Invasive Species:

A challenge to the environment, economy, and society

2016 Study Guide

Manitoba Envirothon

THINK TREES MANITOBA FORESTRY ASSOCIATION

Manitoba

Acknowledgments

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Forward to Advisors

The 2016 North American Envirothon theme is *Invasive Species: A challenge to the environment, economy, and society*. Using the key objectives and theme statement provided by the North American Envirothon and the Ontario Envirothon, the Manitoba Envirothon (a core program of Think Trees – Manitoba Forestry Association) developed a set of learning outcomes in the Manitoba context for the theme.

This document provides Manitoba Envirothon participants with information on the 2016 theme. It focuses on the questions what **invasive species** are, how they are introduced and spread, their management, and how they can impact the **environment**, economy, and society. It also pays special attention to **invasive species** specific to Manitoba.

While it is not comprehensive, the document discusses the major concepts, and provides resources and examples from Manitoba. There are many other examples from Manitoba that could have been used. The authors, editors, and reviewers imply no favouritism by the choices included here.

How to use this document with students

Our document and its Companion Documents form the core resources for the 2016 Manitoba Envirothon Theme. To master the theme outcomes, students need to read this document. The document is split up into sections following the theme topics. Each section contains subsections covering a more detailed overview of the topic.

Students are not responsible for the references cited nor the definitions found in the glossary **alone**. Students are also not responsible for the **entirety** of the list of **invasive species** of Manitoba. However, they should be able to use four or five examples from the list to demonstrate different aspects of **invasive species** and their impacts in Manitoba. Definitions for words and phrases that are **bold** can be found in the glossary.

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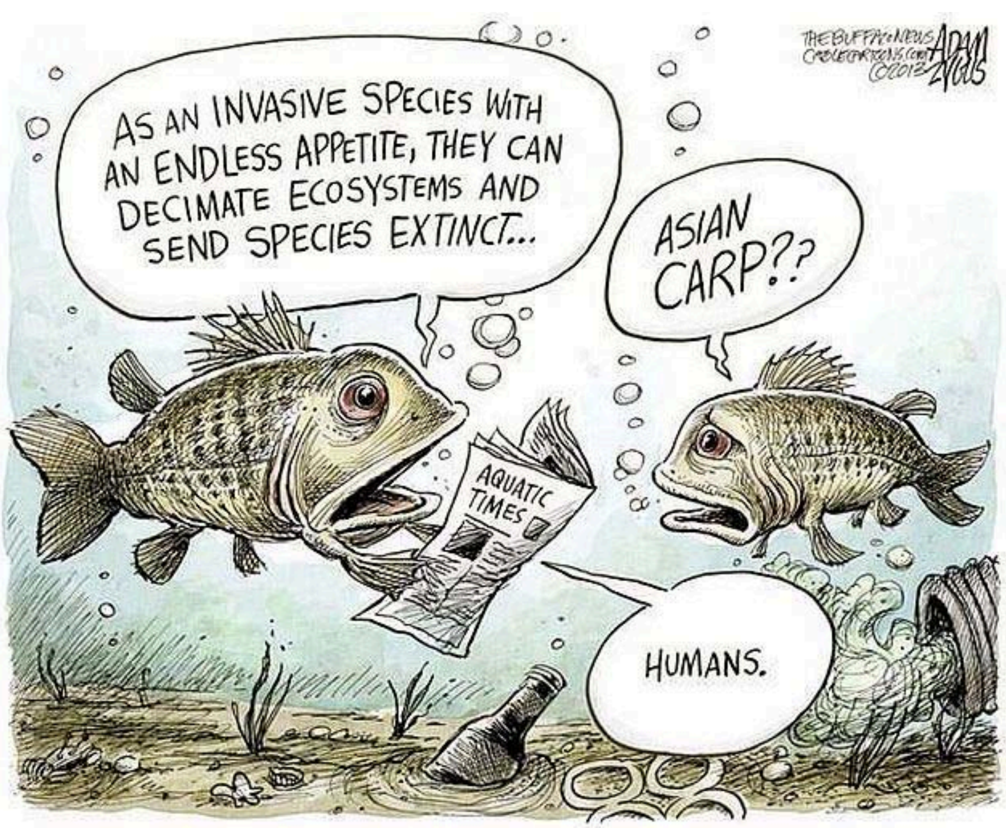
Introduction

Invasive species pose a serious threat to the stability of countless **ecosystems**. **Invasive species** have been shown to disrupt food webs, damage or destroy **habitat**, and contribute to the decline of many **native species**. In addition to their environmental impact, **invasive species** can have a significant impact on local economies. It has been estimated that **invasive species** have cost 1.5 trillion dollars globally in 2013, and in the United States alone it could be estimated that invading species caused up to $137 billion in major environmental damage (McGinley and Duffy 2011).

In the last 200 years, the world has seen an exponential increase in the number of **invasive species** being intentionally and unintentionally introduced through a variety of methods. The vast majority of **invasive species** that have established themselves in North America did so through unnatural or "human assisted" means, which includes being introduced by early settlers for agricultural or cultural purposes. However, many others have been inadvertently transported to new locations through trade and travel, as stowaways on ships or in packing materials, and through horticulture. With the expected increases in exports and trade in the future, we can likely expect greater challenges and **introductions** of **invasive species** in new locations around the globe (Dabrowski et al. 2015).



1. Invasive species and their impacts

1.1 What is an invasive species?

An **invasive species** is an exotic (originating from another region of the world) species whose introduction causes or is likely to cause economic harm, environmental harm, and/or harm to **native species** (including human) health. Species include plants, seeds, eggs, spores, other propagules, and animals (e.g., mammals, reptiles, amphibians, fish, insects and other invertebrates). Often human actions have permitted the species to cross a natural or artificial barrier to dispersal (e.g., mountains, oceans, highways, urban development, etc.). Although all **invasive species** are **non-native species**, not all **non-native species** are invasive. **Non-native species** are only considered invasive if they have harmful ecological, environmental, or economic affects. All **ecosystems** are at risk from the harmful effects of **invasive species**. The adverse effects of **invasive species** do vary widely, from the extirpation or **extinction** of **native species** to small long-term effects on **ecosystem** function (Mack et al. 2000).


Spiny water flea (*Bythotrephes longimanus*)

Invasive species' grow and reproduce rapidly, causing major **disturbance** to the areas in which they are present. These species can threaten an area's **biodiversity** by overwhelming **native species**, damaging **habitat**, disrupting food sources, and introducing **parasites** and disease. Most **invasive species** have little to no **population** control mechanisms in place to help control their **population** levels in the area of introduction and therefore often increase in numbers rapidly. Once **invasive species** are established in a region they can be difficult, or impossible, to control and remove.

Invasive species are often also referred to as aliens, exotics, non-native, or non-indigenous species. In this guide, **invasive species** is used through out and they are considered those that are non-native or outside of their natural **range AND** they are harmful to the new region.

1.2 Invasive species characteristics

Extensive research has demonstrated that **invasive species** often have characteristics that allow them to outcompete **native species**. In nature, success is measured by how well you survive and reproduce. Many new **non-native species** will fail and die, some may have inconspicuous effects, while others will have large negative consequences and therefore become invasive. **Invasive species** often share characteristics that make them successful in their new region.

Invasive species characteristics include:

Few natural enemies

Many **invasive species** do not have any natural enemies (e.g., predators, competitors, **parasites**, and **pathogens**) in the area they invade. Often there are no **predatory** species in the new area that are able to consume the **invasive species**. Further, **pathogens** are often important causes of death and **population** regulation, which would normally help control **population** growth. Unless an **invasive species** brings **pathogens** with them, there may not be any in the new region that are able to infect them or cause them harm. A lack of predators and **pathogens** may allow the **invasive species population** to spiral out of control.

High reproductive rates

Invasive species frequently have rapid growth, very short life cycles, prolific young production (e.g., prolific seed production), and seed dormancy (in plants). Many **invasive species** have a **range** of reproductive strategies. This flexibility allows them to thrive in their new **environment**.

High survival

Invasive species often can tolerate a wide **range** of environmental conditions. They are also most often **generalist** consumers so they can make use of the variety of new food items within their new **environment**. Invasive use a variety of pollinators (e.g., insects (such as bees, wasps, butterflies, etc.) and birds) to complete their life cycle.

Good dispersal

Most **invasive species** can very effectively distribute themselves into new environments. A lack of natural barriers, predators, and intraspecific **competition** may allow them to spread quickly throughout the new region.

Aggressive competitors

Most **invasive species** are superior competitors to **native species**. They may be more effective at obtaining resources like food, water, and/or space (e.g., hunting territory, nesting or denning sites, etc.), avoiding predators, use a wider variety of resources (e.g., **generalist** consumer), or be better specialized at obtaining one specific set of resources.

A combination of these characteristics allows **invasive species** to outcompete **native species** in a region and become established.

1.2.1 Disturbed versus undisturbed environments

Very few **ecosystems** still exist without some type of **disturbance**, anthropogenic (human-caused) or natural. Disturbed **ecosystems** may be more vulnerable to invasions due to the empty niches that are available for colonization. **Invasive species** are characteristically good competitors and they have an ability to move into areas with a wide **range** of conditions. They may fill these empty niches far quicker then the less competitive **native species**. Undisturbed, 'healthier', **ecosystems** have far less empty niches and generally healthy populations of **native species**. Healthier **ecosystems** may be those with high diversity or low **disturbance**. Studies in Europe on invasive plants have demonstrated that in harsh climatic conditions and **nutrient** -poor habitats, invasion levels are low. Invasive plants tend to thrive in **nutrient** -rich and man-made habitats (Chytrý et al. 2008). Mountains, cliffs, bogs, dry grasslands and coniferous woodlands were shown to be more resist invasion, while coastal and riparian habitats, where **nutrient** availability and **disturbance** can be high, were shown to be more prone to invasion by invasive plants (Chytrý et al. 2008). Human-made habitats such as farmland and urban landscapes also facilitate the spread of invasive plants (Chytrý et al. 2008). Besides these, the most invaded habitats include broadleaved deciduous forestry plantations, forest clearings or riverside willow scrub habitats (Chytrý et al. 2008).

Invasive heather (*Calluna vulgaris*)

1.3 Economic, social, and environmental impacts of invasive species

Invasive species tend to crowd out and replace **native species**. They can severely damage **ecosystem** health, and harm human activities, such as agriculture, forestry, fisheries, and recreation.

1.3.1 Economic

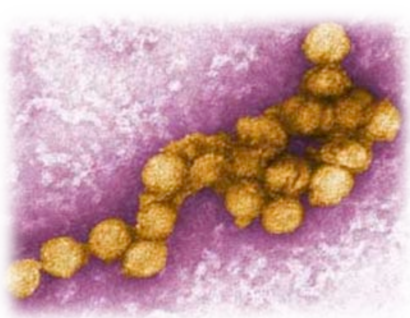
Invasive species can have large impacts on the economy, both positive and negative. **Invasive species** can negatively affect the economy by reducing available grazing land and crop yields. Further, **invasive species** have the ability to limit access to popular recreational areas. Government and private landowners may incur significant cost to repair damage done by **invasive species**. Funds are also spent on **monitoring** and educational programs. In agriculture, the principle **pests** of temperate crops are non-native, and the combined expenses of **pest** control and crop losses constitute a "tax" on food, fiber, and forage production. One study estimated the costs to agriculture, forestry, fisheries, and other human activities by introduced species at around $137 billion per year to the U.S. economy alone (McGinley and Duffy 2011). The global cost of virulent plant and **animal** diseases caused by organisms transported to new ranges and presented with susceptible new hosts is currently estimated at 1.5 trillion dollars, but that number continues to grow annually.

Brown marmorated stinkbug (*Halyomorpha halys*)

Invasive species can also reduce productivity in forestry, agricultural, and fishing sectors. The brown marmorated stinkbug (*Halyomorpha halys*) cost the USA mid-atlantic apple growers $37 million in the 2010 growing season (Woodsen 2012). Originally from Asia, the brown marmorated stinkbug arrived in Pennsylvania, USA in 1996 and rapidly moved across 33 neighboring states. By 2004 it was showing up on farms and in forests across the mid-Atlantic. This stinkbug feeds on more than 300 hosts, primarily fruit trees and woody ornamentals, but also field crops (Woodsen 2012). Almost any crop can be at risk, including: citrus, stone fruit, berries, asparagus, soybeans, honeysuckle, maple, hibiscus, and roses.

Invasive species can lead to export and import trade restrictions. Many countries limit the **import** of fresh goods (e.g., fruits and vegetables) to prevent the accidental introduction of extremely destructive **invasive species**. Other countries spray incoming materials with **insecticides** and herbicides to ensure they are not contaminated with **invasive species**. New Zealand, as an island nation, is extremely vulnerable to **invasive species** and therefore has some of the strictest **regulations** to prevent the accidental introduction of **invasive species**. They have enacted very strict **regulations** on what products can be brought into their country. For example, no food products, plant or plant products (alive or dead), **animal** and **animal** products (alive or dead), equipment used with animals, equipment such as camping gear, golf clubs, and used bicycles, and biological specimens are allowed to be brought into the country. If persons arriving in the country violate these **regulations** they can face a fine up to $100 000 or get a prison term up to five years.

