Study Guide

2016

Invasive Species: A Challenge to the Environment, Economy and Society

This Study Guide is to be used to help Envirothon teams prepare for the 2016 Envirothon Program.

FORESTS ONTARIO

NORTH AMERICAN ENVIROTHON 2016

ENVIROTHON
A NATURAL RESOURCE ENCOUNTER FOR THE NEXT GENERATION

Support for the 2016 North American Envirothon Study Guide has been provided by Sustainable Forestry Initiative.

SUSTAINABLE FORESTRY INITIATIVE
SFI-00001

State and Provincial Sponsors

Thank you to the following state and provincial Envirothon programs for providing support to the 2016 North American Envirothon Study Guide:

- Connecticut Envirothon
- Virginia Envirothon
- North Carolina Envirothon
- Kansas Envirothon
- South Carolina Envirothon
- Nebraska's Natural Resources District Foundation
- PEI Provincial Forest Envirothon
- West Virginia Envirothon
- North Dakota Envirothon
- Utah Envirothon

Acknowledgements

This Study Guide was compiled by students at Fleming College, Frost Campus, in Lindsay, Ontario. Acknowledgements to Sandra Dabrowski, Reuben Van Zeumeren, Jeffery McFarlane and Jonathan Shaddock who contributed to the content of the guide. Thanks also go to Sara Kelly, the Credit for Product Coordinator at Fleming College.

Acknowledgements also given to those who reviewed the study guide:

- Invasive Species Centre
- Ontario Federation of Anglers and Hunters
- Department of Fisheries and Oceans
- Ministry of Natural Resources and Forestry

2016 North American Envirothon

Every year, more than 500,000 students, teachers and families across North America take part in the unique learning experience of Envirothon. The program engages high-school students in learning more about four main areas of the environment—soils, aquatics, wildlife and forests. Students learn in the classroom and through interactive workshops aimed at strengthening scientific knowledge of our natural ecosystems and helping develop foundational skills needed to pursue studies and careers in environmental sciences.

The program supports students in developing:

- A scientific understanding of natural ecosystems (soils, aquatics, wildlife, forests).
    - Each year, a fifth subject area is chosen that is timely and relevant. For 2016, the fifth subject area will be **Invasive Species: A Challenge to the Environment, Economy and Society**.
- Practical experience in resource management practices and technologies.
- The ability to apply scientific knowledge and creativity in developing innovative and sustainable solutions to major environmental challenges.
- Stronger communication, collaboration and problem solving skills.

North American Envirothon (NAE), a program of the National Conservation Foundation, partners with 56 provinces and states that coordinate events in which students receive training in essential resource management technologies and practices such as invasive species monitoring, habitat restoration, water and soil analysis, and forest management. Students are then tested on their ability to apply these practices.

The 2016 North American Envirothon will culminate in a competition that will bring together North America's top teams to compete for the championship title. After successfully coordinating the Ontario Envirothon for over 20 years, Forests Ontario will be hosting the 2016 NAE in Ontario for the first time. This Study Guide will be used by teachers, students and volunteers to help prepare them for Envirothon competitions across North America.

NORTH AMERICAN ENVIROTHON 2016

The 2016 North American Envirothon

After 20 successful years of the Ontario Envirothon, Ontario will be hosting the 2016 North American Envirothon for the first time. This presents a unique opportunity to highlight the province and Canada. The North American Envirothon will be taking place from July 24-28, 2016 at Trent University, Peterborough and will bring together the top performing schools from 50+ regions to compete for the North American Championship title.

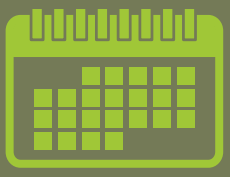
500,000
students, teachers and families each year participate in Envirothon programs

= 10 000

The North American Envirothon is being held in

Ontario

for the first time



30+ years
of Envirothon program

The

5th

subject area for the 2016 North American Envirothon will be Invasive Species

50+ *states, provinces and territories send their top teams to the North American Envirothon*

70%+

of Envirothon students surveyed are exploring education and careers in Science, Technology, Engineering and Math (STEM)

50+
teams

1
champion

SFI STANDS FOR FUTURE FORESTS

The Sustainable Forestry Initiative® (SFI) Inc. is an independent, non-profit organization dedicated to promoting sustainable forest management. While we develop and oversee standards for forest management and the forest products supply chain, we are more than a set of standards — we are a community that stands for future forests. SFI works at the intersection of thriving forests, sustainable communities and responsible procurement.

Learn more at **sfiprogram.org**.

TWENTY
1995 YEARS 2015

DID YOU KNOW?

SFI Program Participants maintain and improve long-term forest health, productivity and economic viability **by protecting forests** from environmentally or economically undesirable wildfire, pests, diseases and **invasive exotic plants and animals**.

Not all forest plants or wildlife are beneficial.

- The kudzu plant was introduced into the Southern United States to control soil erosion and now poses a threat to forests in several states, and is found as far north as Ontario.
- The emerald ash borer was accidentally introduced into North America in the early 2000's and has killed tens of millions of ash trees.
- The European Starling was introduced into New York City in the 1890's, and has spread across North America, it competes aggressively with native birds for food and habitat.

$1.5 BILLION in forest research since 1995

SFI is the only forest certification program in North America that requires participants to support research to improve forest health, productivity, conservation understanding, and sustainable management of forest resources.

$63 MILLION INVESTED in 2014.

DID YOU KNOW?

When you choose a product with an SFI label, you're supporting everything that sustainable forestry stands for: clear air and water, healthy wildlife habitats, conservation, research and much more.

SFI promotes healthy forests, gets youth outdoors and supports initiatives like urban tree planting and green building.

Contents

2016 Learning Objectives

Key Topics

1. Invasive Species and Their Impacts
2. Pathways of Introduction and Spread
3. The Invasive Species Management Cycle (Prevent, Detect, Respond, Control)
4. Roles and Responsibilities (Government, Non-Government, the Individual)
5. Tools in the Toolbox (Models, Detection Tools, Monitoring Tools, Communications)

Learning Objectives

1. Explain what an invasive species is.
2. Describe the economic, social, and environmental impacts of invasive species.
3. Comprehend the effects/impacts of invasive species on aquatic, forest, wildlife and soil ecosystems with specific reference to biodiversity.
4. Explain how ecological impacts may vary by species.
5. Compare theories about the characteristics that assist invasive species in successfully establishing new populations. What makes a good invader?
6. Describe the pathways through which invasive species are introduced.
7. Discuss the stages of the invasive species management cycle and components of an invasive species management plan.
8. Assess the costs associated with controlling an invasive species on a state/province-wide basis.
9. Outline methods of controlling an invasive species.
10. Understand how various levels of government and other organizations are involved in the management of invasive species.
11. Are all invasive species created equal? Describe how risk is assessed.
12. Discuss the means by which invasive species are detected and monitored and have a basic knowledge of models and tools used to monitor invasive species.
13. Demonstrate knowledge of the policies/legislation involved in preventing, detecting, monitoring, and controlling invasive species.
14. Describe the role for non-government and the average citizen in managing invasive species.
15. Investigate ways to reduce the arrival of new invasive species by setting the foundations for environmentally ethical behaviours and sound environmental decision making.
16. Demonstrate knowledge of the various forms of outreach and education being used and assess their effectiveness.

1.0 Invasive Species and Their Impacts

Invasive species pose a serious threat to the stability of many North American ecosystems. Invasive species have been known to disrupt food webs, damage or destroy habitat and contribute to the decline of indigenous species at risk. In addition to their environmental impact, invasive species can have a significant impact on local economies; in the United States alone it is estimated that invasive species cause major environmental damage and loss adding up to almost $120 billion per year (Pimentel, Zuniga, Morrison – 2005).

The 19th and 20th centuries have seen an exponential increase in the number of invasive species being intentionally and unintentionally introduced to North America and around the world 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, including being introduced by early settlers for agricultural purposes. Many others have been inadvertently transported to North America through trade and travel, as stowaways on ships or in packaging materials, and through horticulture. With the expected increases in exports and trade in the future, we can likely expect greater challenges and introductions of new species not yet known to occur in North America.

Students will learn about invasive species prevention, introduction, impact and management.

1.1 Introduction to Invasive Species

"Invasive alien species are emerging as one of the major threats to sustainable development, on a par with global warming and the destruction of life-support systems. These aliens come in the form of plants, animals and microbes that have been introduced into an area from other parts of the world, and have been able to displace indigenous species."

– Preston and Williams, Working for Water Programme, South Africa 2003

Invasive alien species are plants, mammals, fish, insects, other invertebrates, birds, reptiles, molluscs, microbes, and diseases that are introduced to an area and survive, and reproduce, causing harm economically or environmentally within the new area of **introduction**. There are limited population control mechanisms in place that help to balance their populations, allowing them to increase in numbers rapidly.

Invasive species are also referred to as aliens, exotics, or non-indigenous species. In this guide, invasive species are considered those that are aliens or outside of their natural range.

Invasive alien species are one of the greatest threats to the biodiversity of ecosystems. They originate from other regions of the world and in the absence of natural predators or controls, invading species can have devastating effects on native species, **habitats**, and **ecosystems** (Ontario's Invading Species Awareness Program, 2015).

Invasive species can cause disruption to the natural ecosystem by outcompeting **native (endemic, indigenous)** plants and animals for light, water, food, and space; altering habitats which reduces biodiversity as well as potentially causing the extinction of certain native species. Once established invasive species can be difficult, or impossible, to control or eradicate. They are costly to manage, harmful to trade and commerce, and have unwelcome impacts on society, including human health and wellbeing (Invasive Species Centre, 2015).

