

ZEBRA and QUAGGA Mussel Early Detection and Rapid Response Plan for British Columbia



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IMISWG

Inter-Ministry Invasive Species Working Group

BRITISH COLUMBIA

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EXECUTIVE SUMMARY

Since their introduction to the Laurentian Great Lakes in the 1980's, both zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*) have spread across North America, including south western US and Manitoba in recent years. The risk posed to the Provinces of British Columbia, Alberta, Saskatchewan, and the States of Washington, Idaho, Montana, Oregon and Wyoming by the proximity of these new infestations is significant. This plan was developed in response to the increasing likelihood of the successful transport and introduction of Dreissenid mussels into the Province of BC and the PNW. Although prevention remains the most cost-effective means of addressing potential new infestations of aquatic invasive species, if prevention efforts fail, the Province of BC must be prepared to respond rapidly and effectively to minimize environmental and economic impacts and reduce the risk of spread.

The purpose of this plan is to identify prevention and contingency efforts to protect BC's waters, aquatic resources, and facilities from the deleterious effects of zebra and quagga mussel establishment. The potential economic, social and ecological consequences associated with Dreissenid mussel introduction into BC is summarized in the provincial risk assessment. The threat posed by Dreissenid mussels entering BC via transit on a watercraft or equipment is discussed in a separate section of this plan, as it is a crucial first step for preventing their introduction into BC. In the event of a Dreissenid mussel infestation in BC waters, the third section of this plan provides guidance for natural resource managers to plan for and implement a rapid response effort. This plan applies to all Dreissenid mussel species, although the current focus is on zebra and quagga mussels (ZQM), many of the strategies listed herein can be applied to rapid response efforts for other Aquatic Invasive Species (AIS) of concern.

Early Detection and Rapid Response (EDRR) is widely accepted as the most cost-effective means for controlling invasive species. This process aims to find, identify and systematically eradicate, contain or control new infestations of invasive species before they can reproduce and disperse beyond their point of entry. Implementing an EDRR program specific to zebra and quagga mussels, in conjunction with the BC general invasive species EDRR program, increases the likelihood that new incursions will be discovered and eradicated before they become widely established in the province. The BC Zebra and Quagga Mussel EDRR Plan (or BC ZQM EDRR plan) is designed to complement international and federal initiatives and commitments like the *Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and Other Dreissenid Species* drafted by the Columbia River Basin 100th Meridian Team or the *Fisheries and Oceans Canada (DFO) AIS EDRR plan* (Locke et al. 2011). As well as provide stand-alone guidance in the event that Dreissenid mussels are found in BC. The BC ZQM EDRR functions under the framework set by the BC Invasive Species EDRR.

The BC ZQM EDRR plan consists of several steps including early detection, identification, rapid response, and monitor and reassess. This Plan describes potential participants and their roles and responsibilities. Immediate eradication is the primary goal for rapid response, but containment, or a long-term strategy to achieve eradication, may be necessary if Dreissenid mussels are found in large lake or river systems. Rapid response will employ sound procedures to achieve specific objectives for managing Dreissenid

mussels while minimizing adverse effects on economic, social and environmental values. Dreissenid mussels require an immediate incident response because of their potential threat to aquatic ecosystems, their rapid rate and mode of spread, and commitments that BC has established through international agreements.

1 EARLY DETECTION AND RAPID RESPONSE

The *British Columbia Zebra and Quagga Mussel Early Detection and Rapid Response Plan* (ZQM EDRR Plan) has been developed to prepare the province and any partners potentially involved in the event of a zebra, quagga or other Dreissenid mussel introduction into British Columbia (BC). Considering the recent invasion of zebra mussels into Lake Winnipeg in 2013, the risk of a Dreissenid mussel introduction into Western Canada has further increased, and the development of the ZQM EDRR plan is part of the overall zebra and quagga mussel Provincial management approach. The purpose of this plan is to clearly identify the roles and responsibilities of different levels of government and stakeholders and how they may be involved in a ZQM rapid response, as well as the potential eradication, containment and monitoring procedures.

Early Detection and Rapid Response (EDRR) is widely accepted as one of the most cost-effective control methods for preventing the spread of invasive species. Development of EDRR plans for high-risk invasive species is a priority, and subsequent rapid response exercises increase the likelihood that new incursions will be discovered and eradicated before they become widely established in the province. The ZQM EDRR Plan follows the template of the BC Invasive Species Early Detection and Rapid Response Plan (BC EDRR Plan), and is structured around six steps and processes for dealing with the introduction of ZQM into BC (Figure 1). These steps describe the operational components of a successful EDRR program for discovering, identifying, evaluating risk, treating, and monitoring the introduction and treatment of new ZQM incursions.

The ZQM EDRR plan has been separated into two sections; Section 1.3 focuses on the interception of boats/equipment potentially infested with ZQM from entering BC, as prevention is a crucial first step for ZQM management. Section 1.2 provides detail on EDRR program elements specific to a ZQM infestation into BC waters, with immediate eradication being the primary goal, but containment or a long-term strategy may be required depending on the size and location of the infested waterbody.

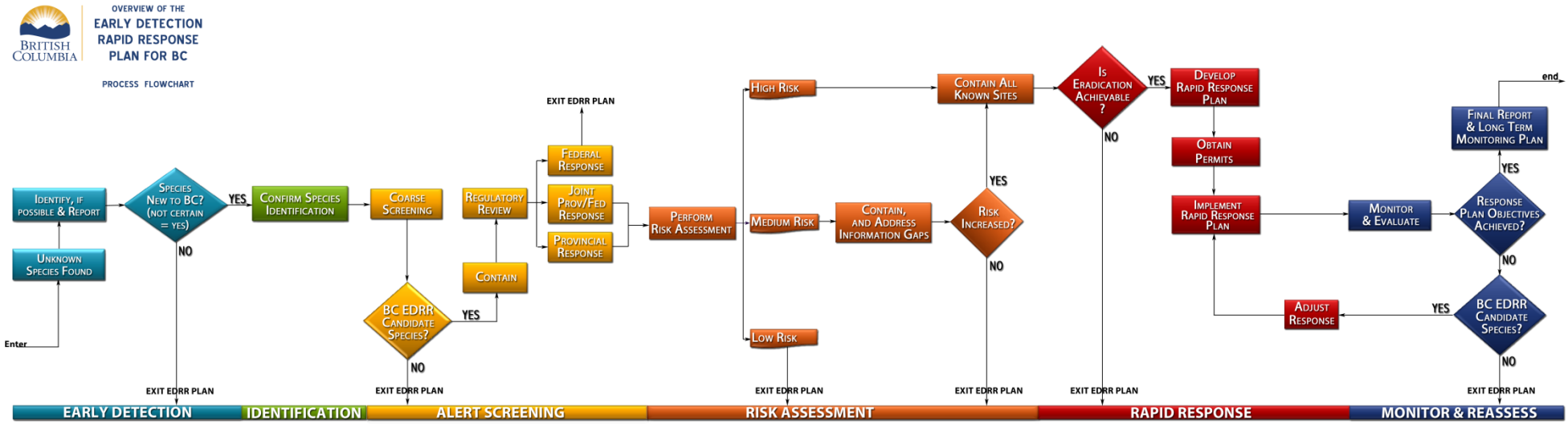

Figure 1 – Overview of the BC Invasive Species Early Detection and Rapid Response Plan

1.1 Roles and Responsibilities

Clearly defined roles and responsibilities are essential for effective program delivery. Key participants to the ZQM EDRR plan and their roles in the process are summarized below (Table 1). Specific responsibilities for each participant are also found under each step of the rapid response plan in Sections 1.1 and 1.2.

Table 1 – Roles of principal agencies and participants in the ZQM EDRR plan

Participant(s)	Role
Inter-Ministry Invasive Species Working Group (IMISWG)	Reports to the IMISWG Assistant Deputy Minister's Committee (Executive Sponsor). Provides provincial leadership, policy direction, and collaborative approaches to preventing invasive Dreissenid mussels from establishing in BC.
EDRR Advisory Committee	Reports to the IMISWG. Provides direction and decision-making on planning, delivery, monitoring, and reporting of ZQM EDRR activities
Provincial ZQM EDRR Coordinator/Aquatic Invasive Species Specialist	The Aquatic Invasive Species Specialist will be the Provincial ZQM EDRR Coordinator. The Coordinator supports the EDRR Advisory Committee and is responsible for planning, implementing, and reporting on all aspects of the Provincial ZQM EDRR plan.
Provincial Ministries and Government Employees (e.g., Ministry of Environment, Ministry of Forests, Lands and Natural Resource Operations (FLNR), Ministry of Health, Ministry of Transportation and Infrastructure, Ministry of Agriculture, BC Parks)	The Provincial government will be involved in the ZQM rapid response for any incursion event occurring in BC. The Provincial government will also serve as the sole media contact for any ZQM incursion events in BC.
First Nations	If the incursion event occurs in traditional territories and/or are part of treaty agreements/negotiations, First Nations will be involved in surveying and reporting of new potential invasive Dreissenid mussels to the Provincial ZQM EDRR Coordinator.
Federal Government Fisheries and Oceans Canada (DFO)	If the incursion event occurs in a waterbody which contains anadromous species or Species At Risk, federal government agencies will be alerted and may identify and coordinate rapid response actions with the Provincial ZQM EDRR Coordinator.
Federal Government Environment Canada and Health Canada (Pest Management Regulatory Agency-PMRA).	If a federal emergency registration or research trial permits needs to be pursued for the use of a molluscicides, federal government (PMRA) will be the permitting authority.
Federal Government Canadian Border Services Agency (CBSA),	If Federal AIS legislation comes into place the CBSA will collaborate with the Province and notify the Provincial ZQM EDRR Coordinator when a high-risk watercraft crosses the border.
Federal Government Parks Canada	If the incursion event occurs in a National Park, federal government agencies may identify and coordinate rapid response actions with the Provincial ZQM EDRR Coordinator.
Trans-boundary Agencies (e.g., Columbia River Basin team)	Liaises with the Provincial ZQM EDRR Coordinator regarding ZQM rapid response actions in the Columbia River Watershed.
Local Government (e.g., municipal government and regional districts)	If an incursion event occurs in a regional park or other waterbody within local government jurisdiction then local government may be involved in the monitoring and response.
Major water license holders (Hydropower Companies, Municipal water supplies, Agricultural Irrigation)	If an incursion event occurs upstream or downstream of dams and/or reservoirs, or other major water extraction infrastructure, water license holders may identify and coordinate rapid response actions with the Provincial ZQM EDRR Coordinator.
Subject Matter Expert(s) (e.g., government employees, universities, laboratories in the Pacific Northwest)	Provides expertise on Dreissenid mussel identification and/or provides laboratory testing of veliger samples.

Participant(s)	Role
Royal BC Museum (Taxonomic Group Curators)	Provides taxonomic expertise for identifying and verifying unknown species and serves as the repository for voucher specimens.
Rapid Response Team	Core team members may include the Provincial ZQM EDRR Coordinator, subject matter experts, Provincial staff/contractors, the Private Land Owner/Occupier, First Nations, and the Regional Invasive Species Organization.
Private Land Owner(s)	Reports any new potential Dreissenid mussel incursion events to the Provincial ZQM EDRR Coordinator.
Observer(s) (e.g., Trained spotters, government employees, regional invasive species organizations, consultants, public)	Reports any new potential Dreissenid mussel incursion events to the Provincial ZQM EDRR Coordinator.
Invasive Species Council of BC (Non-government organization)	May provide communication and extension services, as requested by the Provincial ZQM EDRR Coordinator.
Regional Invasive Species Organizations (e.g., Regional invasive species committees and councils, , stewardship groups)	Reports any new potential Dreissenid mussel incursion events to the Provincial ZQM EDRR Coordinator.

1.2 Invasive Mussel EDRR Plans in the Pacific Northwest

ZQM EDRR Multi-Agency Coordination

Depending on the location of an incursion event, the ZQM EDRR Plan will be relevant to one or more of the following groups: provincial and federal government, First Nations, local governments, non-government agencies, and/or private landowners. Both the Columbia River Basin (CRB) Multi-Agency Coordination Group and Fisheries and Oceans Canada (DFO) Pacific Region will be alerted of any ZQM incursion events in BC and each of these agencies could initiate their own EDRR plans, in addition to the ZQM EDRR Plan. Figure 2 provides a flow chart comparison of the steps involved for the different EDRR plans in the Pacific Northwest. The ZQM EDRR plan will take effect if the mussels are identified as a Dreissenid species and are present anywhere within the province of BC. If zebra and/or quagga mussels are detected in the Columbia River Basin watershed, the CRB EDRR plan will also take effect. If there are aquatic Species at Risk or anadromous fish species present in the waterbody, the DFO AIS EDRR plan may also take effect. Therefore, one to three different EDRR plans may be initiated simultaneously and will require ongoing coordination between agencies to ensure efforts aren't duplicated and outreach/communication to the public remains accurate and consistent.

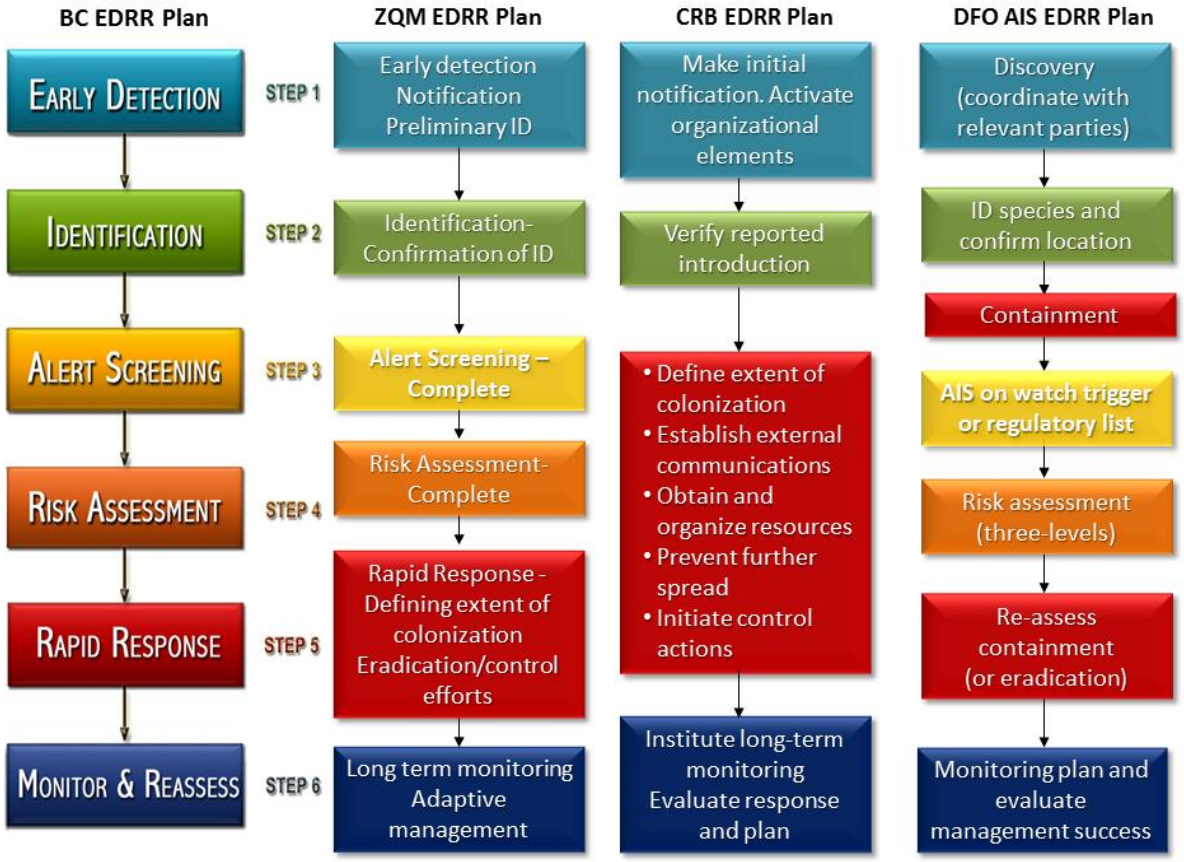

Figure 2 – Flow chart comparing the BC EDRR plan, the ZQM EDRR plan, the CRB EDRR plan and the DFO AIS EDRR plan. The steps in each plan have been colour coded to correspond to the steps in the BC Provincial EDRR plan.