1.3.2 Social



West Nile Virus (Family: *Flaviviridae*)

Invasive species can have negative effects on societies. **Invasive species** can bring novel **pathogens** with them, leading to the introduction of disease. For example, the introduction of the West Nile Virus to North America has led to an aggressive campaign to reduce its impact and educate the public. **Invasive species** also have the potential to increase human health impacts including allergies and irritations. Further, **invasive species** may reduce recreational and tourism opportunities. The introduction of the water hyacinth (*Eichhornia crassipes)* from the Amazon basin to the Lake Victoria has led many communities to move so they can gain better access to open water and fish stocks.

1.3.3 Environment

Invasive species are a major threat to our **environment** because they can:

(1) Threaten **biodiversity**
  a. Introduce **pathogens**
  b. Increase predation and competition
  c. Hybridization

(2) Community structure

(3) Change habitats, fire regimes, and alter **ecosystem** function and services

Biodiversity and community structure

Invasive species are the second most important threat to global **biodiversity**. It has been estimated that almost half of the species in North America that are at risk of **extinction** are endangered because of the effects of **invasive species** on the **environment**. **Invasive species** can threaten **biodiversity** by spreading **pathogens** (causing disease), acting as new predators, **parasites**, or competitors, altering **habitat**, and/or hybridizing with local species.

Pathogens and Parasites

Invasive species often bring novel **parasites** with them (additional **invasive species**) when they move into a region (Hanley et al. 1995). The introduction of new **parasite** species to a region can have many of the same effects as free-living **invasive species**. Their presence may enhance, inhibit, or have no effect on the invasion of a free-living species. If a **parasite** is novel to an area (brought with the invading species) and can be harmful to **native species**, its presence can affect many species interactions and it has the potential to extirpate **native species**. The introduction of the **parasite** *Gyrodactylus salaris* to Norwegian Atlantic salmon through the **import** of contaminated aquaculture broodstock, destroyed populations in over 40 rivers and led to an expensive bill of 450 to 600 million USD (Bakke et al. 2007).

The accidental introduction of the invasive Asian chestnut blight fungus (*Cryphonectria parasitica*) almost completely eliminated American chestnut from 180 million acres of eastern United States forests. The introduction, through the nursery trade, caused an entire transformation of the Eastern deciduous forest **ecosystem**. The loss of the American chestnut was a disaster for many animals that were highly adapted to living in forests that were dominated by this tree species. Eventually, ten moth species that had relied on chestnut trees became **extinct**.

Predation and Competition

Invasive species that are predators can severely reduce the **population** sizes of **native species**, sometimes even to extirpation or **extinction**. Native prey species may not have evolved defenses against these new predators.

- The brown tree snake (*Boiga irregularis*) was introduced to Guam in the cargo of a shipment from the Admiralty Islands. The brown tree snakes eliminated 11 native bird species.

Brown tree snake (*Boiga irregularis*)

- The Nile perch (*Lates niloticus*) was introduced to Lake Victoria, Africa, as a food fish. Predation from the perch has eliminated over 100 species of native cichlid fishes.

- Sailors introduced goats to many remote oceanic islands during the age of European seafaring exploration to provide a source of food whenever the islands were revisited. On St. Helena, the introduced goats eliminated over half the native plant species.

- North American eastern gray squirrels (*Sciurus carolinensis*) are driving the native red squirrels to **extinction** in Great Britain and Italy. The invasive grey squirrels forage more efficiently for nuts and they have become superior competitors.

- Zebra mussels (*Dreissena polymorpha*) were accidently brought to North America from Russia in the ballast of ships. Zebra mussels change **aquatic** habitats by filtering large amounts of water and reducing densities of planktonic organisms. They also settle in dense masses over large areas. At least thirty freshwater mussel species are threatened with **extinction** by **competition** from the zebra mussel.

Hybridization

Hybridization occurs when two different species mate with each other and they produce viable offspring. The introduction of an **invasive species** may lead to new hybridization between the invasive and **native species**. If the **invasive species** is more abundant than the **native species**, this hybridization may lead to a slow disappearance of the **native species** genes, and eventually lead to the **extinction** of the **native species**. Three of the twenty-six species now **extinct** in the United States have gone **extinct** wholly or partially because of hybridization with **invasive species** (McGinley and

Duffy 2011). For example, the hybridization between invasive mallards and the native Hawaiian duck may result in the **extinction** of the **native species** (McGinley and Duffy 2011).

Alter habitat and ecosystem functions

Invasive species, particularly plant invaders, can alter the fire regime, **nutrient** cycling, hydrology, and energy in native **ecosystems**. They can greatly diminish the abundance or survival of **native species** and even block navigation or enhance flooding. **Invasive species** can also cause soil degradation and erosion.

1.3.4 Canadian Impacts

It has been estimated that 24 percent of the species listed as "at risk" in Canada could be threatened with **extinction** by **invasive species** (Government of Canada). Some of the 90 **native species** on this list that are considered threatened by **invasive species** include ancient murrelets, island blue butterfly, golden paintbrush, tiger salamander, northern prairie skink, American chestnut, eastern flying squirrel, and ginseng (Government of Canada). In the Great Lakes, with over 160 **invasive species**, sea lampreys have been implicated in the **extinction** of the deep-water cisco, and zebra mussels have extirpated native mussels from some areas (Government of Canada).

Table 1. Examples of Canadian invasive species and their social, environmental, or economic impacts

Species	Type of impact	Description of impact
Zebra Mussel (*Dreissena polymorpha*)	Environmental	Zebra muscles will colonize almost every hard surface including rocks, boat hulls, and water intake pipes. They can even grow on the shells of our native clam species, reducing their ability to feed and as such increase mortality.
Japanese Knotweeds (*Fallopia japonica & Polygonum cuspidatum*)	Environmental	Japanese Knotweed is a perennial shrub from Asia, often considered one of the most persistent of all **weeds**. Once established in disturbed areas or along stream banks, this highly **invasive species** can displace virtually all other types of vegetation.
West Nile Virus (Family: *Flaviviridae*)	Social	The West Nile Virus originated in Africa and Europe. Since its discovery in North America, public health agencies have been waging an aggressive campaign to inform the public about the risks associated with contracting this disease.
Emerald Ash Borer (*Agrilus planipennis*)	Economic	The cost of **eradication** and control efforts associated with this invasive insect have totaled in the millions per year.

Environment Canada 2013

1.3.5 Global Impacts

The impact of **invasive species** globally is hard to estimate. In New Zealand alone, one bat species, at least 51 birds, three frogs, three lizards, one freshwater fish, four plant species, and a number of invertebrates have all gone **extinct** since human settlement introduced many **invasive species**. The mongoose (Family Herpestidae) threatens many **native species** on tropical cane-growing islands where it has been introduced. They have caused the **population** decrease or **extinction** of many native vertebrates. European red fox (*Vulpes vulpes*) have been introduced into Australia and led to decreases in many small and medium sized rodent and marsupial species. The introduction of the golden apple snail (*Pomacea canaliculata*) to the Philippines led to productivity losses in rice production, costing upwards of 17.8 million (insert Charles and Dukes 2008)

Table 2. Examples of global invasive species and their social, environmental, or economic impacts

Species	Type of impact	Description of impact
Comb Jelly (*Mnemiopsis leidyi*)	Economic	This small jelly, native to estuaries of eastern North and South America, was almost certainly exported to the Black Sea in ship **ballast water**. Since it was first discovered in 1992, it has single-handedly caused the collapse of the entire anchovy fishery, an industry once worth millions of dollars per year.
Brown Tree Snake (*Boiga irregularis*)	Environmental	Brown tree snakes were first introduced to Guam shortly after World War II has caused immeasurable damage to the Island's **ecosystem**. The Brown Tree Snake has been directly linked to the extirpation of several **native species** of birds (8), lizards (3), and mammals (2 bats).
Water Hyacinth (*Agrilus planipennis*)	Social	Originally from the Amazon basin, this water plant has spread to many **aquatic ecosystems** around the world. Whole communities around Lake Victoria, Africa's largest lake, have had to move to gain better access to open water and fish stocks.

Environment Canada 2013

1.4 Invasive Species in the Ecosystem

Invasive species impact many components of the **ecosystem**, with many related to the four main areas of Envirothon— aquatics, forests, soils, and wildlife. Below are just a few of the Manitoba examples of the thousands of **invasive species** that threaten healthy **ecosystems** within North America.

1.4.1 Aquatics example

Eurasian water milfoil (*Myriophyllum spicatum*) is an invasive aquatic plant native to Europe, Asia, and parts of Africa. Since being introduced in North America in the 19th century, it has become one of the most widespread **invasive species** on the continent (Dabrowski et al. 2015). It was likely introduced either through the aquarium trade or **ballast water** of ships. It is a fast growing perennial plant that ends up forming dense mats underwater and it will shade out other native vegetation species. When large stands of milfoil die, they cause a reduction of oxygen levels in the water through the process of decay. It also interbreeds with **native species** and produces an even more aggressive hybrid species that ends up pushing out **native species** from the area and decreasing overall **biodiversity (**Dabrowski et al. 2015).

Eurasian water milfoil (*Myriophyllum spicatum*)

1.4.2 Forestry example

Garlic mustard (*Alliaria petiolata*) is an invasive forest plant species native to Europe, introduced to North America in the 1800s to use as an edible herb. Garlic mustard is an allelopathic ground cover plant, which allows it to out-compete native ground cover plants, and reducing overall groundcover diversity in forests. Its ability to reproduce rapidly expands its distributions in newly settled environments (Dabrowski et al. 2015). While there are methods of control including chemical and manual, timing of control is essential in trying to decrease the potential spread of garlic mustard (Edible Wild Food 2012; Dabrowski et al. 2015). European buckthorn (*Rhamnus cathartica* L.) was introduced from Eurasia in the 1800's to be used for urban landscaping and in parks. The invasive buckthorn has come to dominate mid-level canopies in many disturbed urban forests throughout North America. It has a high fecundity and a prolific growth rate. The success of buckthorn has been accelerated by a lack of natural controls and additional **invasive species** (Nature Manitoba 2014)

Garlic mustard (*Alliaria petiolata*)

European Buckthorn (Rhamnus cathartica)

1.4.3 Soils example

Nightcrawler (*Lumbricus terrestris*)

One of the most common organisms in soils, the earthworm, is in fact an **invasive species** introduced from Europe. All of the 10 species of earthworms found in Manitoba, most are invasive. In fact, all of the last native earthworms in Manitoba were removed during the last glaciation (Ontario's Invading Species Awareness Program 2012). Earthworms can significantly alter **ecosystems** because they break down the litter layer on the forest floor (Dabrowski et al. 2015). While this helps to release **nutrients** and aerate the soil, the litter layer plays an important part in providing **habitat** for critters, and helping to keep the ground cool and moist.

1.4.4 Wildlife example

European starling (*Sturnus vulgaris)*

The European starling (*Sturnus vulgaris*) is an invasive bird species from Europe. The starling is a glossy black bird that was intentionally introduced in the late 1800s. Europeans brought them over as part of a project to bring all the birds mentioned in the works of Shakespeare to North America. Starlings outcompete **native species** for their nesting sites and food sources, as well as substantially impacting the agricultural industry. Additionally, European starlings can transmit zoonotic **pathogens** (Dabrowski et al. 2015).

1.5 Invasive species of Manitoba

Manitoba is home to a multitude of **invasive species**. Some have been recently introduced but many other were introduced so long ago that their invasive status seems to have been forgotten. Early European settlers for economic and/or cultural reasons brought some **invasive species** to Manitoba while others hitched along for the free ride. Manitoba has a diverse array of **invasive species**, including many plants, invertebrates, fish, birds, and mammals. A full list of species is difficult to produce as it is ever changing and many **invasive species** have been here so long it is difficult to recognize their presence as invasive. **Invasive species** are covered by a variety of acts, including the Tomorrow/Now Action plan, The Forest Health Protection Act, The Water Protection Amendment Act (Aquatic Invasive Species), Noxious Weed Act, and the Invasive Species Council of Manitoba's Early detection and rapid response (EDRR) plan.

2. Pathways of introduction and spread

2.1 Invasive Species Establishment

Biotic invasions can occur when a species is transported or moved into a new, often distant, **range** where their young will multiply, spread, and persist (Mack et al. 2000). Invasions of species are not a new process nor exclusively human-caused. However, the scope of these invasions, frequency, and the number of species that are now invasive has grown tremendously as a direct consequence of expanding transport and trade (Mack et al. 2000).

Most species that move into a new area fail to survive and often die on route to the new location (e.g., invertebrates in **ballast water**) (Mack et al. 2000). If the new species reach their new location, most are likely to be eradicated almost immediately by many physical or biological agents (Mack et al. 2000).   Some individual species may survive long enough to reproduce. Species decedents may survive only for a few generations before some physical or biological agent eliminates them from their area. However, a small number of these **non-native species** may persist and eventually become established. Of the **non-native species** that survive and reproduce, a few of these will go on to become **invasive species**.