1.2 What makes a good invader?

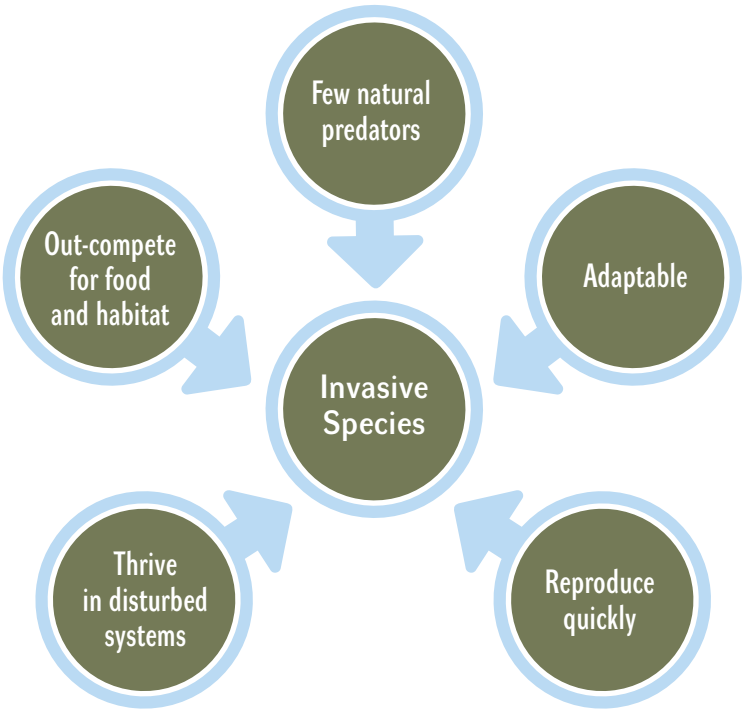
All animals and plants strive to survive and reproduce. In the natural world, success is measured by how you survive. Invasive plants and animals employ a number of different strategies in order to ensure a long successful life. However, this does not mean that all species that are introduced to a new area inevitably become invasive. Many new species will fail and die, some may have inconspicuous effects, while others will have large negative consequences and therefore become invasive. Those non-native species that establish but do not become invasive are known as **naturalized species**.

Invasive species are often so successful and damaging in new territories because they are able to adapt quickly to new **ecosystems**. A series of checks and balances are not present to limit the population sizes of invaders. This allows invasive species to survive and become successfully established in the ecosystem (Figure 1).

Invasive species out-compete native species because of several key characteristics that make invasive species successful (US Forest Service, 2012):

- tolerate a variety of habitat conditions
- grow and reproduce rapidly
- compete aggressively for resources (water, food, habitat)
- lack natural enemies or predators in the new ecosystem
- low susceptibility to disease
- often generalists and can adapt to different environments (live off a wide range of food types)

FIGURE 1. *Why are invasive species so successful? (OFAH, 2015)*



Disturbed vs. Healthy Ecosystems

Disturbed sites may be more vulnerable to invasions because there are empty niches available and invaders are good competitors and may fill these quicker than less competitive, native species would. "Healthier" ecosystems may be less vulnerable to invasion because native species can provide some level of protection. This is termed **biotic resistance**. Healthier ecosystems may be those with high **diversity** or low **disturbance**. Examples of disturbance include development, agriculture, natural disasters, or deforestation.

1.3 Invasive Species Impacts

Invasive species have negative impacts not only on the environment, but inevitably to society and the economy. Understanding the full impact of an invasive species helps to determine the priority of control and management, as well as strategic direction for its future management.

Environmental Impacts:

- Decreases biodiversity—changes landscapes, outcompetes native species for habitat and food, introduces diseases
- Cause native species extirpation and even extinction
- Alters natural processes and disturbance patterns
- Can hybridize and displace native populations
- Decreases food sources and impacts food webs

Societal Impacts:

- Can cause the introduction and spread of disease
- Potential increase in human health impacts including allergies and irritations
- Reduce recreational and tourism opportunities

Economic Impacts:

- Impacts ecological services by altering ecosystems
- Reduces productivity in forestry, agricultural, and fisheries
- Cause export and import trade restrictions
- Reduce property values as a result of changes to ecosystems
- Incur costs associated with prevention and management
- Impacts on recreation and tourism

(Environment Canada, 2013; WWF, 2015)

1.4 Invasive Species in the Ecosystem

Below are several examples of invasive species related to the four main areas of Envirothon—soils, aquatics, wildlife, and forests. These are just a few of the thousands of invasive species that threaten healthy ecosystems within North America. For more examples of invasive species in North America, refer to Appendix 1.

Forests

Garlic mustard is an invasive forest plant species native to Europe, introduced to North Americain 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, reducing overall groundcover diversity in forests. Its ability to reproduce rapidly expands its distributions in newly settled environments. While there are methods of control including chemical and manual (more on this later), timing of control is essential in trying to decrease the potential spread of garlic mustard (Wild Edible Food, 2012).

Aquatics

Eurasian water-milfoil is an invasive aquatic plant native to Europe, Asia and parts of Africa (Figure 2). Since being introduced in North America in the 19th century, it has become one of the most widespread invasive species on the continent. It was likely introduced either through the aquarium trade or ballast water of ships. It is a fast growing perennial plant which ends up forming dense mats underwater and 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 causes an even more aggressive hybrid species that ends up pushing out native species from the area and decreasing overall biodiversity.

FIGURE 2. *An image of Eurasian water-milfoil on the surface of the water (Invasive Species Awareness Program, 2015)*

Soils

One of the most common organisms in soils, the earthworm, is in fact an invasive species introduced from Europe. Of the 19 species of earthworms found in Ontario, 17 are from Europe and two are from the United States (Invading Species Awareness Program, 2015). In fact, all of the last native earthworms in Ontario were removed during the last glaciation. Earthworms can significantly alter ecosystems because they break down the litter layer on the forest floor. 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.

Wildlife

The European starling is an invasive bird species originally from Europe. This glossy black bird was introduced intentionally in the late 1800s into North America with the interest of bringing to the US all of the birds mentioned in the works of Shakespeare. Starlings compete with native species for their nesting sites and food sources, as well as significantly impact the agricultural industry. Additionally, they transmit diseases that infect both humans and livestock.

1.6 Discussion Questions

1. What is an invasive species?
2. What are some impacts of invasive species?
3. Why are invasive species so successful?
4. What are some examples of invasive species within your own state or province?

2.0 Pathways of Introduction and Spread

Pathways of Introduction

Invasive species enter our native ecosystems through a variety of means. Global trade and travel are the largest factors contributing to the worldwide spread of invasive species. Understanding the ways in which invasive species enter a new environment is critical in helping to prevent their introduction (Environmental Protection Agency, 2015).

Some of the ways that humans facilitate the **spread** of an invasive species include:

- transportation of raw wood and other forest products
- transportation of animals and animal by-products such as carcasses or products made from them
- transportation of topsoil
- recreational and commercial boating and fishing
- release of live fish and bait
- gardening and landscaping
- canals and changes to waterways
- ballast water of ships
- water gardens
- aquariums, water garden and the pet trade
- all-terrain vehicles
- intentional stocking (biocontrol)
- illegal release (e.g. cultural release)
- intentional stocking or introduction (e.g. biocontrol)
- construction equipment
- hiking boots
- horses

The above **pathways of introduction** show that invasive species can be introduced through both unintentional and intentional ways. As will be discussed further on in this guide, there are a variety of challenges associated with monitoring and managing invasive species because of the number of pathways of introductions and the reasons for introduction.

Unintentional Introductions: ballast water, movement of firewood, packaging materials, creation of stream connection channels, movement of equipment, movement of diseased wildlife, escape of non-native wildlife in captivity

Intentional Introductions: dumping bait buckets, releasing stock into public waters, deliberately releasing species through horticultural or pet trades

- intentional introductions can be both authorized (e.g. lawful stocking of fish, release of aquatic plants) or unauthorized (e.g. illegal introduction for angling opportunity)

Keep in mind that while humans have a large influence on the movement of any invasive species, the 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 from that area to other locations nearby. This can occur through natural (e.g. active movement or on the fur of animals) or human-assisted movement. How far a beetle may fly, or how far the spores of fungus are transported in the air is all part of the secondary movement of an invasive species.

Climate change can also play a large role, since the changing climatic and environmental conditions may create favourable conditions for invasive species that were previously limited. For example, some invertebrate species may not survive overwintering in northern habitats because of cold temperatures. However, a warming climate may prevent mortality and improve the chances for the survival of the invasive species.

Additional Resource Link:

- Pathways of Introduction—United States Environmental Protection Agency

2.1 Forest Invasive Species: Introduction and Spread

The introduction of invasive species into forest ecosystems occurs through a variety of ways. Through recreational impacts, transportation corridors, or through natural movement of species, forests are impacted significantly by invasive 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 have difficulty defending themselves against invasive species because they may have no natural resistance or are unable to relocate, and as a result this can lead to high tree mortality.

Invertebrates

Invertebrates can have a significant impact on forest health by directly impacting the health of a tree. Invertebrates may defoliate trees or bore into them while going through one of the stages of their life cycle.

Wood boring insects are those that bore into the wood during the larval stage. These invasive species are often transported 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 (EAB) occurred at a much quicker rate than expected in the eastern part of North America because of the movement of firewood. The larval stage (grub) of EAB can stay in the wood and exits upon arrival to a new area (Figure 3). 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 (Emerald Ash Borer, 2015).

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. For example, the Gypsy Moth 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.

FIGURE 3. *EAB galleries inevitably leading to mortality. (EAB, 2015)*

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, both native or non-native are also known as **weeds**. These are plants in the wrong place.