COLUMBIA RIVER BASIN PLAN

BC is a signatory on the 100th Meridian Initiative's Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and other *Dreissena spp*. (Figure 2and Appendix 3; Heimowitz and Phillips 2008). The Columbia River Basin rapid response plan for Dreissenid mussels includes all jurisdictions in the watershed (British Columbia, Washington, Oregon, Idaho, Montana, US First Nations and US federal government agencies). The plan is activated through the US Fish and Wildlife reporting system and the Columbia River Basin (CRB) Notification Coordinator. After receiving a report of a potential infestation, the first step is to make initial notifications, to ensure that all interested parties are informed and engaged. Depending on the size, location and life-stage of the infestation, elements of the response management system will be activated, to share information and resources and support the management of the infestation. Mussel identification can take place through visual identification at the site or by visual and genetic identification of a sample, by an expert. Once identified, the physical range and life cycle phase of the mussels will need to be defined, to inform the response. An external communications

system will be established, and sufficient resources to implement the response objectives will be obtained and organized. Any further spread of the invasive mussels will be prevented through quarantine and pathway management. Different management options will then be evaluated, to determine whether eradication or containment efforts will be initiated. Long-term monitoring will be undertaken; so that both the actual response and the response plan itself can be evaluated for effectiveness and future activations.

Fisheries and Oceans Canada (DFO) EDRR Plan

Fisheries and Oceans Canada (DFO) has a Rapid Response Framework (DFO AIS EDRR plan) for dealing with aquatic invasive species (Figure 2 and Appendix 4; Locke et al. 2011). The discovery of an aquatic invasive species, such as zebra and quagga mussels, is communicated through an established network so that a response plan can be initiated. Notifications should be sent to the **DFO AIS Response Line 1-888-356-7525 and email address (AISPACIFIC@dfo-mpo.gc.ca).** While identification is being verified, the potential for containment is determined. Surveys of the area will be undertaken to determine the spatial extent of the species. Once the invasive mussel species have been positively identified, it will be necessary to determine what containment options are available and whether any of them are feasible. Management options could involve eradication, containment, mitigation, monitoring or no response, with eradication being the first choice, if possible. The effectiveness of the action taken will then be evaluated. This plan was the basis for the rapid response for the zebra mussel introduction into Lake Winnipeg in 2013-2014.

British Columbia Invasive Species EDRR Plan

The *BC Invasive Species Early Detection and Rapid Response Plan (BC EDRR Plan)* has been developed by the Inter-Ministry Invasive Species Working Group (IMISWG) to serve as a template applicable to any invasive species discovered in BC (see Figure 1 for overview of the steps in the BC EDRR Plan and Appendix 5 for the full plan). The ZQM EDRR plan presented here builds on the BC Invasive Species EDRR Plan template and provides information specific to zebra and quagga mussels. In the case of invasive Dreissenid mussels, the risk to BC has been determined to be high (see Section 2), and therefore the Rapid Response step would be activated, with eradication as the main goal. It will then be necessary to implement a response plan followed by surveys to monitor the efficacy of the rapid response. Long-term monitoring and reassessments will determine whether the objectives of the response plan are being achieved or whether the plan needs to be updated or revised.

1.3 ZEBRA AND QUAGGA MUSSEL EDRR (WATERCRAFT INTERCEPTION)

Human assisted dispersal of Dreissenid mussels attached to a watercraft and/or equipment is a high risk for their introduction into BC and this section outlines the necessary steps in the event that a Dreissenid infested watercraft and/or equipment enters BC. While responding to an invasive species prior to its introduction into a natural habitat is not what is considered part of EDRR, it is an important part of the prevention of zebra and quagga mussel introduction into BC. In the case of Dreissenid mussels detected on a watercraft or other equipment prior to entering BC, the established procedures under the *Controlled Alien Species* regulation (the 'CAS Regulation') will be applied to assess the watercraft or equipment. Decontamination and/or quarantine measures will then be conducted as needed. Additionally, if a lake within BC is suspected or confirmed to be infested with zebra and/or quagga mussels, any watercraft leaving that waterbody will also have to be inspected and potentially decontaminated (see Section 1.2 for the EDRR steps in the event of a ZQM infestation into BC waters).

1.3.1 AUTHORITY FOR WATERCRAFT INTERCEPTION

1.3.1.1 Provincial Legislation

Legal authority to take immediate action on Zebra, quagga and Conrad's false mussel is vested through provincial and federal legislation. The BC Wildlife Act, Controlled Alien Species Regulation is the principle legislation that defines, lists, and affords provisions to regulate mussels in BC (Controlled Alien Species Regulation).

Under the CAS Regulation the following prohibitions will apply in relation to any mussel listed in Schedule 4. It will be illegal for a person to:

- possess, breed, ship or transport prohibited mussels;
- release prohibited mussels into BC waters, and
- allow a prohibited mussel to be released or escape into BC waters.

One exemption is dead mussels used for displayed purposes that are embedded in resin.

In order to stop and inspect a watercraft or equipment, or exercise powers under the CAS regulation a person must be designated as an Officer under the *Wildlife Act*, which is defined as:

(a) a constable, a conservation officer, the director, an assistant director or a regional manager,
(a.1) subject to subsection (3), a park ranger appointed under the Park Act, or
(b) an employee of the government designated by name or position as an officer, by regulation of the minister;

There are important distinctions when it comes to the exercise of powers for '**Officers'** and **'Conservation Officers'** under the *Wildlife Act*. In some instances, only Conservation

Officers are allowed to exercise the powers, whereas the other powers can be exercised by an officer, which (as shown above) is defined broadly and can include government employees. Table 2 shows the differences between the exercise of powers for 'Officers' and 'Conservation Officers'.

Table 2 – Distinctions between powers of Officers and Conservation Officers as defined under the *Wildlife Act*

Powers	Provincial Legislation	Officer *	Conservation Officer
Stop motor vehicles or boats to question a person about any mussels that the person may possess.	Section 95(1) of the *Wildlife Act*	✓	✓
Visually inspect a boat or water equipment for signs of mussel contamination.	Section 9(2)(a) of the CAS Regulation	✓	✓
Determine if the boat or water equipment is owned, or is registered, licensed, insured or otherwise authorized to be possessed or operated, in a contaminated province or state.	Section 9(2)(b) of the CAS Regulation	✓	✓
Seek information as to whether the boat or water equipment has been operated in or may have been in contact with waters from province or state listed in Schedule 5 of the CAS Regulation.	Section 9(2)(c) of the CAS Regulation	✓	✓
Seek information as to whether a person is in violation of the prohibitions related to mussels under the Act and CAS Regulation.	Section 9(2)(d) of the CAS Regulation	✓	✓
Issue a decontamination order with respect to invasive Dreissenid mussels.	Section 9(3) of the CAS Regulation	✓	✓
To stop and search a motor vehicle or boat without a search warrant if there are reasonable grounds that a person is carrying prohibited mussels.	Section 93(b) of the *Wildlife Act*		✓
Seize CAS species that are illegal to possess.	Section 94(1) of the *Wildlife Act*		✓
If CAS species are found, then seizure of equipment, if there are reasonable grounds to suspect that the equipment was used in connection with a prohibition for mussels.	Section 94(1)(b) of the *Wildlife Act*		✓
If mussels are seized under the *Wildlife Act* and the CAS Regulation, the power to immediately dispose of mussels (dead or alive) as directed by the Minister.	Section 9.1 of the CAS Regulation which applies section 97.3 of the *Wildlife Act*		✓

1.3.1.2 Decontamination Order

CAS Regulation Part 3, Section 9 explains the "decontamination order" with respect to Dreissenid mussels. The person owning or operating the watercraft or equipment is required to comply with instructions for adequate decontamination. Failing to comply with a decontamination order is an offence under the *Wildlife Act and* CAS Regulation.

1.3.1.3 Federal Legislation

Molluscs are included under the definition of "fish" in the federal *Fisheries Act*. Several amendments to the federal *Fisheries Act* regulations were proposed in 2012 to manage invasive species in all Canadian waters (Canada 2012). Although none of the proposed changes have passed into legislation as of 2014, those most pertinent to BC include:

- Establishing a list of prohibited aquatic invasive species, including zebra and quagga mussels, from importation, possession, transport; and
- Simplified process to conduct control and eradicate invasive species in the aquatic environment.

Once the federal legislation comes into effect, the ZQM EDRR Plan will be updated accordingly.

1.3.2 Step 1. Early Detection

Zebra and quagga mussels attached to a watercraft en-route to BC may be intercepted by having trained personnel conduct visual inspections at selected locations along highways/roadways, provincial and international border crossings or at boat ramps. Public outreach and education on Clean, Drain and Dry is critical for prevention of ZQM entering BC via boats in transit. Neighboring jurisdictions will notify BC if they intercept a high-risk boat destined for BC. The Provincial ZQM EDRR Coordinator will receive notifications through several different sources including;

- the Conservation Officer Services Hotline: 1-877-952-7277 and/or the reportinvasives.ca website,
- the West911 webserver (from US jurisdictions),
- large commercial vehicle permits,
- Canadian Border Service Agency staff will call if they observe an infested boat entering BC.

Within BC the aim is that anybody who might see mussels being transported, or anybody having concerned about potentially transporting zebra or quagga mussels will contact the **Conservation Officer Services Hotline** so the boat can be assessed. For active surveillance, personnel trained in watercraft inspections conduct interviews and visual inspections at selected locations including borders, roadside stations or at boat ramps.

TIMELINE

The Provincial ZQM EDRR coordinator will be notified immediately of any reported ZQM incursion events into BC. Observers are urged to report new invasive mussels as soon as possible.

1.3.2.1 Responsibility Summary

Provincial ZQM EDRR Coordinator

- Responds to reports as soon as possible.
- Informs local officers/Conservation Officers as soon as possible, if required.

Provincial Reporting Line

- Collects information and passes it on to local officers/Conservation Officers and the Provincial ZQM EDRR Coordinator.

Officers and Conservation Officer Services

- Informed of reports from the **Conservation Officer Services Hotline** and the Provincial ZQM EDRR Coordinator.

Watercraft Owner/Hauler

- Complies with officers during watercraft/equipment inspections.

1.3.3 STEP 2. IDENTIFICATION

The identification step for a watercraft or equipment potentially infested with zebra or quagga mussel faces particular challenges, given the short timelines involved. In particular for a commercially hauled watercraft, decisions have to be made immediately based on the best available information, as delays will directly impact their business operations. Additionally, in the case of a boat potentially carrying raw water contaminated with microscopic mussel larvae, decisions will have to be made based on the potential presence of mussel larvae, as available detection methods cannot provide definite answers in the timescale required. Also obtaining independent secondary confirmation of species ID is often not feasible within a short timeframe.

TIMELINE

The timeline for identifying potential Dreissenid mussels on a watercraft may occur immediately or take up to 12 hours depending on the timing of the incursion report and available resources.

Table 3 – Identification outcomes and actions

Identification Outcomes	Actions
1. **Specimen not identified as zebra or quagga mussel**	• For non-regulated invasive species, encourage owner to decontaminate, for native species encourage Clean, Drain and Dry.
2. **Specimen is identified as zebra or quagga mussel**	• Continue to Step 4. Watercraft Risk Assessment.
3. **The species could not be identified**	• Obtain specimen and work with taxonomic experts to identify species as soon as possible. The watercraft is prevented from entering BC waters until species identification is confirmed.

1.3.3.1 Responsibility Summary

Provincial ZQM EDRR Coordinator

- Gathers information from all potential sources, observers, officers, agencies outside BC, haulers, source and destination marinas/storage facilities.
- Obtains samples or high quality photos of suspected zebra and/or quagga mussels.
- Determine if any fouling is likely to be caused by a potential zebra and/or quagga mussel infestation.
- Provides input, as requested, to officers potentially involved at this stage.
- Makes the decision if the Conservation Officer Services needs to be engaged in the process, if not already involved.
- Acts as the sole media contact during the EDRR process to ensure that all information distributed to the public is accurate.

Officers and/or Conservation Officer Services

- Receives training on zebra and quagga mussel identification for watercraft inspections.
- Conservation Officers are engaged if watercraft inspections are required.

Watercraft Owner/Hauler

- Available for officers and the Provincial ZQM EDRR Coordinator to provide additional information, as requested.

1.3.4 Step 3. Alert Screening

Alert screening evaluates the status and likely risk of a new invasive species in BC to determine if it is a candidate for a risk assessment and/or a rapid response. Zebra and quagga mussels have already been determined to pose a significant ecological and economic risk to the Province of BC (see Section 2.0) and are controlled through the provincial *Controlled Alien Species Regulation*, thereby bypassing the need for this alert screening step.

1.3.5 Step 4. Watercraft Risk Assessments

This step is modified from the process laid out in the BC Invasive Species EDRR plan. The provincial Risk Assessment for zebra and quagga mussels has been completed and can be found in Section.2.0 of this document. Instead this section explains how the risk of zebra and/or quagga mussel infestation for an individual watercraft can be assessed. The assessment process is closely modeled after the Uniform Minimum Protocols and Standards for Watercraft Interception Programs for Dreissenid mussels in the Western United States (Zook and Phillips 2012 and Appendix 2). Any watercraft or equipment must be assessed for the presence of both live and dead zebra and/or quagga mussels, as they are both prohibited in BC under the *Controlled Alien Species Regulation*.