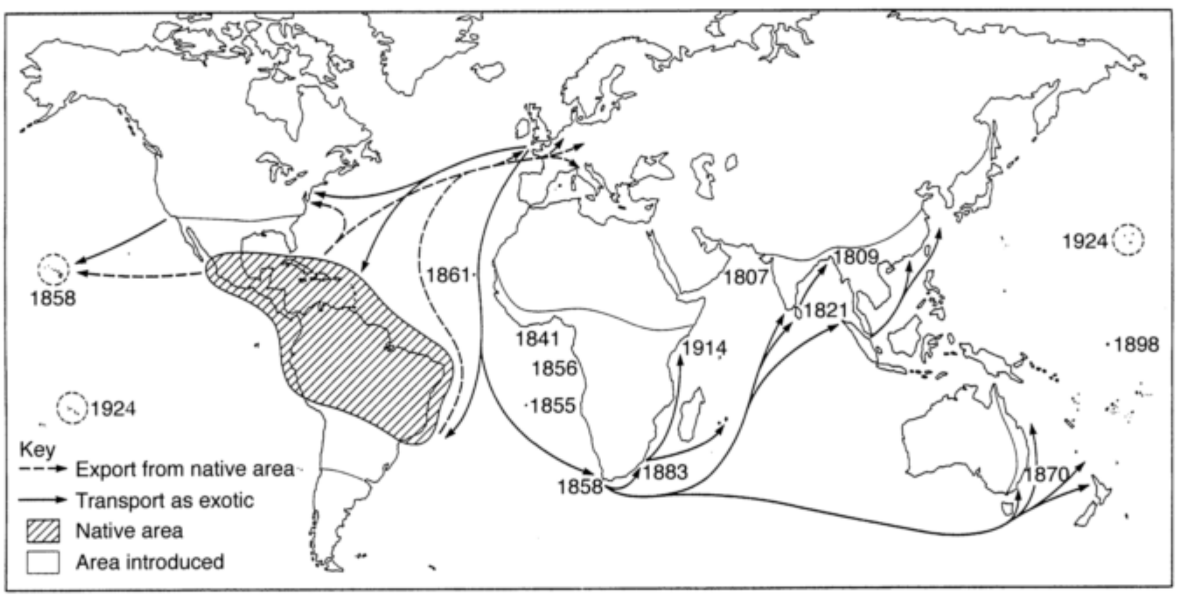
The movement of a species from a non-native immigrant to an **invasive species** often involves a delay or a lag period, followed by a period of rapid exponential increase in **population**. The rise in **population** will continue until the **invasive species** reaches the limits of its new **range** and the **population** growth rate will then stabilize (Mack et al. 2000). For example, the Brazilian pepper (*Schinus terebinithifolius*) was introduced to Florida in the 1800’s but it did not become noticeable until the early 1960’s. As of 2000, it had become established on >280 000 ha of south Florida (Schmitz et al. 2007).

2.2 Invasive Species Spread

Invasive species can be added to a community either by natural **range** extensions or because of human activity. Humans have served as both unintentional and deliberate dispersal agents for millennia (Mack et al. 2000). In the last 200 to 500 years, the increase in human movement and trade has dramatically increased this dispersal (Mack et al. 2000). Human activities may include international, national, and regional trade and travel, horticulture, gardening and ornamentals, transportation and unity corridors, seed mixtures (re-vegetation, bird seed, wildflower), recreation, wildlife, livestock, humans, and pets (including the pet trade).

The global trade market can play a large role in the spread of **invasive species**. Shipping containers and packing materials are potential sources of accidental introduction of seeds, insects, **pathogens**, and other organisms. Cheat grass (*Bromus tectorum*) was introduced to North America in 1889 through shipments of grain seeds from Europe. Wooden packing material is often used to protect shipments of goods. These materials can often harbor invasive plant **pathogens** and insects. The Asian long horned beetle (*Anoplophora glabripennis*) has been intercepted in wood packing materials in the USA and the UK.

Humans tend to take favored flora and fauna with us wherever we may travel. Some ornamental plants may escape from our landscaped areas to the native surroundings where they can establish as **invasive species**. *Hiptage benghalensis*, a native plant in Asia, is a tropical ornamental that has established itself as an **invasive species** in Australian rainforests. Undesired pets are occasionally released by their owners, many of who do not realize the ecological significance of their release. The release of the Mississippian red-eared slider (*Trachemys scripta elegans*) has led to their invasion of wetlands and lakes in the Caribbean and Europe. Burmese pythons (*Python molurus bivittatus*) has been released and successfully established in the Florida Everglades National Park, creating devastating impacts. This introduction has led to a massive removal project, where over 15 000 snakes have been removed thus far.



Some invaders have widely separated new ranges, the products of repeated human dispersal and cultivation. For example, the shrub *Lantania cantara* was carried transoceanically throughout the 19th and early 20th century to many subtropical and tropical locales where it has proliferated. Years refer to dates of introduction in widely separated locales. (Modified from Mack et al. 2000)

Aquatic and marine **invasive species** often are introduced through hull fouling and **ballast water**. Current and expanding global trade threatens to erode biological barriers that have previously separated diverse **ecosystems**. It has been previously estimated that over two-thirds of all non-native algal species globally and about three quarters of all non-native marine invertebrates in Hawaii were introduced through biofouling. Approximately 3-5 billion tonnes of **ballast water** is transferred through the world annually. **Ballast water** is estimated to transport 7000 species daily.

Examples of unintentional and intentional introductions:

Unintentional introductions:

- **Ballast water** of ships
- Movement of raw wood, forest byproducts, firewood, and other forest products
- Packing materials
- Canals and changes to waterways
- Movement of equipment, such as camping gear, backpacks, hiking boots, construction equipment, all-terrain vehicles
- Movement of diseased wildlife, including **animal** and **animal** by-products such as carcasses or products made from them
- Horses
- Escape of non-native wildlife in captivity (e.g., exotic pets)
- Transportation of topsoil
- Recreational and commercial boating and fishing

Intentional introductions:

- Dumping bait buckets
- Releasing fish stock into public waters
- Releasing species through horticulture or pet trades
- **Import** of plants for gardening and landscaping
- Intentional stocking or introduction (e.g., biocontrol)
- Illegal release (e.g., cultural release)

Secondary movement of **invasive species** also impacts their distribution. Secondary movement occurs once the species has been introduced to a new area and starts spreading further into other locations nearby. The further spread can occur through natural (e.g., active movement or through use of other animals (such as fur of animals, bottom of waterfowl feet, seeds in digestive tract etc.) or human-assisted movement.

2.3 Impact of Invasive Species

2.3.1 Aquatic Invasive Species

Water is one of the most common environments in which **invasive species** spread. Unwelcome species have found their way into North American water bodies through numerous pathways including commercial vessels transporting goods in global trade (Dabrowski et al. 2015). Some **invasive species** such as the Zebra Mussels (*Dreissena polymorpha*) have been introduced because they hitchhike on equipment, cling to pipes and **aquatic** structures, and are transported in the ballast of boats. Zebra mussels can clog pipes and hydroelectric equipment, outcompete and smother native mussel populations, reduce plankton abundance, among other devastating effects. The spiny water flea (*Bythotrephes longimanus*) is a planktonic crustacean that is distinguished by its long straight tail that is twice its body length. Originally from Northern Europe and Asia, it was accidently introduced through **ballast water** to the great lake in the mid-1980's (Liebig et al. 2015). The spiny water flea has caused major changes in the zooplankton community structure and competes directly with small fish (Liebig et al. 2015). The tail spines of the spiny water flea also hook on fishing lines, fouling fishing gear (Liebig et al. 2015). Spiny water flea has been implicated as a factor in the decline of alewife (*Alosa pseudoharengus*) in Lakes Ontario, Erie, Huron, and Michigan (Liebig et al. 2015). The spiny water flea also competes with, and possibly preys on, *Leptodora kindtii* (a large zooplankton) and may be a causal factor in the decline of *Leptodora* (Liebig et al. 2015). The presence of spiny water flea was recently reported in the Winnipeg River and Lake Winnipeg (Government of Manitoba).

Spiny water flea (*Bythotrephes longimanus*)

Sea Lamprey (*Petrmyzon marinus*)

Both freshwater and marine **ecosystems** are impacted by **aquatic invasive species**, which can have consequences on the fishing industry. **Aquatic invasive species** have been introduced intentionally in some cases to support new fisheries, to display in aquaria, or to help with erosion control. Sea Lampreys (*Petrmyzon marinus*) were introduced unintentionally into the Great Lakes in the 1900s through **ballast water**. These fish have round sucker-like mouths with sharp teeth, which they use to attach themselves to fish and suck their blood. If the fish survives, the wounds that are left open are prone to infections (Dabrowski et al. 2015). Whether species are intentionally or unintentionally introduced into **aquatic ecosystems**, they are especially challenging to manage because of the fluidity of movement within **aquatic ecosystems**.

2.3.2 Forestry Invasive Species

The **introduction** of **invasive species** into forest **ecosystems** occurs through a variety of pathways. **Invasive species** are introduced into forests recreational activities, transportation corridors, or through natural movement of species. Introduced plant and **animal** species can alter natural functions in forests by removing the canopy, destroying the understory, or preventing natural regeneration. Forests and trees can have difficulty defending themselves against **invasive species** due to a lack of natural resistance or an inability to relocate. As a result, **invasive species** may result in high tree mortality (Dabrowski et al. 2015).

Invertebrates

Emerald Ash Borer (*Agrilus planipennis*)

Emerald Ash Borer galleries

Many species of invertebrates can directly impact the health of a tree. Some invertebrates may defoliate trees or bore into them while going through one of the stages of their life cycle (Dabrowski et al. 2015). Wood boring insects are those that bore into the wood during the larval stage. Invasive wood boring insects are often moved through the transportation of wood products into new areas, in addition to the natural movement of the species. Human transportation often speeds up the rate in which an invasive may move within and to a new **ecosystem**. For example, the spread of Emerald Ash Borer (*Agrilus planipennis*, EAB) occurred at a much quicker rate than expected in the eastern part of North America because of the movement of firewood (Herms and McCullough 2014). Since its accidental **introduction** from Asia, this invasive **pest** has killed untold millions of ash trees (*Fraxinus* spp.) in forest, riparian, and urban settings (Herms and McCullough 2014). The larval stage (grub) of EAB can stay in the wood and exits upon arrival to a new area (Herms and McCullough 2014). The challenge with wood boring insects is that they grow within the tree and can be difficult to detect until they have already created damage and potential tree mortality (Herms and McCullough 2014). Unchecked, EAB could functionally extirpate ash with devastating economic and ecological impacts (Herms and McCullough 2014).

Gypsy Moth
(*Lymantria dispar dispar*)

Foliage feeding insects eat the leaves of trees, and multiple years of defoliation can cause tree mortality. These insects have a native **range** in which they can move, however humans speed up the movement of these species by transporting a life stage of that insect (Dabrowski et al. 2015). For example, the Gypsy Moth (*Lymantria dispar dispar*) can be introduced to new forests through the movement of the larval stage of the insect (the caterpillar) by a car, boat or other means to a new **ecosystem**. The larva or caterpillar of the Gypsy Moth is the damaging stage as it consumes the leaves of trees. They can consume tremendous amounts of leaf material in a short period of time (as much as one square foot of leaves per day). When populations reach outbreak proportions, the caterpillars can completely defoliate host trees over a wide geographic area. Consistent or repeated defoliation over several years can have devastating effects, often leading to tree stress and death (Grupp 2008).

Plants

Invasive plant species introduced into forest **ecosystems** can outcompete native ground cover and impact forest regeneration. Plant species can be introduced through natural seed dispersal from local gardens or along transportation corridors. Plant species that are nuisances, either native or non-native, are also known as **weeds**. These are plants in the wrong place (Dabrowski et al. 2015).

Pathogens

Forest **pathogens** can affect the whole tree, causing defoliation, root decay and stem cankers that reduce the distribution of **nutrients**. The movement of plant material around the world has increased the movement of **pathogens** into native forest **ecosystems** (Dabrowski et al. 2015). Beech Bark Disease is caused by the actions of the beech scale insect (*Cryptococcus fagisuga*) and the fungus (*Nectina faginata*) that infect beech trees (*Fagus grandifolia*). Beech bark disease was first documented in Europe in 1849. The first outbreak of beech bark disease in North America appeared in American Beech (*Fagus grandifolia*) in Nova Scotia around 1920. The **pathogen** then started to spread south and west. In 1929, the first case of beech bark disease was found in the United States in Massachusetts. By 2004, the disease had been found as far west as Michigan and as far south as western North Carolina. The disease is complex in that it is a combination of an introduced scale insect and a native fungus. The introduced scale insect provides an opening in the tree for the native fungus. The insect feeds on the sap of the tree by creating a wound in which the fungus establishes. The disease results in significant die back of the tree, not necessarily causing mortality, but impacting important wildlife **habitat** and food sources. Spread of these disease-causing **pathogens** occurs through the movement of wood and forest products, as well as natural dispersal through animals and air.

Beech Bark Disease

Dutch elm disease is caused by a fungus from the sac fungi (Ascomycota) and is spread by an elm bark beetle (*Scolytus* spp.and *Hylurgopinus rufipes*). It infects elm trees, with

Dutch Elm Disease

American elms being the most susceptible. The infection blocks water movement in elm trees and it will eventually lead to the death of the entire tree. Elm bark beetles breed underneath the bark of the tree. If the tree they have chosen is infected by Dutch elm disease, it will carry the spores with them to the next elm tree, continuing the infection cycle (Government of Manitoba).

