Assessing the Current Threat of Aquatic Invasive Species in Saskatchewan

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Abstract

Aquatic invasive species (AIS) have become a significant and growing problem facing the world. The consequences of AIS are far-ranging, and include degradation of water quality, food-web disruptions, depletion of native biodiversity, as well as secondary economic impacts on fishing, tourism, and other industries. Over the last decades the introduction of several AIS have been observed in plains and prairies of central North America, posing a high risk to waterways and wetlands in Saskatchewan, Canada. The management of AIS is costly and difficult; therefore, conservation agencies and organizations should focus their limited resources, targeting the species that cause major impacts/threats and the areas that are significantly impacted/threatened.

A multi-spatial scale approach was developed to provide an AIS risk assessment for Saskatchewan. Three study scales were selected for this risk assessment: 1) local - Redberry Lake watershed, 2) regional - North Saskatchewan River watershed, and 3) provincial – Saskatchewan. The risk assessment was carried out for 16 AIS, including 7 species recorded in Saskatchewan and 9 species that are likely to enter Saskatchewan in the near future. These species were assessed, scored, and ranked into impact categories of high, medium and low. The categorisation of AIS provides a basis for which conservation agencies and organization, from the local to the provincial level, can focus their attention.

Table of Contents

List of Tables

List of Figures

1. Introduction

Aquatic invasive species (AIS) are aquatic organisms not previously found in an aquatic ecosystem and not expected to have arrived solely as a function of natural processes, with the potential to become a dominant component of the aquatic system (Rahel & Olden, 2008). As a general rule, AIS infestations are not desirable: they threaten the diversity or abundance of native species or the ecological stability and/or human use of these natural resources (Pejchar & Monney, 2009).

AIS have been entering Canadian waters at an alarming pace; every decade, some 15 introduced species are established in coastal or inland waters of the country (Fisheries and Oceans Canada, 2004). The most aggressive of established AIS spread rapidly in the absence of their natural predators. These non-native species impact the environment and the diversity of life in many ways; in addition to the severe and permanent damage to the habitats they invade, AIS also adversely affect individuals by hindering economic development, preventing recreational and commercial activities, decreasing the aesthetic value of nature, and serving as vectors of human disease (Pejchar & Mooney, 2009).

The impacts of invasive species are second only to habitat destruction as a cause of global biodiversity loss. In fact, non-native species are a greater threat to native biodiversity than pollution, harvest, and disease combined (Sala et al., 2000). AIS impact the habitats they invade by reducing the abundance of native species and altering ecosystem processes (Padilla & Williams, 2004). Native species are affected through predation, competition for food and space, hybridization, as well as the introduction of harmful pathogens and parasites (Molnar et al., 2008). AIS may also alter normal functioning of the ecosystem by altering hydrology, nutrient cycling and productivity (Gordon, 1998).

In addition to damage to the environment, AIS are also seen as a threat to economic development (Marbuah et al., 2014). They reduce production of fisheries, decrease water availability, block transport routes, choke irrigation canals, foul industrial pipelines, degrade water quality, accelerate filling of lakes and reservoirs, and decrease property values (Lovell et al., 2006). Through damage to human enterprises, invasive species inflict an enormous economic costs. For example, zebra mussel can damage human infrastructure at costs in excess of millions of dollars per year in Canada (Connelly, 2007). AIS have already been responsible for significant devastation of some native

fish species and fisheries in Canada. In total, AIS cost billions of dollars every year due to lost revenue and the implementation of control measures (Fisheries and Oceans Canada, 2004).This number is likely an underestimate as it does not consider ecosystem health or the aesthetic value of nature, which can influence tourism and recreational revenue. Estimating the economic impact associated with AIS is further confounded as monetary values cannot be given to extinction of species or loss biodiversity and ecosystem services (Pimentel et al., 2005).

Besides, introduction of AIS may cause human health problems (Pejchar & Mooney, 2009). Throughout recorded history, epidemics such as malaria, yellow fever, typhus, and bubonic plague have used introduced organisms as vectors and reservoirs (Lounibos, 2002). Waterborne disease agents, such as cholera bacteria (*Vibrio cholera*), and causative agents of harmful algal blooms are often transported in the ballast water of ships (Drake et al., 2007). Other AIS, such as invasive mussels, may increase human and wildlife exposure to organic pollutants such as Polychlorinated biphenyls (PCBs) and Polycyclic aromatic hydrocarbons (PAHs) as these toxins accumulate in their tissues and are passed up the food chain (Bruner et al., 1994). The effect of AIS on public health extends beyond the immediate effects of disease and parasites as chemicals used to control invasive species can pollute soil and water (Allendorf & Lundquist, 2003).

In order to minimize the introduction of invasive species to Canada and remediate the impact of those already established in the country, *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species* (Fisheries and Oceans Canada, 2004) and *An Invasive Alien Species Strategy for Canada* (Environment Canada, 2004) have been developed. They were proposed to respond to the threat of invasive species by prevention of new invasion, early detection and rapid response to new invaders, and management of established and spreading invaders. Given the size of the problem and the limitation in human and financial resources, priorities for implementations of these measures should be assessed carefully (Zimmerman et al., 2011). Some results can be achieved using existing resources but the urgency and magnitude of the threat suggests the need for new investment.

In Saskatchewan a number of AIS have been found or pose a real threat of becoming established. Given the severity of their impact some of the invaders have been listed as top priority management species by the provincial government. Specifically, five aquatic plant species have been legislated under *The Weed Control Act* (Government of Saskatchewan, 2010), including four prohibited

weeds and one noxious weed. Also, sixteen aquatic animal species have been classified as prohibited species under *The Fisheries Regulations* (Government of Saskatchewan, 1994). Conservation organizations and agencies, such as Saskatchewan Invasive Species Council (SISC, 2015) and Saskatchewan Conservation Data Centre (SCDC, 2015), have been managing and monitoring these regulated AIS to minimize their impacts in the province. However, species that have not been regulated by the provincial government but pose a significant threat should also be monitored to prevent future introduction. A more comprehensive catalogue of AIS in Saskatchewan should be assembled to update invasive species legislation to ensure it is current.

Management of invasive species is difficult, expensive, and requires a long-term commitment. When managing invasive species, management decision makers are, more often than not, faced with escalating pressures in terms of which species to manage coupled with ensuring effective and responsible expenditure of resources to protect native species and ecosystems (Kelly et al., 2013). There are many non-native species already recorded in Saskatchewan, some of which negatively impact on biodiversity while others do not. At present, it is beyond our capability to manage all of the species which have an impact. It is also beyond our capability to prevent all invasive species from arriving to the province. Therefore, managers should focus their limited resources, targeting those species that cause major impacts and those areas that are significantly impacted or threatened (Hiebert, 1997).

Risk assessment is a vital component of any invasive species decision-making process, it is a key tool to assist decision makers in making informed decisions despite the often large element of uncertainty (Kelly et al., 2013). There was a need for a system that enable conservation organizations and agencies to prioritize management actions for invasive species that were already established in Saskatchewan and ones that were likely to invade and impact native biodiversity and ecosystems in the future. In addition, risk assessment of invasive species depends upon the size of the management area (Pauchard & Shea, 2006). A risk assessment framework that can be applied to assess AIS across spatial scales is needed to enable more effective monitoring and management of AIS in Saskatchewan.

The threats of invasion are different between recorded and potential species, and also between plant and animal species. Multiple risk assessment protocols were originally selected.to assess the target species. Specifically, the Invasive Species Assessment Protocol designed by NatureServe

(Morse et al., 2004) were examined to assess plant and animal species that have been recorded in Saskatchewan; a risk assessment protocol designed by Weber and Gut (2004) and Fish Invasive Screening Kit (FISK) developed by Copp et al. (2005) were examined to assess potential plant and animal species respectively. However, it was simply not viable to combine the results of different risk assessment frameworks and rank species on different assessment criteria. Therefore, a risk assessment methodology developed by Kelly et al. (2013), which is able to solve the preceding problem, were adjusted and then applied.

The purpose of this project is to conduct a risk assessment of recorded and potential AIS in the province of Saskatchewan at multiple spatial scales with the aim to develop appropriate recommendations that help conservation organizations and agencies to effectively utilize their limited resources to control the threat of AIS in Saskatchewan.

2. Methods

2.1. Study areas

Patterns of non-native species invasions, and the ecological processes which generate these patterns, vary across spatial scales (Pauchard & Shea, 2004). Therefore, consideration of spatial scale may help to understand impacts of invasive species and to identify more efficient and effective management strategies (Mack et al, 2000). For the purpose of this project, Saskatchewan, North Saskatchewan River watershed and Redberry Lake watershed were selected as study areas to demonstrate the multi-spatial scale approach of AIS risk assessment (Figure 1).

2.1.1. Provincial scale

The province of Saskatchewan is situated in the heart of the prairies of North America. It has a total area of 651,900 km^2, and approximately 9% is water area (e.g. lakes/ponds, reservoirs, and rivers) (Pomeroy et al., 2005). Saskatchewan is experiencing unprecedented economic and population growth, giving rise to increased water demand for industrial, municipal and irrigation uses, and for the production of energy (Saskatchewan Water Security Agency, 2012). At the same time sustainability, health and quality of life require that water quality and important aquatic ecosystems be protected. Once AIS were established in the province, they might negatively impact not only essential power and water-based infrastructures but also native biodiversity and aquatic ecosystems.

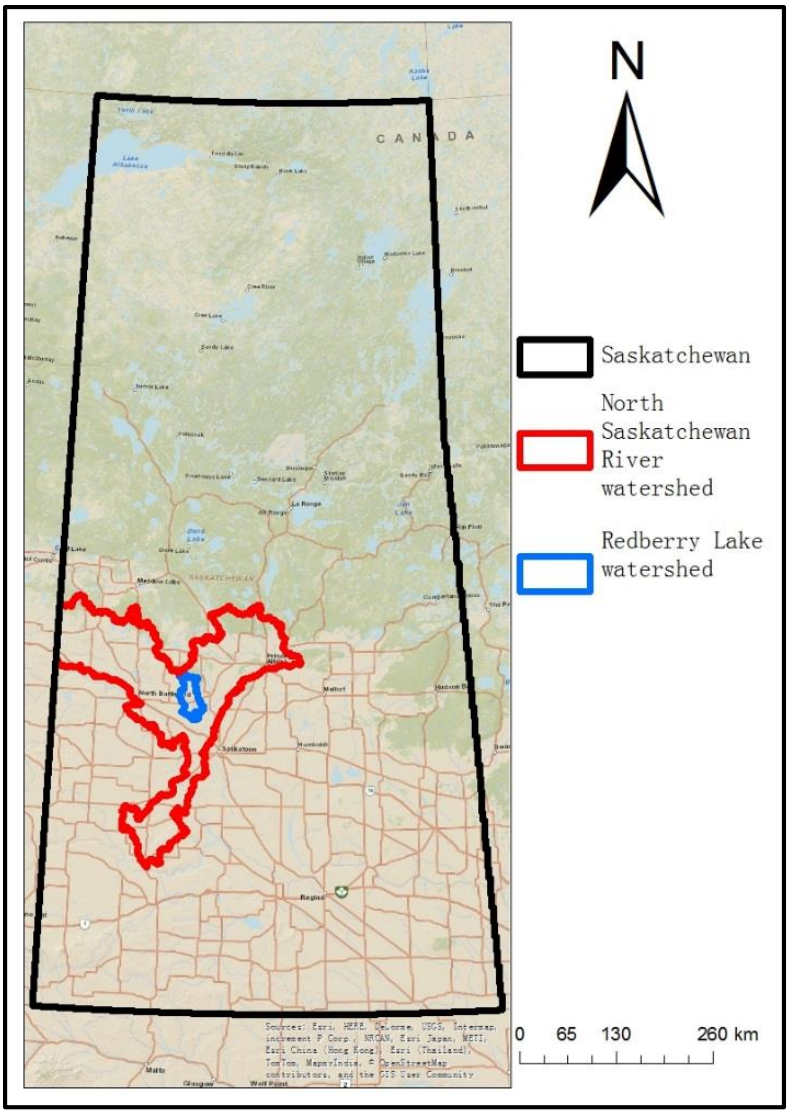

Figure 1. Three spatial scales selected for the risk assessment: 1) local - Redberry Lake watershed, 2) regional – North Saskatchewan River watershed, and 3) provincial – Saskatchewan.