High Risk Watercraft/Equipment

Any watercraft or equipment that has been in any province/ state known or suspected of having zebra or quagga mussels in the past 30 days; or any watercraft or equipment that has recently visited (<90 days) a state / province that is infested with zebra or quagga mussels and is not clean, and to the extent practical, has not been drained and dried. Figure 2 illustrates the Watercraft Decision Flowchart and the blue boxes show the key questions for determining the watercraft risk level, and the orange, and red boxes represent a high-risk watercraft.

As laid out in the Watercraft Decision Flowchart (Figure 2) boats or equipment that have been out of the water for over 30 days still need to be decontaminated, if live or dead mussels, or any standing water or damp areas are found during inspection. The same rationale also applies to high risk vessels that have been found to have live mussels attached which are then decontaminated and quarantined for 30 days. The reason for the re-inspection at the end of the quarantine is that while decontamination will kill all mussels it will not remove all shells especially from through hull fittings and other protected spaces.

The reasoning for decontaminating these vessels is two-fold, first the decontamination acts as an additional insurance that all mussels, or their larvae are definitely dead. Additionally the decontamination will remove the majority of visible mussel shells, which will even stay attached after the death of the organisms. If these shells would be left attached they most likely would then fall off when the boat is used next in a waterbody. These shells could be found by someone and trigger a costly rapid response for these invasive mussels, including potential closure of boat ramps, an intensive and costly monitoring program, and a Columbia River Basin wide alert including our US partner states. In addition, dead Dreissenid mussels can still result in a positive environmental DNA (eDNA) reading, triggering a rapid response. Given these potential consequences the extra cost and effort to request the decontamination of likely dead mussels is the much less costly approach.

Low Risk Watercraft/Equipment

Any watercraft or equipment that has only been used within British Columbia or other non-contaminated provinces or states within the last 30 days (green boxes in Figure 2). The inspection should still be used as an outreach opportunity to inform the watercraft owner about the "Clean, Drain and Dry" approach, but then release the watercraft as soon as possible.

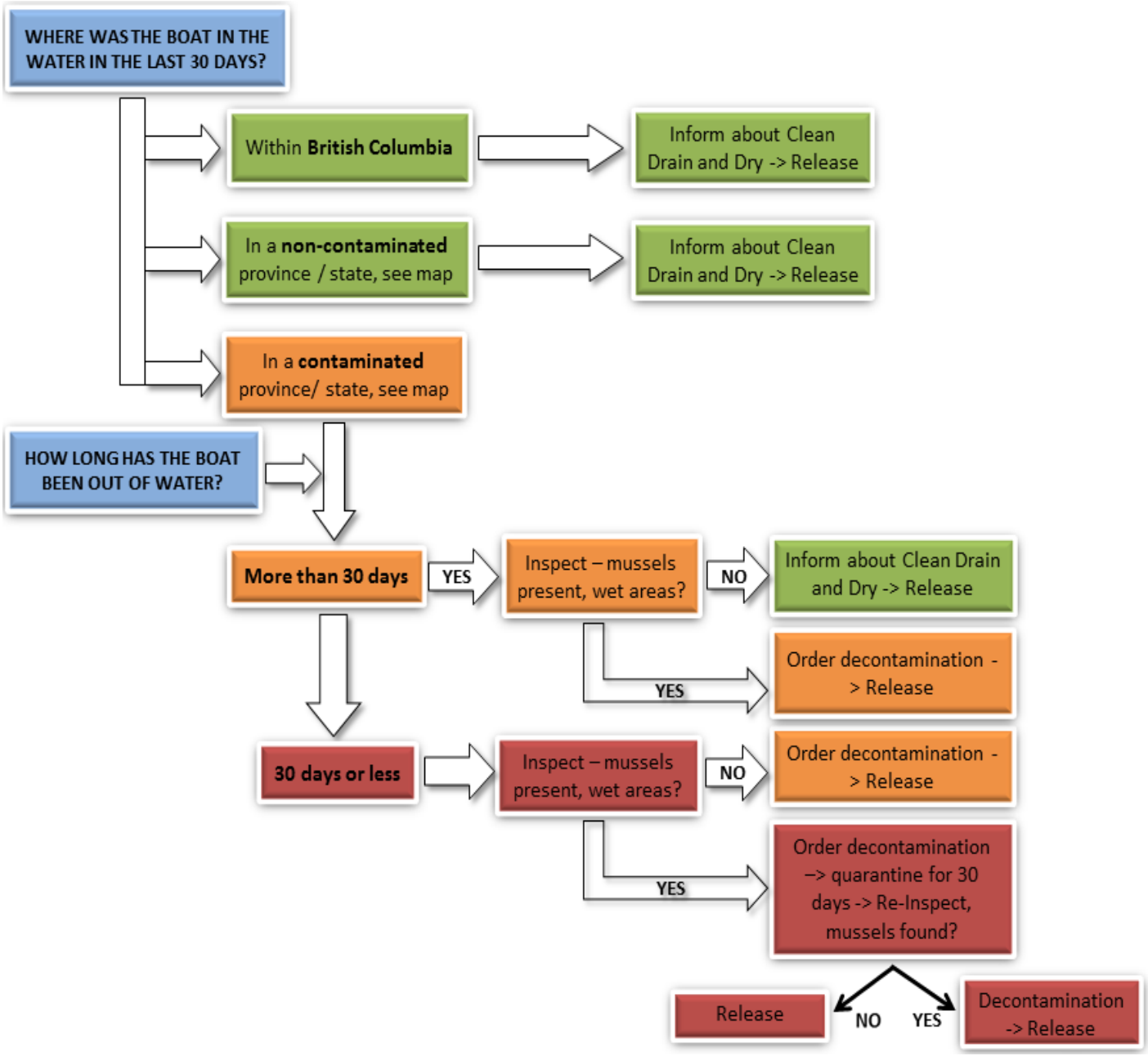

Figure 3 – Decision flow chart to distinguish low risk vs. high risk boats, trailers, fishing equipment or other water based recreational equipment. Blue boxes are the key questions for determining the watercraft risk level, green boxes are low risk and orange/red boxes are high risk

TIMELINE

Officers trained in watercraft inspections will work with the Provincial ZQM EDRR coordinator to complete the watercraft risk assessment. The risk assessment will be completed either immediately or within 12 hours, as information becomes available.

Table 4 – Watercraft risk assessment outcomes and actions. A low risk watercraft corresponds to the green boxes in Figure 3; a high risk watercraft responds to the orange/red boxes in Figure 3.

Risk Assessment Outcomes	Actions
1. **Watercraft is low risk**	• Watercraft can be released and continue its travel, inform owner / transporter about Clean, Drain and Dry.
2. **Watercraft is high risk**	• Watercraft must be decontaminated by trained personnel and may also be quarantined. High risk vessels are re-inspected following the 30 day quarantine period.

1.3.5.1 Responsibility Summary

Provincial ZQM EDRR Coordinator

- Combines information about the history of the watercraft with any specimens observed on the watercraft to determine the risk level.
- Records all the incoming information.
- Provides input, as requested, to officers potentially involved at this stage.
- Makes the decision if the Conservation Officer Service needs to be engaged in the process, if not already involved.
- Acts as the sole media contact during the EDRR process to ensure that all information distributed to the public is accurate.

Officers and/or Conservation Officer Services

- Conducts inspections for boats/equipment deemed to be high risk.

Watercraft Owner/Hauler

- Available for officers and the Provincial ZQM EDRR Coordinator to provide additional information, as requested.

1.3.6 STEP 5. RAPID RESPONSE

In the case of a high-risk watercraft entering BC, rapid response will consist of decontamination and/or quarantine of the watercraft. Table 5 outlines the different watercraft risk levels and the appropriate rapid response actions. The Provincial ZQM EDRR Coordinator will coordinate the rapid response and communicate with officers and Conservation Officer Services regarding the necessary decontamination and quarantine procedures.

1.3.6.1 Inspection/Decontamination

Watercraft inspections and decontaminations are complex and time-consuming procedures that can only be undertaken by trained personnel (Watercraft Inspection Training) based on a decontamination order. Further detail on the inspection and decontamination procedures can be found in the Uniform Minimum Protocols and Standards for Watercraft Interception Programs for Dreissenid mussels in the Western United States.

Clean and Drain

For proper decontamination, the watercraft or equipment must be cleaned with hot water (> 60˚C or 140˚F), using a power wash unit capable of spraying at least 5 gallons/minute or 19 litres/minute with a nozzle pressure of 3,000 psi or greater (not to exceed 3,500 psi) to remove attached visible mussels from all exposed surfaces of the watercraft, pieces of equipment, trailer and engine. All accessible surfaces of a watercraft and equipment trailer should be sprayed with ≥60°C (140°F) water. Since trailers are normally out of the water, juvenile and adult mussel are not normally attached to any surfaces however, mussels can be scraped-off boats or equipment during loading and become lodged on the trailer and should be removed with hot water spray.

Dry (Quarantine or Drying Time)

If boats or equipment are found to carry live zebra or quagga mussels or larvae then they must be held out of water for a period of time necessary to kill all mussels and veligers on-board through desiccation, after decontamination. The amount of time required to achieve complete desiccation varies depending on temperature, relative humidity and size of the mussels, and is set to 30 days to reduce the risk of mussel survival.

Quarantine/drying is likely the most effective way to assure that live mussels are not transported between waterbodies on a trailered watercraft or equipment (Morse 2009). The biggest concern with quarantine/drying is that it does not remove attached mussels. If mussels remain on the watercraft, they will eventually drop off. If that occurs at a boat ramp or beach, the presence of mussel shells can raise concern of a new infestation, triggering alarm and resulting in expensive and unnecessary action. For that reason, we recommend after quarantine, all boats are re-inspected and that all visible mussels be removed from a quarantined/dried watercraft before they are allowed to launch.

Disposing of Mussels

Following decontamination and quarantine any dead or live dreissenid mussels must be disposed of properly to prevent spread (live mussels) or trigger unnecessary alarms (dead mussels). Live mussels removed from a watercraft must be killed as quickly as possible before disposing of them in a landfill. Live dreissenid mussels can be put in a plastic bag and frozen for at least 24 hours or mussels can be exposed to temperatures >40˚C, before disposing them.

Table 5 – Rapid Response outcomes and actions based on watercraft risk levels.

Watercraft Risk Levels	Actions
1. Watercraft within BC or coming from a non-contaminated province/state	• Inform watercraft owner about Clean, Drain and Dry. Release watercraft.
1. Watercraft coming from contaminated province/state AND out of water >30 days	• Inspect for presence of Dreissenid mussels and raw water containing mussel larvae; ○ if none found then inform about Clean, Drain and Dry and release watercraft ○ if found then order decontamination, release the watercraft and properly dispose of the mussel.
3. Watercraft from contaminated province/state AND out of water <30 days	• Inspect for presence of Dreissenid mussels and raw water containing mussel larvae, ○ if none found then order decontamination and release watercraft. ○ If mussels found then order decontamination and quarantine/ban for 30 days.

TIMELINE

The duration of the rapid response will depend on the watercraft risk level. A low risk watercraft will be released immediately following initial inspection. A high risk watercraft will require decontamination and may also require a 30 day quarantine period. The decontamination will be completed as soon as possible but may take between 1-3 days and the watercraft will be held until the decontamination is complete.

1.3.6.2 Responsibility Summary

Provincial ZQM EDRR Coordinator

- Coordinates with the Conservation Officer Service if a high risk watercraft needs to be fully inspected and quarantined.
- Records all the incoming information and provides input, as requested, to officers potentially involved at this stage.
- Acts as the sole media contact during the EDRR process to ensure that all information distributed to the public is accurate.

Officers and/or Conservation Officer Services

- Conducts boat inspections and issues quarantines for high risk boats/equipment.

Watercraft Owner/Hauler

- Complies with decontamination and quarantine orders.
- Available for officers and the Provincial ZQM EDRR Coordinator to provide additional information, as requested.

1.3.7 Step 6. Monitor and Reassess

Recording the outcomes from each rapid response scenario is important to track efforts and improve procedures. Providing outreach information to watercraft owners about the Clean, Drain and Dry program is important for long term prevention.

The reassess step only applies to a high risk watercraft that has been quarantined for 30 days following the initial decontamination. Following the 30 day quarantine period, the watercraft must be re-inspected and if no Dreissenid mussels are found then the watercraft can be released. If Dreissenid mussels are found during re-inspection, a second decontamination must be completed to remove all mussels prior to releasing the watercraft.

Table 6 – Monitor and reassessment outcomes and actions

	Monitor and Reassess Outcomes	Actions
1.	**No Dreissenid mussels are found during re-inspection.**	• Watercraft can be released and continue its travel, inform owner / transporter about Clean, Drain and Dry.
2.	**Dreissenid mussels are found during re-inspection.**	• Watercraft is issued a second decontaminated order prior to release.

Timeline

Re-inspection will occur immediately following the 30 day quarantine period, and if no Dreissenid mussels are found the watercraft will be released immediately. If Dreissenid mussels are found during re-inspection they must be removed before the watercraft is released.

1.3.7.1 Responsibility Summary

Provincial ZQM EDRR Coordinator

- Coordinates the re-inspection of a high-risk watercraft following the 30 day quarantine period, if no mussels are found the watercraft is released.
- Records the timelines and steps taken during the ZQM EDRR process in a central database.
- Provides the opportunity for a debriefing in case of multiple groups and agencies involved.
- Acts as the sole media contact during the EDRR process to ensure that all information distributed to the public is accurate.

Officers and/or Conservation Officer Services

- Conducts re-inspections and determines if the watercraft can be released.

Watercraft Owner/Hauler

- Available for officers and the Provincial ZQM EDRR Coordinator to provide additional information, as requested.
- Complies with decontamination and quarantine orders.

1.4 ZEBRA AND QUAGGA MUSSEL EDRR (BC WATERS)

1.4.1 PURPOSE

The ZQM EDRR plan is designed to efficiently and effectively address any ZQM incursion events in BC waters. This plan is intended to complement international and federal initiatives and commitments like the *Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and Other Dreissenid Species* drafted by the Columbia River Basin 100th Meridian Team or the *Fisheries and Oceans Canada (DFO) AIS EDRR plan* (Locke et al. 2011). As well as provide stand-alone guidance in the event that Dreissenid mussels are found anywhere in BC.

1.4.2 AUTHORITY FOR RAPID RESPONSE IN BC WATERS

See Section 1.3.1 for further information on proposed amendments to federal legislation for aquatic invasive species regulations.