2.3.3 Soil Invasive Species

Soils act as a substrate for living materials including seeds and invertebrates. Movement of soil locally and globally, also introduces the potential movement of these organisms. When a new species finds favorable **habitat** and the right soil conditions, it can establish and spread quickly. *Phragmites* is a grass species that quickly establishes on roadsides in disturbed ditches and habitats. Its seeds are easily transported by wind and once established, grow into dense stands rapidly because of its aggressive reproductive capabilities. Not only do the seeds spread easily, but the roots of the plant also release toxins that hinders the growth of any surrounding plants. In Manitoba from 2010 to 2012, the invasive *Phragmites australis* has been found in several localized paths in Winnipeg, Headingley, and the capital region.

Phragmites australis

2.3.4 Wildlife Invasive Species

The **introduction** of a wildlife species into a new **ecosystem** can have varying impacts. Like any **invasive species**, there have been many examples worldwide in which wildlife species have been introduced intentionally and unintentionally. **Intentional introductions** may have occurred for hunting or for the control of another species. The Sitka black tailed deer (*Odocoileus hemionus sitkensis*) on the Queen Charlotte Islands of British Columbia were first introduced as a food source for islanders. Since there are no natural predators on the islands, populations have exploded and as a result of their eating habits, they have altered the regeneration of west coast forests (Dabrowski et al. 2015).

Sitka black tailed deer (*Odocoileus hemionus sitkensis*)

Unintentional introduction of invasive wildlife has occurred throughout the globe. One example of an **unintentional introduction** is related to the pet trade, is the Red-eared slider (*Trachemys scripta*). This turtle species is a common pet, however it is often "released" into the wild because families no longer want the pet, or there is an assumption that the pet should go live in its natural **environment**. Unfortunately, in North America, this non-native turtle species competes with **native species** for food and **habitat** and can also bring foreign

pathogens into the area further affecting the populations of **native species** (Dabrowski et al. 2015).

Wild Boar (*Sus scrofa*)

Wild boars were introduced to Manitoba in the early 1980's as an agricultural diversification initiative (Government of Manitoba). A number of animals escaped from farms, and started to establish wild populations. Wild boars are intelligent, hardy, and adaptable. They have been able to quickly acclimate to harsh conditions, a variety of habitats, and the presence of human populations. Manitoba has been declared a wild boar control area, which means that only a resident of Manitoba may take wild boar any time of the year (Government of Manitoba).

3. The invasive species management cycle

Four stages of the **invasive species** management cycle are commonly identified as follows: prevention, detection, response and control, and manage and adapt (Dabrowski et al. 2015; United States Environmental Protection Agency).

Identifying future **invasive species** and taking steps to prevent their dispersal and **establishment** is an enormous challenge to both conservation and international commerce (Mack et al. 2000). Preventing, detecting, responding, and controlling **invasive species** are key to their management. Many strategies can be used:

1. Keep potential invasive species out
2. Eradicate possible invasive species soon after invasion
3. Biological control
4. Chemical control
5. Mechanical control

Control of **invasive species** is most effective when it uses a long-term, **ecosystem**-wide strategy versus a tactical approach focused on battling individual species (Mack et al. 2000).

3.1 Preventing invasive species

Preventing the movement of **invasive species** into an area is the most cost-effective and ecologically sound method to control **invasive species** (Mack et al. 2000). Understanding the methods in which species can move into a new **ecosystem** helps to ensure that these pathways are monitored or reduced/eliminated. **Monitoring** common invasion pathways including ship **ballast water**, wood packing material, pet trade, and horticultural plants, can reduce the movement of **invasive species**. Adopting strict **quarantine** laws, like a "guilty until proven innocent" approach, would be a productive first step in preventing the global spread of many **invasive species** (Mack et al. 2000). Prevention has to be a focus at all levels, from international to regional.

On international and national levels, preventing the **introduction** of any invasive alien species occurs at the location of entrance into the country or the location of **import**/export. For example, at the border of Canada and the United States, there are restrictions on transporting certain products across the border including soils, fruits, wood, and some live fish (Dabrowski et al. 2015). When you are travelling, you are required to declare this on the declaration card. This includes the borders of countries, ports, train stations, and airports. This can present a challenge where borders span over a great distance, or where there are multiple points of entry (Dabrowski et al. 2015). While humans may see borders between countries, remember that for **animal** and plant life, these borders are non-existent and do not align with **ecosystem** boundaries. The natural movement of species can easily occur over established borders (Dabrowski et al. 2015).

On a regional level, prevention focuses on ensuring that an **invasive species** that has already been introduced to a neighbouring province or state, or within a province or state, does not spread beyond the initial **introduction**. This often includes extensive education to the community to communicate the potential threat of **invasive species** and ways in which to prevent the **introduction** (Dabrowski et al. 2015).

3.2 Detecting invasive species

Detecting if an **invasive species** has already entered into the new **environment** is the next step of the **invasive species** management cycle. It is important to quickly detect the species to ensure that there is rapid response to prevent its spread and **establishment** (Dabrowski et al. 2015). Research and education are critical parts of the early detection process. Learning what to look for and educating the community on the **invasive species** can provide valuable information for the research part of detection (Dabrowski et al. 2015). Several citizen science examples exist in which citizens are educated on reporting **invasive species** including hotlines (e.g. Invading Species Hotline) or online mapping tools (e.g. EDDMaps). Some ways in which species are detected through **monitoring** techniques include pheromone traps, surveys, and looking for signs of the **invasive species** (Dabrowski et al. 2015).

3.3 Responding to and controlling invasive species

Once an **invasive species** is detected, it is important to respond quickly and put in place control actions. It is much easier to eradicate **invasive species** if they are discovered quickly and the **population** levels are still low. A rapid response can help to lower the overall impact of an **invasive species**. While **eradication** may be the ultimate goal, this can be challenging and costly. If it proves impossible to completely remove an **invasive species**, early action can keep **population** sizes at low levels. For example, Giant African snails (*Achatina fulica*) were effectively eliminated from Florida.

Many strategies can be used to control **invasive species** once they have established themselves in a location. These include: **biological, chemical, and mechanical**. Each method can be used individually or in combination with each other to obtain the best results to control the **invasive species**. It is important to research and use the best management practices to select the correct approach for each **invasive species** and to understand the timing of control.

3.3.1 Biological control

The **introduction** of an enemy of an **invasive species** (e.g., parasite, predator, or competitor) can be used to reduce the **population** size of the **invasive species**. The **biological control** may consume the **invasive species** or cause it to become diseased and die. The enemy of the **invasive species** may be a natural enemy from its original **range**. For example, introducing *Cactoblastis cactorum*, a moth from South America, whose caterpillar feeds on the cactus, has effectively controlled prickly pear cactus. The enemy of the **invasive species** also could be from a different region (a new association) because the **invasive species** may have not evolved the defenses to such an enemy. For example, *myxoma*, a virus from South America, has been used to control European rabbits in Australia. In Spruce Woods Provincial Park, Leafy Spurge beetles (*Aphthona nigriscutis* and *Aphthona lacertosa*) are used to consume the Leafy spurge plant that is overtaking the mixed grass prairies.

Purple loosestrife (*Lythrum salicaria*) is an invasive plant that outcompetes native vegetation in wetland **ecosystems**. **Biological control** in the form of a suite of four different insect species has been used to help control the loosestrife **population** (Wisconsin Department of Natural Resources 2015). These beetles feed on leaves and new growth and have successfully helped to control loosestrife populations.

However, the **introduction** of a new species to control an **invasive species** may cause its own problems. It requires extensive research prior to the **introduction** of another species to determine its potential impact on the native **ecosystem**. In many cases, especially in Australia and New Zealand, the species introduced to control the **invasive species** may become an **invasive species** in its own right. The cane toad (*Rhinella marina*) was introduced from South America into Australia as a way of reducing the cane beetle (*Dermolepida albohirtum*) populations because this proved successful in other parts of the world. Unfortunately, the toad had little impact on the beetle populations. Cane toad populations have exploded across Australia and they have impacted native **biodiversity**.

3.4.2 Chemical control

Chemicals may be used to kill **invasive species**, especially plants. Though chemicals can effectively control some species (e.g., water hyacinth in Florida) **chemical control** have some issues. **Chemical control**s can be expensive and may only be effective for a limited amount of time, as **invasive species** can evolve to be resistant to pesticides. Further, chemicals may affect non-target organisms. In Manitoba, potash has recently been used in an attempt to eradicate zebra mussels from four harbors in Lake Winnipeg. Unfortunately, it became apparent that the zebra mussels had already become established in colonies elsewhere in the lake because zebra mussels recolonized those four harbors after treatment. This example highlights the importance of the necessity of continued treatments in difficult to control established populations.

3.4.3 Mechanical control

Mechanical control often involves machinery or human effort to remove the **invasive species**. This can involve actions such as using a saw to cut down invasive trees, pulling out invasive plants, removing nests, and trapping and hunting invasive animals. It can also include the creation of physical barriers to prevent the **introduction** or spread of **invasive species** (e.g. fishways, controlled burns).

Mechanical control has been an effective control strategy for invasive *Tamarix* in the USA. Timing can be extremely important in **mechanical control**. For example, removing garlic mustard plants can be effective when it is done at the right stage of its life cycle. Remove too late into the year, and the garlic mustard may have already released its seed, and physical removal of the plant at this time may in fact spread more seed into the soil.

3.4.4 Best Management Practices

Choosing a method or combination of methods to control **invasive species** involves extensive research and consideration. The cost and side effects of the plan also must be considered before implementation can take place. In some cases, entire **ecosystem** management has been used to control **invasive species**. Entire **ecosystems** are subject to regular treatments (e.g., simulated natural fire regime) that will favour well-adapted **native species** over most of the **invasive species**. It is an effective method of controlling multiple **invasive species** within one region. For example, the Prairie Management Plan is in place at Spruce Woods Provincial park to control the spread of **invasive species** and to protect our species at risk.

Regardless of the method of control used, it is critical that **monitoring** is done to assess the effectiveness of the method chosen. **Monitoring** should be done to not only assess the **invasive species**, but any potential impact on the native **ecosystem** as well (Dabrowski et al. 2015).

3.5 Long-term Management

The final step in the process is to implement management actions and take steps to control and protect against the impacts of **invasive species** (Dabrowski et al. 2015).

3.5.1 Site Prioritization

When creating management plants, it is important to make the most of resources by prioritizing **invasive species** control.

1. Protect areas where **invasive species** are absent or just appearing
2. Protect rare species and communities
3. Protect important habitats and land values (e .g. industry)

4. Cost and effort:
    a. How hard is it to control?
    b. What treatments are effective?
    c. How costly/time consuming are they?
    d. Does the species spread rapidly?

(Dabrowski et al. 2015)

Management actions:

- Asian carp control in the US (including removal of Asian carps from the Mississippi and Illinois rivers; electric barriers; (http://asiancarp.us/documents/2015Framework.pdf))
- Exotic Plant Management Teams (http://www.nature.nps.gov/biology/invasivespecies/EPMT_teams.cfm)
- Manitoba Weed Supervisors Association (http://www.mbweeds.ca/)
- Sea Lamprey Control Program (http://www.dfo-mpo.gc.ca/species-especes/lampreylamproie-eng.htm)
- Zebra Mussels (http://www.gov.mb.ca/waterstewardship/stopais/zebra_mussel.html)

3.5.2 Management Costs

Controlling and managing an **invasive species** can be very costly. It is not only the cost of management but also the cost that the impact of the **invasive species** has on its new **environment** (Dabrowski et al. 2015). Every year invasive plants cost the forestry and agricultural industries in Canada about $7.3 billion (Government of Canada). This cost includes the loss of productivity to these industries, as well as costs associated with trying to control and manage **invasive species** (Dabrowski et al. 2015). In Manitoba, leafy spurge cost the province an estimated $19 million per year in protecting the land, including grazing and public land. **Invasive species** in total cost the U.S. about $137 billion annually and some of the most destructive species cost the government in excess of $100 million annually. Some of the 2013 estimated economic losses due to **invasive species** are listed below:

Country	Estimated losses (CAD$) per year
Globally	1.5 trillion
U.S.A.	137 billion
EU	18 billion
China	16 billion
New Zealand	3 billion
UK	3 billion

Costs play an important part of management decisions. Costs are spread out over a variety of different groups involved, and collaboration is important to maximize cost efficiency (European Commission 2013; Dabrowski et al. 2015).

4. Roles and responsibilities

4.1 Role and responsibilities of governments

The management of **invasive species** is often difficult and complex, bringing together different levels of government, non-governmental organizations, and the public to help prevent, detect, control, and manage **ecosystems** (Dabrowski et al. 2015).

Regulations, policies, and **legislation** are developed through all levels of government including municipal, provincial/state, national, and international. They are meant to prevent and minimize the spread of **invasive species** by placing **regulations** on the further spread, transport, and **import** of certain **invasive species** (Dabrowski et al. 2015).