2.1.2. Regional scale

The North Saskatchewan River is a glacier-fed river that begins in the Rocky Mountains of Alberta and flows east to central Saskatchewan. In the latter province the total area of the North Saskatchewan River watershed is about 41,000 km^2 and include the cities of Lloydminster, North Battleford and Prince Albert, as well as 51 rural municipalities, 29 First Nations with lands, 17 Indian Reserves, and 100 towns and villages (Saskatchewan Watershed Authority, 2007). Water resources within North Saskatchewan River watershed are valuable assets to a population of

116,500 within this area (Saskatchewan Watershed Authority, 2007), therefore, it is essential to protect the watershed from AIS.

2.2.3. Local scale

In 2000 the entire area of Redberry Lake watershed received designation as one of sixteen Biosphere Reserve in Canada, and it is the only one in Saskatchewan (RLBR, n.d.). The Redberry Lake Biosphere Reserve (RLBR) covers 112,200 hectares of rolling prairie. Redberry Lake is well-known as a saline lake, situated in west central Saskatchewan, providing essential habitats for a number of bird species. Besides the saline lake, the RLBR includes numerous seasonal ponds and marshes (RLBR, n.d.). Since RLBR is an important site for conservation, it is significant to prevent introduction of AIS that may negatively impact the local biodiversity and ecosystems.

2.2. Species selection

Species lists were compiled by searching international and domestic online and published databases and literature on invasive species distributions and impacts. A number of target AIS, including recorded and potential species, were selected for this risk assessment based on their presence and regulated status in Canada, Saskatchewan and the neighbouring prairie provinces (AL, MB), as well as two states (ND, MT) of the USA. These include 1) species that have been recorded and regulated in Saskatchewan, 2) species that have been recorded but not regulated in Saskatchewan, and 3) species that occurs in neighbouring provinces or states and are regulated but not recorded in Saskatchewan.

Although some AIS have not been regulated in Saskatchewan, their presence is recorded in the province. These species have a tendency to spread and are believed to adversely affect the host habitats. Without proper monitoring and management of these species, they would continue to spread and put the native biodiversity and ecosystems at an even higher risk.

Some species, which are present in the neighbouring provinces and states but not recorded in Saskatchewan, are regulated in the province, because they are likely to arrive in the near future due to their proximity. These species were assessed to provide information on their potential to enter and impact Saskatchewan.

2.3. Data collection

A wide variety of existing sources were examined for information on target AIS. These include reports and documents provided by federal and provincial/state governments, academic publications, and databases developed by agencies and non-government organizations. The regulated status of target AIS were confirmed by reviewing relevant federal and provincial/state regulations, such as *Aquatic Invasive Species Regulations* (Fisheries and Oceans Canada, 2014) and *Weed Seeds Order* (Agriculture and Agri-food Canada, 2005). Species distribution information was retrieved from a number of online databases (Table 1). Some of the databases contain detailed location information (i.e. coordinates of occurrences) on each species; species distribution information from these databases were applied for digital mapping. The remainder of them, which do not provide detailed location information, were explored to confirm the presence status of target AIS in Saskatchewan and neighbouring provinces/states.

Table 1. Online databases explored to retrieve information on species distribution.

International	National	Provincial/State
GBIF (Global Biodiversity Information Facility) http://www.gbif.org/	VASCAN (Database of Vascular Plants of Canada) http://data.canadensys.net/vascan/search	Imapinvasives Saskatchewan http://www.imapinvasives.org/skimi/login/?next=/skimi/
GISD (Global Invasive Species Database) http://www.issg.org/database/	USSG NAS Database (United States Geological Survey Nonindigenous Aquatic Species Database) http://nas.er.usgs.gov/	EDDMapS Prairie Region - Manitoba and Saskatchewan http://www.eddmaps.org/prairieregion/
NatureServe Explorer http://explorer.natureserve.org/		EDDMapS – Alberta https://www.eddmaps.org/alberta/
iNaturalist https://www.inaturalist.org/		Invaders Database - Montana and North Dakota http://invader.dbs.umt.edu/
		W.P. Fraser Herbarium (SASK) http://www.herbarium.usask.ca/

2.4. Digital mapping

Presence of each target AIS with adequate data on species distribution were detailed on maps at three spatial scales: 1) local - Redberry Lake watershed (100 m × 100 m), 2) regional - North Saskatchewan River watershed (1 km × 1 km), and 3) provincial – Saskatchewan (50 km × 50 km). Maps were generated by using ArcGIS 10.2 (ESRI, 2011). Fishnet, an ArcGIS geoprocessing

tool, was applied to detail the presence of species at each spatial scale with preceding resolutions. Areas where AIS infestations have been found were color-coded according to numbers of occurrences within the areas.

2.5. Risk assessment

The risk assessment framework developed by Kelly et al. (2013) was updated and applied in this project (Appendix B). The risk assessment consists of answering ten questions designed to assess the relative level of risk and allocate the species into different risk categories. Scores were justified with a comment or reference to published evidence. The total maximum score an AIS can obtain is 25. Separate assessments were carried out for species recorded in Saskatchewan (Table 2) and species which have not yet been recorded in the wild (Table 3). While the recorded and potential species risk assessments are similar they evaluate the risk from different stages of the invasion process:

- For recorded AIS the risk assessment is based on questions relating to the species current status in Saskatchewan, its ability to colonise successfully, invasion history, associated impacts, and management.
- For potential AIS the risk assessment includes the likelihood of a species arriving in Saskatchewan, its ability to survive in respect to suitable climate and habitat, its ability to spread and have an impact on the conservation goals and economy of an area.

Both the recorded and potential species assessments take into account control measures and societal factors that may limit or facilitate the spread of the species.

For the purpose of the project, recorded species were assessed at multiple spatial scales (i.e. provincial, regional, and local), whereas potential species were assessed only at provincial scale. Each of the species was assessed, scored and ranked into high, medium and low risk categories:

- High: 0 – 10
- Medium: 11 – 18
- Low: 19 – 25

Table 2. Risk assessment criteria and scoring system for species that have been recorded in Saskatchewan ('Recorded Species') (reproduced from Kelly et al., 2013).

Factor	Assessment Criteria	Maximum Score
Invasion history	1. Does the species currently have a widespread recorded distribution?	3
	2. Is the species currently expanding its range?	2
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3
Management	10. Are there acceptable and effective control methods that can be applied?	3

Table 3. Risk assessment criteria and scoring system for species that have not been recorded in Saskatchewan ('Potential Species) (reproduced from Kelly et al., 2013).

Factor	Assessment Criteria	Maximum Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2
	4. Is there potential for this species to be introduced intentionally?	2
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3
Management	10. Are there acceptable and effective control methods that can be applied?	3

3. Results

3.1. Target species

A list of 16 target species was compiled using various sources of information on their distribution and regulated status (Table 4), including 8 plant, 3 mollusk, 3 fish, and 2 crustacea taxa. The list consists of 7 recorded species and 9 potential species. The 4 recorded species, purple loosestrife, flowering rush, curly-leaved pondweed and common carp, have been regulated in Saskatchewan, whereas the remainder of them, European common reed, narrow-leaved cattail and reed canary grass are not regulated. All of the potential species selected for assessment are regulated in Saskatchewan and have been recorded in the neighbouring provinces or states. Despite the fact that 12 other species are also regulated in Saskatchewan (Appendix A), they are not recorded in Saskatchewan and neighbouring province/states. Therefore, they were considered of less concern and were not included in this risk assessment due to low likelihood of their occurrence in Saskatchewan in the near future.

Table 4. Species selected for the risk assessment based on their presence and regulated status. Species that are present/regulated in the particular jurisdictions were noted as 'P'/'R'.

Status	Species name	Taxonomic group	Canada		SK		AL		MB		ND		MT	
			P	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**
Recorded Species	purple loosestrife (*Lythrum salicaria* L.)	plant	P	R[1]	P	R[3]	P	R[5]	P	R[8]	P	R[9]	P	R[11, 12]
	flowering rush (*Butomus umbellatus* L.)	plant	P	-	P	R[3]	P	R[5]	P	R[8]	P	-	P	R[11, 12]
	curly-leaved pondweed (*Potamogeton crispus* L.)	plant	P	-	P	R[3]	P	-	-	R[8]	P	R[10]	P	R[11, 12]
	common carp (*Cyprinus carpio* L.)	fish	P	-	P	R[4]	-	-	P	-	P	R[10]	P	-
	European common reed (*Phragmites australis*(Cav.) Trin. ex Steud. *subsp. australis*)	plant	P	-	P	-	P	-	P	R[8]	P	-	P	-
	narrow-leaved cattail (*Typha angustifolia* L.)	plant	P	-	P	-	-	-	P	R[8]	P	-	P	-
	reed canary grass (*Phalaris arundinacea var. picta* L.)	plant	P	-	P	-	P	-	P	-	P	-	P	-
Potential Species	zebra mussel (*Dreissena polymorpha* Pallas)	mollusk	P	R[2]	-	R[4]	-	R[6]	P	R[7]	P	R[10]	-	R[11, 12]
	Eurasian water-milfoil (*Myriophyllum spicatum* L.)	plant	P	-	-	R[3]	-	R[5]	-	-	P	R[10]	P	R[11]
	saltcedar (*Tamarix* spp.)	plant	P	-	-	R[3]	-	R[5]	-	-	P	R[9]	P	R[11, 12]

Potential Species	faucet snail (*Bithynia tentaculata* L.)	mollusk	P	R[2]	-	R[4]	-	-	-	-	-	R[10]	P	-
	New Zealand mudsnail (*Potamopyrgus antipodarum* J.E. Gray)	mollusk	P	R[2]	-	R[4]	-	-	-	R[7]	-	R[10]	P	R[11, 12]
	spiny waterflea (*Bythotrephes longimanus* Leydig)	crustacea	P	R[2]	-	R[4]	-	-	P	R[7]	-	R[10]	-	R[11, 12]
	round goby (*Neogobius melanostomus* Pallas)	fish	P	R[2]	-	R[4]	-	-	P	R[7]	-	R[10]	-	R[11, 12]
	rusty crayfish (*Orconectes rusticus* Girard)	crustacean	P	R[2]	-	R[4]	-	-	P	R[7]	-	R[10]	-	R[11, 12]
	silver carp (*Hypophthalmichthys molitrix* Valenciennes)	fish	-	R[2]	-	R[4]	-	-	-	R[7]	P	R[10]	-	R[11, 12]

Note: 1. Weed Seeds Order (Agriculture and Agri-food Canada, 2005); 2. Aquatic Invasive Species Regulations (Fisheries and Oceans Canada, 2014); 3. The Weed Control Act (Government of Saskatchewan, 2010); 4. The Fisheries Regulations (Government of Saskatchewan, 1994); 5. Weed Control Regulations (Government of Alberta, 2010); 6. General Fisheries Regulations (Government of Alberta, 1997); 7. Manitoba Fisheries Regulations (Government of Manitoba, 1987); 8.The Noxious Weed Act (Government of Manitoba, 1987); 9. Noxious Weed Control (North Dakota Century Code, 2003); 10. North Dakota's Aquatic Nuisance Species - Species List (North Dakota Game and Fish Department, 2014); 11. Montana Noxious Weed List (Montana Department of Agriculture, 2013); 12. Montana Aquatic Nuisance Species Management Plan (Montana Aquatic Nuisance Species Technical Committee, 2002).

3.2. Risk assessment framework

Case studies of purple loosestrife and zebra mussel are presented below to demonstrate the process of risk assessment for recorded and potential species respectively.

3.2.1. Case study of the recorded species: purple loosestrife

Purple loosestrife (*Lythrum salicaria* L.), a serious invader of wetlands, has spread widely in North America. Purple loosestrife is ranked by IUCN 50th in the *100 of the World's Worst Invasive Alien Species* (Lowe et al., 2000). It is highly invasive and forms dense, monotypic stands that reduce both plant and wildlife diversity (Lindgren & Walker, 2013). The species has been listed as prohibited species in Saskatchewan under *The Weed Control Act* (Government of Saskatchewan, 2010).

Invasion history

Purple loosestrife has a widespread distribution in Saskatchewan. According to NatureServe (2015), the species has been recorded at 107 locations in Saskatchewan (Appendix C), which are mainly located in the southern and central portion of the province (Figure 2). Its distribution range stretches across 4 latitudinal degrees (49˚07′8.82″ - 53˚11′21.17″ N) and 6 longitudinal degrees

(102˚18′38.87″ - 108˚06′59.73″ W). However, the number of documented occurrences is believed to be an underestimate as no sightings have been reported in the Northern Saskatchewan. To date, purple loosestrife has been found at 9 locations in the North Saskatchewan River watershed (Figure 3). Although the species has not been recorded in the Redberry Lake watershed, the nearest infestation, approximately 4 km east of the watershed boundary, is posing a risk to the local aquatic ecosystems (Figure 4).