1.4.2.1 Containment – Waterbody/Boat Ramp Closure Protocols

Part of a rapid response of zebra and quagga mussels in a waterbody is to contain the mussels to that waterbody, while the extent of the infestation is determined. One crucial component of containment is to make sure all boats leaving that water body are decontaminated to prevent them from spreading mussels to other areas. This can be enforced through the Controlled Alien Species Regulations prohibition of the possession and transport of live or dead zebra or quagga mussels. In the case of smaller lakes the most effective approach might be to collaborate with boat owners to remove all boats from the lake and close it subsequently to boating. Boat use on lakes is legislated by Transport Canada and outside Provincial legislation. To voluntarily have all boats removed from a lake and then close all boat ramps. If boat ramps are on Crown Land the Province can close the access to that boat ramp, however a large number of boat ramps either are on land belonging to local government, natural resource industry or are on privately land. In these cases a closure of access points needs to be developed collaborative with all land owners. In case of higher use or larger waterbodies with large resident boating populations, decontamination crews must be on site to clean every boat leaving. This option is more costly and complicated, as decontamination crews must be positioned at all major exit routes from the waterbody and also boats must be prevented from leaving outside opening times of the decontamination stations.

See Section 1.3 for further information on watercraft inspection and decontamination procedures.

1.4.2.2 Eradication – Permitting and Regulations

Permits and/or agreements will be established to implement a ZQM response plan, and will need to be acquired before any treatment actions occur in order to provide

authority to access land, apply treatments, or conform to safety standards. The Provincial government will be responsible for administering the use of mollusicides for ZQM treatment within BC.

The Pest Management Regulatory Agency (PMRA) of Health Canada is the federal permitting authority and the Provincial ZQM EDRR Coordinator will work with PMRA on an on-going basis to develop shelf ready ZQM molluscicide treatment options.

However, if the molluscicide is not already registered in Canada, the Provincial ZQM EDRR Coordinator will need to request a one year Federal Emergency registration or research trial permit based on feedback from PMRA. The Provincial ZQM EDRR Coordinator will apply for the one year Federal permit immediately following initial identification of an invasive Dreissenid mussel in BC waters, in the event that identification is confirmed and eradication is considered feasible.

1.4.2.3 Rapid Response – Species at Risk

The federal Species at Risk Act (SARA) could become relevant if monitoring/treatment is planned in a waterbody with a reported SARA listed species. Under Sections 32 and 33 of the Species at Risk Act (SARA—2002, c. 29) it is an offence to:

- *"kill, harm, harass, capture or take an individual of a listed species that is extirpated, endangered or threatened;*
- *possess, collect, buy, sell or trade an individual of a listed species that is extirpated, endangered or threatened, or its part or derivative;*
- *damage or destroy the residence of one or more individuals of a listed endangered or threatened species or of a listed extirpated species if a recovery strategy has recommended its reintroduction into the wild in Canada."*

SARA permits are federally managed through Fisheries and Oceans Canada (DFO) and the Pacific Region DFO office should be contacted to determine if a SARA permit will be required for monitoring and/or treatment within a given waterbody.

1.4.2.4 Rapid Response – Cross Border Movement

Special provisions are in place under the authority of Customs Tariff Item No. 9993.00.00 and the Goods for Emergency Use Remission Order in the event of an environmental emergency and during a rapid response situation, if requested by the Provincial government, emergency service providers and equipment can enter Canada without the normal work permits, taxes and duties required. The Provincial ZQM EDRR Coordinator will work with the local Canadian Border Services Agency (CBSA) staff to implement the specific protocols.

1.4.3 STEP 1. EARLY DETECTION

Early detection is the process of finding new potential invasive mussel species before they establish high-density, persistent populations and disperse. Consequently, early detection is essential for eradication or effective containment.

If a suspected invasive Dreissenid mussel is spotted, it should be reported to **the Conservation Officer Services (COS) hotline 1-877-952-7277 and/or the reportinvasives.ca website**. The Provincial ZQM EDRR Coordinator will be notified of any ZQM incursion events.

1.4.3.1 Process and Outcomes

Early detection can occur either through passive (incidental discoveries) or active (structured surveys) surveillance. Adult mussels may be detected incidentally on contaminated boats in transit to waterbodies (see Section 1.3.2 for further information) or detected through active surveillance such as substrate sampling (see Appendix 6). Veligers may be detected by conducting active surveillance using plankton tows in high-risk lakes (see Appendix 6).

Due to the large number of lakes and rivers present in BC, early detection efforts should be focused on those lakes, which are at the highest risk for introduction and establishment. Characteristics of high risk lakes include; popular angling and recreational boating (waterskiing, wakeboarding, and jet skis) destinations, lakes with road access and/or boat ramps, and lakes in close proximity to populated areas. The federal dreissenid environmental risk assessment identified drainages in BC at risk of zebra and quagga mussel establishment based on suitable calcium concentrations (see Figure 8 and Figure 9).

TIMELINE

The time from receiving the initial report to completing preliminary identification should be approximately one week. Preliminary identification will occur during early detection, and the final identification will be made in Step 2. Identification by a subject matter expert or laboratory testing Due to the sensitive nature of preliminary sightings, this information must be treated as highly confidential until a final identification has been made. This will prevent initial sightings that turn out to be false alarms from escalating into misinformation that may confuse the public. False alarms and misinformation can negatively impact outreach and communication efforts with the public, and must be prevented by maintaining the confidentiality of sightings until identification by the Provincial ZQM EDRR Coordinator or a subject matter expert has been completed.

The Provincial ZQM EDRR Coordinator will conduct a preliminary assessment, which will result in one of three outcomes (**Error! Reference source not found.**). Depending on the utcome, the Provincial ZQM EDRR Coordinator will proceed with Step 2 to confirm

identification of a potential new invasive mussel species, or the specimen is identified as a native mussel species to BC and exits the ZQM EDRR process.

Table 7 – Early detection outcomes and actions

Early Detection Outcomes	Actions
Specimen identified as a native mussel species in BC	• Species exits the ZQM EDRR process, and does not proceed to Step 2.
1. **The species is initially identified as a zebra or quagga mussel.**	• Provincial ZQM EDRR Coordinator moves forward to Step 2: Identification and may inform DFO and CRB team.
2. **The non-native mussel species could not be identified**	• Provincial ZQM EDRR Coordinator moves forward to Step 2: Identification.

1.4.3.2 Responsibility Summary

Multi-Agency Coordination:

- The Provincial ZQM EDRR Coordinator will inform the CRB Multi-Agency Coordination Group and DFO Pacific region of ZQM alerts, who will then decide whether to initiate their own EDRR plans.
- If multiple jurisdictions are affected, an external communication system will be developed to ensure coordination across all jurisdictions.

Provincial ZQM EDRR Coordinator

- Produces ZQM alerts to the EDRR advisory committee, relevant Federal government agencies, regional invasive species groups and the CRB Multi-Agency Coordination Group.
- Provides ZQM EDRR training for regional invasive species organizations, local governments and other program participants as required.
- Conducts surveillance, locates new potential infestations of zebra and/or quagga mussels, records location and physical site information.
- Coordinates and identifies the required permitting.

Provincial Government Employee(s)

- Conducts surveillance, locates new potential infestations of zebra and quagga mussels, records location and physical site information, and photographs the entire specimen and diagnostic parts.
- Engage with Federal/Provincial EDRR working groups and the CRB Multi-Agency Coordination Group.

Observer(s)

- Learns to recognize zebra and quagga mussels.
- Reports new potential infestations of zebra and/or quagga mussels to the Provincial ZQM EDRR Coordinator.

Private Land Owner

- Learns to recognize zebra and quagga mussels.
- Reports new potential infestations of zebra and/or quagga mussels to the Provincial ZQM EDRR Coordinator.

Regional Invasive Species Organization(s)

- Reports new potential infestations of zebra and/or quagga mussels to the Provincial ZQM EDRR Coordinator.

Invasive Species Council of BC

- Reports new potential infestations of zebra and/or quagga mussels to the Provincial ZQM EDRR Coordinator.

1.4.4 Step 2. Identification

1.4.4.1 Processes and Outcomes

Identification will be verified by subject matter experts (adult mussels can be identified by the Royal BC Museum and/or the Provincial ZQM EDRR Coordinator) however microscopic veliger identification is more challenging and any suspect or inconclusive samples will be sent on to laboratories in the Pacific Northwest that are experienced with invasive mussel identification. Laboratory testing will require obtaining a water sample of veligers, which is potentially difficult in large waterbodies, or waterbodies with high flow. In addition, veligers are only present at certain times of the year, primarily July-August. The presence of dead Dreissenid mussels (either in the waterbody itself or on a watercraft or other equipment present in the system) does not mean that there is an established colony as they could have fallen from a watercraft or equipment and not be viable. Therefore, additional sampling and on-going monitoring will be required in order to determine if there is also live Dreissenid mussels present in a system.

The minimum criterion for Dreissenid mussel detection varies with the different life stages. In the case of adult Dreissenid mussels, it requires identification by two subject matter experts and the specimens are confirmed to the species level. In the case of Dreissenid veligers, there are two different genetic analysis methods that can be used (Table 8. Interim protocols for verifying adult and veliger stages of dreissenids, with corresponding waterbody determinations (from DeBruyckere et al. 2014). Note this is the same classification system used by Washington, Oregon and the CRB.). One is based on visual observation of larvae in plankton samples using cross polarized microscopy (XPLM). Another method is genetic analysis of water or plankton samples using polymerase chain reaction (PCR)) or environmental DNA analysis. For XPLM of veligers, there will need to be positive identification by two different labs, or positive

identification by both microscopy and PCR methods. For PCR of veligers, there will need to be positive microscopy results as well as two independent PCR results, performed by two different labs. While any potential introduction of invasive mussel species is being verified, the waterbody in question receives a status level (see Table 9).

Table 8. Interim protocols for verifying adult and veliger stages of dreissenids, with corresponding waterbody determinations (from DeBruyckere et al. 2014)[1]. Note this is the same classification system used by Washington, Oregon and the CRB.

Adult		**Veliger/Microscopy (XPLM)** (Veliger sample preservation/handling to meet minimum PCR requirements (e.g., 70% buffered EtOH, cold storage, isopropyl alcohol)	
Visual ID of settled adult by expert	Plausible report, no shell/specimen available, survey water body	Strong positive visual ID [multiple larval states, high quality sample]	Weak visual ID [suspect bivalve, poor quality sample]
Confirmation of visual ID by additional expert [photo okay]		Independent expert confirmation of Dreissenid veliger [photo okay] – must be confirmed by at least 2 independent experts	[Evaluate other samples if avail.]
Confirmation of ID and determination of species		Microscopy by independent lab and/or PCR by independent lab	PCR confirmation X 2 and gene sequence match

"Inconclusive sample, additional testing required"

Additional Laboratory Testing Occurs /Provincial Preparation Begins

"Suspected Infestation, preliminary laboratory tests are positive"

[1] Unusual or contradictory results to be evaluated on a case-by-case basis by committee. Microscopy refers to cross-polarized light microscopy or XPLM. Protocols for scanning electron microscopy or SEM have not yet been developed.

Table 9 – Identification outcomes, waterbody status and actions for adult and veliger Dreissenid mussel samples

Adult Identification Outcomes	Actions
Specimen identity verified as not a new invasive mussel species to BC	• Species exits the ZQM EDRR process.
Specimen identity verified as zebra or quagga mussel.	• Provincial EDRR Coordinator moves forward to Step 5: Rapid Response.
Specimen identified as other new invasive mussel species	• Species moves to the provincial BC EDRR Plan and Step 3: Alert Screening.
Veliger Identification Outcomes/Waterbody Status	**Actions**
1. ***Inconclusive* – Genetic sample (XPLM and/or PCR) has only one positive test result**	• Temporary status of *Inconclusive* is assigned by the Provincial ZQM EDRR Coordinator until further lab tests are completed. Further samples are collected if required and / or feasible.
2. ***Suspect* – Positive identification through at least two genetic samples (XPLM and/or PCR)**	• Provincial ZQM EDRR Coordinator assigns a status of *Suspect;* further samples are collected if required and / or feasible; and moves forward to Step 5: Rapid Response.
3. **Positive**	• Multiple subsequent samples meet minimum criteria for positive identification, and moves forward to Step 5: Rapid Response.
4. **Infested**	• Waterbody has an established population of zebra or quagga mussels. Moves forward to Step 5: Rapid Response.

TIMELINE

The time from receiving an initial identification of an invasive mussel species to having the species verified by experts should be as fast as possible, but could range from a week to a month or more, depending on the life stage, and identification methods available.

1.4.4.2 Responsibility Summary

Multi-Agency Coordination

- Identification actions will be coordinated with the CRB Multi-Agency Coordination Group and/or relevant Federal government agencies to ensure efforts aren't duplicated across multiple jurisdictions.
- A single media contact will be established for all agencies involved to ensure that only accurate and consistent information is released to the public.

Provincial ZQM EDRR Coordinator

- Assists in confirming species identification with the RBCM curator or taxonomic group networks or laboratories for veliger samples.
- Submits voucher specimens to the RBCM for confirmation and storage in the RBCM natural history collection.
- Notifies the EDRR advisory committee, regional invasive species groups, the CRB Multi-Agency Coordination Group and relevant Federal government agencies once species identification has been confirmed.
- Coordinates and identifies the required permitting. Coordinates targeted surveys to acquire additional information on zebra and/or quagga mussels.
- Updates the appropriate EDRR database and website with species information once identification has been confirmed.

Royal BC Museum

- Confirms species identification in collaboration with the taxonomic group networks and the Provincial ZQM EDRR Coordinator.
- Stores and records voucher specimens in the RBCM natural history collection.

Taxonomic Group Networks

- Participates in confirming species identification in cooperation with the Provincial ZQM EDRR Coordinator and the RBCM curators.
- Forwards voucher specimens for deposit in the RBCM natural history collection.

Laboratory

- Performs independent testing of veliger samples, as requested by the Provincial ZQM EDRR Coordinator.
- Communicates results to the Provincial ZQM EDRR Coordinator.

1.4.5 Step 3. Alert Screening

As mentioned in the previous section, the alert screening step is bypassed in the EDRR process for zebra and quagga mussels as they have already been identified as a significant risk to the province (federal risk assessment, Therriault et al. 2013) and they are on the provincial prohibited species list, under the *Controlled Alien Species Regulations*.

1.4.6 Step 4. Risk Assessment

Section 2 of this document summarizes the provincial risk assessment, which identified zebra and quagga mussel introductions as a high risk to BC.

1.4.7 Step 5. Rapid Response

The first step of a Rapid response is to contain the invasive species at the sites it is known to occur. The next steps are to determine if eradication is feasible, developing a response plan,

obtaining land access and treatment permits and implementing response activities for Dreissenid mussel introductions into BC waters. Eradication feasibility is determined by the EDRR Advisory Committee through an analysis of treatment availability, consequences, and cost. In the case of ZQM incursion events eradication feasibility could be influenced by the size and depth of the waterbody, time of year, the costs and the native species present (i.e., presence of species at risk and/or anadromous fish).

1.4.7.1 Processes and Outcomes

EXTENT OF COLONIZATION

If a waterbody is classified as "suspect" of being infested with Dreissenid mussels (see Table 9), it will be necessary to determine the extent of the colonization and the life-stage(s) of Dreissenid mussel present in the waterbody. The sampling methods used will depend on the season, the location and size/depth of the infested waterbody. Plankton sampling will be used to detect the presence of veligers, while shoreline, substrate and dive surveys can be used to sample for adult Dreissenid mussels.