Pathogens

Pathogen is an agent that causes infection or disease including bacteria, fungi and viruses. Forest pathogens can affect the whole tree, causing defoliation, root decay and stem cankers that reduce the distribution of nutrients (OISAP, 2015). The movement of plant material around the world has increased the movement of pathogens into native forest ecosystems. Beech Bark Disease (*Nectina coccinea*) is a disease that affects beech trees (*Fagus grandifolia*). 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 this disease occurs through the movement of wood and forest products, as well as natural dispersal through animals and air.

2.2 Aquatic Invasive Species: Introduction and Spread

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. Some invasive species such as the Zebra Mussel have been introduced because they hitchhike on equipment, cling to pipes and aquatic structures, and are transported in the ballast of boats. Both freshwater and marine ecosystems are impacted by aquatic invasive species, which can have significant 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. The invasive potential of these species may not have been assessed or were underestimated, and therefore their impact was greater than expected.

One commonly known aquatic invasive species, Sea Lamprey (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, essentially killing them from the inside out. If the fish survives, the wounds that are left open are prone to infections (Invading Species Awareness Program, 2012) (Figure 4).

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. It is also challenging to see the impact from the surface, literally!

FIGURE 4: *Sea Lamprey (ISAP, 2012).*

2.3 Soil Invasive Species: Introduction and Spread

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 favourable 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, grows 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. There are many native Phragmites species that resemble the invasive one, however they are different in that they are less aggressive an often mix well with other native species.

2.4 Wildlife Invasive Species: Introduction and Spread

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 been 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.

One example of an unintentional introduction of wildlife is related to the pet trade, and is the Red-eared slider (*Trachemys scripta*). This turtle species is a common pet, however 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 diseases into the area further affecting the populations of native species (Toronto Zoo, n.d.).

2.5 Discussion Questions

1. Which actions in your day-to-day life might influence the introduction and spread of invasive species?
2. Has there ever been an alien species introduced that had a positive impact that was greater than the negative impact?

Case Study—Round Goby—Lake St. Clair—1990

The Round Goby was first discovered in the St. Clair River in 1990 (See Figure 5) and has spread rapidly through the Great Lakes and inland lakes since then. Data collected in 2014 indicates the spread of the round goby has not stopped (See Figure 6). Round Goby is a fish that resembles the native mottled sculpin but with a singular pectoral fin. Round Goby is a bottom-dweller that eats the eggs and young of the native fish, spawns multiple times each season, claims the broad habitat requirements and can survive in poor quality water (Michigan Sea Grant, n.d.). Round Goby is a very aggressive species that is known to pressure native fishes out of their nests and seize the sites for themselves. All of these things cause it to be extremely adaptable to new environments and easily displace native fishes.

Native to the Black and Caspian Sea regions, Round Goby was introduced to the Great Lakes through ballast water. Round Goby is considered to be an invasive species because it originates in another part of the world, was introduced to the Great Lakes, and has had a negative impact on the Great Lakes Ecosystem (United States Geological Survey, 2013). Adult Round Gobies spend their time at the bottom of water bodies but the larval stage will swim to the surface at night where it can be sucked into ballast tanks of commercial vessels. This means of invasion allowed Round Goby to spread through the Great Lakes and become established at several ports around the Great Lakes (See Figure 7).

The arrival of Round Goby has given a new food source to gamefish, water snakes, loons, cormorants, and smallmouth bass. This is an issue because the goby is a known carrier of a disease called Type E botulism. Type E botulism caused the deaths of over 7,000 birds in Lake Michigan during 2007 (Michigan Sea Grant, n.d.). The outbreaks of botulism are not fully understood because they do not occur every year. It is known, however, that that the botulism toxin accumulates in mussels in areas with depleted oxygen. Round Goby feeds on the mussels and they then begin to accumulate botulism that will be passed on to larger predators that feed on them. Bioaccumulation can also seriously affect the health of humans. If toxins and harmful toxins are allowed to persist in an environment it will enter the tissue of the smallest organisms in the food web. Predators need to consume multiple individuals to satisfy their need for energy and if their prey is infected it will result in the **bioaccumulation** or build-up of dangerous toxins or compounds. This condition is most common in aquatic environments that have been subject to industrial pollution and dumping and can occur in species that humans consume everyday like salmon and shrimp.

It is near impossible for researchers to predict the total cost in dollar value that the round goby has caused but estimates are in the high millions. The major impacts of the round goby are best understood in the ecological and cultural systems. Having a negative impact on the sport fish in the Great Lakes has affected the choices available for recreational activities.

Causing a decline in **biodiversity** and negatively affecting the food chain make these small fish a big problem. The best methods of control for Round Goby include fish poisons that target bottom-dwellers, seismic guns and water guns, and a biological research into goby pheromones (Michigan Sea Grant, n.d.). Though they have the greatest effect, the majority of these methods were not successful enough to form control programs.

The individual can play a very important role in the control of Round Goby. The cleaning and inspection of fishing and boating gear and a constant lookout will help improve the status of the Great Lakes ecosystem as well as any inland water bodies.

According to the Ontario Fishing Regulations Summary:

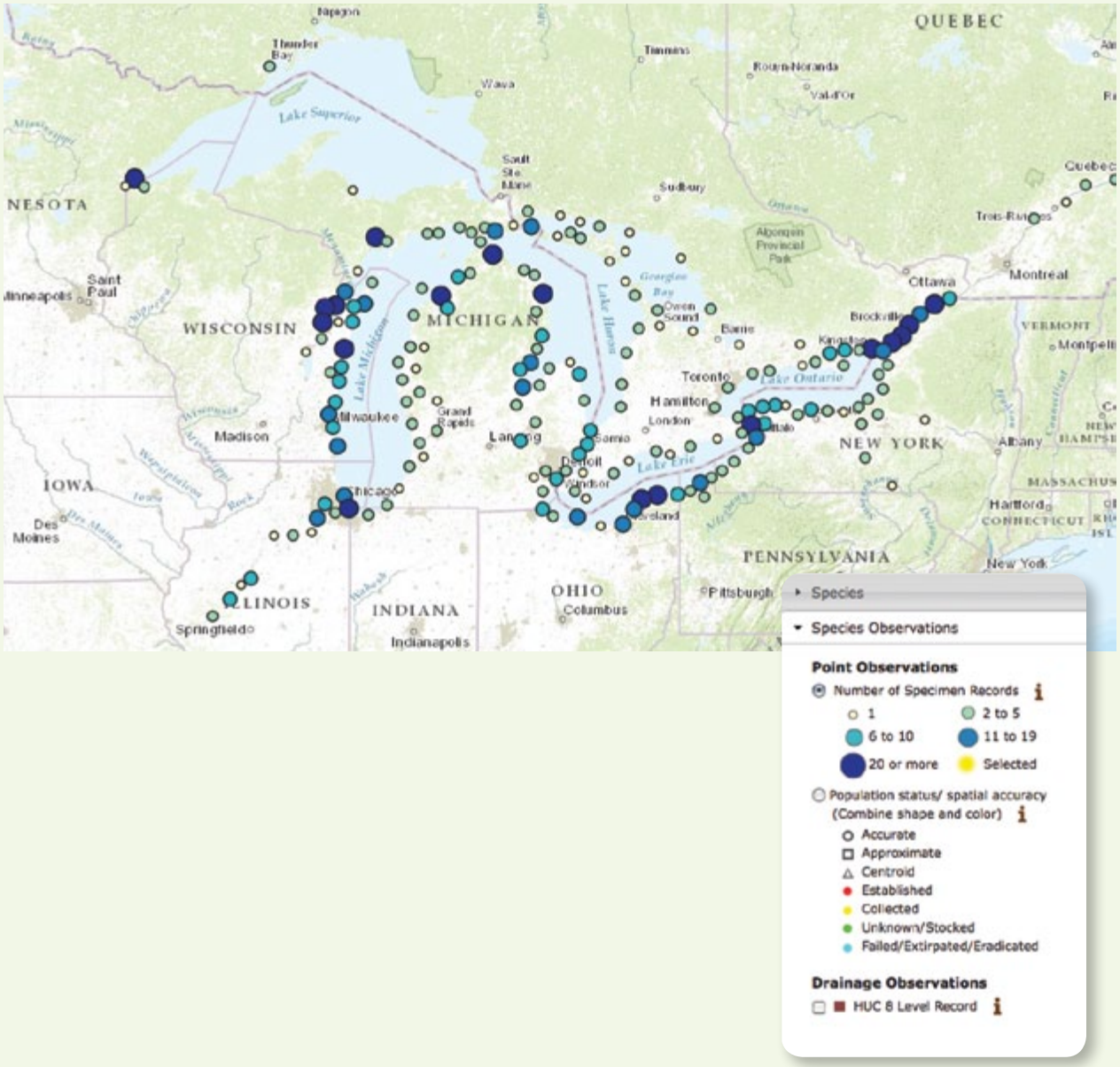
What you can do?