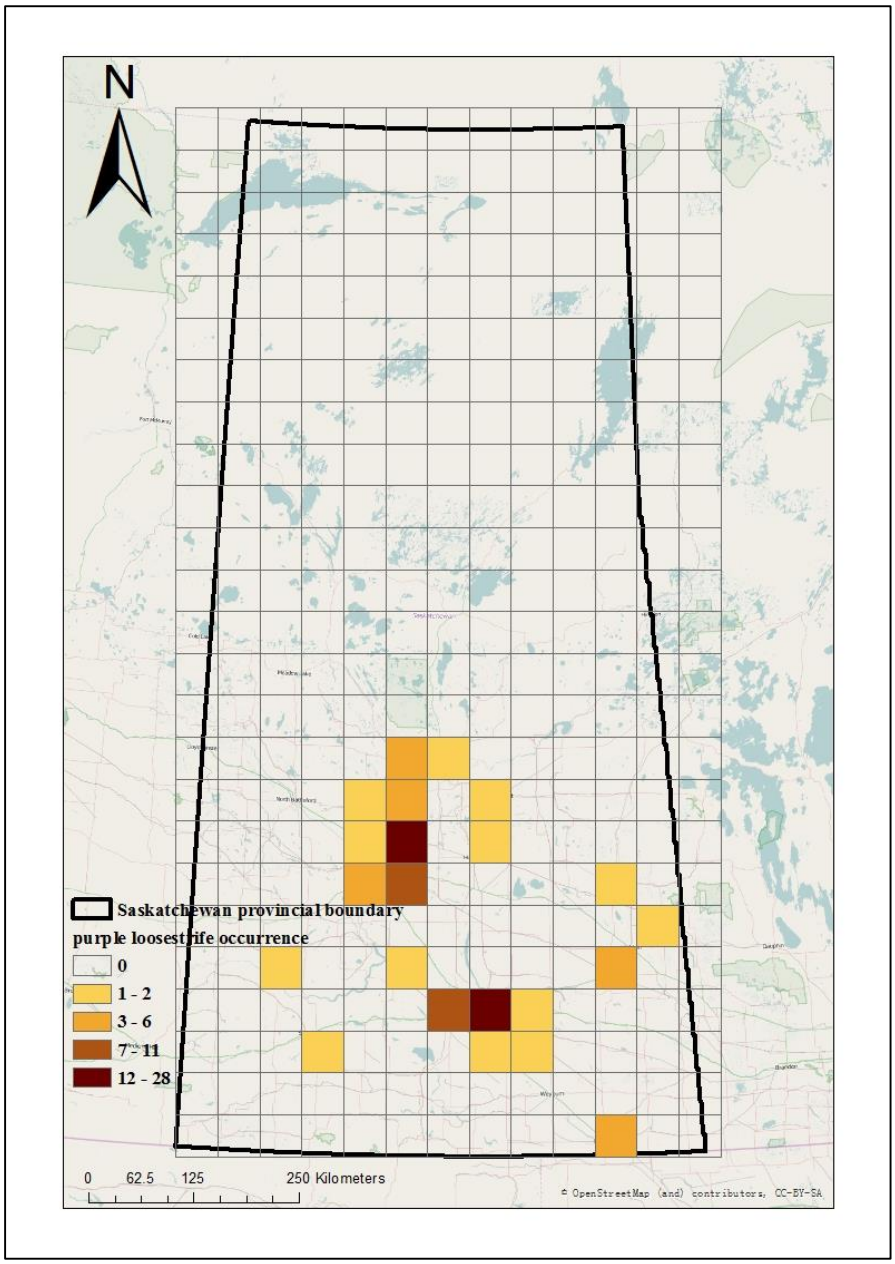

Figure 2. Documented occurrences of purple loosestrife in Saskatchewan (NatureServe, 2015). Infested areas are categorized and color-coded based on the intensity of infestation. There are four categories of infestation intensity, including 1-2, 3-6, 7-11, and 12-28 occurrences of purple loosestrife.

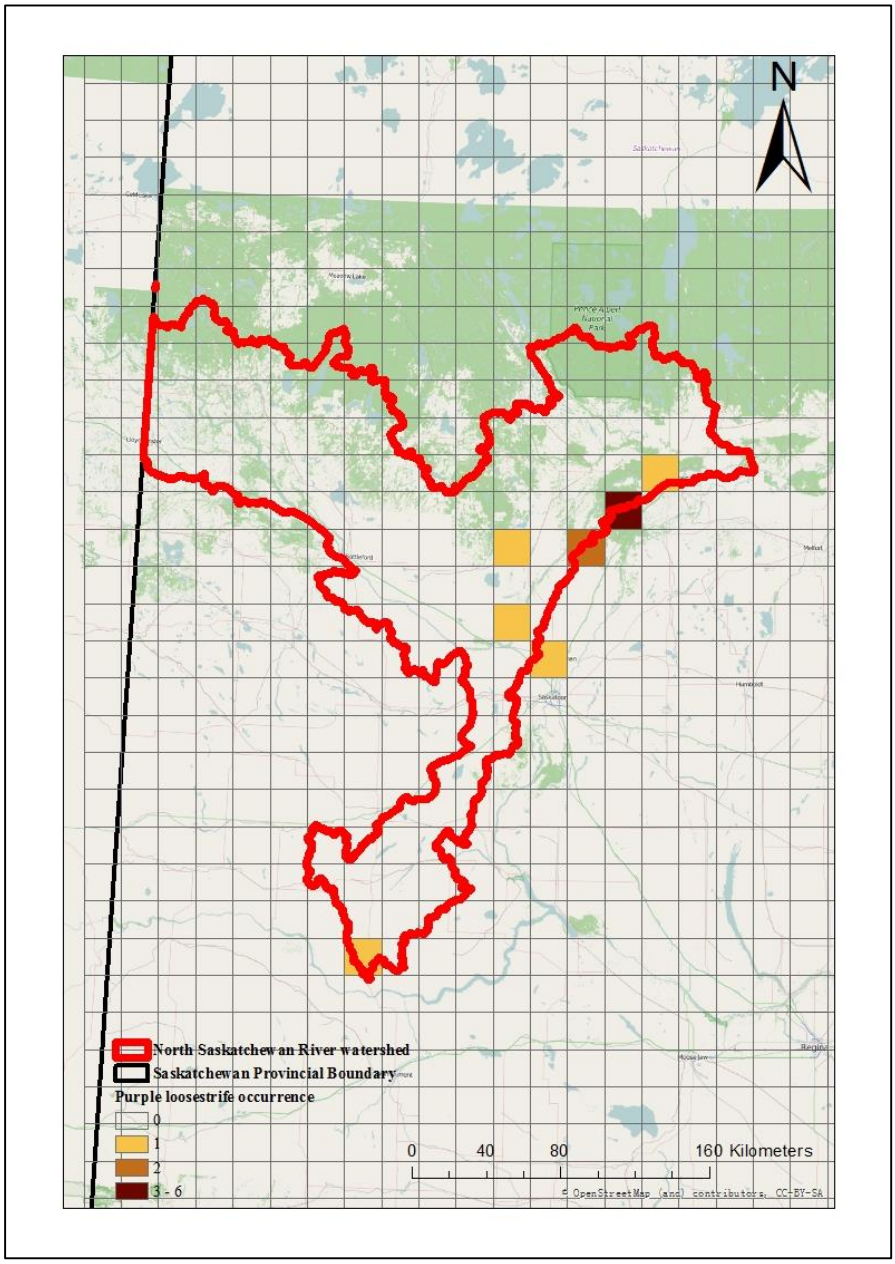

Figure 3. Documented occurrences of purple loosestrife in the North Saskatchewan River watershed (NatureServe, 2015). Infested areas are categorized and color-coded based on the intensity of infestation. There are three categories of infestation intensity, including 1, 2, and 3-6 occurrences of purple loosestrife.

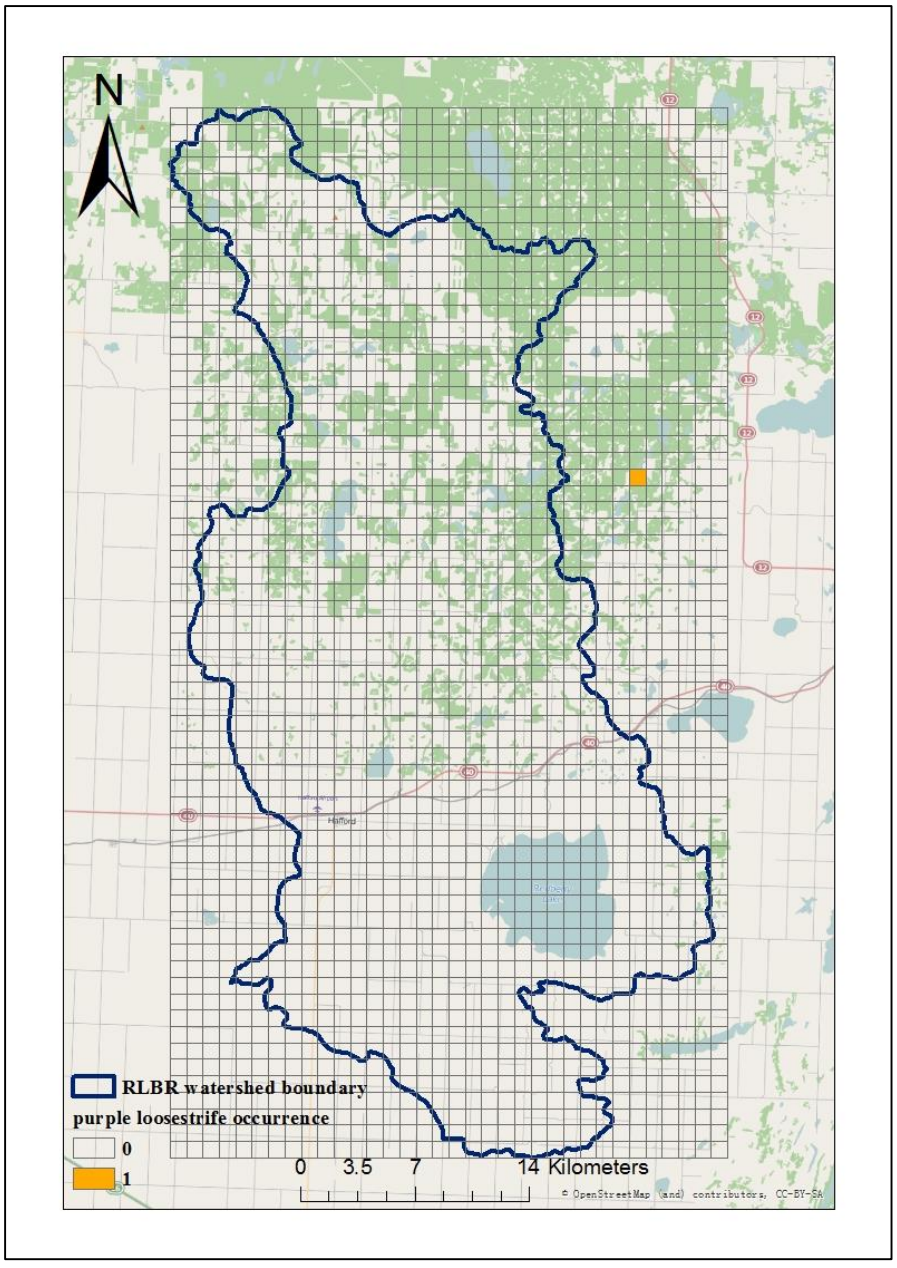

Figure 4. Documented occurrences of purple loosestrife within the adjacent area of Redberry Lake watershed (NatureServe, 2015). Although there are no known infestations of purple loosestrife in the watershed, the nearest infestation is only 4 km east of the watershed boundary.

Purple loosestrife has been expanding its range since the first sighting reported from the County of Corman Park in 1971. The number of occurrences in Saskatchewan has dramatically increased from 1 to 107 between 1980s and 2010s (Figure 5). Based on the generated trend line, the number of occurrences of purple loosestrife in the province was estimated to increase by 30 per decade and will reach 140 in the 2020s.