Plankton sampling for veligers requires the use of a boat, and should take place between July and August; high sampling frequency increases the likelihood of collecting veligers. Sampling should focus on boat launches and marinas, in areas where plankton tend to collect (downstream/downwind), near inflows and outflows, and in nearshore and open water areas (see Appendix 6 for full sampling protocol).

Substrate sampling is desirable as it requires minimal cost and effort and can easily be done by private land owners and community groups. The substrate sampler is deployed in an area of high boat traffic, in approximately 8 meters of water. The substrate should then be checked once a month during the growing season (May-October) (see Appendix 6 for full sampling protocol).

SCUBA divers can conduct underwater searches to confirm the location of a Dreissenid mussel infestation. However, it is very expensive and inefficient to search over large areas using this method, therefore, SCUBA divers should only be used to confirm the presence and extent of the infestation but not for early detection monitoring. A list of divers that have completed advance training or commercial dive training should be maintained; this action will simplify the deployment of a dive team if required (see Appendix 7).

CONTAINMENT/PREVENTION OF FURTHER SPREAD

If possible, the area containing the Dreissenid mussels should be quarantined or temporarily closed, until methods are in place for preventing further spread or eradication. Any hatcheries or aquaculture sites located on the infested waterbody should also be quarantined. If the waterbody has a dam, try to slow the release of water

to uninfested areas, or draw water from below the thermocline. See Section 1.4.2.1 for further information on authority for closure of waterbodies and boat ramps.

Alternatively, if closure and quarantine is not an option, all boats or equipment leaving the infested or suspect waterbodies must be decontaminated; decontamination stations should be present on site (See Section 1.3.6 for further information). Boaters using the infested system will need to be identified and interviewed, to determine what their movements were prior to the detection and therefore potential sites of further dispersion. All boats and equipment potentially travelling from the infested area to a new waterbody should be inspected before launch. All waterways located downstream of the infested waterbody should also be identified for potential long-term monitoring.

ERADICATION/CONTROL METHODS

Eradication feasibility will be assessed by the Provincial ZQM EDRR Coordinator and subject matter experts based on treatment availability, consequences, and cost. In the case of a ZQM incursion event eradication feasibility will be influenced by the level of risk, the size and depth of the waterbody, the time of year, the cost of eradication and potential environmental/economic impacts. There may also be narrow timing windows for when different eradication methods can be applied to a waterbody based on the native species present (e.g., amphibians and anadromous fish species). Mechanical/Physical methods can be effective at removing Dreissenid mussels, however it may only be effective for containment and not eradication (Culver et al. 2014). See Section 2.2.4 for more information on previous eradication efforts in other jurisdictions.

If eradication is considered feasible, the most appropriate treatment method will need to be chosen, based on location and level of infestation. Potential treatment options could include, diver removal, covering / smothering, or chemical treatment. Covering / smothering would potentially require collaboration with Fisheries and Oceans, Canada, due to its impact on fish habitat. In case of chemical treatment, there are currently no molluscicides registered for open water user in Canada by the Pest Management Regulatory Agency (PMRA), therefore a one year Federal Emergency registration/research trial permit would have to be requested. In parallel a provincial Pesticide Use Permit (PUP) would have to be obtained and public notification and consultation completed according to the permit. ZQM eradications have only been attempted in a few cases inNorth America, and the best approach is highly dependent on the physical and chemical properties of the waterbody and the level of infestation (See Section 2.2.4 for summary). Chemical treatments of waterbodies are operationally complex and have to be accompanied by a strong public education and outreach effort to gain public support and minimize the risk of a public appeal during the PUP consultation and notification process. Key for success is immediate containment and treatment at the earliest possible time.

TIMELINE

The exact timeline for rapid response is highly dependent on the specific incursion event including the location and size of the infested waterbody and the time of year. In addition, establishing the necessary permitting may significantly affect the timeline for treatment. The coordinator will request a one year Federal Emergency registration or research trial permit immediately, and in parallel a Provincial Pesticide Use Permit, following positive identification of ZQM in BC waters, if eradication is considered feasible. Containment of the infested lake or river should begin as soon as possible to increase the chances of controlling further spread into surrounding waterbodies.

Table 10 – Rapid response planning outcomes and actions

Response Planning Outcomes	Actions
1. Eradication is feasible.	• Species continues in EDRR and response plan objectives and treatments established; permits and authorizations obtained; response plan implemented.
2. Eradication is <u>not</u> feasible.	• Species is referred to Provincial ZQM EDRR Coordinator for provincial long-term containment and/or regional management.

1.4.7.2 Responsibility Summary

Multi-Agency Coordination

- Determine if containment and eradication is feasible.
- A single media contact will be established for all agencies involved to ensure that only accurate and consistent information is released to the public.

Provincial ZQM EDRR Coordinator

- Organizes and coordinates the Rapid Response Team and develops the response plan.
- Obtains or renews registration of molluscicides with PMRA and permits to access lands, and/or apply treatments, as required.
- Coordinates and applies response treatments according to the response plan, enters treatments into the relevant database.
- Adjusts response plan in collaboration with the Rapid Response Team and with the guidance of the EDRR Advisory Committee.
- Communicate response plan implementation progress by updating the EDRR website with invasive mussel species status.

Local Government

- May participate on the Rapid Response Team.
- May assist in developing the response plan with the Rapid Response Team.
- Assists in acquiring or renewing permits and providing access.

Subject Matter Expert

- May participate on the Rapid Response Team and may assist in developing the response plan.

Private Land Owner

- Assists in providing land access, as requested by the Provincial ZQM EDRR Coordinator.

Regional Invasive Species Organization

- May participate on the Rapid Response Team.
- Assists with implementation of response plan, as requested by the Provincial ZQM EDRR Coordinator.

Hydropower Companies

- May participate on the Rapid Response Team.
- Assists in acquiring or renewing permits and providing access, as requested by the Provincial ZQM EDRR Coordinator.

Federal Government Agencies

- May participate on the Rapid Response Team.

Invasive Species Council of BC

- Provides education and outreach support, as requested by the Provincial ZQM EDRR Coordinator.

1.4.8 Step 6. Monitor and Reassess

1.4.8.1 Processes and Outcomes

Immediate eradication is the goal of the ZQM EDRR plan; however, it may be necessary to focus on containment or a longer-term eradication strategy. Long-term monitoring will include sampling of the affected area, to determine whether the objectives of the rapid response plan are being met and are effective at eradicating or reducing the spread of the invasive Dreissenid mussels. If not, the rapid response plan should be re-evaluated with management adapted to meet the new objectives.

It will be necessary to identify waterbodies that are most connected to the potentially infested site, either through water connectivity or human movement and monitor those intensely. These new locations, as well as neighbouring and downstream systems, will need to be sampled and monitored to determine whether mussels have invaded these waterbodies. Facilities that could be affected by a mussel infestation, such as hydropower installations, fish hatcheries, and irrigations systems, should be identified.

The three possible outcomes of rapid response and the necessary actions are listed in Table 11.

Table 11 – Monitor and Reassess outcomes and actions

Monitor and Reassess Outcomes	Actions
1. Eradication successful	• Long term monitoring for a minimum of five years will be required to ensure treatment success and no re-infestation.
***2.* Unsuccessful eradication; continued rapid response**	• Adjust the objectives and treatments of the rapid response plan and continue to attempt eradication.
3. Unsuccessful eradication; focus on long-term containment.	• Eradication is not considered feasible. Focus on containment of infestation to a limited number of waterbodies.

COMMUNICATION

Intensive public education and outreach will be necessary to contain the spread of these mussels, and will need to focus on the **Clean, Drain, and Dry** method, as well, as the use of hot water wash decontamination stations. Signage at all affected boat ramps, as well as press releases to local media outlets, will be required. All initiatives in eradicating or containing the mussels, and the results from these efforts, should be made available (in databases, journals, or other media) so that other agencies can learn from this EDRR plan.

TIMELINE

In order for a waterbody to be re-classified as negative, either after an inconclusive or suspect sample or following an eradication, specific long-term monitoring actions are required (Table 12). The necessary long-term monitoring actions are based on the original status assigned to the waterbody, which are defined in Table 9.

Table 12 – Long-term monitoring actions required to re-classify a waterbody as negative, based on the original waterbody status defined in Table 9.

Original Waterbody Status	Actions for Re-Classification
1. Undetected/Negative	• No long-term monitoring required.
2. Inconclusive	• Minimum of one year of negative testing including a sample taken in the same month as the initial positive sample.
3. Suspect	• Three years of negative testing
4. Positive	• Five years of negative testing and final report is prepared.
5. Infested	• Following a successful eradication event, a minimum of five years of testing with negative results.

1.4.8.2 Responsibility Summary

Multi-Agency Coordination

- Long-term monitoring efforts will be coordinated between relevant agencies and results from annual surveys and/or any changes to a waterbody status will be communicated.
- A single media contact will be established for all agencies involved to ensure that only accurate and consistent information is released to the public.

Provincial ZQM EDRR Coordinator

- Monitors treatment efficacy, and evaluates treatment results compared to the objectives set out in the response plan.
- Coordinates and manages long term monitoring over the minimum five year period to ensure no re-infestation occurs.
- Makes recommendations to the EDRR Advisory Committee to remove the species from the EDRR process or continue treatments based on the results of the monitoring and reassessment.
- If eradication is unsuccessful, adjusts the objectives and treatments of the rapid response plan with the help of the rapid response team for continued long-term rapid response.
- When eradication is not considered feasible, then the coordinator focuses on implementing long-term containment of the infestation with the help of the rapid response team.
- Obtains or renews registration and permits for additional treatment, if required.
- Enters monitoring records in to relevant database and updates species status on the EDRR website.
- Prepares public education material on **Clean, Drain and Dry** method to help prevent spread.

Local Government

- Adjusts the response plan with the Rapid Response Team, as requested by the Provincial ZQM EDRR Coordinator.
- Assists in acquiring and renewing permits and providing access, as requested by the Provincial ZQM EDRR Coordinator.
- Assists in communication and outreach to the public on **Clean, Drain and Dry**, as requested by the Provincial ZQM EDRR Coordinator.

Hydropower Companies

- Adjusts the response plan with the Rapid Response Team, as requested by the Provincial ZQM EDRR Coordinator.
- Assists in acquiring and renewing permits and providing access, as requested by the Provincial ZQM EDRR Coordinator.

Subject Matter Expert(s)

- Adjusts the response plan with the Rapid Response Team, as requested by the Provincial ZQM EDRR Coordinator.

Private Land Owner

- Assists in acquiring and renewing permits and providing access, as requested by the Provincial ZQM EDRR Coordinator.

Regional Invasive Species Organization(s)

- May assist with long-term monitoring, as requested by the Provincial ZQM EDRR Coordinator.

Invasive Species Council of BC

- Provides information on EDRR activities and updates, as requested by the Provincial ZQM EDRR Coordinator.

1.4.9 Reporting and Outreach

Regular reporting and increased knowledge are important components of the EDRR program. Although considerable communication will be accomplished informally by various means, formal reports are necessary to inform governments, the IMISWG, program partners, and land managers of EDRR program progress.

The following reports will be prepared:

- **Annual ZQM EDRR Progress Report** – The Provincial ZQM EDRR Coordinator will prepare a report for the EDRR program decision-makers, program participants, and directly-affected parties documenting annual progress of the ZQM EDRR program. This report will document methods, participants, timelines, results of assessment and monitoring, and future plans for managing ZQM. The final report may also include recommendations for changes to the EDRR process and an analysis of the resources required to achieve the plan's objectives. This report will be submitted to the EDRR Advisory Committee for consideration and signoff.
- **ZQM status updates** on the IMISWG website to inform on ongoing eradication and management.
- **ZQM incursion report -** A final rapid response report will be prepared for Dreissenid mussels at the end of the response. This report will document methods, participants, timelines, results of assessment and monitoring, and future plans for managing the Dreissenid mussels. The final report may also include recommendations for changes to the EDRR process and an analysis of the resources required to achieve the plan's objectives. This report will be submitted to the EDRR Advisory Committee for consideration and signoff.

Outreach and extension create awareness among professionals and the general public regarding ZQM. They are also an important tool to encourage professionals and the public to report new ZQM incursions in the province. Some extension mediums may include:

- Participation in the Invasive Species Council of BC Annual Forum;
- Professional presentations;
- Poster presentations;
- Field days and displays;
- The IMISWG website, EDRR section;
- Brochures, pamphlets and invasive species alerts; and
- News releases to the media.

2 ZEBRA AND QUAGGA MUSSEL RISK ASSESSMENT

This is a combined risk assessment for zebra and quagga mussels, as both species belong to the *Dreissena* genus and are very similar in biology, pathways of spread, and environmental and economic impacts.

2.1 BACKGROUND

2.1.1 IDENTITY OF ORGANISM

NAME

Dreissena polymorpha (Pallas, 1771) and *Dreissena rostriformis bugensis* (Andrusov, 1897).

SYNONYMS

Zebra mussel: *Mytilus hagenii*, *Mytilus polymorpha* Pallas 1771, *Mytilus polymorphus* (Pallas), *Tichogonia chemnitzii* (Rossm.).

Quagga mussel: None

COMMON NAMES

Common names *for Dreissena polymorpha* include zebra mussel and wandering mussel (Encyclopedia of Life 2014). Quagga mussel is the only English common name for *Dreissena rostriformis bugensis* (Encyclopedia of Life 2014).

SIMILAR SPECIES & LOOK-ALIKES

Conrad's false mussel (*Mytilopsis leucophaeata*) is a brackish water mussel of the same family (Dreissenidae) as zebra and quagga mussels. In particular juvenile Conrad's false mussel shells can display the stripe or zigzag patterns, making them difficult to distinguish from zebra and quagga mussels (Verween et al. 2010). As adults, Conrad's false mussel have concentric rings on their shell that range from cream to dark brown in color, making them easier to identify. Conrad's false mussel occasionally also shows up on boats entering the Pacific Northwest and represents a threat to brackish waters. This document focuses only on zebra and quagga mussels based on their threat to freshwater ecosystems in BC. The federal Dreissenid risk assessment should be referenced for more information on Conrad's false mussel (Therriault et al. 2013).

DESCRIPTION

Zebra (*D. polymorpha*) and quagga (*D. rostriformis bugensis*) mussels are relatively small mussels, ranging in size from 1 mm to 3 cm as fully grown adults. The distinguishing characteristic between the two species is that the quagga mussel is larger, rounder and wider and the ventral surface is convex rather than flat which is seen in zebra mussel (Mackie and Claudi 2009). While they often have the characteristic zebra stripes this can be highly variable in both the species and should not be used as a distinguishing feature. The shells of zebra and quagga mussels can also be brown or cream coloured. Their shape resembles a propeller blade. One unique, distinguishing feature is that zebra and quagga mussels are the only freshwater mussel species in North America that can attach to solid surfaces, often forming clumps, like some marine mussels.