- Report new sightings. If you catch a round goby, report it to the Invading Species Hotline 1.800.563.7711 or visit www.eddmaps.org/Ontario.
- Always dispose of your unwanted bait and the contents of your bait bucket or bait bucket water on land or in the trash. It is illegal to dump the contents of a bait bucket into any waters or within 30 metres of any waters.
- Never use gobies as bait. It is against the law to use gobies as bait or have live gobies in your possession

FIGURE 5. *Round Goby sightings in 1994, Great Lakes (United States Geological Survey, 2015)*

FIGURE 6. *Round Goby sightings in 2014, Great Lakes (United States Geological Survey, 2015)*

FIGURE 7. *Round Goby population density in the Great Lakes (United States Geological Survey, 2015)*

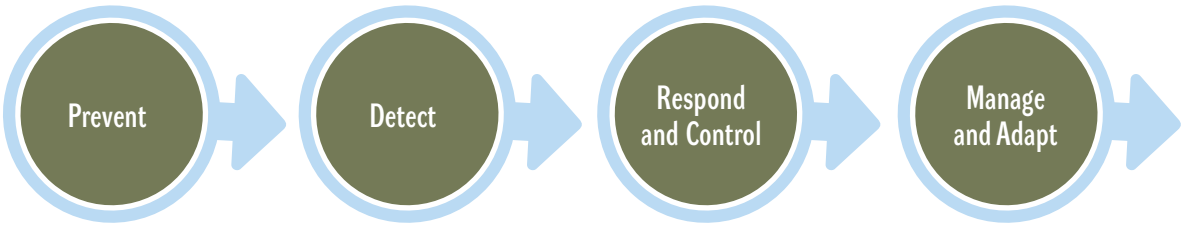


3.0 The Invasive Species Management Cycle

3.1 Introduction to the Invasive Species Management Cycle

The stages of the invasive species management cycle go as follows: prevent, detect, respond and control, and manage and adapt (Figure 8).

FIGURE 8. *Invasive Species Management Cycle*



3.2 Prevent

The first step to managing invasive species is to prevent the introduction of an invasive species. To prevent species from being introduced it is important to fully understand the various pathways of introduction (see Section 2). Understanding the ways in which species can enter a new ecosystem helps to create protocols to ensure that these pathways are monitored or reduced/eliminated. Prevention is a focus at international, national, provincial and regional levels.

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. 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. 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.

On a regional level, prevention focuses on ensuring that an invasive 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.

3.3 Detect

Detecting if a 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. 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. 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. More about detection and monitoring techniques can be found in Section 5—Tools in the Toolbox.

3.4 Respond and Control

Now that you have detected the invasive species, it is important to respond quickly and put in place control actions. 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.

There are three main methods to control invasive species. These include: biological, chemical, and mechanical. These three methods can be used individually or in conjunction with each other in order to get the best results to control the invasive species. It is important to research and use **best management practices** to select the appropriate method for the species, and to understand the timing of control. Using a method at the inappropriate time in the year or life stage of the species, can be an inefficient use of resources and could potentially impact native species.

Biological Control

Biological control consists of using another species to control an invasive species by reducing or eliminating the population. The biological control may consume the invasive species or cause it to become diseased and die. While this method can be quite effective, it requires extensive research prior to the introduction of another species to determine its potential impact on the native ecosystem. This includes an assessment of the potential invasiveness of that species. Often the biological control agent comes from the area of origin of the original invasive species where it helped to maintain its populations naturally.

Biological control agents include parasitoids, pathogens and predators.

parasitoids: have an immature life stage that develops within or on another host and ultimately kills the host. They slowly kill their host by feeding on their tissues, laying eggs within them, or paralyzing them. Parasitoids vary in the life stage that they attack as well as where they attack their host.

pathogens: these are disease-causing organisms (bacteria, viruses, fungi) that control or eliminate an insect population. These need to be applied at certain life stages of the host.

predators: these eat or kill the pest. This method is risky because the predator may also impact native species populations.

Purple loosestrife is an invasive plant that outcompetes native vegetation in wetland ecosystems. Biological control in the form of beetles are used to help control the loosestrife population. These beetles feed on leaves and new growth and have successfully helped to control loosestrife populations.

There are many examples of unsuccessful biological control methods, but one of the most famous worldwide examples is the cane toad. The toad was introduced from South America into Australia as a way of reducing the cane beetle populations because this proved successful in other parts of the world. Unfortunately, the toad had little impact on the beetle populations and their populations have exploded across Australia and have impacted native biodiversity.

Chemical Control

Chemical control involves using chemicals, such as **pesticides**, **herbicides**, **piscicides**, **lampricide**, **fungicides** or **insecticides**, to remove or prevent the spread of an invasive species. This method of control requires extensive regulation of the application of the chemicals to ensure that it doesn't have impacts on non-targeted species in the ecosystem. Some examples include lampricide for controlling Sea Lamprey or herbicides to control for Giant Hogweed.

Mechanical/Physical Control

Mechanical control involves using any physical method of control, or **manual control**. 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 (e.g. fishways, controlled burns). Mechanical control can have varying degrees of success, dependent on the species being removed. For example, removing garlic mustard plants can be an effective method of removal 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.

Best Management Practices

Before any method is chosen, it is important to research and choose the most appropriate treatment for that species. Once the appropriate method is chosen, you must also consider using the method at the appropriate life stage of the invasive species. Applying an insecticide that works during a larval stage requires knowing the lifecycle of the insect, and understanding the timing in which you have to apply that insecticide.

Regardless of the method of control used, it is critical that monitoring is done to assess the effectiveness of the method chosen. This should be done to not only assess the invasive species, but any potential impact on the native ecosystem as well.

Information included above was taken in part from the Invasive Species Centre website. Visit www.forestinvasives.ca for more information.

3.5 Manage and Adapt

The final step in the process is to implement management actions and take steps to control and protect against the impacts of invasive species.

Site Prioritization

When creating management plants, it is important to make the most of resources by prioritizing invasive species control. The following will help you to prioritize sites and areas within site for control.

1. Protect areas where invasive species are absent or just appearing.
2. Protect rare species and communities. These include federal, provincial and regionally listed 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? What treatments are effective? How costly/time consuming are they? Does the species spread rapidly?

Management actions (aquatic examples):

- Sea Lamprey Control Program (http://www.dfo-mpo.gc.ca/species-especes/lamprey-lamproie-eng.htm)
- 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)
- Zebra Mussels and other species: a lot of management efforts are focused on public education. (e.g., invadingspecies.com)

3.6 Costs associated with controlling invasive species

Controlling and dealing with an invasive species can be very costly as it's not only the cost of management but the cost that the impact of the invasive species has on its new environment. Every year invasive plants cost the forestry and agricultural industries in Canada about $7.3 billion. This cost includes the loss of productivity to these industries, as well as the costs associated with trying to control and manage an invasive species. In the aquatic world, in Ontario alone the impact from zebra mussels has cost the government $75-91 million per year to help clean up their impact to industries, beaches and communities (MNRF, 2014). 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 (see Figure 9) (Texas Invasives, 2011).

FIGURE 9. *Showing economic losses globally from invasive species (European Parliamentary Research, 2013)*

Estimated economic losses due to invasive species across the globe

Country	Estimated losses
Globally	€1 trillion/year
US	€90 billion/year
EU	€12 billion/year
China	€11 billion/year
New Zealand	€2 billion/year
UK	€2 billion/year

Data source: European Commission (2013)

Costs play an important part of decision making. Analyzing the costs of doing something versus nothing can also impact the decision made. Costs are spread out over a variety of different groups involved, and collaboration is important to maximize cost efficiency. In the next section, a better understanding of the variety of roles and responsibilities among various stakeholders will help to show the importance of collaboration not only in costs but in effective control and management of invasive species.

3.7 Discussion Questions

1. What are the four stages of the invasive species management cycle and how do they work together?
2. What would a proper response be if you found an invasive species in your area?

Case Study—Nutria—Maryland's Blackwater National Wildlife Refuge—1943–2014

The first introduction of Nutria to Maryland's Blackwater National Wildlife Refuge can be traced back to 1943 when a fur trade was set to be established. The Nutria is a large rodent that resembles the beaver but with a long thin tail (See Figure 10). The Nutria has thick brown fur and can weigh as much as 20 pounds. Nutria spend much of their time in the water, have webbed feet and ears and eyes located high on their heads. This allows them to breathe while still partially submerged (Maryland Department of Natural Resources, n.d.).

Nutria pose a large threat to the significant salt marshes across Maryland, including Chesapeake Bay. They are responsible for destroying over 7,000 acres of salt marsh as a result of their feeding activity (See Figure 11); the cumulative effects of this habitat destruction, erosion and sea level rise have contributed to an ecosystem loss. The diet of Nutria consists mainly of wetland plants while specifically targeting the roots, rhizomes, and tubers of Cordgrass, bulrush, spikerush, chafflower, pickerelweed, cattails, arrowheads, and flatsedges (Maryland Department of Natural Resources, n.d.). By eating the wetland plants Nutria directly influence the rate of erosion of the plant-bearing soil.

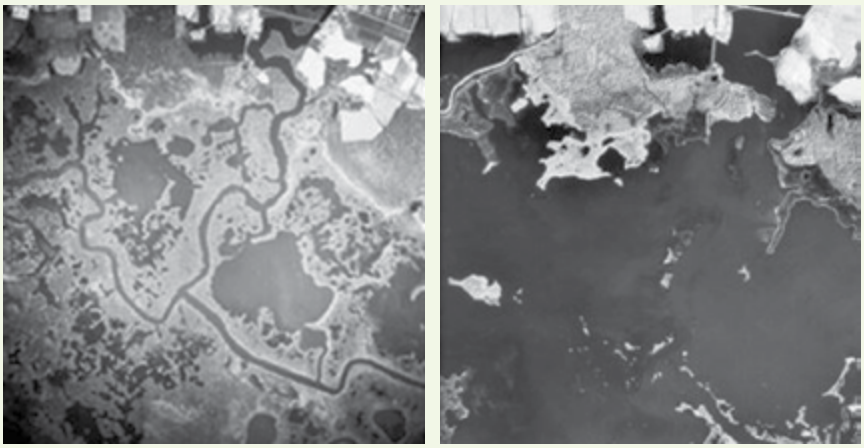
Nutria are also known to create swimming channels that are a hindrance to native species that rely on connected marsh systems. The actions of Nutria have contributed to the loss of habitat for nesting waterfowl and wetland birds such as black ducks and the black rail which are both on the decline. Destruction of salt marsh also has a negative effect of the native crabs and fish that rely on these systems for food and protection from predators (Maryland Department of Natural Resources, n.d.). This is particularly damaging because marshes and wetlands are unique ecosystems that are beneficial for to the environment by maintaining clean water.