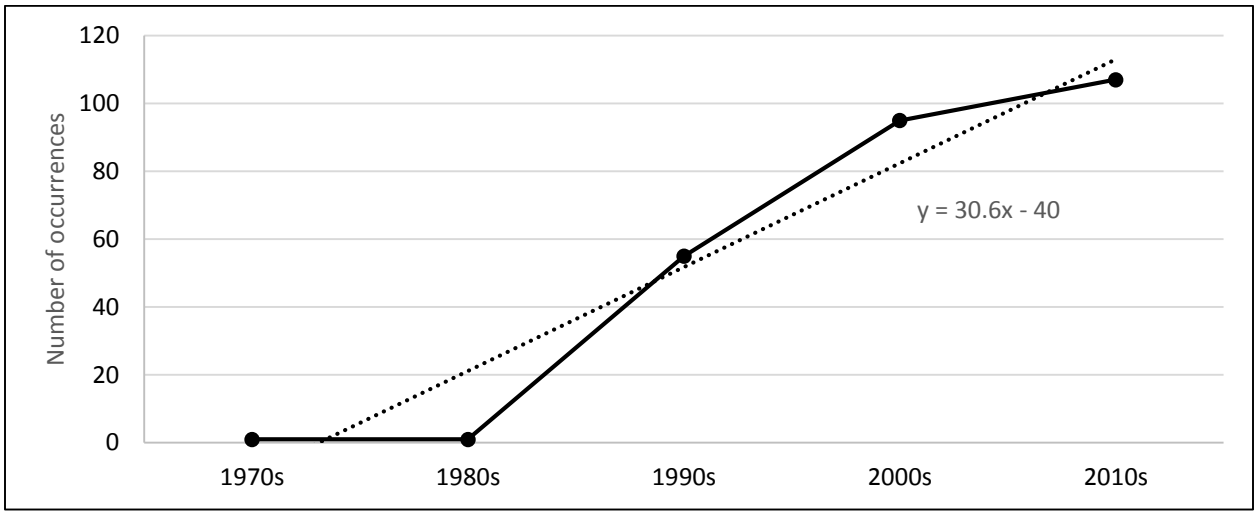

Figure 5. Documented occurrences of purple loosestrife from 1970s to 2010s in Saskatchewan (NatureServe, 2015).

Availability of suitable habitats

Purple loosestrife occurs widely in wet habitats, such as marshes, bogs, fens, sedge meadows, and wet parries, but it also occurs in roadside ditches, on river banks, and at the edges of reservoirs (Blossey et al., 2001). In Saskatchewan there is a considerable amount of wet habitats that offer favorable living conditions to purple loosestrife - it is estimated to be 9% or 59,000 km^2 of Saskatchewan's total area (Pomeroy et al., 2005). However, prairie wetlands are a diminishing resource, facing serious threats from drainage and degradation. Since the time of settlement, it has been estimated that Saskatchewan has lost 40% of its wetlands and half of those remaining are threatened (Saskatchewan Wetland Conservation Corporation, 2000). The loss of wetlands may result in a gradual decrease in suitable habitats for purple loosestrife in Saskatchewan.

In this risk assessment climatic suitability was considered to be the primary limiting factor when assessing the habitat suitability for purple loosestrife. Considering the fact that there are no known purple loosestrife infestations in the northern half of Saskatchewan and the two neighbouring provinces (i.e. Alberta and Manitoba), the northern half of the province was presumed to be

unsuitable for establishment of purple loosestrife due to the cold climate. The area of Saskatchewan has been divided into 250 cells by using fishnet (Figure 2), including 110 in the northern half and 140 in the southern half. Besides the 22 cells infested by purple loosestrife, the remaining 118 cells or 47.2% of the province were considered to be at risk of infestation.

Purple loosestrife is tolerant of salinities up to about 5 ppt (Steven & Peterson, 1996) and its establishment have been recorded in the North Saskatchewan River watershed where freshwater systems are commonly found. Interestingly, salinity at Redberry Lake (20.9 ppt), the core area of the RLBR, has already exceeded purple loosestrife's tolerance limit (Bowman & Sachs, 2008). Therefore, the availability of suitable habitats in Redberry Lake was considered to be low, although there are plenty of small freshwater lakes and ponds within the watershed.

Species spread potential

Purple loosestrife was introduced to North America in the early 20th century: possible sources include unloading of solid ship ballast containing seed, imported wool or sheep with attached seeds, or deliberate introduction for medicinal purpose or as a nectar and pollen sources in beekeeping (Stuckey, 1980). Considering the fact that the species has been listed as prohibited species in Saskatchewan, possibility of such intentional introductions was considered to be low in our study areas. However, purple loosestrife can be used as an ornamental plant of ponds and outdoor water gardens where it may have been intentionally planted and could escape into new areas as plant material is discarded into a waterway and/or carried off by flooding during rain events (Thompson et al., 1987). It can spread between water bodies via plant material such as root buds or tiny seeds which can attach to, and be transported with, boats, boat trailers and other equipment (e.g. fishing gear) (Mullin, 1998).

Impact assessment

Saskatchewan is in the process of establishing a network of ecologically important land and water areas across the province. The Saskatchewan Representative Areas Network (RAN), a program developed by Saskatchewan Environment, is tended to conserve representative and unique landscapes in each of Saskatchewan's 11 ecoregions (Government of Saskatchewan, 2005). The network consists of a series of lands and waters representing the natural landscape diversity of the province and are protected and managed to retain that diversity (Appendix D). AIS found in the protected areas are considered to impact upon the conservation objectives of the network. A

scoring system for evaluating an AIS's impact upon the conservation objectives (assessment criteria 6) was developed (Table 5). Score assigned to assessment criteria 6 is associated with AIS impact score which is calculated based on number of occurrences in each protected areas. Table 6 shows the calculation of purple loosestrife's impact score at provincial level.

Table 5. Scoring system for risk assessment criteria 6 for recorded species.

Score assigned to assessment criteria 6	AIS impact score
0	0
1	1 – 15
2	16 – 50
3	51 – 100
4	>100

Table 6. Calculation of purple loosestrife's impact score in Saskatchewan.

Area percent protection	Impact score per AIS occurrence	No. of occurrences	Impact score
<3%	1	0	1 × 0 = 0
3%-5.9%	2	31	2 × 31 = 62
6%-11%	3	23	3 × 23 = 69
>11%	4	23	4 × 23 = 92
Sum of impact score	0 + 62 + 69 + 92 = 229		

Purple loosestrife has a major negative impact on native wetland habitats, resulting in reduced productivity of native plants and loss of biodiversity (Schooler et al., 2006). Although the species does not pose a risk to human health, loss of native habitat and wildlife interferes with various levels of the ecosystem. Managing purple loosestrife is costly; for example, Great Lakes regions is spending $500 million per year on managing this invasive species. According to Saskatchewan Environment (2003), the province is spending $7 million per year on prevention and control of purple loosestrife. In addition, the species' impacts on environment influences many recreational activities, creating a negative effect on the social and economic well-being of local communities (Moccoy, 1998). With the loss of recreational land for fishing, boating and hunting, the local communities may also lose revenue from tourism.

Management

Purple loosestrife has no native natural enemies and outcompetes other plants, making it difficult to stop the species from spreading (Skinner et al., 1994). Management approach includes a variety of mechanical, chemical and biological methods. Mechanical methods such as manual removal,

mowing and disking and prescribed burning can only applied for small areas and are expensive (Wilcox, 1989). By contrast, biological control can be applied for large areas and is more cost-effective (Malecki et al., 1993). Several insect species have been introduced from Europe to North America, including the root weevil (*Hylobius sp*.) and two species of beetles (*Galerucella pusilla* and *G. calamariensis*) (Yeates et al., 2012). These insects, in combination with other naturally competing plant species, help control purple loosestrife in sites that are not easily accessible for other control methods. While herbicides are available for controlling purple loosestrife, their use may be limited because of wetland habitats (Netherland et al., 2005). Herbicide selection and application rate are critical in providing selective control of purple loosestrife and not damaging native wetland plants. When carefully used, herbicides can be effective tools in stopping the expansion of purple loosestrife, especially considering that biological control agents are slow in achieving the desired level of control.

Table 7 shows the results of risk assessment of purple loosestrife. The overall risk assessment score of purple loosestrife is 19, 11 and 6 at the provincial, regional and local scale respectively.

Table 7. Risk assessment of recorded species (purple loosestrife) at provincial, regional and local scale.

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	3	1	0
	2. Is the species currently expanding its range?	2	2	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	1	0
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	2	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	4	2	0
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	2	2	2
Management	10. Are there acceptable and effective control methods that can be applied?	3	1	1	1
Overall score			**19**	**11**	**6**

3.2.2. Case study of the potential species: zebra mussel

Zebra mussel (*Dreissena polymorpha* Pallas), a small aquatic animal that resembles freshwater clams, is originally native to southern Russia and has become the most aggressive freshwater invader in many countries (Strayer, 2008). It is ranked by IUCN 31th in the *100 of the World's Worst Invasive Alien Species* (Lowe et al., 2000). Zebra mussel has been listed as prohibited species in Canada under the *Aquatic Invasive Species Regulations* (Fisheries and Oceans Canada, 2014) and in Saskatchewan under the *Fisheries Regulations* (Government of Saskatchewan, 1994).

Identification of nearest donor region

Since the initial introduction of zebra mussel in North America in 1980s, the species has steadily invade south-eastern Canada and the majority of the eastern half of the United States (Griffiths et al., 1991). Although zebra mussels have not been found in Saskatchewan, the species is present in two of the adjacent provinces/states (North Dakota and Manitoba). In 2010 microscopic, larval zebra mussels were found for the first time in the Red River within North Dakota (Benson, 2013). Since then, zebra mussels have begun to invade the Red River. In October, 2013, Manitoba Conservation and Water Stewardship confirms that adult zebra mussels have been found in Lake Winnipeg. The latest occurrence in Manitoba was confirmed in the Manitoba section of the Red River in the spring of 2015 (Manitoba Conservation and Stewardship, 2015).

Occurrence in similar climate

Climatic condition is a major factor that affects the likelihood of establishment success in invasive species. Climatic suitability of each AIS assessed was determined based on the Köppen Climate Classification which is one of the most widely used climate classification systems (Kottek et al., 2006). The Köppen climate classification scheme divides climates into five main groups (A, B, C, D, E), and each of them has several types (e.g. Cf) and subtypes (e.g. Cfa) (Appendix E).

Due to Saskatchewan's location in the Canadian Prairies, and its distance from both mountains and oceans, the province has a temperate continental climate (Carder, 1970). According to the Scheme, Saskatchewan's climate is classified into three types. Approximately the northern 55% of the province falls into the Dfc or continental subarctic zone. About 15% of the province, located in the southwest, is BSk or semiarid mid-latitude steppe. The remainder has Dfb or warm summer continental climate which is the same as Lake Winnipeg and the Great Lakes region where zebra

mussel infestations have been found. Therefore, zebra mussel was considered likely to survive and establish in the climatically suitable areas of Saskatchewan.

Pathway of introduction

In Canada, it is prohibited for any person to import, possess, transport, release, or engage in any activity that may lead to the release of, zebra mussels (Fisheries and Oceans Canada, 2014). Therefore, there is a low likelihood of intentional introduction of zebra mussels in Saskatchewan. However, the species can be introduced unintentionally due to the fact that they can be transported from one lake or river system to another by hitchhiking on boats, boat trailers, barges, and other aquatic equipment (Johnson, 1996). Juvenile and adult mussels can attach to boat hulls, engines, anchors, and other submerged equipment, as well as to plant material that may get caught on boats and trailers. In their microscopic juvenile stage, they can also be carried in boat bilge water, live wells, and bait buckets (Johnson, 1996).

Suitability of habitats

Although several environmental variables (e.g. temperature, pH, dissolved oxygen, calcium) may limit successful zebra mussel invasions (Mackie, 1991), the suitability of habitats (probability of survival) has been often characterized by calcium thresholds in many studies, such as Whittier et al. (2008) and Neary and Leach (1992). Zebra mussel primarily inhabit freshwater ecosystem but have been reported from lower salinity, brackish environments as well (Neary & Leach, 1992). Fisheries and Oceans Canada conducted a risk assessment of zebra mussels in freshwater ecosystems of Canada and they also used calcium concentration as the primary factor determining habitat suitability of zebra mussels (Weise et al., 2013). The results of risk assessment suggested that habitat suitability of zebra mussel is very high in freshwater ecosystems of over half of the province's area due to the high calcium concentrations of water bodies sampled in Saskatchewan (Weise et al., 2013).