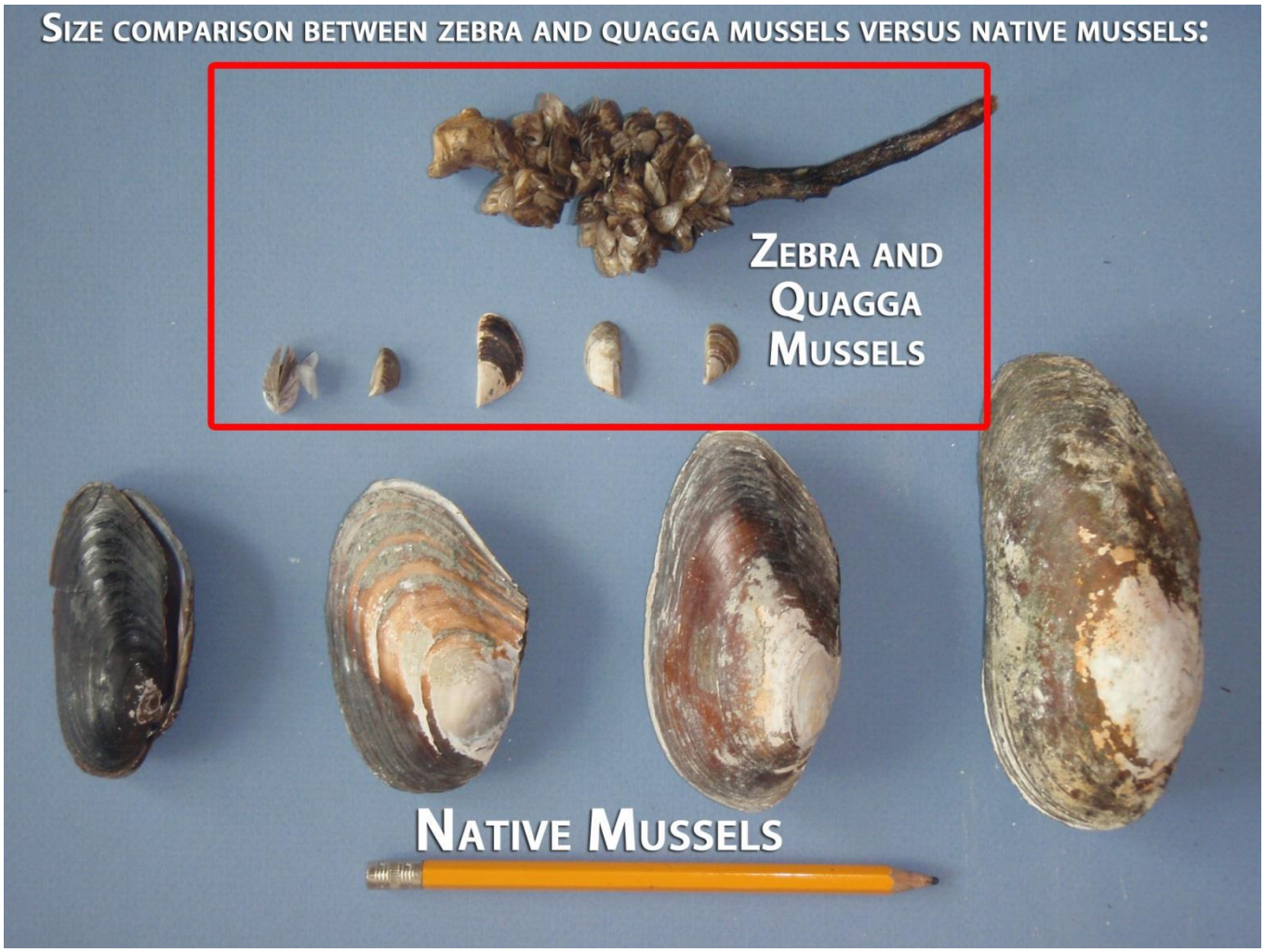

Figure 4 – Size range of zebra and quagga mussels (top) compared to native mussels (bottom)

Figure 5 – Example pictures of zebra and quagga mussels attached to various substrates.

2.1.2 Organism Status

Presence/Absence in B.C.

At present, no zebra or quagga mussels have been found in BC waters, and the province does have an ongoing monitoring program (for current and past monitoring in the Pacific Northwest see the Columbia River Basin Aquatic Invasive Species (CRBAIS) Database). The Ministry of Forests, Lands and Natural Resource Operations (FLNR) - Zebra and Quagga mussel factsheet is available for download here.

Presence/Absence in Canada

Within Canada, Zebra and/or quagga mussels are currently present in **Manitoba, Quebec and Ontario.**

Presence/Absence in United States

The US states currently considered free of zebra and quagga mussels are: **Alaska, Washington, Idaho, Montana, Oregon and Wyoming**.

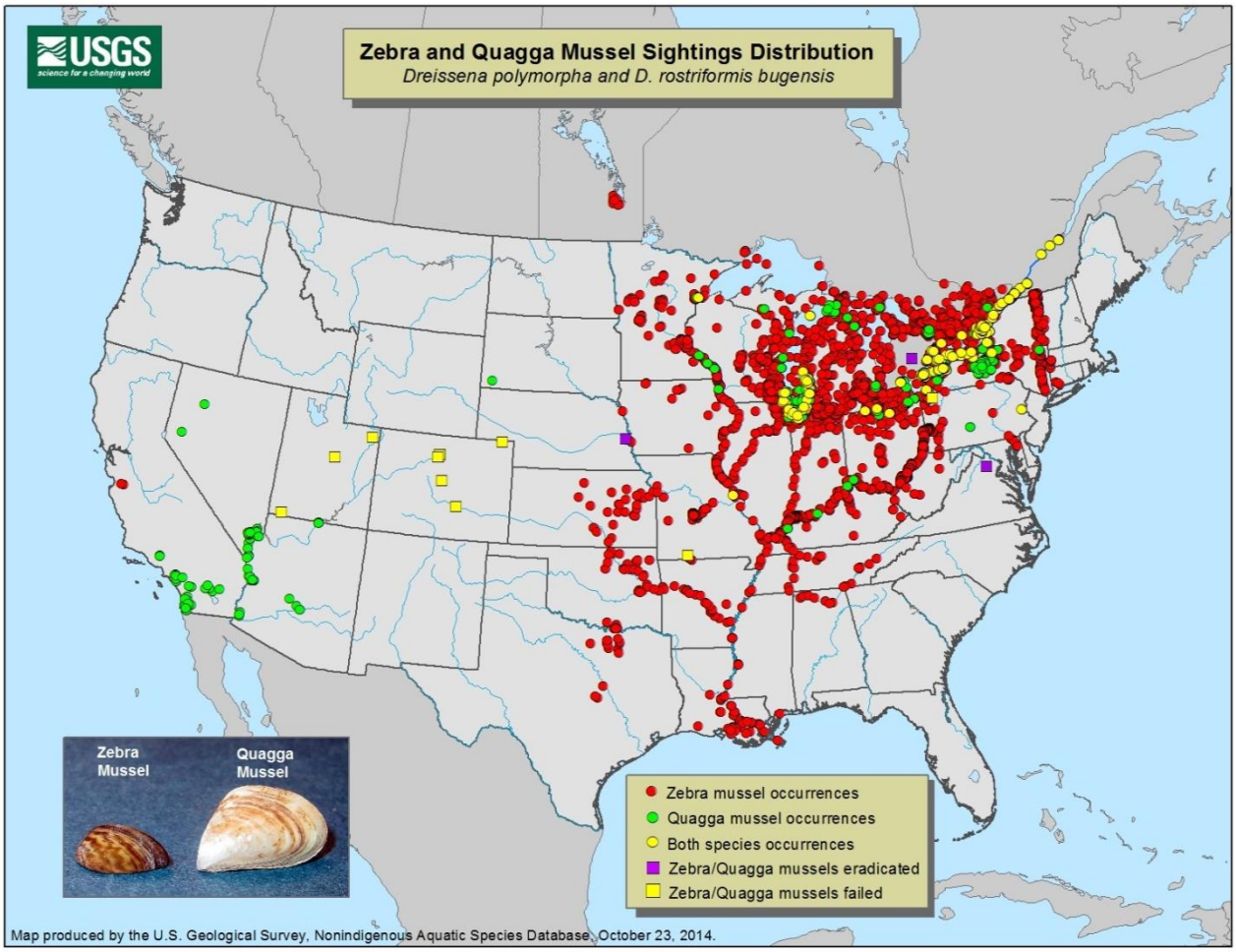

Figure 6 – The current distribution of zebra and quagga mussels in North America (Map Source: USGS 2014)

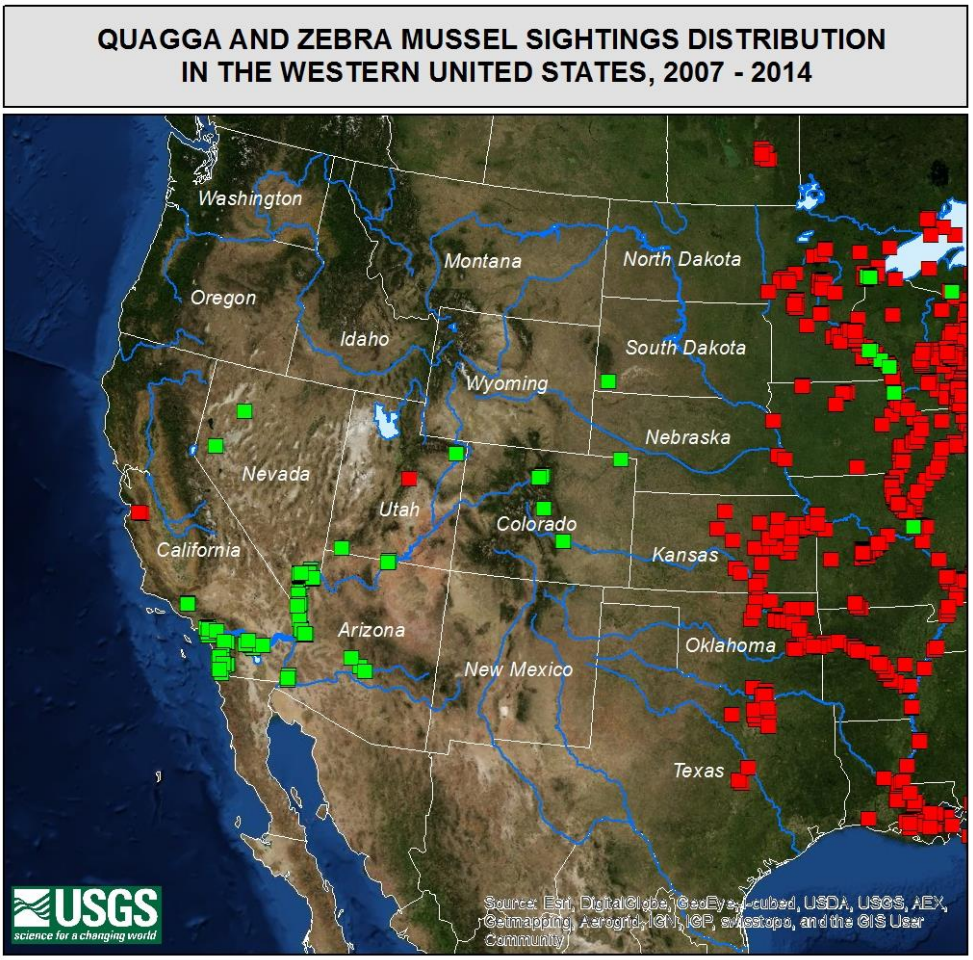

Figure 7 – The current distribution of zebra and quagga mussels in the western US. Please not that this map lists the waterbodies in the western US with known zebra or quagga mussel populations (Map Source: USGS 2014)

2.1.3 Current Regulatory Status

British Columbia

See Section 1.3.1 for further information on authority and legislation for ZQM prevention in British Columbia.

Canada

Within Canada, Alberta, Manitoba and Saskatchewan have regulations in place regarding the possession and transport of zebra and quagga mussels; please refer to the provincial regulations for more detail. See Section 1.3.1 for further information on proposed Aquatic Invasive Species amendments to the federal Fisheries Act. **Manitoba, Quebec and Ontario** are listed as contaminated with zebra and/or quagga mussels under Schedule 5, Section 9 of the *Controlled Alien Species* Regulation under the B.C. *Wildlife Act*.

United States

There is both federal and state legislation in place for ZQM within the United States. Many states including New York, Ohio, Indiana, Pennsylvania, Wisconsin, Minnesota, Michigan and Illinois have regulations in place under which one or more of the following actions may be unlawful; possess, introduce/release, transport and/or sell zebra and/or quagga mussels. Please refer to US state specific regulations for more information. Table 13 provides the provinces and US states listed as contaminated with zebra and/or quagga mussels under the *Controlled Alien Species* Regulation. The most up to date information is available via the USGS website, which includes static and zoom able maps of all known locations with introduced populations of zebra and/or quagga mussels.

Table 13 - Provinces and States listed as contaminated under the Controlled Alien Species Regulation (October 2014)

Canada				
Ontario	Quebec	Manitoba		
USA				
Alabama	Arizona	Arkansas	California	Colorado
Connecticut	Illinois	Indiana	Iowa	Kansas
Kentucky	Louisiana	Maryland	Massachusetts	Michigan
Minnesota	Mississippi	Missouri	Nebraska	Nevada
New Mexico	New York	North Dakota	Ohio	Oklahoma
Pennsylvania	South Dakota	Tennessee	Texas	Utah
Vermont	West Virginia	Wisconsin		

2.2 Risk Assessment

2.2.1 Probability of Entry

Natural Introduction

Zebra and quagga mussels are not native to any part of North America. They are also not present in any watersheds that extend into BC waters; therefore there is no risk of natural entry into British Columbia.

Human-Assisted Introduction

Zebra and quagga mussels have been introduced by trans-continental shipping from the Baltic Sea to the Great Lakes. From there, they have spread throughout North America by attaching to boats or equipment hauled between waterbodies (Benson et al. 2014a,b). These species can be moved between watersheds while attached as juvenile or adult mussels to boats that are transported between waterbodies. Lakes in close proximity to international and provincial borders that are in close proximity to populated areas and have road access and boat launches are considered high risk for human assisted introduction of Dreissenid mussels. Zebra and quagga mussels can survive for extended periods of time out of the water and can be easily overlooked in the smaller juvenile stages when attached to a boat. Their microscopic free-swimming larvae can also survive for up to 27 days in standing water in boats or other equipment. Five years of boat inspections in Idaho found 11% of the 105 mussel infested boats, intercepted were destined for BC. In October 2013, the presence of zebra mussels was confirmed in Lake Winnipeg, Manitoba, and despite a focused eradication attempt in 2014; mussels were subsequently found throughout the southern basin of the lake.