Overall the diet of the Nutria has reduced the value of the local fisheries and ecotourism. Nutria are extremely damaging to natural systems and their exceptional ability to breed furthers the potential damages. Native to South America, the Nutria is capable of producing litters up to three times a year and these litters can range from 4 to 12 offspring that are able to go out on their own after just 4 days of nursing (United States Fish & Wildlife Service, 2011). These **establishment** strategies allowed the Nutria population in Maryland to swell to over 7,000 individuals. This led to the U.S. Fish and Wildlife Service to take action by spending two million U.S. dollars in conjunction with a team of trappers to eliminate the non-native Nutria (United States Fish & Wildlife Service, 2013).

Conditions improved for the Maryland Blackwater National Wildlife Refuge after this large collaborative effort. After costing the state 2.8 million dollars' worth of cultural and environmental damages, Nutria have been declared eradicated from Blackwater National Wildlife Refuge since 2004. Although the rodents remain in Maryland, officials are optimistic after this major victory. Maryland's elimination of the invasive Nutria provides hope for Texas, Georgia, Florida, and all the other states in where populations of Nutria can be found (Farenthold, 2004).

FIGURE 10. *Nutria profile (United States Fish & Wildlife Service, 2011)*

FIGURE 11. *Nutria impact from space, Maryland Blackwater National Wildlife Refuge, 1938 and 1989 (United States Fish & Wildlife Service, 2011)*



4.0 Roles and Responsibilities

4.1 Roles and Responsibilities of Government

The management of invasive species is complex, bringing together different levels of government, non-government actors and the public to help combat the threat. Governments are responsible for developing the different regulations, policies and legislations that help prevent, detect, monitor and control **invasive species**.

Regulations, **policies** and **legislations** are developed through all levels of government including municipal, provincial/state, national and international. Regulations, legislation and policies are meant to prevent and minimize the **spread** and **introduction** of invasive species by placing regulations on the transport and import of certain exotic species.

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 (CBD, 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.

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 alien 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
  - Control measures should focus on mitigating effects rather than merely on reducing numbers of the invasive species

Global Invasive Species Database

The Global Invasive Species Database aims to increase awareness about invasive alien species and to facilitate effective prevention and management activities. This 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 alien invasive species that has been found. To see a list of the 100 of the world's worst invasive alien species visit http://www.issg.org/database/species/reference_files/100English.pdf

International Example

New Zealand is a collection of islands isolated from any significant landmasses. There are many species that have been introduced intentionally in the past that have become invasive including sheep and cow. These have significantly altered the natural landscape. To help prevent future introduced invasive species, New Zealand focuses on biosecurity with strict border control measures. Passengers and their baggage are checked for unwanted organisms, and anything that is found is incinerated. Places such as airports also have dogs roaming to sniff out any potential risks.

4.1.2 CANADA

An 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):

- integrating environmental considerations into decision-making with economic and social factors
- enhancing co-ordination and co-operation 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. They work alongside provincial ministries each taking on various roles and responsibilities in the management of invasive species.

To view a copy of the strategy visit:

http://publications.gc.ca/collections/collection_2014/ec/CW66-394-2004-eng.pdf .

Aquatic Invasive Species Regulations

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

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 AIS 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 AIS.
- Enforcement powers: Enforcement officials (i.e. Fishery Officers and Fishery Guardians) have the power to enforce the prohibitions on import, 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.

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.

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. 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)

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.

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.

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

4.1.4 CANADA-UNITED STATES RELATIONSHIPS

Canada and the US 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. 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 US/Canadian inspection program. These regulations, along with monitoring have significantly reduced the risk of aquatic invasive species.

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. 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 occurence of aquatic nuisance species (aka invasive species). The Great Lakes Panel focuses its efforts on education, research coordination and policy coordination.

For more information about the Great Lakes Panel visit http://projects.glc.org/ans/panel.html

4.1.5 PROVINCIAL

Like international borders, provincial borders are political boundaries that invasive species do not obey. While it is important that provinces work to manage invasive species within their own jurisdictions, it is also crucial that there is collaboration and work between provinces and nationally as mentioned above.

Ontario

The Ontario Invasive Species Strategic Plan provides details on how Ontario will meet the goals set out in the National Strategy. Compared to other provinces in Canada, Ontario has the highest number of invasive species. This is as a result of favourable environmental conditions and the nature of the society being urbanized, large quantities of imports, geographical location, a significant goods-producing industry sector and the multiple points of entry for invasive species (OISSP, 2015).

Ontario's Invasive Species Strategy is a collective strategy that includes the information and policies set forth by many strategies, action plans and agreements below:

- An Invasive Alien Species Strategy for Canada
- Ontario's Biodiversity Strategy 2011: Renewing Our Commitment
- Ontario Government Plan to Conserve Biodiversity
- Climate Ready: Ontario's Adaptation Strategy and Action Plan
- Environmental Commissioner of Ontario Annual Reports
- Canada Ontario Agreement Respecting Great Lakes Basin Ecosystem
- Ontario's Draft Great Lakes Strategy 2012

At a provincial level in Ontario, there are various ministries involved in the management of invasive species. These include the Ministry of Natural Resources and Forestry (lead role), Ministry of Agriculture, Food and Rural Affairs, Ministry of Transportation, and the Ministry of Environment.

In 2014, the *Invasive Species Act* was re-introduced to help protect the province's natural environment from invasive species and the significant social, environmental and economic costs. If the act is passed, it will give Ontario the tools to ban activities such as possessing and transporting certain species, allow the government to intervene earlier and enable rapid response actions, and help promote compliance. If this Act is passed, Ontario would be the first and only jurisdiction in Canada to enact standalone invasive species legislation.

Manitoba

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. Persons are not to possess aquatic invasive species in Manitoba, introduce, release or transport aquatic invasive species.

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 (Government of Manitoba, 2015).

British Columbia

The Invasive Species Council of British Columbia is a council that coordinates and unifies efforts across the province to reduce the harm of non-native species. The main role is to provide education and outreach on the impacts of invasive species.

There are various pieces of legislation in place that help to control the impact of invasive species in British Columbia. For more information, visit: http://bcinvasives.ca/invasive-species/about/regulated-invasive-species-in-bc/

4.1.6 STATES

Similarly to the provincial challenges above, states have to work in conjunction with each other to ensure that invasive species are managed appropriately and efficiently. Below are just some of the examples of the approaches of various states and organizations.

Washington

The Washington Invasive Species Council is tasked with providing policy level direction, planning and coordination for combating harmful invasive species throughout the state and preventing the introduction of others that may be potentially harmful. The council provides direction and coordination on a strategic plan that builds upon local, state and regional efforts including education and communication on invasive species.

The main strategic goals are:

- foster cooperation, coordination and communication
- prevent the introduction and establishment of invasive species and reduce their adverse impacts
- refine and coordinate statewide capacity to identify, report and respond
- assist those who manage invasive species through containment, control and eradication
- support restoration and rehabilitation

Michigan

The Michigan Invasive Species Coalition supports the efforts of regional and local groups working to control invasive species in Michigan. The guiding principles are to provide a network for local and regional invasive species coordinators, address common challenges in implementing control efforts, enhance communication on invasive species statewide and share information.

Virginia

The Virginia Invasive Species Management Plan was developed by the Virginia Invasive Species Advisory Committee in 2012 for the Invasive Species Working Group. The Advisory Committee is comprised of stakeholders including state, federal and local government agencies, private industry interests and nongovernmental organizations. The plan identifies seven goals and supporting strategies that guide invasive species prevent, early detection, rapid response, management, research and educational efforts (Virginia Department of Conservation and Recreation, 2010)

Within Virginia there are various pieces of legislation that act to protect terrestrial and aquatic ecosystems from the introduction and impact of invasive species.

- Virginia Pest Law
- Nonindigenous Species Act
- Noxious Weed Act

4.1.7 MUNICIPAL

At a very local level, municipalities work to manage the introduction and spread of invasive species. Because they work directly with the community, municipalities can play an important role in engaging citizens to be actively involved with the management of invasive species. Additionally, municipalities need to 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 species.

Saanich, British Columbia has had many natural areas devastated by invasive species. The District of Saanich is working within the municipality and with partners to manage new and existing invasive threats. The Environmental Services and Parks takes the lead on management, outreach and prevention. Saanich's invasive species management program includes public and staff education, provides guidance for proper removal and includes bylaw enforcement. The District of Saanich also works in cooperation with other districts as part of the Capital Region Invasive Species Partnership. (http://www.saanich.ca/living/natural/stewardship/invasive.html?ref=shortURL)

4.2 Roles of Non-Government Organizations

Non-Government Organizations (NGOs) play an important role in the education and management of invasive species. A large part of the work that is done by non-government organizations is around community engagement including removal of invasive species, education, and preventing the introduction and spread. 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.

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. In Ontario, the Ontario Federation of Anglers and Hunters works collaboratively with local, provincial, and federal agencies on education and outreach.

4.3 Role of the Individual

While government and non-government agencies can play important roles in the introduction, spread and management of invasive species, it also comes down to the individual to help ensure that species are managed appropriately.