Impact assessment

Zebra mussel invasions have resulted in disruptions of traditional food chains of many inland lakes in North America (Maclsaac, 1996). Regardless of their size, inland lakes represent unique ecological systems. When zebra mussels enter into these fragile system, their voracious filter feeding depletes the availability of microscopic organisms that play a critical part in each lake's ecological food web (Nalepa, 1992). Although this may improve infested lake's water clarity, it

creates less food for other aquatic animal species including fishes that support sport and commercial fisheries. In addition, zebra mussels are threatening native mussel population in infested areas as a result of their habit of attaching themselves to hard surfaces (Ricciardi et al., 1998). This behavior is known as bio-fouling and with the spread of zebra mussels, native mussel population have been reported to reduce severely in infested areas.

Zebra mussel infestations have had major economic impacts in North America. The species can clog pipes, water intakes systems (e.g. hydropower facilities, agriculture irrigation systems), and municipal water supply. This can increase maintenance costs for operating hydroelectric, industrial and agricultural facilities. Since 1989, some water treatment plants located in areas of extensive zebra mussel colonization have reported significant reductions in pumping capabilities and occasional shutdowns (Nalepa, 1992). Congressional researchers estimated that an infestation of zebra mussel in the Great Lakes cost the power industry alone $3.1 billion in the 1993 – 1999 period, with a total economic impact on industries, business, and communities of more than $ 5 billion (Idaho Invasive Species Council, 2009).

Zebra mussels can also pose a risk to human health. As significant filter feeders, zebra mussels may increase human and wildlife exposure to organic pollutants (PCBs and PAHs) (Bruner et al., 1994). Early research shows that zebra mussels can rapidly accumulate organic pollutants within their tissues to levels more than 300,000 times greater that concentrations in the environment (Reeder & Vaate, 1992). In addition, they deposit these pollutants in their pseudofeces. These contaminants can be passed up the food chain so that any fish or waterfowl consuming zebra mussels will also accumulate these organic pollutants (Vanderploeg et al., 2001). Moreover, human consumption of these fish and waterfowl may result in further risk of exposure.

Management

Zebra mussels have few natural controls to limit their growth and spread in the wild. Once a population of zebra mussels has become established it is impossible to eradicate them without complete destruction of everything else that also lives in the water (Johnson & Padilla, 1996). Introducing natural predators of the zebra mussel, such as waterfowl, sturgeon, yellow perch, catfish and sunfish, into an infested body of water is one way of lowering a population (Maclssac, 1996). However, anything that feeds heavily on zebra mussels will build up high levels of

contaminants in its body. It is unlikely that predation will have a profound effect on reducing the nuisance caused by zebra mussels.

There have been some successful procedures developed to prevent the invasive mussels from clogging water intakes. These include using molluscicides to kill mussels at the entrance of water intake pipes, physically removing the mussels by scrapping, pigging, or high pressure washing, hot water or steam injection into infested pipes, and using toxic coatings containing copper or zinc on screens of intake pipes and boat bottoms to discourage attachment (Vander Zanden & Olden, 2008). However, these control methods require substantial resources both in terms of continuous capital investment and person hours. The most cost-effective control strategy is to raise public awareness about zebra mussels and to prevent both intentional and unintentional introductions. Prairie Waters Working Group is leading a consistent public awareness program about zebra mussels and delivering informational material and workshops for Watershed Stewardship organizations and other stakeholders to prevent and early detect zebra mussel infestations.

Table 8 shows the results of risk assessment of zebra mussel at the provincial level. The overall risk assessment score is 21.

Table 8. Risk Assessment of potential species (zebra mussel) at the provincial level.

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	3
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	2
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	4
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	2
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	1
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	3
Management	10. Are there acceptable and effective control methods that can be applied?	3	2
Overall score			**21**

3.3. AIS ranks

Table 9 presents a summary of the overall score for each AIS assessed at particular spatial scales (See Appendix F for detailed risk assessment for all AIS). Species were ranked into low, medium and high categories. 3 out of the 17 species assessed at the provincial scale fall into high risk category and another 3 species fall into low risk category, and the remainder fall into medium risk. With regard to species assessed at the regional scale, 2 of the 7 recorded species fall into medium risk category and the remainder fall into low risk category. Interestingly, all of the 7 recorded species were determined to have a low risk at the local level.

Table 9. Risk assessment score obtained by each AIS. Species were ranked into low (0-10), medium (11-18), and high risk (19-25) categories.

Status	Species name	Overall Score		
		Provincial	Regional	Local
Recorded Species	purple loosestrife (*Lythrum salicaria*)	19	11	6
	flowering rush (*Butomus umbellatus*)	10	7	6
	curly-leaved pondweed (*Potomogeton crispus*)	11	7	6
	common carp (*Cyprinus carpio*)	15	9	8
	European common reed (*Phragmites australis subsp. australis*)	10	7	8
	narrow-leaved cattail (*Typha angustifolia*)	12	10	10
	reed canary grass (*Phalaris arundinacea var. picta*)	13	11	10
Potential Species	zebra mussel (*Dreissena polymorpha*)	21	-	-
	Eurasian water-milfoil (*Myriophyllum spicatum*)	14	-	-
	saltcedar (*Tamarix* spp.)	19	-	-
	faucet snail (*Bithynia tentaculata*)	17	-	-
	New Zealand mudsnail (*Potamopyrgus antipodarum*)	14	-	-
	spiny waterflea (*Bythotrephes longimanus*)	12	-	-
	round goby (*Neogobius melanostomus*)	12	-	-
	rusty crayfish (*Orconectes rusticus*)	9	-	-
	silver carp (*Hypophthalmichthys molitrix*)	15	-	-

3.3.1. Recorded species

Among the recorded species assessed at the provincial level, purple loosestrife is the only species falling into the high risk category, with an overall score of 19. This matches the fact that the species has been recorded widely across the province, threatening native biodiversity and ecosystem services. The risks posed by common carp, reed canary grass, narrow-leaved cattail and curly-leaved pondweed are primarily limited by their sparse distributions recorded. As a result, they fall into the medium risk category. The remaining 2 recorded species, flowering rush and European common reed, were ranked into the low risk category. There is only one known infestation of flowering rush in Saskatchewan and it has been well-managed since the species was confirmed (Neufeld, 2012). There are currently a limited amount of documented occurrences of European common reed in Saskatchewan, therefore, a low score was assigned to this species.

At the regional level no species were ranked into high risk category. This is due to the fact that the 7 recorded species have limited distributions or have not been found in the North Saskatchewan River watershed. Purple loosestrife and reed canary grass fall into the medium risk category. Although these species have moderately distributed in the watershed, no significant impacts of them have been documented.

All of the recorded species assessed at the local level fall into the low risk category. This could be explained as a result of data gaps on species distribution in the Redberry Lake watershed. There are currently no documented occurrences of selected AIS in the Redberry Lake watershed. In addition, habitat suitability for some species (i.e. purple loosestrife, flowering rush, curly-leaved pondweed) may be limited by the high-saline nature of the surface waters and associated lake deposits of the watershed.

3.3.2. Potential species

Zebra mussel and saltcedar were determined to be the 2 potential species of high risk to Saskatchewan. Zebra mussel has been reported from two of the neighbouring provinces/sates (i.e. Manitoba and North Dakota), and the potential for the species to enter Saskatchewan is very high. As described in the preceding case study, once a population of zebra mussels has become established it is impossible to eradicate them and it is also very costly to control. With regard to saltcedar, the species has replaced large tracts of native vegetation stands in some regions of North America. Saltcedar accumulates salt among leaf scales and the resulting leaf litter increases salinity

of the soil overtime, making it unsuitable for native vegetation (Brock, 1994). Therefore, the species has lower wildlife value and greater water uptake than native tree stands.

There are 6 recorded species ranked into the medium risk category, including 2 mollusks (faucet snail and New Zealand mudsnail) and fishes (round goby and silver carp) and 1 plant (Eurasian water-milfoil) and crustacean (spiny waterflea). Faucet snail and New Zealand mudsnail, which have been found in Manitoba, have a higher potential to arrive in Saskatchewan as they have dispersal mechanisms similar to some invasive mollusks such as the zebra mussel (Munawar et al., 2006). Eurasian water-milfoil can interbreed with native milfoil, creating a more aggressive form of invasive species. It can be easily spread when water currents, boat propeller, trailers or fishing gear carry plant fragments to new areas (Smith & Barko, 1990). Silver carp and round goby, as prohibited species in Saskatchewan, have a low likelihood of intentional introduction in the province, although their associated impacts can be significant. Though tiny, the spiny waterflea has the potential of doing a great deal of damage in the aquatic food web. Spiny waterfleas have been reported to cause the decline or elimination of some species of native zooplankton in some infested lakes of Ontario, reducing important food for native fishes (Yan et al., 2001). A classic dispersal mechanism of spiny waterfleas is attaching to fishing equipment.

Rusty crayfish is the only potential species falling into low risk category. This species is an invasive crustacean that have spread to several U.S. states along with Ontario and recently Manitoba. Rusty crayfish have likely spread through bait bucket release by anglers, aquarium release by hobbyists, activities of commercial harvesters, and live study specimen release. However, the likelihood of these intentional introductions is low as such activities are illegal in Saskatchewan.

3.4. Limitations

Since all of the data were collected from existing sources, the study was limited by the availability of species distribution data and the quality of data used. Limited resources make it difficult for conservation agencies and organizations to effectively monitor and document an invasive species across a large area, resulting in large gaps in our knowledge of current distribution of target AIS in Saskatchewan. For example, there are few documented occurrences of assessed AIS in the northern half of Saskatchewan. In addition, most of the occurrences of AIS were documented without details such as infestation area and density. Therefore, assumptions of their associated

impacts were made based on literature reviewed. Moreover, although some of the data used for this risk assessment were collected by academicians and governmental organizations, a major part of them were collected by citizens and nongovernmental organizations. The quality of data used in this study may be questioned as many of them are subject to observational errors. Some species (e.g. common reed and reed canary grass) include both native and exotic subspecies, it is difficult to distinguish native and exotic subspecies in the field as they are similar in physical characteristics. Although the W.P. Fraser Herbarium (SASK) contains a large number of samples of common reed and reed canary grass, they are not identified as native or exotic subspecies. Therefore, SASK's data on common reed and reed canary grass distribution could not be used in this risk assessment.

4. Community Outreach and Education

This project has been presented and discussed at Native Prairie Restoration/Reclamation Workshop (January 28-29, 2015) (Zhang & Kricsfalusy, 2015) and the Aquatic Invasive Species Workshop (February 11, 2015) (Prairie Waters Working Group, 2015).The prevention, control, and eradication of AIS have become a critical component of the resource stewardship responsibilities of RLBR. In order to employ a variety of integrated management techniques against these invaders of aquatic systems, more information on the location, magnitude, and rate of spread of AIS infestations is needed. To achieve this need, a variety of widely-accepted survey and inventory techniques can be applied to systematically collect statistically-valid infestation and population data. People of the local communities are encouraged to learn these techniques, to collect and submit data on AIS that they have found, and therefore, to help control AIS in the local area.

To address this issue, the AIS awareness workshop was held on June 24th, 2015, at Hafford Central School to involve schoolchildren and members of the local community in monitoring and management of AIS (Figure 6). The purpose of the workshop was to educate the participants about the threat of AIS and what they can do to help control AIS.

Figure 6. AIS awareness workshop on June 24th, 2015, at Hafford Central School. (Photo credit: Susanne Abe)

The AIS awareness workshop consisted of three sections including a presentation about AIS issues, an exercise of field data collection of invasive species, and a practice of reporting sightings of invasive species. After the workshop participants were able to:

1) understand what AIS are and how they can impact the environment and well-being of humans
2) understand how AIS are introduced and what can be done to prevent spreading them
3) identify some of the most harmful AIS that have been recorded in Saskatchewan or are likely to arrive
4) collect distribution data on the occurrences of AIS in the field appropriately
5) report sightings of invasive species by using iMapInvasives (NatureServe, 2015).

The presentation was given to create awareness of AIS issues, and ideally, to enable participants to identify some of the most aggressive AIS such as zebra mussel and purple loosestrife. A number

of examples of AIS invasion were discussed to demonstrate their environmental, economic and social impacts (Appendix G). Actions that help to prevent the risk of AIS transfer (e.g. clean, drain and dry watercraft) were also demonstrated.