4.1.1 International

The following are a list of guiding principles from the *United Nations Environment Programme's Convention on Biological Diversity* from 2000 (Convention on Biological Diversity 1999)). While these are not law-abiding principles, the goal is to guide countries in developing their own strategies and work collaboratively on an international level (Dabrowski et al. 2015). Some of the guiding principles for the prevention, **introduction**, and mitigation of impacts of **invasive species** are included below:

- General
    - Precautionary principle: lack of information regarding the impact of a **non-native species** should not preclude the preventative action to reduce the risk of **introduction** of that **non-native species**; lack of certainty about the long-term implication of an invasion should not be a reason for postponing **eradication**, containment or control measures
    - Countries should understand their role in preventing the **introduction** of **invasive species** and should take action to minimize the risk
    - Countries should research and **monitor** any potential **invasive species**
    - Countries should facilitate education and public awareness associated with the **introduction** of **invasive species**
- Prevention
    - Countries should implement border control and **quarantine** measures
    - Countries should support the Global Invasive Species Database and exchange information
    - Coordination should occur between countries to prevent potential of invasive **introduction** by sharing information
- Introduction of Species
    - No **intentional introduction** without the authorization of the national authority; a **risk assessment** should be part of the evaluation process;

benefits of an **intentional introduction** should greatly outweigh the adverse effects or costs
    - All countries should have provisions to address **unintentional introductions** including statutory and regulatory measures with the appropriate resources; common pathways of **introduction** need to be identified and provisions to minimize such introductions should be in place
- Mitigation of Impacts
    - Once a species is detected, steps should be taken to eradicate, contain and control, and mitigate effects
    - **Eradication** should be given priority where it is feasible and cost-effective
    - Containment (limiting spread) should be a strategy where **eradication** is not appropriate or possible
    - Control measures should focus on mitigating effects rather than merely on reducing numbers of the **invasive species**

(Convention on Biological Diversity 1999; Dabrowski et al. 2015)

Global Invasive Species Database

The *Global Invasive Species Database* aims to increase awareness about **invasive species** and to facilitate effective prevention and management activities. The GIS database is managed by the *Invasive Species Specialist Group of the Species Survival Commission of the International Union for Conservation of Nature*. The database allows you to search by location or species to determine the **invasive species** that has been found implement border control and **quarantine** measures.

4.1.2 Canada

Canada was the first industrialized country to ratify the *United Nations Convention on Biological Diversity* in December 1992. Under Article 8(h) of the Convention on Biological Diversity, Canada is required to "prevent the **introduction** of, control or eradicate those alien species which threaten **ecosystems**, habitats or species". The Convention on Biological Diversity required the development of a national **biodiversity** strategy, which was released in Canada in 1995. An updated *Invasive Alien Species Strategy for Canada* was developed in 2004 to establish a framework to address **invasive species** by meeting the following four strategic challenges (Environment Canada 2013; Dabrowski et al. 2015):

- Integrating environmental considerations into decision-making with economic and social factors
- Enhancing coordination and cooperation to respond rapidly to new invasions and pathways of invasion
- Strengthening programs to protect natural resources under pressure from increased global trade and travel

- Maximizing collaboration to ensure limited resources are used on highest priority issues
- The main focus of Canada's **invasive species** management is to focus on the pathways of **introduction**. One regulation is Canada's **ballast water** control and management regulation, which forces ships that are entering Canadian waters to treat and or exchange their **ballast water** before entering into Canadian Jurisdiction. This is done to help prevent the **introduction** and spread of invasive **aquatic** species into Canadian waters via **ballast water** (Transport Canada 2012).

Environment Canada plays a lead role in the **invasive species** strategy for Canada and Fisheries and Oceans Canada plays a key role in the prevention and management of **aquatic invasive species (**Dabrowski et al. 2015). They work alongside provincial ministries each taking on various roles and responsibilities in the management of **invasive species (**Dabrowski et al. 2015).

Aquatic Invasive Species Regulations

The *Aquatic Invasive Species Regulations* provides a suite of regulatory tools to help control and manage **aquatic invasive species**. These **regulations** were published on June 17th, 2015. The current structure of management includes a variety of different levels of government (Government of Canada; Dabrowski et al. 2015).

The regulations include:

- List of prohibited species: Prohibitions on **import**, transport, possession and/or release of certain species. This provides a first line of defense to prevent the **introduction** of **aquatic invasive species** by enforcing this at the Canadian border. Species include Asian Carp and Zebra Mussels.
- List of controlled species: List of species in specific geographic areas for which control activities may be undertaken. Species include green crab and tunicates.
- General prohibition: Prohibition against the **introduction** of any **aquatic** species into an area where it is not native without a permit or license.
- Control and eradication: **Regulations** facilitate the rapid response and control of **aquatic invasive species**.
- Enforcement powers: Enforcement officials (i.e. Fishery Officers and Fishery Guardians) have the power to enforce the prohibitions on imp ort, possession, transport and release of listed species, and the general **introduction** of non-indigenous species. They also can take actions to control the listed species.

Forestry Invasive Species Regulations

The *Forest Health Protection Act* provides comprehensive **legislation** that protects forest resources from invasive forest threats. The act tries to protect the health of all trees and forests in Manitoba by preventing **invasive species** entering or establishing in the province; detecting, containing, suppressing, and eradicating **invasive species**; and developing programs to protect and promote the health of trees and forests (Government of Manitoba).

The regulations include:

- Control and eradication: It sets out actions by provincial inspectors to prevent or control an outbreak of an **invasive species**
- Communication: allows notices to be issued prohibiting the movement of an **invasive species** or related material,
- Enforcement powers: gives inspectors the power to issue a **quarantine** order (prohibiting moving and tampering with any possibly infected forest products).
- Forest threat response zone: in established zones, moving, pruning, or work on certain forest products can be prohibited.
-

4.1.3 United States

At the federal level, the *Lacy Act* and the *Animal Health Protection Act* both direct **invasive species** management actions for the protection of agricultural and natural resources (Dabrowski et al. 2015). In the United States, the *National Invasive Species Council* (NISC) is responsible for ensuring that Federal programs and activities on the management of **invasive species** are well organized, effective and efficient (Dabrowski et al. 2015). The NISC consults and receives advice from a non-federal group of experts and stakeholders called the *Invasive Species Advisory Committee*. Some major roles and responsibilities of the NISC include:

- Drafting and revising of the National Invasive Species Management Plan
- Drafting of the Interdepartmental Invasive Species Performance Budget
- Reviewing progress under the National Invasive Species Management Plan and EO 13112
- Working with the Department of State to provide input for international **invasive species** standards

(National Invasive Species Council 2005; Dabrowski et al. 2015)

The *National Invasive Species Act* (NISA) is a federal law intended to prevent **invasive species** from entering inland waters through **ballast water** carried by ships. NISA authorizes regulation of **ballast water**, funding for prevention and control research, and education and technical assistance programs to promote compliance with **regulations** (Dabrowski et al. 2015).

National Strategy and Implementation Plan for Invasive Species Management

This *National Strategy* was developed for the US Forest Service in their efforts to reach their goals. The *National Strategy* follows a similar cycle to the **invasive species** management cycle of prevention, early detection and rapid response, control and management, and rehabilitation and restoration (Dabrowski et al. 2015).

National Invasive Species Information Center

The *National Invasive Species Information Center* (NISIC) is the gateway to **invasive species** information, covering Federal, State, local and international sources. The NISIC manages the following website that serves as the main portal of information for **invasive species** (http://www.invasivespeciesinfo.gov/index.shtml) (Dabrowski et al. 2015).

4.1.4 Canada-United States Relations

Canada and the United States not only share extensive land borders, but they also share the Great Lakes. They are a major source of transportation and exchange of goods internationally through the St. Lawrence Seaway (Dabrowski et al. 2015). All vessels that are entering into the seaway on their way to the Great Lakes are required to exchange their **ballast water** and flush their tanks prior to entering. All vessels are checked through a joint United States/Canadian inspection program. These **regulations**, along with **monitoring** have significantly reduced the risk of **aquatic invasive species** (Dabrowski et al. 2015).

The *Great Lakes Panel on Aquatic Nuisance Species* coordinates the development of education, research, and **policy** to prevent new **aquatic invasive species** from entering the Great Lakes basin and to control and mitigate those populations already established (Dabrowski et al. 2015). This panel is a coordinate effort among states and provinces surrounding the Great Lakes. Since 1991, the Great Lakes Panel has worked to prevent and control the occurrence of **aquatic** nuisance **species** (aka **invasive species**). The Great Lakes Panel focuses its efforts on education, research coordination and **policy** coordination (Dabrowski et al. 2015).

4.1.5 Provincial

The *Water Protection Amendment Act* provides protection for Manitoba's water resources and **aquatic ecosystems**. Along with provisions for improving water quality standards, the Act also prohibits and regulates harmful **non-native species** (Dabrowski et al. 2015). Persons are not to possess **aquatic invasive species** in Manitoba, introduce, release or transport **aquatic invasive species**. The *Forest Health Protection Act* provides comprehensive **legislation** that protects forest resources from invasive forest threats (Dabrowski et al. 2015).

Invasive Species Council of Manitoba works to promote awareness, education, cooperation and action regarding **invasive species**. This non-profit organization is a collaboration of various members representing municipalities, community groups, associations, government and parks. The goal is to provide provincial leadership for **invasive species** coordination within Manitoba (Dabrowski et al. 2015;Government of Manitoba 2015).

4.1.6 Municipal

Municipalities work to manage the **introduction** and spread of **invasive species** within their borders. As municipalities tend to work directly with their communities, they can play an important role in engaging citizens to be actively involved with the management of **invasive species (**Dabrowski et al. 2015). Additionally, municipalities work in partnership with neighbouring communities to communicate potential threats and best management practices. An integrated approach locally can help to prevent **introduction** or slow the spread of already introduced **invasive species (**Dabrowski et al. 2015).

4.2 Role of Non-governmental organizations

Non-Government Organizations (NGOs) play an important role in promoting awareness, education, and management of **invasive species**. A large part of the work that is done is around community engagement including removal of **invasive species**, education, and preventing the **introduction** and spread (Dabrowski et al. 2015). NGOs may conduct research on different **invasive species** and help to determine best management practices. They work to provide the public with information such as which **species** are invasive, how they are introduced, how they spread, and how to manage them (Dabrowski et al. 2015). Non-government organizations can also play a critical role in bringing together different groups that are impacted by **invasive species**. For example, they may bring together landowners and municipalities to work together to manage an **invasive species (**Dabrowski et al. 2015).

The *Canadian Council on Invasive Species* (CCIS) works collaboratively across jurisdictional boundaries to help identify **invasive species** and reduce their threat and impacts. *Invasive Species Council of Manitoba* provides a centralized and coordinated province-wide leadership body and adopts a collaborative approach to the prevention, early detection, management and potential **eradication** of **invasive species** in Manitoba.

4.3 Role of the Individual

Individuals have a large part to play in preventing and reducing the spread of **invasive species**. Every individual can educate themselves on the issue of **invasive species**, particularly understanding what an **invasive species** is and the potential negative impact that they can have. Additionally, learning how to identify the different **invasive species**, and learning how to properly deal with **invasive species** on your property are also important.

Citizen Science

Individuals can become a part of an *Early Detection and Rapid Response* (EDRR) *Network* and help to slow the spread of **invasive species** and reduce their environmental and economic impacts. Everyone can be trained to identify, track and control **invasive species (**Dabrowski et al. 2015).

Individual responsibilities:

- Make sure the plants you are buying for your home or garden are not invasive.
- Contact your province's native plant society for a list of native plants.
- When boating, make sure to clean your boat thoroughly before putting it into a different body of water. Also make sure to never dump your bait while fishing.
- Clean your boots before you hike in a new area.
- Don't take home any animals, plants, shells, firewood, or food from different **ecosystems**.
- Never release pets into the wild.
- Volunteer at your local park, refuge, or other wildlife area to help remove **invasive species**. Most parks also have **native species** restoration programs.

(Nature Conservancy 2015)

5. Tools in the toolbox

5.1 Monitoring

Prevention, early detection, rapid response, and effective management are key for saving habitats from **invasive species**. **Invasive species monitoring** is essential in making well-informed management decisions to meet goals effectively and efficiently. **Monitoring** is a survey repeated through time to determine changes in the status and demographics of **abiotic** resources, **species**, habitats or ecological communities. It is conducted on a regular basis, following trends over time, and involves collecting data through sampling. **Monitoring** is a good way of seeing how an area may have changed over time.

Monitoring:

- Detects new populations
- Determine status and trends over time in **population** size and distribution of **species**
- Determine the effects of the **invasive species** on the **ecosystem**
- Measure the success of restoration projects
- Measure the success of management practices that are meant to prevent the **introduction** and/or spread of an **invasive species**

(United States Fish and Wildlife Service 2012)

5.1.1 Types of Monitoring

- Monitoring for early detection
    - Implemented before **species** arrive in an area. Provides information on baseline (pre-invasion) conditions and helps detect **species** early on when **eradication** and/or containment efforts may be possible. Most cost effective and control efforts are minimal
    - Early Detection and Rapid Response (EDRR)— **Citizen science** that focuses on educating the public to help **monitor** to prevent **invasive species**' impacts
- Monitoring the effects of management actions on target **invasive species**
    - Helps determine the most effective control method and if actions should continue
- Monitoring the effects of management actions on non-target **species** and the **environment**
- Monitoring the status and trends of target **species** populations
    - Measuring the currents characteristics of a **population** including metrics such and abundance and distribution

(Dabrowski et al. 2015).

5.1.2 Monitoring Techniques

Invasive species can be monitored using a variety of techniques. The techniques used depend on the **species** being studied. Different techniques are used for animals versus plants, **terrestrial** versus **aquatic**, **pathogen** versus invertebrate (Dabrowski et al. 2015). Techniques also vary depending on the timing of sampling, type of **monitoring** being performed, and cost effectiveness (Dabrowski et al. 2015).