Firstly, you can educate yourself about the issue of invasive species. The most important step is to understand 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. Another thing to do is to take responsibility and be sure to not introduce an invasive species into an ecosystem. Thirdly, you can volunteer at events to assist in the removal of invasive species such as garlic mustard pulls, where you can help bring back native species in your community.

Citizen Science

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. You could be trained to identify, track and control invasive species. Check with your local state or province to see if you can join an EDRR Network close to you. **What you can do (Nature Conservancy, 2015)**

- Make sure the plants you are buying for your home or garden are not invasive. Contact your state'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.
- 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.

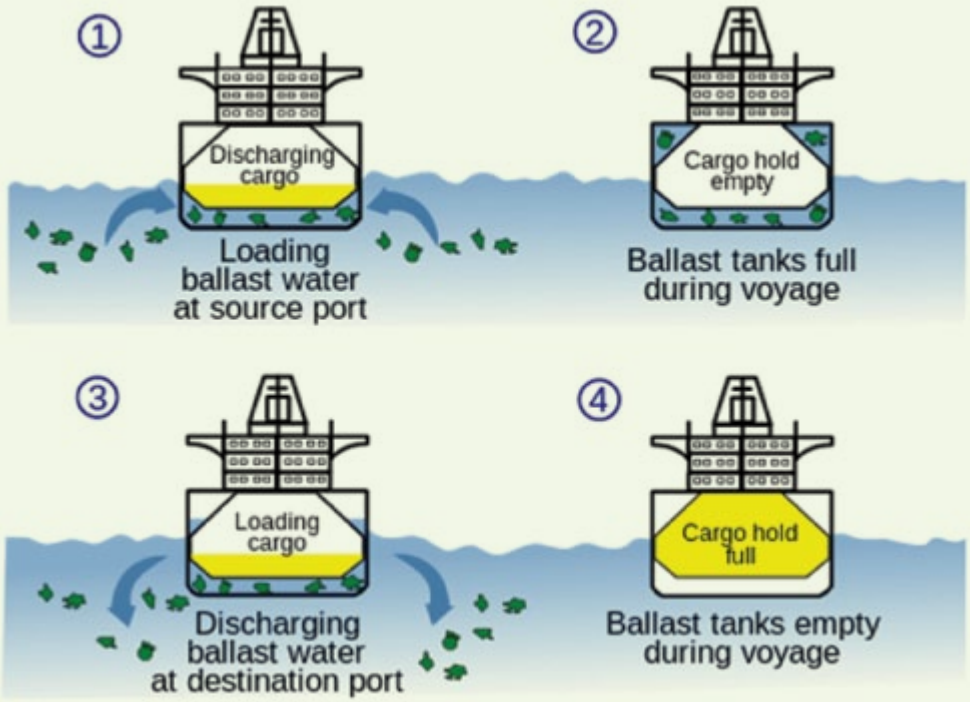
4.4 Discussion Questions

1. Why are regulations related to invasive species important?
2. How can different levels of government work together?
3. What are some ways that NGOs help with invasive species?
4. Find and research an NGO that deals with invasive species. Do you have an EDRR Network you could become a part of?
5. What are some ways that you can help with the spread of invasive species?

Case Study: Canada's Ballast Water Control and Management Regulations

Ballast is either a solid or liquid substance that ships use to increase draft, change the trim, and regulate stability or to maintain stress loads. Traditionally, ballast was made up of rocks and sand but since the 1980s water has become the more popular choice for ballast. Ballast water is one of the main sources for invasive aquatic species to be introduced into Canadian waters. This occurs when a ship comes from one area of the world to another and exchanges its ballast water. This, consequently, releases any invasive species that were in that ballast water to now be introduced into the new **ecosystem** (see Figure 12) (Transport Canada, 2010).

FIGURE 12. The process of how ballast water can introduce invasive species.



Since 1959, it has been found that at least 56 invasive aquatic species have been introduced into the Great Lakes, with 34 of these species being introduced through transoceanic shipping. Some species that have been introduced into Canadian waters because of ballast water being discharged at port include the sea lamprey, zebra mussels, bloody red shrimp and the round goby (Fisheries and Oceans Canada, 2015).

The Ballast Water Control and Management Regulations (BWCMR) was introduced under the *Canada Shipping Act* of 2001 to combat the issue of accidental **introduction** of **non-native** species. The BWCMR requires all vessels, except those specifically exempted under provisions of the regulations, to treat or exchange their ballast water prior to the discharge of the ballast within waters under Canadian jurisdiction. This tackles the fact that oceanic water's high salinity is effective enough to remove any freshwater living or tolerant invasive species (Transport Canada, 2010).

Fisheries and Oceans Canada did some research into how effective the BWCMR was on the introduction of invasive aquatic species into the Great Lakes. They used 4 types of evidence to determine if the regulations were working:

- Is salt water ballast exchange and flushing demonstrably effective?
- Is salt water ballast exchange and flushing effective under operational conditions?
- Can compliance be achieved on a broad scale?
- Are desired changes observed in the environment?

Fisheries and Oceans Canada found through their control studies that the salt water ballast water exchange is effective in decreasing the amount of organisms that could start an invasive population in the Great Lakes. They also found through random sampling of ships coming into the Great Lakes that the exchange and flushing of the ballast water greatly reduced the amount of individual organism in the ballast tanks. Their study found that there was a very high compliance rate among the vessels. They found that there has been a decline in the rate of invasive species introduction into the Great Lakes since 1995 and that there has been no new ballast water related introductions since 2006. Overall, they found that the Ballast Water Control and Management Regulations to very effective (Fisheries and Oceans Canada, 2015).

5.0 Tools in the Toolbox

5.1 Monitoring

What is Monitoring?

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 (United States Fish & Wildlife Service, 2012).

Why Monitor?

Invasive species monitoring is essential in making well-informed management decisions to meet goals effectively and efficiently. Monitoring results can show where management actions have met objectives and where improvements need to be made (United States Fish & Wildlife Service, 2012). Monitoring is important in all stages of the invasive species management cycle, from detection to response.

We monitor to:

- Detect 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 & 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 condainment efforts may be possible. Most cost effective and control efforts are minimal
  - Early Detection and Rapid Response (EDRR)—Citizen science that focusing on educating the public to help monitor to prevent invasive species' impacts
- Monitoring for the effect of management actions on target invasive species
  - Helps determine the most effective control method and if actions should continue
- Monitoring for the effects of management actions on non-target species and the environment
  - Helps determine if applied management actions for the invasive species are affecting other species negatively

- Monitoring for the status and trends of target species populations
  - Measuring the currents characteristics of a population including metrics such and abundance or distribution

(United States Fish & Wildlife Service, 2082).

5.1.2 MONITORING TECHNIQUES

There are a wide variety of techniques used to monitor invasive species. These monitoring techniques are dependent on what kind of species is being studied. Whether the invasive species is a terrestrial or aquatic plant or animal, disease or invertebrate, and depending on the type of monitoring being performed, techniques need to be adjusted to best suit the circumstances. Here are a few examples of monitoring techniques:

Collection of Dead Animals

Samples are collected of dead animals to test for disease.

Pheromone Traps (see figure 11)

Pheremone 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. This is used when trying to monitor the spread of an invasive species, by establishing these traps at the furthest point of the suspected range. If a species is found in the trap, then this indicates that is has spread beyond its initial range and poses a threat to the new ecosystem.

FIGURE 13. This picture shows an example of a pheromone trap that can be used to attract and trap insects. This is a common technique used for general management of insects.

Trapping

Traps are set up to capture animals. 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 disease or simply counted and released. This technique is used on both land and water.

Video Monitoring

Cameras are set up to record animal movement. This technique offers the opportunity to monitor activities both during the day and night over a long period of time.

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. This technique is used for plant species.

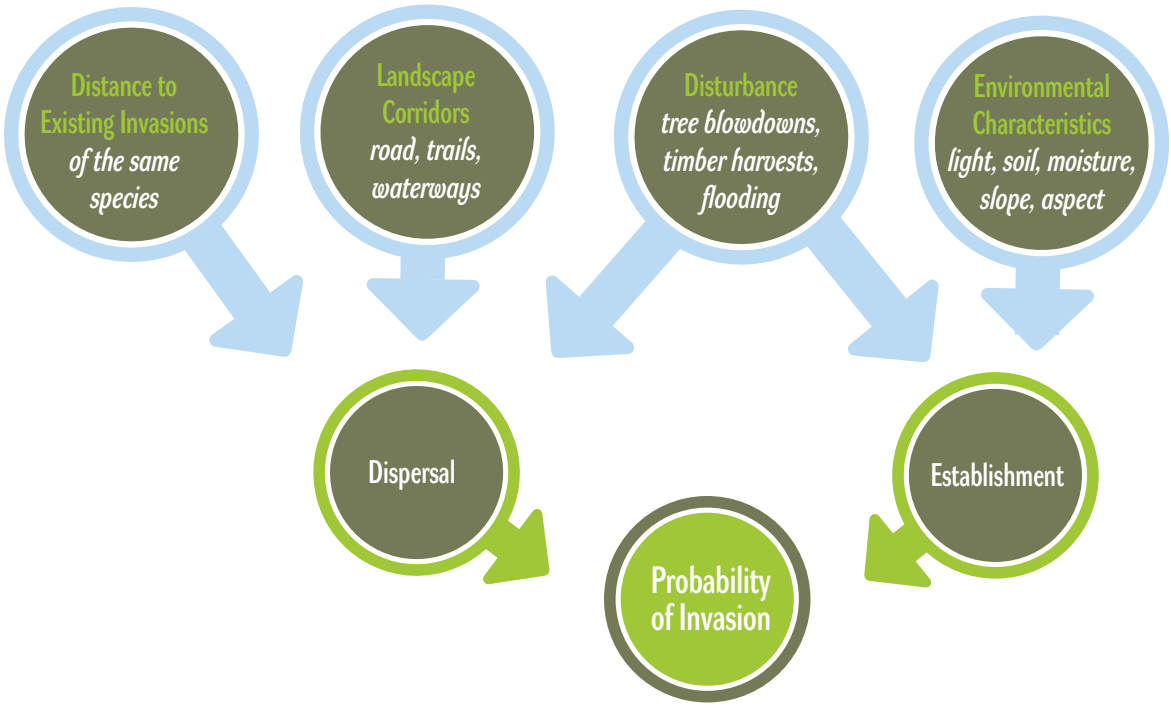
Electrofishing

Specialized electrofishing equipment is used to apply electric current to the water which stuns nearby fish, allowing them to be captured. This technique can be used to detect species presence/absence and to count and measure individuals. This provides the opportunity to monitor if any invasive species have made their presence in the water body.