The exercise of field data collection aimed to educate participants to gather species distribution data when reporting a sighting. Two locations of invasive weeds (leafy spurge and common burdock) were visited to demonstrate what information should be collected and how to collect it appropriately. A field data collection sheet was distributed to participants and they were asked to record key information on the invasive species (Appendix H). During the exercise participants were also trained to get coordinates of infestation by using a GPS.

After field data collection session participants learned how to report sightings of invasive species. iMapInvasives, an online, GIS-based data management system develop by NatureServe, was introduced to participants. Participants were able to report the sightings of invasive species they have found during the workshop to iMapInvasives, submitting information they collected in the field.

5. Conclusion and Recommendations

AIS are threatening the integrity of Saskatchewan's ecosystems, resulting in reduced biodiversity, damaged wildlife habitat, and diminished aesthetic values of the land, costing the province's economy a large amount of money each year. All of the jurisdictions of Saskatchewan, from the local to the provincial level, play a role in AIS prevention, monitoring and management activities. The magnitude and nature of the problem vary from jurisdiction to jurisdiction, thus the priorities for actions should be assessed carefully. This study presents a multi-spatial scale approach that provides a basis for more effective AIS control.

It is simply not viable to undertake a risk assessment for all AIS in Saskatchewan. To undertake such a task would require substantial resources both in terms of capital investment and person hours. 16 AIS, including 7 recorded species and 9 potential species, were selected for this risk assessment based on their presence and regulated status in Saskatchewan and neighbouring jurisdictions in Canada and the USA. These AIS were considered to be (or could become) established in Saskatchewan and tend to have a major impact. Although there are some other AIS

regulated by the provincial government, they were not considered as species of top priority for the risk assessment due to their low likelihood of introduction in the near future.

The risk assessment framework developed by Kelly et al. (2013) was modified to assess the relative level of risk of the target AIS at the provincial, regional and local level. This risk assessment process allows for risk impact ranking and categorisation of the AIS assessed into high, medium and low risk categories. The results of risk assessment indicated that purple loosestrife, zebra mussel and saltcedar should be considered as species of top priority for control in Saskatchewan (provincial level). Purple loosestrife and reed canary grass, with the highest risk assessment score at the regional level, were suggested to be top priority species in the North Saskatchewan River watershed. By contrast, no top priority species were identified in the Redberry Lake watershed as all of the species were ranked into the low risk category at the local level.

The success of risk assessment depends on the availability of information for the target AIS. It was easy to conduct a detailed risk assessment for a species with adequate data, such as purple loosestrife and flowering rush. For most of the target AIS, their current distributions and associated impacts were uncertain, which made the assessment difficult. However, this risk assessment framework allows for the collation of data and attempts to present this in a manner that is useful to conservation agencies and organizations.

In order to minimize the spread of AIS in Saskatchewan, the following recommendations were made:

- Raise awareness among the public and interested groups to encourage them to take actions to prevent both intentional and unintentional introduction of AIS, and to report sightings of AIS
- Share AIS monitoring information with neighbouring provinces and states, and with the federal government to improve our ability to detect and respond to AIS
- Build an effective communication network with municipalities, conservation authorities, NGOs and other key stakeholders to improve coordination and communication, avoid duplication of effort, and ensure the most effective use of available resources for early detection, rapid response, and effective management of AIS

- Undertake surveillance activities in geographic areas at high risk of invasive species introductions, especially at near-border locations and in transboundary waters
- Examine provincial legislative and policy framework for invasive species management to determined where information needs to be added or updated
- Enhance enforcement of invasive species legislation, regulations and policy to prevent the introduction of banned species (e.g. border crossings)
- Develop science-based standard monitoring protocols that are appropriate for particular species, geographic regions, and pathways.

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Appendix A

Potential AIS that are regulated in the Saskatchewan but not present in the province and neighbouring provinces/states. Species that are regulated in the particular jurisdictions are noted as 'R'.

Species name	Taxonomic group	Regulated Status					
		Canada	SK	AB	MB	ND	MT
Asian tapeworm (*Bothriocephalus acheilognathi* Yamaguti)	cestoda	-	R[2]	-	-	R[5]	R[6,7]
fishhook waterfleas (*Cercopagis pengoi* Ostroumov)	crustacea	R[1]	R[2]	-	-	R[5]	-
northern snakehead (*Channa argus* Cantor)	fish	R[1]	R[2]	-	-	R[5]	-
Asian clam (*Corbicula fluminea* Muller)	mollusk	R[1]	R[2]	-	R[4]	R[5]	-
freshwater jellyfish (*Craspedacusta sowerbyi* Lankester)	fish	-	R[2]	-	-	-	-
grass carp (*Ctenopharyngodon idella* Val.)	fish	R[1]		-	R[4]	R[5]	R[6,7]
quagga mussel (*Dreissena bugensis* Andrusov)	mollusk	R[1]	R[2]	-	R[4]	R[5]	R[6,7]
Chinese mitten crab (*Eriocheir sinensis* H. Milne-Edwards)	crustacea	R[1]	R[2]	-	-	-	-
Conrad's false mussel (*Mytilopsis leucophaeata* Conrad)	mollusk	-	R[2]	-	-	-	-
yellow floating heart (*Nymphoides peltata* Gmel.)	plant	-	R[3]	-	-	-	-
channeled applesnail (*Bithynia tentaculata* L.)	mollusk	-	R[2]	-	-	-	-
water soldier (*Stratiotes aloides* L.)	plant	-	R[3]	-	-	-	-

Note: 1. Weed Seeds Order (Agriculture and Agri-food Canada, 2005); 2. The Fisheries Regulations (Government of Saskatchewan, 1994); 3. The Weed Control Act (Government of Saskatchewan, 2010); 4. Manitoba Fisheries Regulations (Government of Manitoba, 1987); 5. North Dakota's Aquatic Nuisance Species - Species List (North Dakota Game and Fish Department, 2014); 6. Montana Noxious Weed List (Montana Department of Agriculture, 2013); 7. Montana Aquatic Nuisance Species Management Plan (Montana Aquatic Nuisance Species Technical Committee, 2002).

Appendix B

Risk assessment criteria and scoring system for recorded species

Factor	Assessment Criteria	Maximum Score	Justification				
Invasion history	Does the species currently have a widespread recorded distribution?	3	0	1	2	3	
			No occurrences are recorded in the area	The species is sparsely distributed in the area	The species is moderately distributed in the area	The species is widely distributed in the area	
	Is the species currently expanding its range?	2	0	1	2		
			The species is not expanding its range	It is uncertain that the species is currently expanding its range	It is certain that the species is currently expanding its range		
	Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	0	1	2		
			The species has no negative effects on native species, habitats or ecosystems	The species has minor effects on native species, habitats or ecosystems	The species is believed to cause significant effect on native species, habitats or ecosystems		
Species spread potential	Is there potential for this species to be spread intentionally or unintentionally?	2	0	1	2		
			There is no potential for this species to be spread intentionally or unintentionally	There is potential for this species to be introduced unintentionally by human vectors (e.g. recreational boats)	There is potential for this species to be introduced for purposes of benefiting agriculture, aquaculture, or other economic activities		
Availability of suitable habitats	How widespread are suitable habitats to allow establishment of the species?	2	0	1	2		
			The habitats are not suitable for establishment of this species at all	Less than 50% of the habitats are suitable for establishment of this species	More than 50% of the habitats are suitable for establishment for this species		
Impact assessment	Where the species has become established has it impacted upon the conservation objectives for the area?	4	0	1	2	3	4
			The species has no impacts upon the conservation objectives	The species has minimal impact upon the conservation objectives	The species has moderate impact upon the conservation objectives	The species has severe impact upon the conservation objectives	The species has deblitating impact upon the conservation objectives
	Is the species poisonous, or does it pose a risk to plant and animal health?	2	0	1	2		
			The species is not poisonous and it does not pose a risk to native biodiversity	The species is not poisonous but it threatens native biodiversity indirectly	The species is poisonous and threatens native biodiversity directly		
		2	0	1	2		

	Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?		The species is not poisonous and it does not pose a risk to human health due to its parasites or pathogens or other intrinsic factor	The species is not poisonous but it poses a risk to human health indirectly due to its parasites or pathogens or other intrinsic factor	The species is poisonous and it poses a risk to human health directly or indirectly due to its parasites or pathogens or other intrinsic factor		
	Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	0 The species has not caused any economic losses directly or indirectly	1 The species has caused low economic losses directly or indirectly	2 The species has caused moderate economic losses directly or indirectly	3 The species has caused significant economic losses directly or indirectly	
Management	Are there acceptable and effective control methods that can be applied?	3	0 Control methods are effective with low resource requirement	1 Control methods are effective but resource intensive with minimal ecological impact	2 Control methods are effective but resource intensive with a high degree of ecological impact	3 There are no described control methods or control methods are ineffective	

Risk assessment criteria and scoring system for potential species

Factor	**Assessment Criteria**	**Maximum Score**	**Justification**				
Identification of nearest donor region	In which of the following donor regions is the nearest population?	3	0 The species is not found in Canada and U.S	1 The nearest population is found in Canada/U.S.	2 The nearest population is found in one of the neighbouring province/state	3 Populations are found in more than one neighbouring province/state	
Occurrence in similar climate	Does the species occur in a similar climatic region?	2	0 The species does not occurs in the same type of climate	1 The species occurs in the same type but different subtype of climate	2 The species occurs in the same subtype of climate		
Pathway of introduction	Is there a realistic pathway for unintentional introduction?	2	0 There is no realistic pathways for unintentional introduction	1 It is uncertain that there is a realistic pathway for unintentional introduction	2 It is certain that there is realistic pathway for unintentional introduction		
	Is there potential for this species to be introduced intentionally?	2	0 There is no potential for this species to be introduced intentionally	1 It is uncertain that there is potential for this species to be introduced intentionally	2 It is certain that there is potential for this species to be introduced intentionally		

Suitability of habitats	Are habitats suitable to allow establishment of the species?	2	0 The habitats are not suitable to allow establishment of the species	1 Less than 50% of the habitats are suitable to allow establishment of the species	2 More than 50% of the habitats are suitable to allow establishment of the species		
Impact assessment	Where the species has become established has it impacted upon the conservation objectives for the area?	4	0 The species has no impacts upon the conservation objectives	1 The species has minimal impact upon the conservation objectives	2 The species has moderate impact upon the conservation objectives	3 The species has severe impact upon the conservation objectives	4 The species has deblitating impact upon the conservation objectives
	Is the species poisonous, or does it pose a risk to plant and animal health?	2	0 The species is not poisonous and it does not pose a risk to native biodiversity	1 The species is not poisonous but it threatens native biodiversity indirectly	2 The species is poisonous and threatens native biodiversity directly		
	Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0 The species is not poisonous and it does not pose a risk to human health due to its parasites or pathogens or other intrinsic factor	1 The species is not poisonous but it poses a risk to human health indirectly due to its parasites or pathogens or other intrinsic factor	2 The species is poisonous and it poses a risk to human health directly or indirectly due to its parasites or pathogens or other intrinsic factor		
	Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	0 The species has not caused any economic losses directly or indirectly	1 The species has caused low economic losses directly or indirectly	2 The species has caused moderate economic losses directly or indirectly	3 The species has caused significant economic losses directly or indirectly	
Management	Are there acceptable and effective control methods that can be applied?	3	0 Control methods are effective with low resource requirement	1 Control methods are effective but resource intensive with minimal ecological impact	2 Control methods are effective but resource intensive with a high degree of ecological impact	3 There are no described control methods or control methods are ineffective	