(1) Collection of Dead Animals
- Samples are collected from dead animals to look for **pathogens**

(2) Pheromone Traps
- Pheromone traps use chemicals that attract the **species** and help with presence/absence surveys. The benefit of pheromone traps is that they are sensitive and can attract **species** even at low **population** levels.
- Commonly used to collect invertebrates, such as insects.

(3) Live trapping
- Traps are set up to capture vertebrates (e.g., mammals, birds, reptiles, amphibians, fish, etc.). These animals can be tagged (marker put on them for either tracking or as a mark to show that they have already been counted), tested for **pathogens** and signs of disease, or simply counted and released.
- Used in **terrestrial** and **aquatic** environments

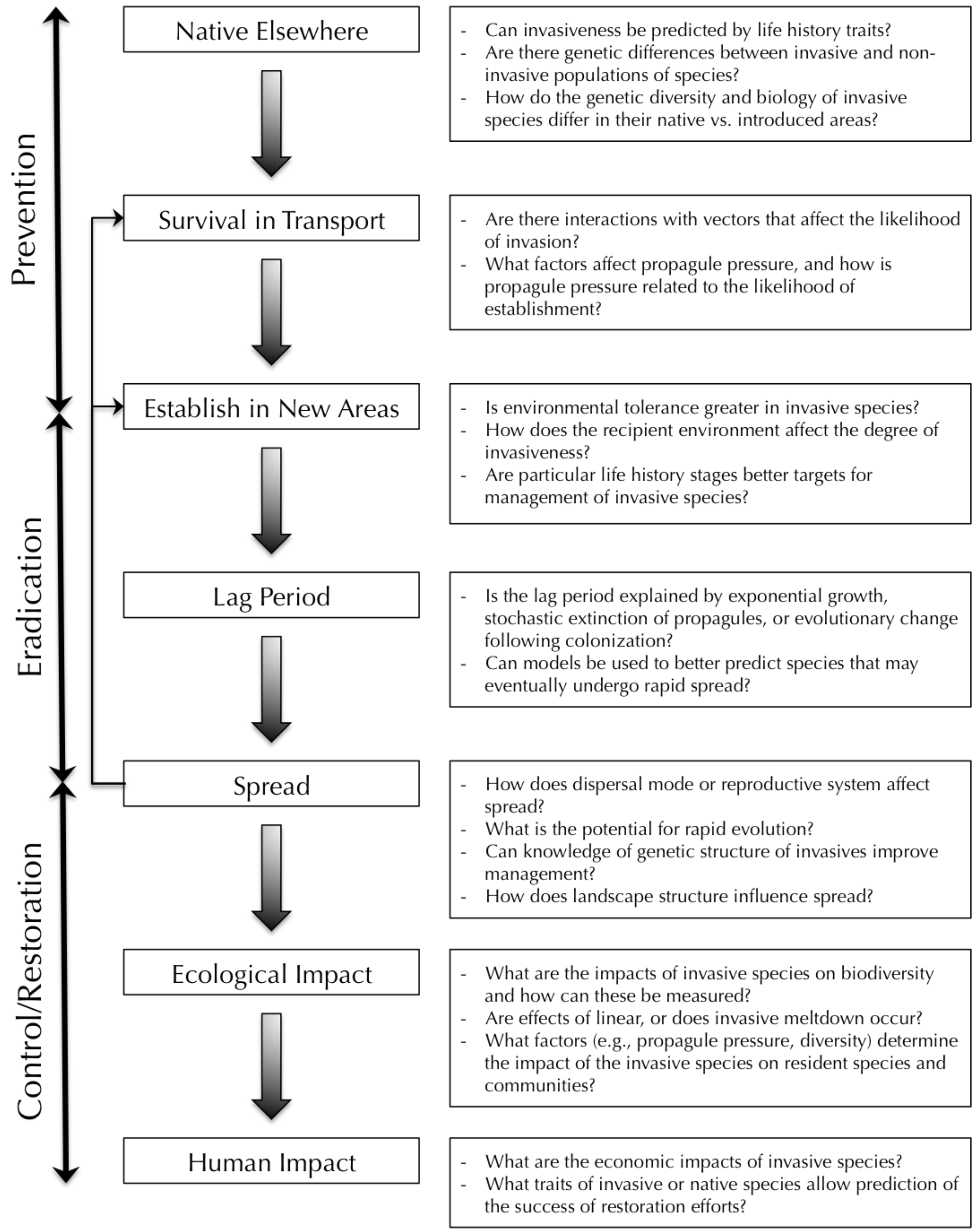
(4) Video monitoring
- Cameras are set up to record **animal** movement.
- Offers the opportunity to **monitor** activities both during the day and night over a long period of time.
- Mostly used for **terrestrial** animals, particularly mammals and birds

(5) Plot surveys
- Plots are selected and an inventory is made of the presence of a **species**. These numbers are compared to the numbers of previous **monitoring** counts.
- Used for plant **species** and other sessile organisms (e.g., zebra mussels, etc.).

(Dabrowski et al. 2015).

5.2 Risk Assessment and Analysis

Actions taken towards preventing the **introduction** of and controlling **invasive species** are partially based on the intensity of risk (Dabrowski et al. 2015).



Modified from Sakai et al. 2001

Invaders that hold a high degree of risk for damages will be prioritized for immediate and intense management actions. Some invasive are not considered to pose a high risk because they are not likely to spread quickly and do not pose a significant threat on any people, plants, animals or the **ecosystem** as a whole. Such **species** and potential invasion locations are kept on the radar but not prioritized for immediate action. **Risk assessment** looks at the likelihood of **introduction**, **establishment**, spread and consequences; risk is based on **species** biology, environmental conditions, and pathways of spread.

A high probability of invasion suggests high risk. Management actions need to be put in place as soon as possible to fight an **invasive species** when they are high risk. It is also important to assess sites that have not been invaded. Areas that have a high risk of invasion can have preventative measures put into place. If actions are taken before an invasion occurs, the chances of one happening or the intensity of an invasion are drastically reduced because preventative measures are the most effective.

5.3 Communications

Risk communication is an important part of preventing invasions as it educates the public and other stakeholders the results of the **risk assessment** and helps people make informed decisions. A successful management plan to address **invasive species** issues depends on the public's understanding and acceptance of the actions needed to protect our valuable resources. Some of the most effective programs target particular user groups and recreationalists such as gardeners, boaters, fishermen, and pet owners. Many states and local governments have their own education and outreach programs and materials, including best management practices.

6. Case Studies

6.1 Aquatic Invasive Species: Zebra Mussels – Interview with Dr. S Higgins

Prepared by Lee Hrenchuk

What is a zebra mussel?

It's a freshwater mollusc from the genus *Dreissena*. Like other bivalves it has two shells that come together. However, it's very small, about the size of your fingernail. Zebra mussels are filter feeders, meaning that they remove particles such as phytoplankton from the water. Unlike almost all other freshwater molluscs (e.g. clams and snails) zebra mussels grow attached to hard substrates such as rocks and plants. You see this type of attachment more in marine mussels, where harbours and boats can be covered in mussels; zebra mussels grow very similarly to that.

Dr. Scott Higgins, Research Scientist, IISD Experimental Lakes Area

What is the difference between zebra and quagga mussels?

Zebra mussel (*Dreissena polymorpha*)

Quagga mussels are another mussel **species** in the same genus (*Dreissena*). It's difficult to tell them apart unless you're a taxonomist because there are few telltale signs, and a lot of overlap. Zebra mussels have a flat part of their shell while quagga mussels are more rounded, but other than that they are very similar. For example, while zebra mussels are named for their striped pattern, quagga mussels can also have this design. They are also of similar size and lifespan. From an ecological perspective there are some important differences. Zebra mussels often grow attached to **aquatic** plants. Quagga mussels often grow attached to softer substrates such as consolidated muds and sand, and they can also reproduce at temperatures below 4° C. Since zebra mussels can't reproduce at those low temperatures, it means that quagga mussels can grow right to the bottom of lakes (up to 60-80 m deep), while zebra mussels are restricted to surface waters (top 10-15 m).

Where did zebra mussels originate?

They are from the Ponto-Caspian region of Europe, including the Black and Caspian Seas and their tributaries.

When did zebra mussels arrive in Canada?

They were first detected in 1986 in Lake Erie. Within a few years, they spread all around Lake Erie and into the rest of the Great Lakes. They established in harbours to start and were able to travel around the lakes attached to boats moving from harbour to harbour. They move really quickly; they went from being in one lake in North America to being in thousands of lakes and rivers within a span of about a decade.

What makes zebra mussels such great invaders?

Zebra mussels have several characteristics that make them good invaders. They can attach to hard surfaces and be carried to new locations (such as on boats, on **aquatic** macrophytes caught on boat trailers). They can survive out of water or in harsh conditions (such as hot water or chemical exposure) for 7 to 10 days. To do this, they just close up their shells and sit dormant without needing to feed. This means that if a boat is used in a lake with zebra mussels on one weekend, brought home and left to dry for the week, and then used again in another lake the following weekend, any zebra mussels that may have traveled with the boat could still be alive when the boat goes in the water again. The juvenile form (called a 'veliger') is microscopic and can be transported in things like bilge or **ballast water**, or attached to equipment such as fishing line or nets. The veligers aren't able to survive as long as adults out of water, but if you don't empty the bilge water of your boat they can easily be transported among water bodies.

What are some of the impacts zebra mussels can have on lakes?

There are two categories of problems: impacts on the **ecosystem**, and impacts to infrastructure. In terms of the **ecosystem**, the impacts are diverse and the magnitude can be high. Zebra mussels are **ecosystem** engineers in that they restructure the lake bottom, and their impacts are extensive partly because of the total numbers they can achieve. Estimates indicate that, collectively, they may filter the total volume of some invaded lakes in a single day. If you're a phytoplankton or zooplankton in that lake, you're at risk of being filtered out; if you're something that eats phytoplankton or zooplankton, you're going to have less to eat. While there is considerable variability in the size of their impact, on average zebra mussels cause about a 50% decline in phytoplankton. The salmon fishery in Lake Huron, which is a multimillion dollar fishery, seems to have collapsed because of the zebra and quagga mussel invasion.

Zebra mussels can also directly impact biota. For example, fish **species** that are not used to eating mussels can be injured by the sharp shells in their stomachs. Native mussel **species** are also at risk; the rule of thumb is that in an invaded water body, you will have a 90% decline in native mussel **species** in 10 years. Although the mussels are not in direct **competition** for **habitat**, zebra mussels will actually grow directly attached to native mussel **species**. This restricts the water flow to the feeding apparatus of the native mussels, and also puts the two **species** in direct **competition** with one another for food.

From an ecological perspective, energy flow and **nutrients** drive **aquatic** food webs. Zebra mussels take energy away from offshore food webs (which impacts phytoplankton, zooplankton, and pelagic fishes), and put that energy into near shore food webs. Things that do well in the presence of zebra mussels are near shore algae, **benthic** invertebrates, and fish such as perch and smallmouth bass.

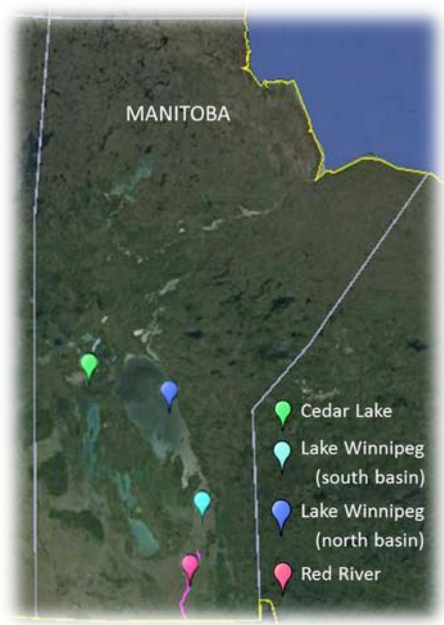
In terms of infrastructure, zebra mussels can grow on docks, piers, boats, water intakes, hydroelectric dams, navigational buoys and any other hard surfaces present in lakes. This affects everyone on the lake and has huge economic implications. For example, when they can slow or completely restrict the cooling water intake of boat motors, causing them to overheat, with potential damage to the engine. They attach very firmly and can be difficult to remove without damaging the surfaces they are attached to.

How do you think zebra mussels were introduced to Manitoba?

We will likely never know for sure, but we think that they came in via the Red River, either in the form of a veliger or an adult floating down the river attached to debris/plant material. It is also possible that they arrived overland attached to a boat or other equipment being transported from an invaded **habitat**. The closest invaded habitats are in North Dakota and Minnesota.

What is the current range of zebra mussels in Manitoba?

They have been found in the Red River in several locations (map to the right), in the South basin of Lake Winnipeg (where they are rapidly expanding), the north basin of Lake Winnipeg near George Island (a single veliger in the autumn of 2015), and there was a veliger detected in Cedar Lake which is west of Lake Winnipeg.



What effects will zebra mussels have on aquatic ecosystems in Manitoba?

The magnitude of the effects largely depends on the size of the zebra mussel populations that establish. As I mentioned before, the trophic cascade effects will impact every level of the food webs of invaded lakes. In terms of physical effects, we will likely see improvements in water clarity as the mussels remove particles from the water; this can impact other things such as hydrodynamics and thermoclines. For chemistry, mussel feces and pseudofeces deposited on the bottom of lakes contain **nutrients** such as nitrogen and phosphorus. Some of these **nutrients** will be resuspended in the water, but lots will be permanently buried and unavailable to the food web (meaning a decline in **nutrients** overall). Calcium concentrations should decline initially because zebra mussels use it to build their shells, but these concentrations will eventually reach a new steady state. There may be effects on the fish community, but it is too early to say.