RISK RATING FOR PROBABILITY OF ENTRY

HIGH = 3 (Uncertainty negligible=0)

Rationale

- Primary pathways of entry are through human assisted transport of zebra and quagga mussel infested boats and equipment travelling to new uninfested waterbodies.
- Sub-drainages in British Columbia were assessed to have moderate to low risk of human assisted transport of zebra and/or quagga mussels. However, the ongoing interception of infested boats destined for BC suggests that zebra and quagga mussel introductions are still very possible in BC.
- The recent introduction of zebra mussels into Lake Winnipeg in 2013 possess a risk for their spread further west in Canada including British Columbia.

UNCERTAINTY & INFORMATION GAPS

- Based on the extensive information available on zebra and quagga mussel infestations in other parts of North America there are very little information gaps.

2.2.2 PROBABILITY OF ESTABLISHMENT

NATIVE RANGE

The quagga mussel (*D. rostriformis bugensis*) is native to the Dneiper River drainage of Ukraine and the Ponto-Caspian Sea (Benson et al. 2014b), while the zebra mussel (*D. polymorpha*) is native to the Black, Caspian and Azov Seas (Benson et al. 2014a).

GLOBAL RANGE

The zebra mussel began to spread beyond its native range in Europe in the late 18th and early 19th centuries (Benson et al. 2014a). It first spread into Great Britain and has since established into Denmark, Sweden, Finland, Ireland, Italy and throughout Europe and at present only Norway and Iceland remain free of the zebra mussel **(**Benson et al. 2014a). Zebra mussels were first introduced into the Great Lakes through ship ballast water in 1988 and by 1990 they were established in all the Great Lakes and in 1991 they spread into the Illinois and Hudson rivers. See Table 13 for the list of US states currently infested with zebra mussel (Benson et al. 2014a***).***

In Europe, quagga mussels have spread into waterways in the Caspian basin and also in Ukraine, Hungary, Germany, Netherlands and Romania (Benson et al. 2014b). The quagga mussel was first discovered in the Great Lakes in 1989; however it took several years before it was identified as a separate species from the zebra mussel (Benson et al. 2014b). The first reported occurrence of quagga mussels outside the Great Lakes was in 1995; however their distribution is not as widespread outside the Great Lakes as that of the zebra mussel (see Figure 6 for their current distribution).

BRITISH COLUMBIA RANGE

Several drainages in eastern and central BC have been assessed as high risk for zebra and quagga mussel survival based on suitable calcium concentrations (>25 mg/L) (Figure 8 and Figure 9; Therriault et al. 2013). Many of these high risk drainages are adjacent to provincial and/or international borders, which are high risk vectors for Dreissenid mussel entry into BC. Only a small number of drainages in northwestern BC may be temperature limiting (<10˚C mean air temperature in the warmest quarter) for zebra mussel establishment and survival (Therriault et al. 2013). However, the risk of zebra and quagga mussel establishment in BC is highest during the summer months (May to September) when temperatures are warmest, and recreational activity such as fishing and boating is highest (Karatayev et al. 2010). Zebra and quagga mussel establishment in BC is limited during the winter months for lakes with ice cover due colder temperatures and reduced boater/recreational activity in lakes.

Dreissenid mussels have readily dispersed to novel habitats across broad geographic scales and they display robust environmental tolerances, in particular for temperature and salinity (Therriault and Orlova 2010), and likely have the ability to adapt to environmental conditions of many BC lakes. Natural predators of zebra and quagga mussels include fish and crayfish (Hoddle 2011), however predation has not been identified as a limiting factor for their establishment in other regions. Potential waterbodies suitable for Dreissenid mussel establishment in BC are those with suitable calcium and temperature conditions (Figure 8 and Figure 9), lakes with road access and boat ramps, lakes close to city centers and provincial/international borders, and lakes popular for recreational activities such as fishing and boating.

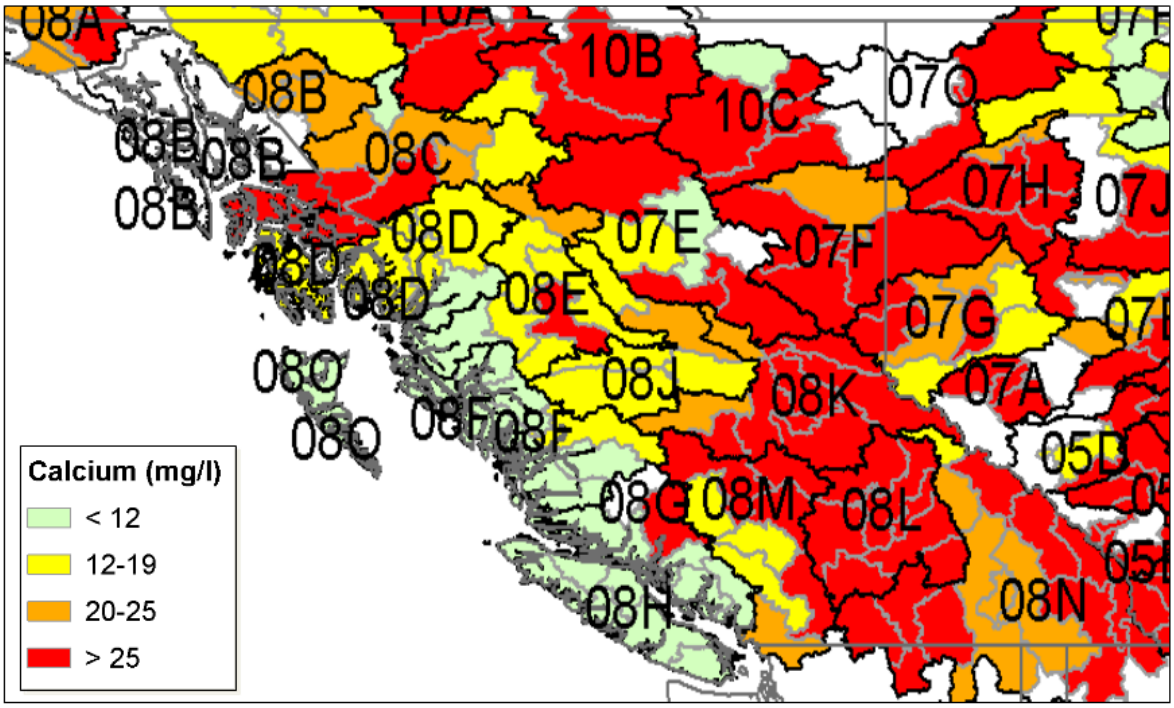

Figure 8 – Calcium concentrations (mg/L) for drainages in BC. Drainages were ranked on their suitability for zebra mussel survival based on: (<12 mg/L = very low (pale green); 12-19 mg/L = moderate (orange); 20-25 mg/L = high (orange); > 25 mg/L = very high (red). Figure modified from Therriault et al. (2013)

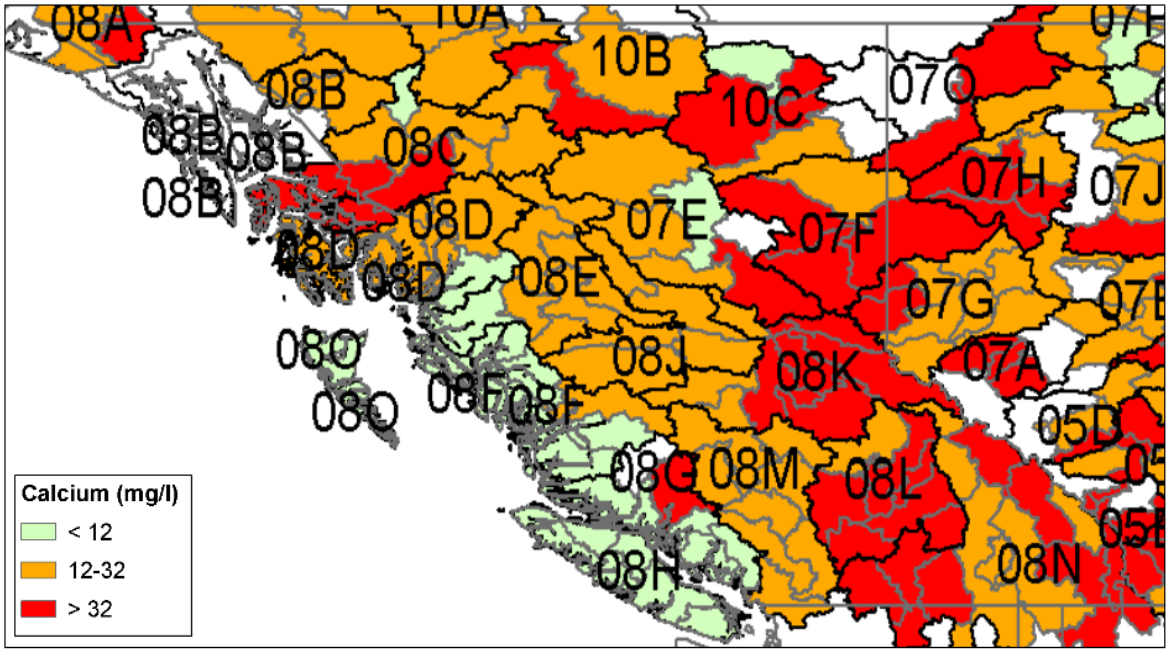

Figure 9 – Calcium concentrations (mg/L) for drainages in BC. Drainages were ranked on their suitability for quagga mussel survival based on: (< 12 mg/L = very low (pale green); 12-32 mg/L = high (orange); > 32 mg/L = very high (red)). Hatched watersheds had less than 5 sampling sites. Figure modified from Therriault et al. (2013).

HABITAT PREFERENCES

Zebra mussels are primarily found in shallow waters (4-7 m) in warmer, eutrophic systems, and they are rarely found in deeper depths with colder temperatures (>50 m). Compared to the zebra mussel the quagga mussel can be found in colder more oligotrophic conditions, and therefore can be found in both littoral and profundal zones of lakes and rivers (Roe and MacIsaac, 1997; Baldwin et al., 2002). Quagga mussels have been reported at depths of up to 130 m in some of the Great Lakes (Mills et al., 1993; Mills et al., 1996; Claxton and Mackie, 1998). Both zebra and quagga mussels attach to a variety of hard substrates, such as rocks and shellfish; however, zebra mussels can be found on submerged aquatic plants, while quagga mussels prefer cobble, gravel or sediment. Zebra and quagga mussels can tolerate a wide range of water temperatures, and can tolerate pH levels in a range of approximately 7.4-8.5. Zebra and quagga mussels are only found in freshwater, and require 10 mg Ca^{2+}/L to initiate shell growth and 25 mg Ca^{2+}/L to maintain shell growth (Hincks and Mackie 1997).

RISK RATING FOR PROBABILITY OF ESTABLISHMENT

HIGH = 3 (Uncertainty low =1)

RATIONALE

- Zebra and quagga mussel have established in many other parts of North America including three provinces in Canada (Winnipeg, Ontario and Quebec).
- Calcium concentrations and temperature are the two limiting factors for the establishment of zebra and quagga mussels in British Columbia, and drainages in eastern British Columbia including the Fraser and Columbia watersheds were identified as high risk based on suitable calcium concentrations for zebra and quagga mussels.
- Several drainages in northwestern British Columbia were identified as low risk for infestation due to water temperatures potentially being too low for zebra mussels (<10˚C mean air temperature at the warmest quarter).
- Several drainages on Vancouver Island were identified as low risk due to calcium concentrations being too low for zebra and quagga mussel survival.

UNCERTAINTY & INFORMATION GAPS

- Zebra and/or quagga mussels have not yet been reported in British Columbia, and there is limited calcium data for lakes in B.C., which creates information gaps on the risk of their establishment in the province.

2.2.3 PROBABILITY OF SPREAD

RATE OF SPREAD

The Dreissena genus is highly polymorphic and prolific making them a high risk for spread once they have established (Mills et al. 1996). Factors that can assist their spread in North American

waters includes larval drift in waterways or fishing and boating activities that permits land based transport or movement of Dreissenid mussels from infested to non-infested watersheds.

Potential for Spread in B.C.

Therriault et al. (2013) assessed the risk of Dreissenid mussel survival in drainages throughout Canada based on calcium concentrations. Drainages in eastern BC have been determined to be at high risk for Dreissenid mussel survival, due to calcium concentrations and this includes the Fraser and Columbia watersheds. Some drainages along the west coast with low calcium levels have been classified as low risk, while some drainages in northwestern BC are believed to be too cold to support zebra mussel populations (Therriault et al. 2013). Quagga mussels are typically found in deeper and colder waters and therefore temperature was not used to assess their probability of survival in the federal risk assessment. Frequently used waterbodies, such as lakes popular for motorized boating and fishing, with boat ramps and marinas, are also considered to be a high risk.

Reproduction

Zebra and quagga mussels mature after 1-2 years, and they are dioecious (separate sexes) with external fertilization. The optimal temperature for spawning is between 18-28˚C, but spawning can occur at reduced levels when temperatures are >10˚C (McMahon 1996). A fully mature female mussel is capable of producing up to one million eggs per season (Benson et al. 2014a).

Life Cycle

Eggs are fertilized in the water column and hatch into trocophore larva (Figure 10) with no shell which lasts for 6-20 hours after which they become free-swimming veliger larvae (80-100 µm) (McMahon 1996). This planktonic larval stage lasts for approximately one month, which can result in long-distance dispersal to downstream areas. They develop a foot after 2-3 weeks (200-400 µm) and at around 3-5 weeks they enter the juvenile stage (>400 µm) which allows the mussel to settle and attach to substrates through byssal threads (McMahon 1996). Before reaching the adult stage, the mussels are most vulnerable to predation, and also require specific temperature, oxygen, substrate and water velocities for successful colonization (see Habitat Preferences section for more details).

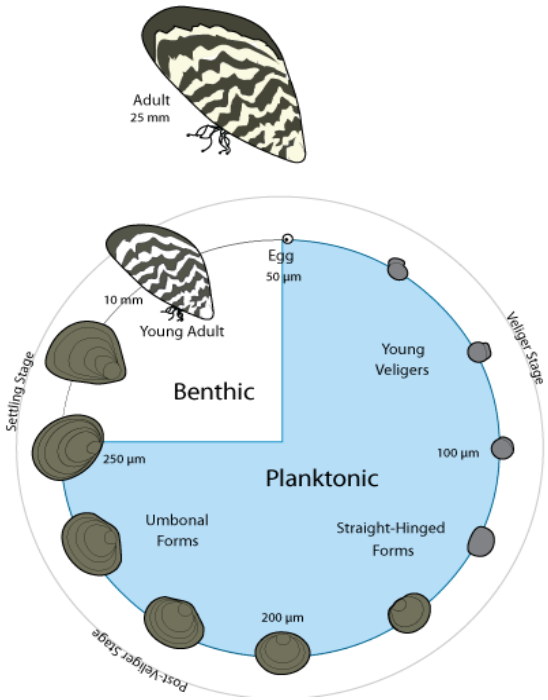

Figure 10 – Life cycle of zebra mussel, not the size and planktonic (free swimming phase) vs. benthic (attached phase). Image source: 100th Meridian Initiative.