Appendix C

Time and location of purple loosestrife infestations recorded in Saskatchewan

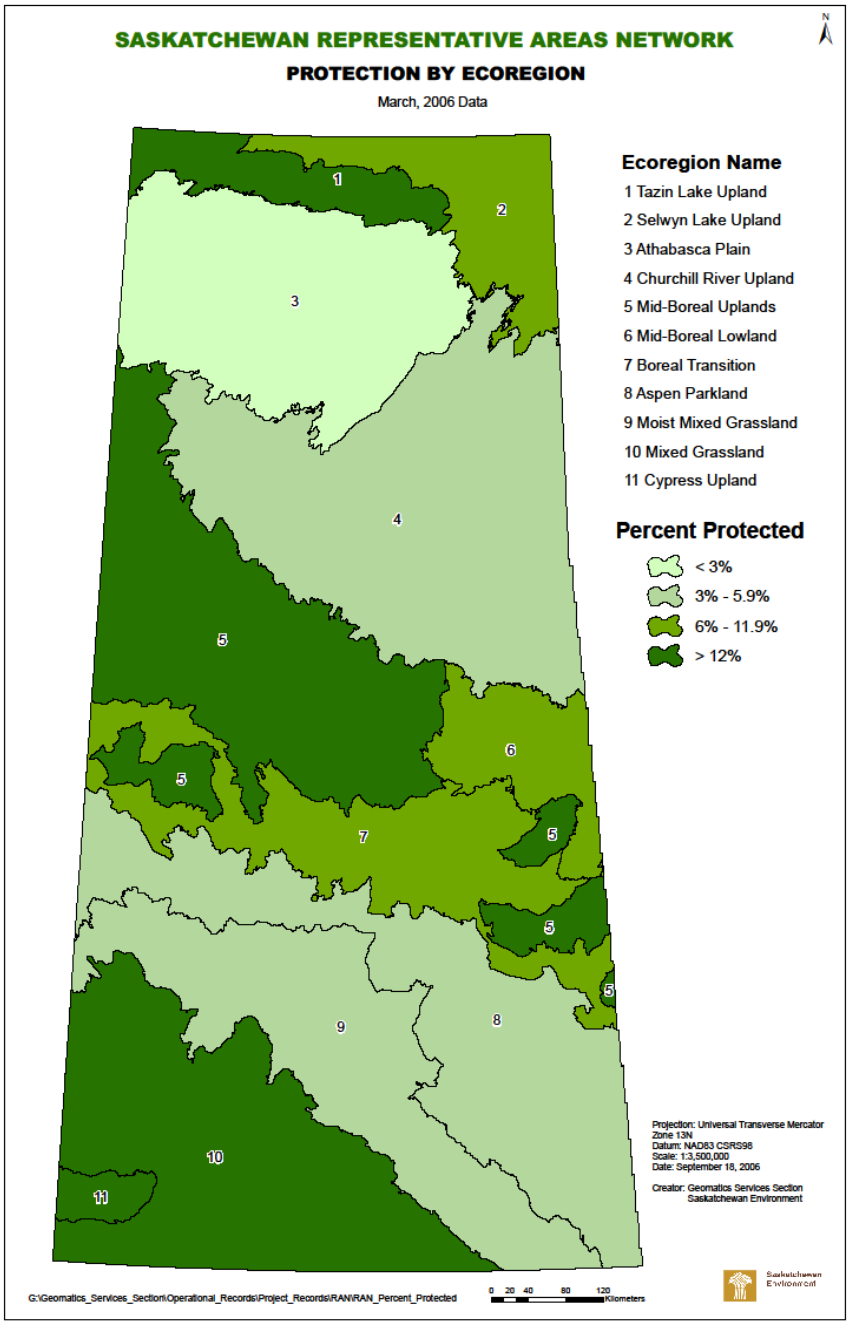
Date	X	Y	County	Watersheds
1971/8/5	389969.4513	5784504.818	Corman Park	South Saskatchewan River
1990/1/1	529893.4116	5585503.483	Sherwood	Wascana Creek
1990/1/1	676675.8959	5677331.903	Orkney	Assiniboine River
1990/8/31	389870.6785	5780056.202	Corman Park	South Saskatchewan River
1990/8/31	389186.6902	5780071.431	Corman Park	South Saskatchewan River
1992/8/1	385664.3627	5775700.439	Corman Park	South Saskatchewan River
1992/8/1	388477.7113	5778974.608	Corman Park	South Saskatchewan River
1992/8/1	384928.2813	5773491.976	Corman Park	South Saskatchewan River
1995/1/1	403237.1669	5798691.986	Aberdeen	South Saskatchewan River
1995/10/16	392968.1044	5796678.762	Corman Park	South Saskatchewan River
1995/10/16	385792.3702	5781261.138	Corman Park	South Saskatchewan River
1995/10/16	391092.4396	5773353.137	Corman Park	South Saskatchewan River
1995/10/16	379610.8933	5775209.151	Corman Park	South Saskatchewan River
1995/10/16	379662.0525	5775341.445	Corman Park	South Saskatchewan River
1995/10/16	384243.379	5773507.875	Corman Park	South Saskatchewan River
1996/1/1	570500.197	5625837.176	North Qu'appelle	Lower Qu'Appelle River
1996/8/15	406949.7893	5778593.936	Aberdeen	South Saskatchewan River
1996/8/16	408873.7888	5808598.042	Aberdeen	South Saskatchewan River
1996/8/16	679814.8781	5647385.326	Cana	Assiniboine River
1996/8/17	393927.0993	5777742.491	Corman Park	South Saskatchewan River
1996/8/27	426597.6233	5856141.016	Duck Lake	South Saskatchewan River
1996/8/28	400421.873	5794297.433	Corman Park	South Saskatchewan River
1996/8/30	426205.9318	5784945.079	Grant	South Saskatchewan River
1996/9/3	520008.4343	5554234.26	Bratt's Lake	Moose Jaw River
1997/5/30	524138.5827	5588720.934	Sherwood	Wascana Creek
1997/7/20	529002.8558	5585965.539	Sherwood	Wascana Creek
1997/7/24	462879.4008	5582157.832	Moose Jaw	Moose Jaw River
1997/7/29	525350.5158	5583244.709	Sherwood	Wascana Creek
1997/8/1	656481.1381	5659236.736	Cana	Assiniboine River
1997/8/1	506767.7567	5831484.137	Lake Lenore	Carrot River
1997/8/19	530255.3737	5863466.036	Star City	Carrot River
1997/8/20	386501.6594	5782357.584	Corman Park	South Saskatchewan River
1997/8/21	688982.3815	5722305.465	Sliding Hills	Assiniboine River
1997/9/6	358816.4683	5865435.8	Redberry	North Saskatchewan River
1998/7/1	463075.1764	5581689.435	Moose Jaw	Moose Jaw River
1998/7/1	463073.0021	5581378.1	Moose Jaw	Moose Jaw River
1998/8/1	531169.1759	5587212.159	Sherwood	Wascana Creek
1998/8/1	661099.0837	5766588.61	Preeceville	Assiniboine River
1998/8/19	460518.9657	5584020.811	Moose Jaw	Moose Jaw River
1998/8/27	299802.1969	5573540.581	Swift Current	Swift Current Creek
1998/9/1	385810.6842	5775808.347	Corman Park	South Saskatchewan River
1999/7/1	426485.9947	5855886.814	St. Louis	South Saskatchewan River
1999/7/1	490398.1185	5783537.163	Humboldt	Upper Qu'Appelle River
1999/8/1	549853.8606	5572221.259	Lajord	Wascana Creek
1999/8/9	394139.1649	5787662.983	Corman Park	South Saskatchewan River
1999/8/18	422346.8971	5773723.555	Blucher	South Saskatchewan River
1999/8/19	387252.205	5777455.621	Corman Park	South Saskatchewan River
1999/8/19	387528.0036	5777237.951	Corman Park	South Saskatchewan River

1999/8/20	393743.354	5787048.363	Corman Park	South Saskatchewan River
1999/8/20	395286.0157	5787939.007	Corman Park	South Saskatchewan River
1999/8/20	396254.8254	5788853.24	Corman Park	South Saskatchewan River
1999/8/20	400529.0783	5793861.342	Corman Park	South Saskatchewan River
1999/8/20	399549.0891	5792646.134	Corman Park	South Saskatchewan River
1999/8/21	679107.1882	5647516.641	Cana	Assiniboine River
1999/8/23	515929.1473	5603512.1	Lumsden	Upper Qu'Appelle River
2000/1/1	392778.3152	5777488.998	Corman Park	South Saskatchewan River
2000/1/1	529033.3508	5592037.014	Sherwood	Wascana Creek
2000/1/1	462479.1172	5581849.306	Moose Jaw	Moose Jaw River
2000/7/5	461121.5964	5584794.725	Moose Jaw	Moose Jaw River
2000/7/28	463166.5102	5581533.122	Moose Jaw	Moose Jaw River
2000/7/28	462871.828	5581079.278	Moose Jaw	Moose Jaw River
2000/7/28	463170.7704	5582144.674	Moose Jaw	Moose Jaw River
2000/8/1	528906.8181	5585342.317	Sherwood	Wascana Creek
2000/8/1	529404.1075	5585345.062	Sherwood	Wascana Creek
2000/8/1	529700.7301	5585658.07	Sherwood	Wascana Creek
2000/8/1	529102.302	5585966.086	Sherwood	Wascana Creek
2000/8/1	529004.566	5585654.2	Sherwood	Wascana Creek
2000/8/1	530090.5473	5585815.951	Sherwood	Wascana Creek
2000/8/1	530388.8945	5585817.66	Sherwood	Wascana Creek
2000/8/14	463074.0892	5581533.767	Moose Jaw	Moose Jaw River
2000/8/14	463075.1764	5581689.435	Moose Jaw	Moose Jaw River
2000/8/16	277812.2844	5645633.403	Lacadena	North Saskatchewan River
2000/8/31	515138.0393	5617565.159	Longlaketon	Lower Qu'Appelle River
2001/1/1	523730.4555	5589486.329	Sherwood	Wascana Creek
2001/8/1	491502.2839	5777818.106	Humboldt	Upper Qu'Appelle River
2001/8/15	645890.5842	5444456.072	Estevan	Upper Souris River
2001/9/1	532860.1295	5589379.634	Sherwood	Wascana Creek
2002/1/1	516184.5618	5603334.967	Lumsden	Upper Qu'Appelle River
2002/1/1	520692.1156	5587705.539	Sherwood	Wascana Creek
2002/8/6	526710.3574	5582773.27	Sherwood	Wascana Creek
2002/8/20	646578.9389	5441893.617	Estevan	Upper Souris River
2002/9/20	646222.0391	5444342.476	Estevan	Upper Souris River
2002/10/2	525904.9519	5587572.88	Sherwood	Wascana Creek
2003/1/1	532999.2836	5585288.466	Sherwood	Wascana Creek
2003/1/1	452704.5854	5893929.972	Prince Albert	North Saskatchewan River
2004/8/3	371125.7606	5822052.33	Laird	North Saskatchewan River
2005/1/1	528920.0119	5592003.032	Sherwood	Wascana Creek
2008/8/19	431179.0623	5883138.579	Duck Lake	North Saskatchewan River
2008/8/19	431162.8993	5881965.004	Duck Lake	North Saskatchewan River
2008/8/19	431162.8993	5881965.004	Duck Lake	North Saskatchewan River
2008/8/19	431119.5102	5879219.705	Duck Lake	South Saskatchewan River
2008/8/19	431088.9059	5877131.783	Duck Lake	South Saskatchewan River
2008/8/19	431077.4857	5876522.24	Duck Lake	South Saskatchewan River
2008/8/19	403197.5009	5861459.669	Duck Lake	North Saskatchewan River
2008/8/22	403202.6039	5861714.387	Duck Lake	North Saskatchewan River
2010/9/3	661263.2136	5766979.061	Preeceville	Assiniboine River
2011/7/13	387881.3589	5657936.255	Maple Bush	South Saskatchewan River
2013/7/18	385078.0422	5779550.069	Corman Park	South Saskatchewan River
2014/5/25	496145.6872	5610004.35	Lumsden	Upper Qu'Appelle River
2014/8/6	528932.4108	5592070.93	Sherwood	Wascana Creek
2014/8/13	525493.6398	5586101.306	Sherwood	Wascana Creek

2014/8/14	531851.1084	5586607.027	Sherwood	Wascana Creek
2014/8/19	522827.3425	5590079.99	Sherwood	Wascana Creek
2014/8/20	393454	5777157	Corman Park	South Saskatchewan River
2014/9/9	385801	5775770	Corman Park	South Saskatchewan River
2014/9/11	382984.092	5773382.805	Corman Park	South Saskatchewan River
2014/9/21	385803.8684	5775779.164	Corman Park	South Saskatchewan River