What effects are we likely to see in Lake Winnipeg specifically?

Lake Winnipeg is one of the largest lakes in the world. We're lucky in that it's not the first lake to be invaded so we can learn from other systems like the Great Lakes, but we have to remember that Lake Winnipeg is unique and won't behave in exactly the same way as other lakes. The **limiting factor** for Lake Winnipeg will be the availability of hard substrates. The south basin may not see such large effects because it's mostly mud and sand; the north basin has rocky substrate and will eventually be covered in zebra mussels. In terms of the **ecosystem**, we will likely see some improvements in water clarity, some decreases in **nutrient** concentrations, and potential problems with nearshore water quality. The south basin of the lake is very shallow and mixes fully to the bottom so these effects may be dampened there. In terms of infrastructure, hard structures such as boats, docks, harbours, and hydroelectric dams will be heavily impacted and will require constant maintenance.

What social and/or economic impacts might zebra mussels have in Manitoba?

The costs will measure in the tens to hundreds of millions of dollars. Municipalities will need to protect and clean their water supplies, Manitoba Hydro will have to do routine maintenance on all of their power plants, individuals will need to clean and protect their property. The costs will add up quickly. The thing about **aquatic invasive species** is that they are here to stay; this is not a one-time cost, but one we will have to continue to pay indefinitely.

On the positive side, if you're a consulting company that does work cleaning water intakes and other things like that, your services will be in high demand. We need to develop local expertise for controlling and removing zebra mussels. If you develop or sell products such as antifouling paints (which prevent growth of organisms) or methods of reducing zebra mussel colonization, you will see an increase in business. Not to mention the large number of students who will be required to conduct **monitoring** activities. We will see lots of money changing hands.

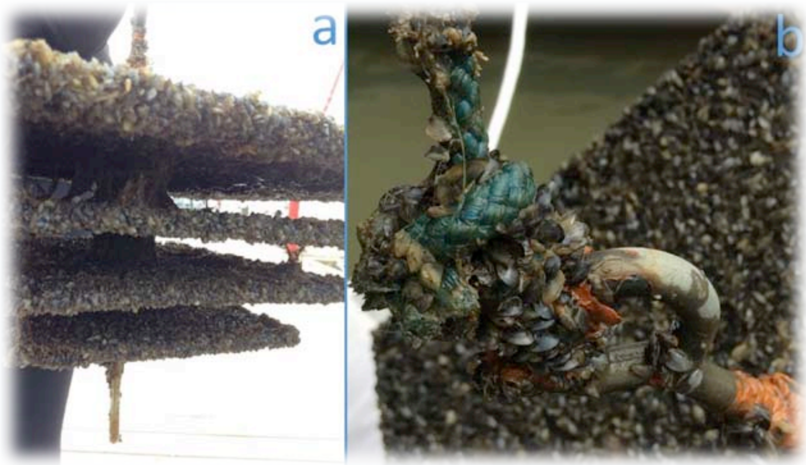
One impact is that users of Lake Winnipeg and the Red River will have to decontaminate their boats and trailers before moving them to other locations. Sport fishing tournaments which bring in a lot of boaters may be restricted, or boaters may need to prove they have had their boats decontaminated.

Do zebra mussels have any predators in Manitoba?

There is one **species** of fish in Lake Winnipeg that eats molluscs (freshwater drum, *Aplodinotus grunniens*), and shorebirds may feed on mussels. However, there is little evidence that predation can effectively reduce zebra mussel populations.

Now zebra mussels are here, what has been and can be done to protect lakes in Manitoba?

Unfortunately, there aren't any really effective methods of control at the lake scale. When the mussels were first detected in 4 harbours in Lake Winnipeg, it was decided that an attempt would be made to eliminate zebra mussels in those harbours before they were able to reproduce. A potash addition was done in the harbours, which contains potassium chloride; which zebra mussels are sensitive to. These treatments effectively eliminated zebra mussels from the harbours, but those harbours were reinvaded again during the summer, meaning that viable populations of mussels had already established in other areas of the lake and had not been restricted to those 4 original harbours. Since then, a rigorous **monitoring** program has been established looking for veligers and adults throughout the lake (see above). The province of Manitoba has also started a prevention campaign called "Slow the Spread" which involves portable boat wash stations and outreach activities to educate people who use the lake.



What can people do in Manitoba to prevent the expansion of zebra mussel populations?

The provincial message of "clean, dry, drain, dispose" any boats and equipment that you have in the water is great advice. The best advice I can give is to be well-informed about what zebra mussels are and what you can do to stop their spread. Especially people who use Lake Winnipeg, but other lakes as well. If you move equipment between lakes, it is essential that you become very informed about how to clean your boat/equipment properly, follow the guidelines set by the province of Manitoba, and encourage others to do so too.

Researcher profile

When did you start working on aquatic invasive species?

In 2001 when I was a PhD student at the University of Waterloo. I studied the effects of zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis* respectively) in the Laurentian Great Lakes.

Why are you interested in aquatic invasive species?

I'm an algal ecologist, and during my PhD thesis I made the connection that zebra and quagga mussels were causing coastal algal blooms in the Laurentian Great Lakes. **Benthic** algae (algae that grows on things like rocks and plants) need several things in order to grow: light, **nutrients** (particularly phosphorus), and a surface to grow on.

Zebra mussels provide all three of these things; they have a hard shell that algae can attach to, they improve water clarity which increases light penetration in the water, and they release **nutrients** in the form of feces, pseudofeces and metabolic waste products. Connections like these mean that the invaders can have wide impacts across the food web, which is really interesting to me.

Where have you studied aquatic invasive species in the past?

I did my PhD at the University of Waterloo studying the impacts of zebra mussels in the Laurentian Great Lakes. After that I completed a post-doctoral fellowship at the University of Wisconsin where I conducted an analysis of the **ecosystem** level impacts of zebra and quagga mussels on lakes and rivers in Eurasia and North America. I've written a number of scientific papers and a book chapter on zebra and quagga mussels, and collaborated on several broader papers about **aquatic invasive species**.

How were you involved in identifying the zebra mussel invasion in Manitoba?

At the time, I was the Aquatic Invasive Species Coordinator for Fisheries and Oceans Canada (DFO) in Winnipeg. In October 2013, I got a call from a provincial representative who had received photos of a zebra mussel specimen collected in Lake Winnipeg. Based on these photos, I tentatively confirmed that these were zebra mussels, and worked with the provincial representative to select a **specialist** in mussel taxonomy for confirmation. Zebra mussels were subsequently identified in 4 harbours and a private dock in the south basin of Lake Winnipeg.

How are you involved in studying zebra mussels in Manitoba now?

Although I'm not actively conducting research on zebra mussels, I am a member of two advisory groups: the Manitoba Zebra Mussel Science Advisory Committee, and the Lake Winnipeg Science Advisory Council. My role on these councils mostly involves giving presentations and advice to different organizations about what they should do to **monitor** and prevent the spread of zebra mussels. I was also a committee member for a M.Sc. student examining how zebra mussel invasion of Manitoba may affect Walleye **habitat**.

Do you have anything else to add about your role with aquatic invasive species?

Aquatic invasive species are very serious and have become a whole focused area of study in biology and ecology. **Aquatic invasive species** have large potential impacts on the environments they invade on two fronts: impacts on the **aquatic** systems themselves, and impacts on the management side (including different aspects like prevention and education). While research on **aquatic invasive species** should be considered an aspect of community ecology, it is unique in the sense that these **species** have not co-evolved with other **native species** and often come without their natural predators or **pathogens**. This means that they may have a distinct advantage over native plants and animals in the systems they invade. It's really interesting to work in this field because of all the challenges and the broad scale of their implications.

6.2 Wildlife Invasive Species: White-Nose Syndrome

Prepared by Amelia Peterson and Jennifer Bryson

Background

White-Nose Syndrome (WNS) is a lethal infection caused by the cold and humidity-loving invasive fungus *Pseudogeomyces destructans* that affects hibernating insectivorous bats. Manitoba has three **species** of hibernating insectivorous bats: the little brown bat, the northern long-eared bat and the big brown bat. These **species** spend almost 8 months of the year hibernating in caves or old mines, called hibernacula. *P. destructans* thrives in the cool, damp conditions of these hibernacula, which stay at just above freezing and at >90% relative humidity all year. WNS is named after the distinctive white fungal growth found on the noses of bats killed by the fungus, and has been responsible for the deaths of millions of bats since its emergence in North America in 2006. WNS has caused the largest mammalian decline on record. North America's bat **species** are important consumers of many insects that are harmful to humans as well as crops.

Spread

Though exactly how WNS was introduced into North America is unclear, it was first detected in a cave in New York State in 2006. Since then, it has spread to 25 states and 5 provinces. It is estimated that the fungus can travel approximately 200 km per year. WNS is spread from bat to bat through direct contact, though transmission through cave soil and human contact can also occur.

Several aspects of bat ecology allows for WNS spread very quickly through populations once infected. In both winter hibernacula and summer roosts, bats will cuddle in large groups to preserve warmth. Also, bats have been known to fly up to 1000 km from their summer roosts to their hibernacula, facilitating the long-distance transport of WNS.

Symptoms

WNS causes skin lesions on the wing membranes of infected individuals. These lesions may cause bats to wake up more frequently, for longer periods of time, and earlier in the season than normal, which results in faster depletion of fat stores. This leads to starvation for most individuals. Bats that survive WNS will often have wing damage. Infected bats can also behave strangely. WNS can cause bats to emerge from the hibernaculum during the winter or move from the hibernaculum into a nearby roost.

Conservation

As of 2014, WNS has been found in caves as west as Thunder Bay, Ontario. It is estimated that the disease will make it to Manitoba in the next 3 years. Currently, Manitoba has several conservation methods in place to help protect the affected bat **species** as well as help them recover once the fungus hits. In 2015, the little brown bat

(*Myotis lucifigus*) and the northern long-eared bat (*Myotis septentrionalis*) were added to the province's endangered **species** list, which allows for greater protection of the bats and their **habitat**. Strict decontamination procedures have been put in place to prevent the spread of WNS from cave to cave; all equipment used in or around caves must be bleached before removal from the area.

Current Research

Currently, research is being completed in WNS-affected areas to determine if there are ways of treating infected bats to stop the progression of the fungus and to stop the transmission of the disease to other bats or hibernacula. While there has been recent progress, field trials for treatments have only just begun. Researchers in Manitoba are currently working with citizens to find bat colonies throughout the province in order to tag bats and take genetic samples before WNS arrives, in hopes to find out if there is genetic immunity in the bats that survive WNS.

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6.3 Soil Invasive Species - Earthworms

Prepared by Lindsey Andronak, Paul Hazlett, Emma Holmes and Alison Murata

When you think of **invasive species**, you likely think of plants and animals. Purple loosestrife, zebra mussels and the fungus that causes Dutch Elm Disease. Do soils have **invasive species**? Does land use affect **invasive species**?

Earthworms are invertebrates found in the class Oligochaeta. Worldwide, there are approximately 6,000 **species**; however, only about 150 **species** are widely distributed. They are commonly known for their benefits to soil, especially agricultural and garden soils.

Lumbricus terrestris, also known as a nightcrawler

These benefits include:

- Transforming organic matter into humus. Humus contains **nutrients** in a more plant available form, thereby increasing soil fertility. Earthworms also transport these **nutrients** further down the soil profile, making them more accessible to roots.

- Creating burrows. Burrows increase both soil aeration and drainage.

However, many of these **species** are invasive. Glaciers eliminated native earthworms from many northern temperate forests 15 000 years ago and they have been earthworm free ever since. About 30 years, people noticed that earthworms from both Europe and Asia had started to colonize some forests in northeastern North America (Korzekwa 2015). Up to 16 different **invasive species** can be found in these soils (Korzekwa 2015). **Species** include European **species** from the family Lumbricidae family (e.g., *Lumbricus rubellus* and *Lumbricus terrestris*). Evidence suggests they were introduced to the United States during colonial times. More recently species from the genus *Amynthas* have been introduced from Asia.

Effects of Invasive Earthworms

The most obvious effect of this invasion is that the top layer of the forest floor will disappear within just two-five years. As this forest floor disappears, so do the other **species** that use this area as their **habitat**. The invasion has impacted the **biodiversity** of the soil, which can serve as **habitat** to other **species** including salamanders, small mammas, and ground nesting birds (Korzekwa 2015). The disappearance of the forest floor can also lead to increased susceptibility to erosion and drought, alterations to the ability to sequester carbon, and affect carbon, nitrogen, and phosphorus cycling (Korzekwa 2015).

The nitrogen content of some studied soils did not decline with the carbon. However, this caused the carbon to nitrogen ratio to decrease, and reduced the forest soil's ability to hold on to atmospheric nitrogen or from runoff from agricultural or urban areas (Korzekwa 2015). Earthworms may be causing two different problems with phosphorus in forests. Earthworms appear to cause the loss of phosphorus that the plants need. However, at the same time they seem to bring up phosphorus from deep in the soil where the plants need it.

The disappearance of the forest floor can also increase the probability of drought as it can act like mulch to keep the soil moist (Korzekwa 2015). Additionally, earthworms can interrupt the relationships trees have with mycorrhizal fungi (Korzekwa 2015). This may lead to a reduction in tree health (Korzekwa 2015).

