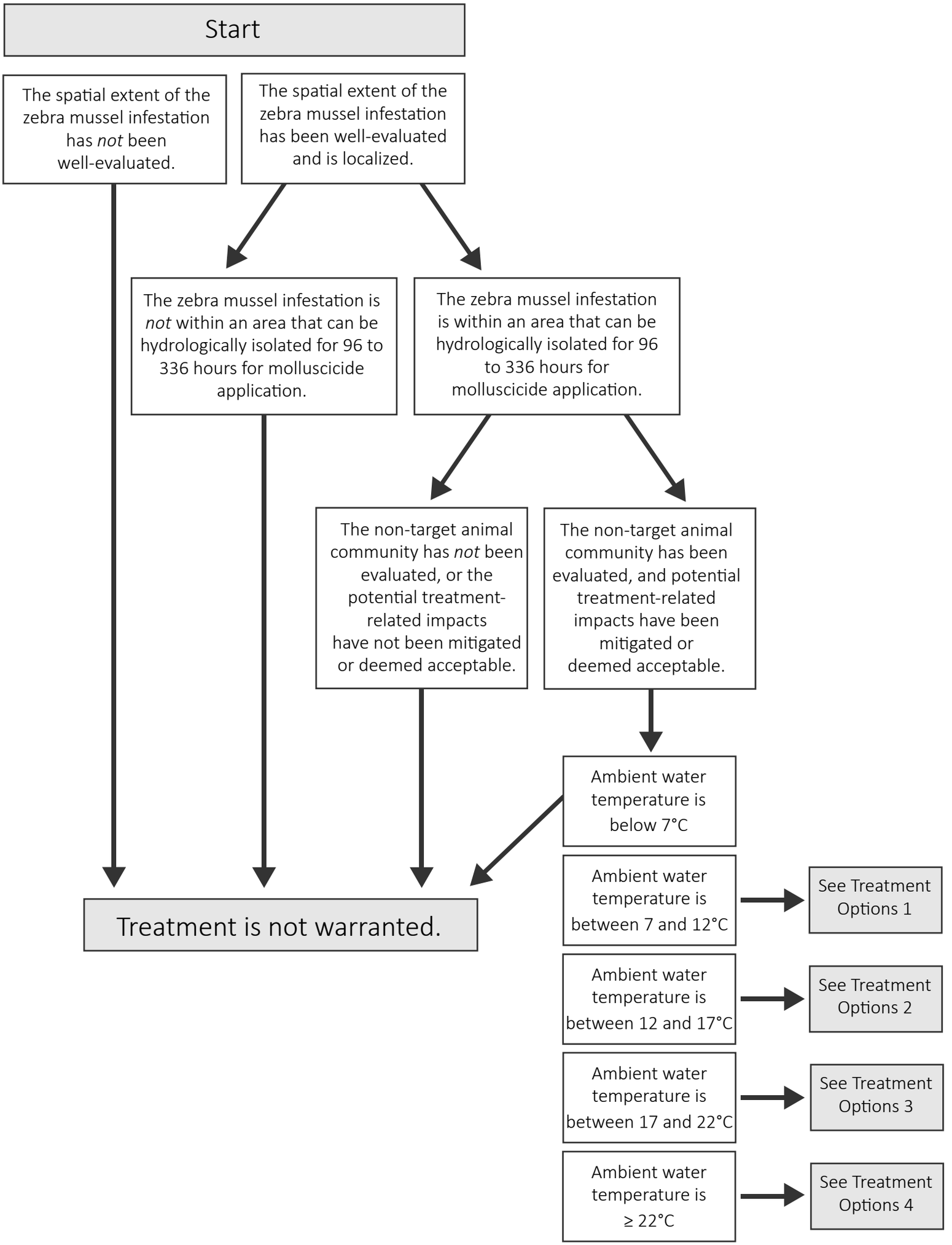
Temp (°C)	Exposure duration (h)	EarthTec QZ (mg/L)	Niclosamide (mg/L)	Potassium chloride (mg/L)	Exposure duration (h)	Zequanox (mg/L)
7	24 96 336	NE >58.8 11.3	>0.552 >0.189 0.054	NE NE >586	8 12 24	NE NE NE
12	24 96 336	>150.4 25.5 4.5	0.182 0.066 0.053	NE NE 165	8 12 24	NE NE NE
17	24 96 336	>47.6 9.5 2.0	>0.200* 0.100* 0.075*	>2,071 422 147	8 12 24	NE NE >323
22	24 96 336	>49.6 21.5 5.8	0.181 0.137 >0.092	>3,066 220 125	8 12 24	NE >315 >310