5.2 Risk Assessment/Analysis

Actions taken towards preventing the introduction of and controlling invasive species are partially based on the intensity of risk. Invaders that hold a high degree of risk for damages will be prioritized for immediate and intense management actions. Some invasives 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 (see figure 12). Risk assessment looks at the likelihood of introduction, establishment, spread and consequences; risk is based on species biology, environmental conditions and pathways of spread.

FIGURE 14. *This diagram displays factors that can be used to assess the probability of an invasion (Indiana University, 2011).*



A high probability of invasion suggests high risk. Management actions need to be put in place as soon as possible to tackle 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 can have preventative measures put into place. If actions are taken before an invasion occurs, the chances of one happening or the intensity of one is drastically reduced because preventative measures are the most effective.

Risk communication is an important part of preventing invasions as it communicates to the public and other stakeholders the results of the risk assessment and helps people make informed decisions.

5.3 Other Management Options

Quarantine/management zones

Some invasive species become established in an area. To slow or halt the spread of the invasive species to another area, a **quarantine** or management zone is established that may restrict the movement of objects (e.g. firewood).

Restoration

The ultimate goal of any management for invasive species is to help restore the native ecosystem. Through the control measures listed above, the removal of invasive species is the first step. Managing these populations can help to bring native ecosystems back to health, along with actively restoring sites. Restoration may include reintroducing populations of native organisms or restoring habitat to its pre-invasion condition. Restoration efforts are often a collaborative effort between governments, non-governments and individuals to most efficiently and cost-effectively restore the ecosystem.

5.4 Discussion Questions

1. Why is it necessary to have different types of monitoring techniques?
2. Discuss the importance and benefits of monitoring areas before they are invaded as opposed to only after.

Case Study—Zebra Mussel—The Great Lakes—1988

The zebra mussel jumped into focus in 1988 by invading Lake St. Clair and pushing out 13 native species of mussels in the process. It violently entered Lake Erie as well, which pressured 10 native mussel species to near-extinction (see figure 15). The zebra mussel is so adept at rapid colonization that is has even begun to take over the inland lakes of Ontario (Office of the Auditor General of Canada, 2002).

There is no question that this invasive mussel spreads quickly after it was able to multiply in the Rideau River to a density of 383,000 individuals per square meter after just three years of being in the ecosystem. This hostile takeover of the river also resulted in the absence of native mussels. Zebra mussels are extremely harmful to infrastructure by attaching themselves to municipal and industrial water intakes and outfalls as well as hindering hydroelectric projects by negatively affecting water flow and plant efficiency (Office of the Auditor General of Canada, 2002).

Ontario Power Generation has created estimates to assess the economic impact that this non-native mussel has had on various plants. Nuclear power stations in Darlington and Pickering have had increased operation costs in the range of $500,000 to $1 million Canadian dollars. Fossil fuels plants at Nanticoke, Lambton, and Lakeview have experienced economic setbacks in the amounts of $150,000, $75,000, and $50,000 respectively (Office of the Auditor General of Canada, 2002).

The impacts of the zebra mussel on water treatment facilities and other industries are so severe that these costs can be felt by homeowners and consumers as well as cultural systems of Ontario. Nearly 200,000 cottagers will be affected at their summer getaways. Once established, the mussel is capable of clogging water lines and interfering with piers, engines, and boats. It is also possible that the zebra mussel is responsible for adding an offensive odour and taste to the drinking water (Office of the Auditor General of Canada, 2002).

One of the many health concerns associated with the zebra mussel is their ability to absorb hazardous compounds such as the infamous polychlorinated biphenyls (PCBs). PCBs are a deadly poison that is persistent in organisms and the environment.

FIGURE 15. Zebra mussel distribution in Ontario (Office of the Auditor General of Canada, 2002)

6.0 Glossary of Terms

A

Adapt: become adjusted to new conditions

Alien/ Non-native species: A species that spread beyond its native range, not necessarily harmful, or species introduced to a new range that establish themselves and spread.

Allelopathic: A species that produces one or more chemicals to influence the growth, survival and reproduction of other species. Normally are plant species.

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 be easily pumped in and out, and poses little to no stability problems.

Best management practices: a practical, affordable approach

Biological control or biocontrol: The human use of natural predators for the control of pests or weeds. The release of one species to control another.

Biological diversity or biodiversity: Used to describe species richness, ecosystem complexity, and genetic variation.

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 or lampricides to control exotic plants, animals and diseases.

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

D

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

E

Ecosystem(s): A discrete unit, or community of organisms and their physical environment (living and non-living parts), that interact to form a stable system.

Endemic: A species or taxonomic group that is restricted to a particular geographic area because of such factors as isolation or response to soil or climatic conditions.

Eradication: The elimination of an agent from a country or zone.

Establishment: The process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival.

Exotic species: An introduced, non-native species, or a species that is the result of direct or indirect, deliberate or accidental introduction by humans, and for which introduction permitted the species to cross a natural barrier to dispersal. Similar to alien species.

Export: To send or transmit to another place, especially to another country.

Extinct: no longer in existence

Extinction: when a species becomes extinct

Extirpation: to remove or destroy totally

F

Fungicide: a chemical that destroys fungus

H

Habitat: The place, including physical and biotic conditions, where a plant or an animal usually occurs.

Herbicide: Pesticide that specifically targets vegetation.

I

Import: To bring in or carry from an outside source.

Insecticides: a substance used for killing insects

Intentional introduction: the act of deliberately bringing a species into a region it did not originate in

Introduction: The movement by human agency, indirect or direct, of an alien species outside of its natural range.

Invasive species: Subsets of plants or animals that are introduced to an area, survive, and reproduce, and causes harm economically or environmentally within the new area of introduction.

L

Lampricide: A chemical that targets the larvae of sea lamprey in river systems before they turn into parasitic adults. (see Piscicide)

Legislation: laws, collectively

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/ Indigenous species: A species that occurs naturally in an area, and has not been introduced by humans either intentionally or unintentionally.

Naturalized species: A non-native species that forms self-sustaining populations but is not necessarily an invasive species.

Non-native/ Alien species: A species that spread beyond its native range, not necessarily harmful, or species introduced to a new range that establish themselves and spread.

P

Pathogen(s): A bacterium, virus, or other microorganism that can cause disease.

Pathway(s): Any means that allows the entry or spread of a pest.

Pest(s): A destructive insect or animal that attacks plants, trees, crops etc.

Pesticide: A chemical or biological agent intended to prevent, destroy, repel, or mitigate plant or animal life.

Piscicide: A chemical that is poisonous to fish, usually used to eliminate a dominant species of fish in a body of water, in preparation to repopulate with a different species. They are also used to combat parasitic and invasive species of fish.

Policies: a course or action proposed by a government, party, business, or individual

Q

Quarantine: A state, period, or place of isolation in which animals that have arrived from elsewhere or been exposed to infectious or contagious disease are placed.

R

Range: The geographical area within which that species can be found.

Regulations: a rule made by an authority

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

S

Secondary movement occurs once the species has been introduced to a new area and starts spreading from that area to other locations nearby.

Species: A group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding, the taxon rank in the hierarchy of biological classification below genus; the basic unit of biological classification.

Spread(ing): Expansion of the geographical distribution of a particular species within an area.

U

Unintentional introduction: An introduction of nonindigenous 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.

7.0 References

Convention on Biological Diversity, 1999. Retrieved from: https://www.cbd.int/doc/meetings/sbstta/sbstta-05/official/sbstta-05-05-en.pdf

Eating Garlic Mustard is a Win-Win. (2012, April 1). Retrieved from Wild Edible Food: http://www.ediblewildfood.com/blog/2012/04/eating-garlic-mustard-is-a-win-win/

Emerald Ash Borer. (2015, April). Retrieved from Emerald Ash Borer: http://www.emeraldashborer.info/#sthash.x1MNGH1l.dpbs

Environment Canada. (2013, August 26). Invasive Alien Species Partnership Program: 2005–2010 Report. In *Government of Canada*. Retrieved March 23, 2015, from https://ec.gc.ca/nature/default.asp?lang=En&n=B008265C-1

Estimated economic losses due to invasive species across the globe. (2013, December 2). Retrieved from European Parliamentary Research: http://epthinktank.eu/2013/12/03/tackling-invasive-alien-species-in-europe/estimated-economic-losses-due-to-invasive-species-across-the-globe/

Invding Species Awareness Program (ISAP), 2015. Eurasian Water-milfoil. Retrieved from Ontario's Invading Species Awareness Program: http://www.invadingspecies.com/invaders/plants-aquatic/eurasian-water-milfoil/

Farenthold, D. (2004, November 17). Blackwater Refuge now Nutria-free. Retrieved March 23, 2015, from http://www.washingtonpost.com/wp-dyn/articles/A55356-2004Nov16.html