Factors Behind Invasion

Multiple factors are considered to be behind the invasion (Korzekwa 2015). Current evidence suggests that the invasion is human-driven, with **habitat** fragmentation is a large contributor (Korzekwa 2015). It has also been suggested that human fishing habits may have lead to introductions. Invasive earthworms have been found around lakes (Korzekwa 2015). Although this may just be good **habitat** for them, there is a suggestion that anglers leaving bait at fishing spots may have led to this invasion (Korzekwa 2015). Climate change also may be accelerating the invasion by earth worms. As particular areas experience warmer temperatures, previously excluded **species** are able to survive cold winter temperatures (Korzekwa 2015).

6.4 Forestry Invasive Species – Emerald Ash Borer

Prepared by Kyla Maslaniec

Background

Emerald ash borer, *Agrilus planipennis,* is a highly destructive invasive wood boring beetle that kills ash trees. This insect kills trees when the larvae feed in the nutrient conducting vessels of ash trees. Originating from parts of Asia, emerald ash borer was first detected in North America in 2002, in Ontario and Michigan. It is thought that Emerald ash borer was introduced to North American through ash packing material used in shipments from China. Since then, it has spread to several other states and to Quebec. Since Emerald ash borer is very hard to detect in the early stages, it often goes unnoticed until it is too late. For this reason,

Emerald ash borer (*Agrilus planipennis*)

Emerald ash borer has been difficult to control and manage. Millions of ash trees have been killed in Ontario and the U.S.

How does it spread?

This highly destructive pest continues to spread throughout North America through the movement of nursery stock and raw-untreated ash wood, particularly firewood.

Hosts

Emerald ash borer only attacks ash trees (*Fraxinus* species). Mountain ash is not a true ash tree and is not susceptible to Emerald ash borer. All North American species of ash are vulnerable to Emerald ash borer. In Manitoba there are two native species of ash; green and black ash. Manchurian ash and cultivars of green, black and Manchurian ash have been planted in many communities that are also vulnerable to Emerald ash borer.

Life Cycle

Emerald ash borer has a one to two year life cycle depending on infestation levels and climate conditions. The larvae overwinter under the bark of ash trees and pupate in early spring (mid-April) with adult emergence in late May to the end of June.
The adults feed on ash foliage for two to four weeks that is characterized by a notched feeding pattern on the leaves. This stage is not damaging to the trees. After this period, from the end of June until the end of August, the adult female lays up to 300 individual eggs (average 75) on the bark of ash trees or in bark crevices.
The larvae bore directly into the bark after hatching and begin feeding just under the bark in the phloem (food conducting tissue) of the tree creating s-shaped galleries. This is the damaging stage of the insect as the flow of nutrients in the tree is disrupted by the larval feeding.

Description

The average length for an adult emerald ash borer is 7.5 to 13.5 mm long and 4 mm (1/6 in) wide. The larvae are approximately 1 mm in diameter and 26 to 32 mm long, and are a creamy white color.

Damage

Emerald ash borer larvae feed on the phloem of trees just under the bark and disrupt the flow of nutrients in the tree resulting in the tree's death. It takes one to four years of infestation to kill the tree. At low levels, the Emerald ash borer is hard to detect, but after the population builds, ash trees start dying. In places like Michigan where the population of Emerald ash borer went undetected for many years, millions of ash trees have been killed by this pest. In most cases, 90 per cent of the ash population is lost within 10 years of infestation starting in an area. Since ash has been planted so extensively in many North American cities, Emerald ash borer infestations can cause the loss of a significant percentage of urban forest canopy cover in affected areas.

What can we do to protect Manitoba from EAB?

Native to eastern Asia (China, Korea, Japan, Russia, Mongolia), Emerald ash borer is well suited to Manitoba's climate and could establish a population here. And since Emerald ash borer is difficult to detect and manage, prevention measures and early detection measures are the best defense against this devastating invasive forest pest.

Monitoring:

- The province is monitoring for emerald ash borer in several locations in southern Manitoba using baited sticky green prism traps.

- Visual surveys are also being conducted at trap sites.

Sanitation/Quarantines:

- Emerald ash borer populations are controlled by removing and destroying infested trees.

- Movement restrictions have been put in place in Ontario and Quebec on ash material by the federal government under the *Plant Protection Act*.

- Quarantines and sanitation programs could be established in Manitoba if Emerald ash borer were detected here. Emerald ash borer is regulated in Manitoba under *The Forest Health Protection Act* and *Forest Health Regulations* which is administered by the Forestry and Peatlands Management Branch of Manitoba Conservation and Water Stewardship.

Chemical:

- There are insecticides approved for use in Canada for the management of Emerald ash borer, but it is not recommended that ash trees be chemically treated at this time, since Emerald ash borer has not yet been found in Manitoba.

Biological:

- Parasitoids: Non-stinging wasps have been released in Canada and the U.S. that are the natural enemies of Emerald ash borer in its native habitat.

- Fungus: Research is being conducted on control methods using a fungal pathogen that kills Emerald ash borer.

Where is EAB now?

EAB has been found in Ontario and Quebec and much of the north-eastern U.S., including Minnesota and Wisconsin. The closest infestation to Manitoba is in Duluth, Minnesota, which is only 400 kilometers from the Manitoba border. Emerald ash borer has not yet been found in Manitoba

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9. Glossary of Terms

A

Abiotic - nonliving component of the **environment** (e.g. soil, water, air, etc.)

Adaptation - genetically determined characteristic (e.g. behavioural, morphological, etc.) that will improve a **species** ability to survive and reproduce in certain conditions

Amphibian - a class made by three groups, caecilians, salamanders, and frogs and toads. They are poikilothermic vertebrates, with a larval stage that develops in water, and soft non-scaly skin that is important in cutaneous respiration

Animal - a multicelular, heterotrophic organism. Most commonly motile at least at some point in their life cycle and have sensory apparatus that detect changes in the **environment**

Aquatic - living in or near fresh water or taking place in fresh water

B

Ballast water - ballast is any solid or liquid that is brought on board a vessel to regulate the stability or maintain stress loads. Water is the ballast of choice because it can easily be pumped in or out, and poses little to no stability problems.

Benthic - lower most regions or bottom of **aquatic ecosystems**

Biodiversity - all aspects of biological diversity, including **species** richness, **ecosystem** complexity, and genetic variation

Biological control - the human use of natural predators/**pathogens** for the control of **pests** or other **invasive species**. The release of one **species** to control another

Biotic - living components of an **ecosystem**

Biotic resistance - a theory that can be used to predict how well ecological communities resist **invasive species**

C

Chemical control - control method that employs herbicides, pesticides, **piscicides**, **lampricide**s, or other chemicals to control **invasive species**

Citizen science - the collection of data related to the natural world by members of the public

Coevolution - joint **evolution** of two or more nonbreeding **species** that have a close relationship and through reciprocal selective pressure, the **evolution** of one **species** depends on the **evolution** of the other

Competition - interaction that is detrimental to both participants

D

Disturbance - an event or change in the **environment** that alters the composition and successional status of a biological community. This may deflect succession onto a new trajectory, such as a forest fire, hurricane, glaciation, agriculture, and urbanization

E

Ecosystem - natural unit that consists of living and non-living parts

Endemic - a **species** or taxonomic group that is native to a particular region

Environment - the external surroundings within which an organism lives

Eradication - the elimination of a **species** from a particular area

Establishment - the process of an **invasive species** in a new **habitat** successfully producing viable offspring with a likelihood of continued survival

Evolution - change, with continuity in successive generations of organisms (e.g. descent with modification)

Exotic species - a **species** originating from another region (see **non-native species**)

Extinct - any taxon where no member is living at this present time

Extirpation - local **extinction** of a **species** from a previously occupied region. The **species** still remains in other regions of its **range** or in captivity.

F

Fungicide - A chemical that destroys fungus

G

Generalist - a **species** that eats a wide variety of food items, based on their abundance in the **environment**.

H

Habitat - the living place of an organism or community, characterized by **abiotic** or **biotic** factors

Herbicide - pesticide that specifically targets vegetation

I

Import - to bring in from an outside source

Insecticides - a substance used to kill insects or other invertebrates

Intentional introduction - the act of deliberately bring a **species** into a region it did not originate in

Introduction - the movement of a **species**, either intentionally or not intentionally, of a **non-native species** outside of its **range**

Invasive species - An **invasive species** is an exotic (originating from another region in the world) **species** (including plants, animals (e.g., mammals, reptiles, amphibians, fish, insects and other invertebrates, seeds, eggs, spores, or other propagules) whose introduction causes or is likely to cause economic harm, environmental harm, or harm to **native species** (including human) health.

K

Keystone species - a **species** that has a disproportionately strong influence within a particular **ecosystem**, so that its removal results in severe destabilization of the **ecosystem** and can lead to further **species** loses

L

Lampricide - a chemical that targets the larvae of lamprey in river systems before they turn into adults

Legislation - is law which has been enacted by a legislature or other governing body or the process of making it

Limiting factor - any environmental condition or set of conditions that approaches most nearly the limits of tolerance for a given organism

M

Manual control - Removal that involves the use of tools such as shovels, axes, rakes, grubbing hoes, and hand clippers to expose, cut, and remove flowers, fruits, stems, leaves, and/or roots from target plants or actions like hunting to control animals

Mechanical control - Removal that involves the use of motorized equipment such as mowers, "weed-whackers", and tractor-mounted plows, disks, and sweepers as well as burning.

Monitor - observe and check the progress or quality over a period of time

N

Native species - a **species** that occurs naturally in an area

Non-native species - an introduced **species** that is the result of a direct or indirect, deliberate or accidental introduction by humans. **Non-native species** introduction permitted the **species** to cross a natural or artificial barrier to dispersal. **Non-native species** are not necessarily **invasive species**.

Nutrient - a substance that provides nourishment essential for growth and the maintenance of life

P

Parasite - a **parasite** obtains food, shelter, or other requirements from its host

Pathogen - any **parasite** (e.g. virus, bacteria, nematode, platyhelminth, etc.) or prion that causes disease

Pest - an **animal** that competes with humans by consuming or damaging food, fibre, or other materials intended for human consumption or use

Piscicide - a chemical that is poisonous to fish and can be used to eliminate fish populations

Polices - statement of intent, and is implemented as a procedure or protocol

Population - a group of organisms all of the same **species** that occupies a particular area

Predatory - an organism that obtains energy by consuming, usually killing, another **species**

Q

Quarantine - a state, period, or place of isolation in which animals that have arrived from elsewhere or been exposed to infectious or contagious **pathogen** are placed

R

Range - The geographical area within which that **species** can be found

Regulations - creates, limits, constrains a right, creates or limits a duty, or allocates a responsibility

Risk assessment - a systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking

S

Specialist - an organism that selects specific types of food, despite the abundance of food sources in the **environment**

Species - a group of organisms that resemble one another closely, usually that can breed with each other facilitating gene flow

T

Terrestrial - referring to land, such as a terrestrial **animal** would live on land

U

Unintentional introduction - an introduction of **non-native species** that occurs as the result of activities other than the purposeful or **intentional introduction** of the **species** involved, such as the transport of nonindigenous **species** in ballast or in water used to transport fish, mollusks or crustaceans for aquaculture or other purposes

W

Weed - a plant in the wrong place, being one that occurs opportunistically on land or in water that has been disturbed by human activities or on cultivated land, where it competes for **nutrients**, water, sunlight, or other resources with cultivated plants such as food crops

Z

Zoonotic (zoonoses) - a **pathogen** that can be transmitted from animals to humans and vice versa

Appendix 1: Index of Manitoba Invasive Species

Please **do not** spend time memorizing every **species** on this list. Focus on specific **species** highlighted throughout the rest of the document. If there are **species** missed on this list, it is by accident.

Baby's breath
Bird Vetch
Blue weed
Bouncing bet
Bull thistle
Canada thistle
Common burdock
Common carp
Common Crupina
Common Tansy
Cow cockle
Creeping bellflower
Curly Leaf Pondweed
Dalmatian toadflax
Dame's rocket
Diffuse Knapweed
Downy Brome
Dutch elm disease fungi
Emerald Ash Borer
Eurasian Watermilfoil
European buckthorn
European Frog-Bit
Field bindweed
Field scabious
Flowering Rush
Flowering rush
Garlic mustard
Giant hogweed
Himalayan Balsam
Hoary alyssum
Hound's tongue
Hybrid Cattail
Hydrilla
Invasive Phragmites
Japanese brome
Japanese Knotweed
Jointed Goat Grass

Kudzu Vine
Leafy spurge
Lily Leaf Beetle
Mile-a-minute weed
Mosquitofish
Narrow-leaved Cattail
Nodding thistle
Orange hawkweed
Ox-eye daisy
Paterson's curse
Perennial Sow Thistle
Puncture Vine
Purple loosestrife
Purple Nutsedge
Rainbow smelt
Red bartsia
Reed Canary Grass
Round Goby
Russian Knapweed
Rusty Crayfish
Salt Cedar
Scentless chamomile
Scotch thistle
Spiny Water Flea
Spotted Knapweed
St. John's wort
Tall buttercup
Tansy Ragwort
Water Hyacinth
White cockle
Woolly Cupgrass
Yellow Flag Iris
Yellow starthistle
Yellow toadflax
Zebra Mussels