Treatment guide

This guide uses a dichotomous key to help managers select treatment options that may be effective for zebra mussel extirpation. The following step-by-step guide will end with recommended treatments that may be effective for zebra mussel extirpation, or with the recommendation of no available treatment.

Due to variations in sensitivity observed in the laboratory bioassays, molluscicide concentration recommendations are the greater of the minimum lethal concentration observed at the warmest temperature tested (22 °C) or the minimum lethal concentration observed at that particular temperature of interest (i.e. 7, 12, or 17 °C). EarthTec QZ treatments are listed as concentrations of product (w/v) and EarthTec QZ treatment recommendations in *italics* are equal to or less than the maximum active ingredient (copper) concentration allowed by the product label (1.0 mg/L of copper, including background).

All instructions on the product label must be followed. Treatment concentrations should be monitored at least daily and bump applications may be required to maintain treatment concentrations. The frequency of bump applications and amount of molluscicide that must be applied during the bump applications will be dependent on site specific parameters (aquatic vegetation, suspended solids, water chemistry, etc.) that may influence the bioavailability of the molluscicide.


Start
The spatial extent of the zebra mussel infestation has *not* been well-evaluated.
The spatial extent of the zebra mussel infestation has been well-evaluated and is localized.
The zebra mussel infestation is *not* within an area that can be hydrologically isolated for 96 to 336 hours for molluscicide application.
The zebra mussel infestation is within an area that can be hydrologically isolated for 96 to 336 hours for molluscicide application.
The non-target animal community has *not* been evaluated, or the potential treatment-related impacts have not been mitigated or deemed acceptable.
The non-target animal community has been evaluated, and potential treatment-related impacts have been mitigated or deemed acceptable.
Ambient water temperature is below 7°C
Ambient water temperature is between 7 and 12°C
See Treatment Options 1
Ambient water temperature is between 12 and 17°C
See Treatment Options 2
Ambient water temperature is between 17 and 22°C
See Treatment Options 3
Ambient water temperature is ≥ 22°C
See Treatment Options 4
Treatment is not warranted.

Treatment options

1

Treatment options, scenario 1:

- EarthTec QZ: *12.0 mg/L* for 336 hours
- Niclosamide: 0.06 mg/L for 336 hours

2

Treatment options, scenario 2:

- EarthTec QZ: 26.0 mg/L for 96 hours or *6.0 mg/L* for 336 hours
- Niclosamide: 0.10 mg/L for 336 hours or 0.14 mg/L for 96 hours or 0.20 mg/L for 24 hours
- Potassium chloride: 165 mg/L for 336 hours

3

Treatment options, scenario 3:

- EarthTec QZ: *20.0 mg/L* for 96 hours or *6.0 mg/L* for 336 hours
- Niclosamide: 0.10 mg/L for 336 hours or 0.14 mg/L for 96 hours or 0.20 mg/L for 24 hours
- Potassium chloride: 150 mg/L for 336 hours

4

Treatment options, scenario 4:

- EarthTec QZ: *20.0 mg/L* for 96 hours or *6.0 mg/L* for 336 hours
- Niclosamide: 0.10 mg/L for 336 hours or 0.14 mg/L for 96 hours or 0.20 mg/L for 24 hours
- Potassium chloride: 125 mg/L for 336 hours or 220 mg/L for 96 hours

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For more information and details on the methods used to inform these recommendations, please see:

Luoma J., Severson T., Barbour M., and Wise J. (2018). Effects of temperature and exposure duration on four potential rapid response tools for zebra mussel (*Dreissena polymorpha*) eradication. *Management of Biological Invasions*, 9(3).

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For more information about the control and management of aquatic invasive species, please visit www.MAISRC.umn.edu.

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