Fisheries and Oceans Canada. (2015, March 20). Ballast Water Management in the Great Lakes Reduces the Introduction of Aquatic Invasive Species: Fisheries and Oceans Canada Study. In *Government of Canada*. Retrieved March 23, 2015, from http://www.dfo-mpo.gc.ca/science/publications/article/2011/06-13-11-eng.html

World Wildlife Fund (WWF), (2015). Impact of Invasive Alien Species. Retrieved from World Wildlife Fund: http://wwf.panda.org/about_our_earth/species/problems/invasive_species/

Invading Species Awareness Program, (2015). Invasive Earthworms. Retrieved from Ontario's Invading Species Awareness Program: http://www.invadingspecies.com/invaders/forest/invasive-earthworms/

Indiana University. (2011, January 26). Predictive Model of Invasive Species Spread. Retrieved March 24, 2015. http://www.indiana.edu/~preserve/InvasiveSpread/model.html

Maryland Department of Natural Resources. (n.d.). Nutria. Retrieved March 23, 2015, from http://www.dnr.state.md.us/wildlife/Plants_Wildlife/invNutriafaq.asp

Michigan Sea Grant. (n.d.). Retrieved March 23, 2015, from http://www.miseagrant.umich.edu/explore/native-and-invasive-species/species/fish-species-in-michigan-and-the-great-lakes/round-goby/

National Invasive Species Council. (2005, January 1). About National Invasive Species Council. In *US Department of the Interior*. Retrieved March 20, 2015, from http://www.doi.gov//invasivespecies/index.cfm

Nature Conservancy (2015). Invasive Species. Retrieved from: http://education.nationalgeographic.com/encyclopedia/invasive-species/

Office of the Auditor General of Canada. "2002 October Report of the Commissioner of the Environment and Sustainable Development." *Government of Canada, Office of the Auditor General of Canada.* 15 Nov. 2207. Web. 24 Mar. 2015 http://www.oag-bvg.gc.ca/Internet/English/att_c20021004se01_e_12345.html.

Ontario's Invading Species Awareness Program. (2015). Retrieved from Invading Species: http://www.invadingspecies.com/

Ontario Ministry of Natural Resources & Forestry. (2014, November 5). How government combats invasive species. Retrieved March 23, 2015, from https://www.ontario.ca/environment-and-energy/how-government-combats-invasive-species

The Government of Manitoba. "Forestry Branch." |Conservation and Water Stewardship. Web. 8 Apr. 2015.

Transport Canada. (2010, January 20). Ballast Water. In *Government of Canada*. Retrieved March 23, 2015, from https://www.tc.gc.ca/eng/marinesafety/oep-environment-sources-ballastwater-1722.htm

Transport Canada. (2012, February 27). A Guide to Canada's Ballast Water Control and Management Regulations TP 13617 E. In *Government of Canada*. Retrieved March 20, 2015, from https://www.tc.gc.ca/eng/marinesafety/tp-tp13617-menu-2138.htm

United States Fish & Wildlife Service. (2011, October 19). Chesapeake Bay Nutria Eradication Project. Retrieved March 23, 2015, from http://www.fws.gov/chesapeakeNutriaproject/FAQs.html

United States Fish & Wildlife Service. (2012, January 1). The cost of Invasive Species. Retrieved March 23, 2015, from http://www.fws.gov/verobeach/PythonPDF/CostofInvasivesFactSheet.pdf

United States Fish & Wildlife Service. "MANAGING INVASIVE PLANTS: Concepts, Principles, and Practices." Monitoring. 18 Feb. 2008. Web. 24 Mar. 2015.

United States Geological Survey. (2013, June 6). Nonindigenous Aquatic Species. Retrieved March 23, 2015, from http://nas.er.usgs.gov/queries/SpeciesList.aspx?Group=Fishes

United States Geological Survey (2015, January 2). "Round Goby - Point Map." *Round Goby - Point Map*. 24 Mar. 2015. Web. 24 Mar. 2015.

United States Geological Survey. "River Barrier." Sea Lamprey Mitigation. Web. 8 Apr. 2015.

Virginia Department of Conservation and Recreation (2010). *Invasive Species in Virginia*. Retrieved from http://www.dcr.virginia.gov/natural_heritage/vaisc/

Texas Invasives, 2011. What Are Invasive Species? (2011). Retrieved from Texas Invasives: http://www.texasinvasives.org/i101/

Invasive Species Centre, 2015. What are Invasive Species? (2015). Retrieved from Invasive Species Centre: http://www.invasivespeciescentre.ca/SitePages/default.aspx

Why Are Invasive Alien Species a Problem? (2013, July 19). Retrieved from Environment Canada: https://www.ec.gc.ca/eee-ias/default.asp?lang=En&n=4612AC81-1

Appendix 1: Examples of Invasive Species in North America

Invasive Species	Origin and introduction	Current Location in North America	Major Impact	Management Options
Kudzu	Asia	Southern US	forms dense monocultures that outcompete native ground cover and forests	• herbicides • grazing
Burmese Pythons	Pet trade	Everglades	outcompete native species for food and habitat and pose risk to humans	• hunting
Hemlock woolly adelgid	Asia	Eastern US and Eastern Canada	kills hemlocks and impacts forest ecosystems	• insecticide • biological control
Spiny water flea	• Europe and Asia • Ballast water	Great Lakes	competes with native fish for prey, spines prevent predation	• mechanical removal • electron irradiation
Snakehead fish	• Africa and Asia • Live fish trade	Eastern US	top level predators that compete with native fish for food	• physical removal
Phragmites	Europe	Canada and US	outcompetes native vegetation; fire danger	• manual removal • herbicides
Glossy Buckthorn	• Europe • Ornamental plant	Eastern US and Canada	outcompete native forest vegetation	• manual removal • prescribed burning • chemical treatment
Purple Loosestrife	• Europe and Asia • Ballast soil • Ornamental plant	Canada and US	invades wetlands and chokes out native plants	• biological control • manual removal • herbicides
European green crab	• Europe • Boats and ballast water	Eastern US and Canada	preys on native species and threatens fishing industry	• mechanical removal (use as a food source)
Gypsy moth	Europe	Canada and Northern US	defoliates plants and can cause mortality	• insecticide
Dog strangling vine	• Europe and Asia • Ornamental plant	Eastern US and Canada	can form thick mats and outcompete native ground vegetation	• physical removal • herbicides • biological control
Giant hogweed	• Asia • Ornamental plant	US and Canada	outcompetes native vegetation; harmful to humans	• mechanical removal • herbicides
Fanwort	• Southern US and South America • Boats	Northern US and Ontario	forms thick mats that blocks sunlight and disrupts aquatic ecosystems; impacts recreation (boating)	• mechanical removal • herbicides
Japanese knotweed	• Asia • Ornamental plant	Canada and US	outcompetes native vegetation and reduces biodiversity	• herbicides • mechanical removal

Appendix 2: Non-Governmental Organizations

Invasive Species Centre

The Invasive Species Centre (ISC) is a Canadian non-profit organization that builds partnerships and collaborative projects to protect Canada's ecosystems from the damaging effects of invasive species. The ISC coordinates workshops, seminars, webinars and other educational opportunities to engage with the public and private sector. www.invasivespeciescentre.ca

Center for Invasive Species and Ecosystem Health

The Center for Invasive Species and Ecosystem Health serves as a lead role in development, consolidation and dissemination of information and programs focused on invasive species, forest health, natural resource and agricultural management through technology development, program implementation, training, applied research and public awareness at the state, regional, national, and international levels. www.invasive.org

Ontario Federation of Anglers and Hunters

The Ontario Federation of Anglers and Hunters runs the Invading Species Awareness Program (ISAP) to raise awareness about invasive species and how to prevent them from spreading into Ontario's forests, lakes and streams. www.ofah.org

Ontario Invasive Plant Council

The Ontario Invasive Plant Council (OIPC) provides leadership, expertise and a forum to engage and empower Ontarians to take action on invasive plant issues. www.ontarioinvasiveplants.ca

Forests Ontario

Forests Ontario is a non-profit organization that is working to increase the forested landscapes in Ontario through restoration, stewardship and education programs. Forests Ontario partners with municipalities, other NGOs, government and landowner groups to educate and inform about the impacts of invasive species. www.forestsontario.ca

North American Invasive Species Network (NAISN)

A non-profit organization that was formed by university and government scientists from across North America. NAISN aims to unify and connect existing regional invasive species efforts into a single network to improve communication, collaboration and overall coordination to help current invasive species management and prevention efforts across the continent.

North American Invasive Species Management Association (NAISMA)

The North American Invasive Species Management Association is a network of professionals challenged by invasive species. Their mission is to promote & empower invasive species management in North America. www.naisma.org

Appendix 2: Recommended Resources

North American Invasive Species Network
http://naisn.org/

Canadian Council on Invasive Species
http://canadainvasives.ca/

Invasive Species Centre
http://www.invasivespeciescentre.ca/SitePages/default.aspx

Ontario's Invasive Species Strategic Plan
https://dr6j45jk9xcmk.cloudfront.net/documents/2679stdprod-097634.pdf

Ontario's Invading Species Awareness Program
http://www.invadingspecies.com/invaders/

EDDMaps—Invasive Species Mapping in Ontario
http://www.eddmaps.org/ontario/

Ontario Invasive Plant Council
http://www.ontarioinvasiveplants.ca/

Invasive Alien Species Strategy for Canada
https://ec.gc.ca/eee-ias/default.asp?lang=En&n=1A81B051-1

Canadian Food Inspection Agency
http://www.inspection.gc.ca/plants/plant-protection/invasive-species/eng/1328252634101328325333845