Feeding and Diet

Zebra and quagga mussels are filter feeders and they use cilia to pull water into their shell cavity where it passes through an incurrent siphon. They are capable of filtering about one liter of water per day (Benson et al. 2014a). Zebra and quagga mussels primarily consume phytoplankton but also filter other suspended particulate in the water column including bacteria, protozoans, Dreissenid mussel veligers, other microzooplankton and silt. Their feeding preferences can result in a shift in the aquatic ecosystem from a pelagic to a benthic food chain and can substantially reduce the phytoplankton biomass, and pelagic fish populations, in lakes when they are introduced (Strayer 2009).

Genetic Information

Laboratory studies have shown that hybridization between zebra and quagga mussels is possible; however there is evidence of species specific sperm attractants, suggesting that hybridization would be very rare in nature (Mills et al. 1996).

Natural Dispersal (within non-native range)

Once introduced into a watershed zebra and quagga mussels can rapidly spread downstream into connected waterways and neighbouring watersheds through its free-swimming larval stages which lasts up to 30 days (see Figure 10) (Ricciardi et al. 1995). Dispersal distances of

mussel veligers in lake-stream systems can vary significantly depending on the characteristics of the system. Studies in the Illinois River have found zebra mussel larvae can travel a minimum of 300 km before settling, and were tracked moving 128 km over 5 days (Stoeckel et al. 1997; Schneider et al. 2003). Conversely, other studies have found very few veligers more than 1 km downstream from where dense vegetation occurred (Bodamer and Bossenbroek 2008). Wetlands and densely vegetated aquatic ecosystems have been found to restrict veliger dispersal due to reduced water velocity and particle retention, and may serve as a potential barrier to help prevent the spread of Dreissenid mussels (Bodamer and Bossenbroek 2008; Miller and Haynes 1997, Horvath 2004).

HUMAN-ASSISTED DISPERSAL

Zebra and quagga mussels have spread throughout North America by attaching to a watercraft and/or equipment hauled between waterbodies. These species can be moved between watersheds while attached as juvenile or adult mussels. See Section 1.3 for further detail on zebra and quagga mussel introduction by watercraft transport.

RISK RATING FOR PROBABILITY OF SPREAD

HIGH = 3 (Uncertainty negligible=0)

RATIONALE

- Zebra and quagga mussels have rapidly spread throughout North America since they were first introduced due to both natural and human assisted dispersal based on extensive data from other regions.
- In their free-swimming larval stage they can rapidly spread downstream of an infested lake or river.
- Zebra and quagga mussels can survive extended periods of time out of water and due to their small size as adults they can easily be overlooked when cleaning boats and equipment, making human assisted dispersal through watercraft transport a high risk.

UNCERTAINTY & INFORMATION GAPS

- There is very limited data on lakes with boat launches and boater movement within BC which creates information gaps for predicting lakes at risk of potential spread of zebra and quagga mussel. There is extensive data available on zebra and quagga mussel spread in other parts of North America which can be used to help predict their potential spread in BC.

2.2.4 POTENTIAL ECONOMIC AND ENVIRONMENTAL CONSEQUENCES

BEHAVIOUR IN NATIVE RANGE

In their native range zebra mussels are found in a wide range of habitats including freshwater and oligohaline waters of rivers, estuaries and coastal shallows in the Caspian Sea (Van Damme

2011). The quagga mussel is found in freshwater or oligohaline waters of rivers, lakes and canals, and between depths of 0-28 m in their native range in the Ukraine (Rintelen and VanDamme 2011).

Behaviour in Non-Native Range

Environmental Impacts

Zebra and quagga mussels are frequently referred to as ecosystem engineers due to their ability to alter nutrient flow from the pelagic to the benthic food web with marked impacts on native pelagic fish communities (Strayer 2009; Vanderploeg et al. 2002). This is due to their remarkable ability as filter feeders to remove substantial amounts of phytoplankton from the water column, which can decrease food availability for zooplankton, and alter the food web. This can also lead to increased water clarity and therefore increase light penetration, which allows for aquatic plants to proliferate, and further alter the ecosystem (Claxton et al. 1998). Zebra and quagga mussels can accumulate 300,000 times more organic pollutants within their tissues than the concentrations in the surrounding environment. The organic pollutants are found in their pseudofeces, and can be passed up the food chain, which increases the potential for wildlife exposure to organic pollutants (Snyder et al. 1997). These mussels are also responsible for the extirpation of native unionid mussels (Ricciardi et al. 1998) and have recently been identified as a threat to BC's Rocky Mountain Ridged Mussel (*Gonidea angulata*) by COSEWIC (2010). Quagga mussels can be linked to increased environmental impacts relative to zebra mussel due to their preference of soft substrates and deeper depths allowing for more widespread colonization within a waterbody (Therriault et al. 2013). For further detail on environmental effects of zebra and quagga mussel introductions see the federal Dreissenid mussel risk assessment (Therriault et al. 2013).

Economic Impacts

In a model developed by Leung et al. (2004), they predicted that increasing economic costs associated with the prevention of Dreissenid mussel introduction, even in just a single lake with a power plant, is still more economical than dealing with the invasion itself. Preliminary studies show that the annual costs of a potential zebra or quagga mussel invasion into BC could be over $28 million (Robinson et al. 2013). This estimate includes the costs for power plants, water supply, recreational boaters and golf courses; however, this does not include impacts on commercial and recreational fisheries, agricultural irrigation, etc. (Figure 11; Robinson et al. 2013). Water intake systems (for power plants, drinking, agricultural irrigation systems and other water supply systems) will require ongoing mechanical or chemical treatment to keep mussels from clogging the pipe and equipment. Boaters will face increased costs for hull and engine maintenance.

Impacts	Number of Units	Final Estimate ($/unit, 2012)	Preliminary Damage Estimate
Power generation – General	10,415 MW	612	6,373,980
Power generation – Run of River (ROR)	246 MW	612	150,552
Water supply	183 small	44,629	8,167,236
	7 large	154,910	1,084,372
			Sub-total: 9,251,608
Recreational boating	21,429 vessels	578	12,385,962
Golf Courses	38	286	10,867
Total			**28,172,969**

Figure 11 – Estimate of potential annual costs if zebra and quagga mussels were to be introduced in BC

The economic impact of zebra and quagga mussels to the hydropower system on the Columbia and Snake Rivers is of particular concern. If introduced into the Columbia River Basin (CRB), Dreissenid mussels could affect all submerged components and conduits of this system, including fish passage facilities, navigation locks, raw water distribution systems for turbine cooling, fire suppression and irrigation, trash racks, diffuser gratings, and drains.

In 2005, the Bonneville Power Administration commissioned a study of the costs associated with zebra mussel control on hydro-power facilities in the Columbia River. The study found that the one-time cost for installing zebra mussel control systems at hydroelectric projects could range from the hundreds of thousands of dollars to over a million dollars per facility (Phillips et al. 2005). When additional study estimated maintenance costs are considered over five years, the cost estimate for 13 hydroelectric projects grows to $52 Million (Pacific States Marine Fisheries Commission, unpublished data). The costs of zebra mussel control cited in this study will increase significantly, potentially 2-3 fold or more, when mitigation costs for juvenile and adult fish passage facilities, and maintenance and cleaning down time for systems and equipment are included. Systems requiring additional maintenance are generators, fire suppression/deluge, heating, ventilation, and air conditioning equipment, drain galleries, sumps, oil water separator and forebay/tailwater sensors.

Social Impacts

Tourism could also be affected, as mussel shells can injure swimmers along shorelines and next to docks, and algal blooms (caused by the increased clarity of the water and shift in aquatic food web structure) can decrease the quality of the recreational experience and potentially harm drinking water. In addition, zebra and quagga mussel infestations could negatively impact recreational and First Nations fisheries.

Eradication feasibility

Eradication feasibility will be assessed by subject matter experts based on treatment availability, consequences, and cost. In the case of a ZQM incursion event eradication feasibility will be influenced by the level of risk, the size and depth of the waterbody, the time of year, the cost of eradication and potential environmental/economic impacts. There may also be narrow timing windows for when different eradication methods can be applied to a waterbody based on the native species present (e.g., amphibians and anadromous fish species). Mechanical/Physical methods can be effective at removing Dreissenid mussels, however it may only be effective for containment and not eradication (Culver et al. 2013).

The treatment costs will depend on the chemical used and whether the entire water column (veliger and adults) or just the benthic environment (bottom 12 inches of open water where adult mussels are found) will be treated. The approximate cost to treat about 21 hectares of a waterbody for mussels using liquid potash can cost around $346,245, at a price of $375/tonne for liquid potash. Overall planning, coordination and implementation of mussel treatment for an area of 21 hectares can be up to $800,000. Additional costs that are not included in this estimate are permitting fees, signage, advertisement in local papers, stakeholder meetings, and staff salaries and training.

In October 2013, the presence of zebra mussels was confirmed in Lake Winnipeg, Manitoba, and despite a focused eradication attempt in 2014 using liquid potash, mussels were subsequently found throughout the southern basin of the lake. The only known successful eradication of mussels in North America involved using potassium chloride solution in a small pond in Virginia (Culver et al. 2013). At present there is no registered molluscicide in Canada for treating ZQM in open waters. An important next step will be to work with PMRA to develop shelf ready ZQM treatment options that are readily available if ZQM treatment is required.

International Status

The Global Invasive Species Database has nominated the zebra mussel as among 100 of the World's Worst Invasive Alien Species.

Zebra and quagga mussels are both listed as of Least Concern in their native range by IUCN due to their abundant distribution.

Uses

Due to their sensitivity to anthropogenic influences Dreissenid mussels serve as an important bio-indicator and bio-monitoring organism (Birnbaum 2006) for water quality surveys. The shells of zebra mussels have been crushed up and used as fertilizer and poultry feed (Birnbaum 2006), and zebra mussels have also been used as fishing bait and for fishmeal production.

RISK RATING FOR POTENTIAL ECONOMIC AND ENVIRONMENTAL CONSEQUENCES

HIGH = 3 (Uncertainty low = 1)

RATIONALE

- The magnitude of environmental and economic impacts of zebra and quagga mussel introductions is dependent on the density and extent of the introduced population. In addition environmental impacts are likely to be low in ecosystems with low calcium concentrations but significant ecosystem impacts are likely at higher calcium concentrations (Therriault et al. 2013).
- Based on invasions elsewhere, impacts on fish communities are moderate to high, with low uncertainty and the magnitude of impacts may be largely dependent on the filtering capacity of the introduced Dreissenid population (Strayer 2009).
- Impacts to physical environment ranges can range from low to high with a very low level of uncertainty due to the extensive literature available on Dreissenid invasions elsewhere. Impacts to the physical environment include fouling of hard surfaces such as piers, docks, water intakes, and ship propellers.
- Preliminary estimates of the economic costs if Dreissenid mussels were to be introduced into BC starts at around $28 million per annum.
- Economic impacts of Dreissenid mussel introductions elsewhere have been very high and are assessed as high for BC with negligible uncertainty due to extensive data available for other regions.

UNCERTAINTY & INFORMATION GAPS

- At present, there are no molluscicides registered in Canada for treating ZQM infestations in open waterbodies and this presents a large information gap for eradication feasibility in BC.
- There is little information available on successful eradication treatments in other parts of North America presenting further information gaps on ZQM treatment options in BC.

2.2.5 SUMMARY

Risk Score: Probability of introduction and spread **(27)** = Probability of entry **(3)** x Probability of establishment **(3)** x Probability of spread **(3)**

Consequence Score: Ecological/Economic = **(3)**

Total Score: High (30) = Risk Score **(27)** + Consequence Score **(3)**

Total Uncertainty Score: **Low (2)** = Uncertainty of introduction and spread **(1)** + Uncertainty of Consequence **(1)**

2.2.6 Technical Issues for Consideration

As adults, zebra and quagga mussels can be distinguished from native mussels due to their small size and distinct zebra like shell pattern, however their small size makes them difficult to detect during monitoring and inspections. Identification of their microscopic veliger stage requires specific training and currently few people in BC can analyze veliger samples. Sufficient veliger samples for detection can be difficult to obtain from large waterbodies and fast moving waterways, and improper samples can lead to false negative results. Laboratory testing of veliger samples can delay the identification step of the EDRR plan, however proper identification is critical for preventing costly eradication and containment plans based on a false positive result.

At present there is limited data available on boater movement within BC, which creates a challenge for predicting high risk lakes for zebra and quagga mussel introductions. An important next step will be to use available data (e.g., pH, calcium, road access, boater activity) from a subset of lakes in BC to develop models to predict high risk lakes for zebra and quagga mussel introduction across all of BC. In addition, there are no molluscicides currently registered in Canada for ZQM treatment in open waterbodies and to date there has only been one successful ZQM eradication in North America, which presents a large information gap on available treatment options for BC. Important next steps will be to establish shelf-ready ZQM treatment options for BC.

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Appendix 1. Controlled Alien Species regulations

The most recent amendments to the Controlled Alien Species (CAS) regulations can be accessed from: http://www.bclaws.ca/Recon/document/ID/freeside/94_2009

Appendix 2. USMPS standards

The *Uniform Minimum Protocols and Standards for Watercraft Interception Programs for Dreissenid Mussels in the Western United States* (January 2012 Version) is available for download from: http://www.aquaticnuisance.org/wordpress/wp-content/uploads/2010/01/UMPS_II_doc2_APRIL_5_2012_FINAL_final_edits.pdf

Appendix 3. 100TH Meridian Initiative

More information on the 100th Meridian Initiative for zebra and quagga mussels is available from; http://www.100thmeridian.org/zebras.asp

Appendix 4. DFO AIS EDRR plan

The Fisheries and Oceans Canada EDRR plan is available for download from: http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/resdocs-docrech/2010/2010_114_b.pdf

Appendix 5. BC Provincial EDRR Plan

The Provincial Invasive Species BC EDRR Plan will be available for download from the IMISWG EDRR Website: http://www.for.gov.bc.ca/hra/invasive-species/edrr.htm

Appendix 6. Aquatic Invasive species sampling protocol

The Provincial Aquatic Invasive Species Sampling Protocol will be available for download from the IMISWG EDRR Website: http://www.for.gov.bc.ca/hra/invasive-species/edrr.htm

Appendix 7. USGS Dive survey protocol.

The US Department of the Interior and US Geological Survey (prepared in cooperation with the US Fish and Wildlife Service) *Procedures for Conducting Underwater Searches for Invasive Mussels (Dreissena sp.)* report is available for download from: http://pubs.usgs.gov/of/2010/1308/pdf/ofr20101308.pdf