Appendix D

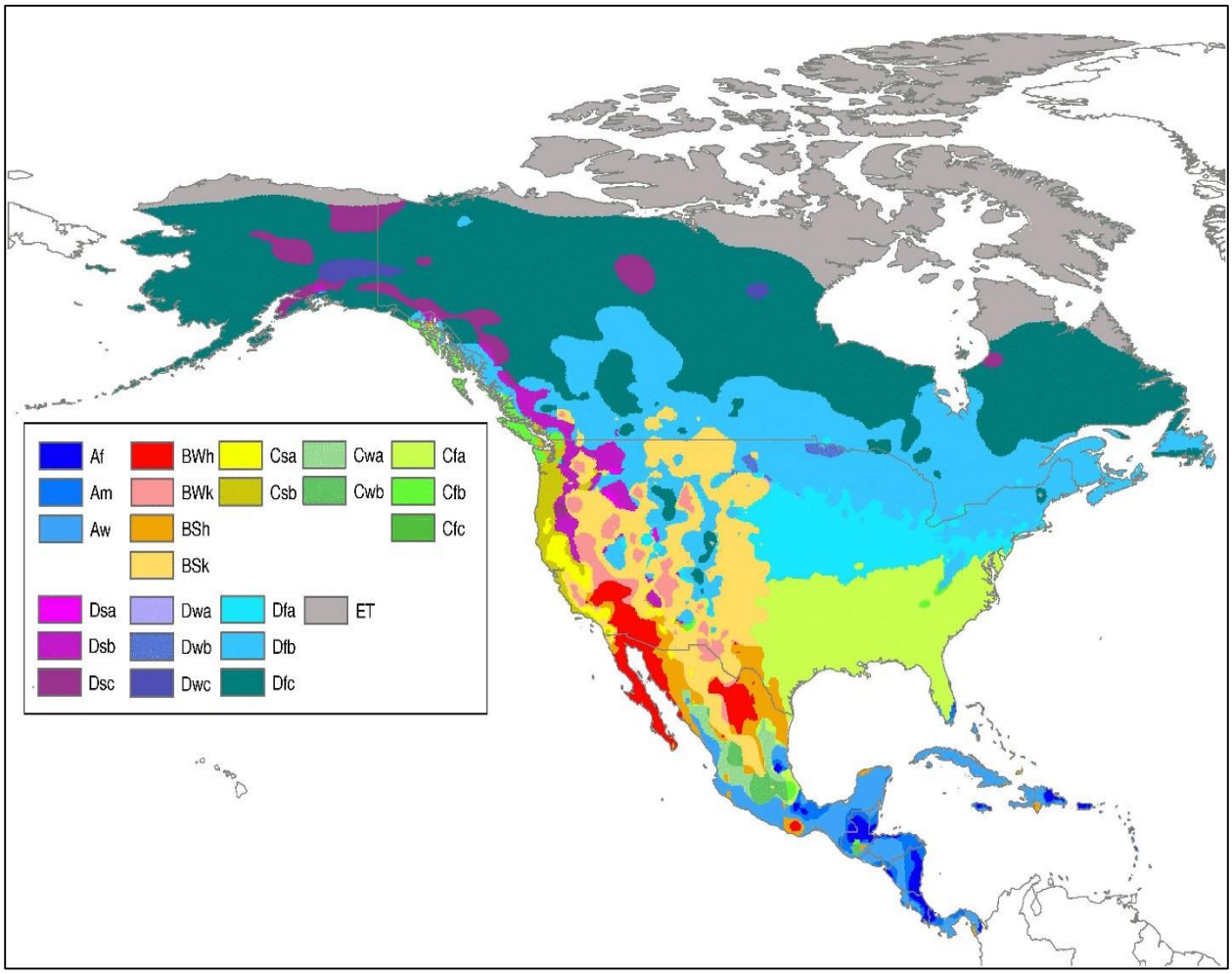
Ratio of protected area by ecoregion within Saskatchewan Representative Areas Network



Adapted from Government of Saskatchewan (2005)

Appendix E

Köppen Climate Classification – North America



Adapted from Peel et al. (2007)

Appendix F

Risk assessment of flowering rush at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	1	0	0
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	0	0
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	2	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	1	0	0
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1	1	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	1	1	1
Overall score			10	7	6

Risk assessment of curly-leaved pondweed at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	1	0	0
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	0	0
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	2	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2	0	0
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1	1	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	1	1	1
Overall score			11	7	6

Risk assessment of common carp at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	2	0	0
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	0	0
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	2	1	0
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	1	1	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2	0	0
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	3	3	3
Management	10. Are there acceptable and effective control methods that can be applied?	3	2	2	2
Overall score			15	9	8

Risk assessment of European common reed at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	1	0	0
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	0	0
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	1	1	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	1	0	0
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1	1	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	2	2	2
Overall score			10	7	8

Risk assessment of narrow-leaved cattail at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	2	1	1
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	1	1
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	1	1	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2	1	1
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1	1	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	2	2	2
Overall score			12	10	10

Risk assessment of reed canary grass at the provincial, regional and local scale

Factor	Assessment Criteria	Maximum Score	Score		
			Provincial	Regional	Local
Invasion history	1. Does the species currently have a widespread recorded distribution?	3	2	1	1
	2. Is the species currently expanding its range?	2	1	1	1
	3. Is the species in its present range known to be invasive (i.e. to threaten species, habitats or ecosystems)?	2	1	1	1
Species spread potential	4. Is there potential for this species to be spread intentionally or unintentionally?	2	1	1	1
Availability of suitable habitats	5. How widespread are suitable habitats to allow establishment of the species?	2	2	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	3	2	2
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1	1	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0	0	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1	1	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	1	1	1
Overall score			13	11	10

Risk assessment of Eurasian water-milfoil at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	3
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	1
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	3
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	2
Overall Score			**14**

Risk assessment of saltcedar at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	3
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	1
	4. Is there potential for this species to be introduced intentionally?	2	2
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	4
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	2
Management	10. Are there acceptable and effective control methods that can be applied?	3	2
Overall Score			**19**

Risk assessment of faucet snail at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	2
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	2
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	3
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	2
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	1
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	2
Overall Score			**17**

Risk assessment of New Zealand mudsnail at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	2
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	1
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	2
Overall Score			**14**

Risk assessment of spiny waterflea at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	2
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	1
Overall Score			**12**

Risk Assessment of round goby at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	2
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	0
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	2
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	2
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	2
Management	10. Are there acceptable and effective control methods that can be applied?	3	1
Overall Score			**12**

Risk Assessment of rusty crayfish at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	1
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	1
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	1
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	1
Management	10. Are there acceptable and effective control methods that can be applied?	3	1
Overall Score			**9**

Risk assessment of silver carp at the provincial scale

Factor	Assessment Criteria	Maximum Score	Score
Identification of nearest donor region	1. In which of the following donor regions is the nearest population?	3	2
Occurrence in similar climate	2. Does the species occur in a similar climatic region?	2	1
Pathway of introduction	3. Is there a realistic pathway for unintentional introduction?	2	0
	4. Is there potential for this species to be introduced intentionally?	2	0
Suitability of habitats	5. Are habitats suitable to allow establishment of the species?	2	1
Impact assessment	6. Where the species has become established has it impacted upon the conservation objectives for the area?	4	4
	7. Is the species poisonous, or does it pose a risk to plant and animal health?	2	1
	8. Is the species poisonous, or does it pose a risk to human health due to its parasites or pathogens or other intrinsic factor?	2	0
	9. Has the species directly or indirectly caused economic losses at its home range or where it has become invasive?	3	3
Management	10. Are there acceptable and effective control methods that can be applied?	3	3
Overall Score			**15**

Appendix G

Purple Loosestrife (*Lythrum salicaria*)

Description

Lythrum salicaria is an erect, perennial herb with a woody four-sided stem and whorled leaves. Mature plant can have 30 to 50 stems emerging from a single rootstock and are prolific seed producers. L. salicaria can grow from 1.2 to 3 m high[1].

http://richard.rathe.org/summer-bike-vacation-2010/

Habitat

Lythrum salicaria is capable of invading a variety of wetland habitats, including marshes, river and stream banks, pond edges, lakes, roadside ditches, and reservoirs[1].

Distribution

Lythrum salicaria is currently widespread in the southern half of Saskatchewan[2].

Introduction Pathways

Lythrum salicaria is likely introduced when its seeds were included in soil transported to a new location. The plant was also spread by early settlers in North America and is still used in flower gardens and occasionally sold in nurseries today[3].

https://commons.wikimedia.org/wiki/File:Lythrum_salicaria,_purple_loosestrife_5/

Impact

Lythrum salicaria is often reported to outcompete and replace native grasses, sedges, and other flowering plants that provide a higher quality food source and habitat for wildlife[1].

Management

Physical: Small infestations of *Lythrum salicaria* can be controlled by cutting and pulling[1].

Chemical: Herbicides are most commonly used for quick, effective control of *Lythrum salicaria*. In Canada, only Roundup is registered for the control of Lythrum in terrestrial areas only[1].

Biological: *Galerucella* beetles species have been confirmed to have significant impacts on *Lythrum salicaria* at the individual level (i.e. shorter plants and reduced flowering rates[1].

1. Global Invasive Species Database. (2010). *Lythrum salicaria*. Retrieved July 4, 2015, from http://www.issg.org/database/species/ecology.asp?si=93&fr=1&sts=sss&lang=EN
2. NatureServe. (2015). Imapinvasives: an online data system supporting strategic invasive species management. Retrieved January 18, 2015, from http://www.imapinvasives.org.
3. Ontraio's Invading Species Awareness Program. (n.d.). Purple Loosestrife. Retrieved July 6, 2015, from http://www.invadingspecies.com/invaders/plants-terrestrial/purple-loosestrife/

Flowering Rush (*Butomus umbellatus*)

Description

Butomus umbellatus is a moderately tall, rush-like perennial. Its leaves are basal originating from a stout rhizome that is stiff and erect when immersed or lax and floating when in deep water[1].

Habitat

Butomus umbellatus is mostly found on shores of lakes, ponds and riverbanks, and it is intolerant of salt or brackish water[1].

Distribution

There is currently only one known infestation of *Butomus umbellatus* in Saskatchewan, approximately 8 km south of the Village of Young[2].

Introduction Pathways

Butomus umbellatus is probably spread over long distances by people who plant it in gardens. Boaters can also transport the plants on their equipment[1].

http://www.thewildflowersociety.com/wfs_diary/0_wfs_new_illustrated_diary_2012/04_new_record_book_thumbnails_2012_page_4.htm

http://www.greatgardenalternatives.com/flowering-rush.html

Impact

Butomus umbellatus can displace native riparian vegetation, and can be an obstacle to boat traffic. Once established in a marsh, the population increase and persist indefinitely[1].

Management

Physical: Cutting flowering rush below the water surface is an effective method of control. Multiple cuts may be required throughout the summer as flowering rush grows back from the root[3].

Chemical: It is very difficult to kill flowering rush with herbicides. Herbicides easily wash away from the narrow leavers of this plant. Herbicides are more effective on dry banks or in very shallow water. There is no herbicide that is selective for flowering rush and care must be taken to avoid damage to valuable wetland plants[3].

1. Global Invasive Species Database. (2010). *Botumos umbellatus*. Retrieved July 4th, 2015, from http://www.issg.org/database/species/ecology.asp?si=610&fr=1&sts=sss&lang=EN
2. Neufeld, C. (2012). Flowering Rush Removal 2012 Report. Native Plant Society of Saskatchewan.
3. Johnson, M., Rice, P. M., Dupuis, V., & Ball, S. (2009). Addressing the Invasive Aquatic Flowering Rush (Butomus umbellatus) in the Headwaters of the Columbia River System–A Multi-Partner, Interdisciplinary Project. The view from the North, 76.

Curly-leaved Pondweed (*Potamogeton crispus*)

Description

Potamogeton crispus is a submerged, perennial aquatic plant easily identified by lanceolate, reddish-green, wavy leaves with finely toothed margins. The leaves are 0.5-1.5 cm wide and 3 cm to 10 cm long. Stems are branched and somewhat flattened[1].

http://dnr.wi.gov/topic/invasives/fact/curlyleafpondweed.html

Habitat

Potamogeton crispus is found in freshwater lakes, ponds, rivers and streams, and in slightly brackish waters. It is tolerant of low light, low water temperature, and is a species of alkaline or nutrient-rich water[1].

Distribution

Potamogeton crispus has been found sparsely in south-central Saskatchewan[2].

Introduction Pathways

Potamogeton crispus can spread by plant fragments attached to boats and equipment that are not properly cleaned[1].

http://mtweed.org/weeds/curly-leaf-pondweed/

Impact

Potamogeton crispus can grow in dense beds which outcompete native aquatic plants. The dense surface mats may also interfere with water-based recreational activities[1].

Management

Physical: Management activities, including raking and cutting, should be undertaken in spring or very early summer to have the maximum benefit[3].

Chemical: Chemicals that can be used to control Potamogeton crispus include the herbicides diquat (Reward, Weedtrin-D), endothall (Aquathol, Hydrothol 191), and floridone (Sonar A.S., Sonar SRP). Endothall-based herbicide such as Aquathol K is recommended as it is effective in 15 degree C water allowing for earlier treatment[3].

1. Global Invasive Species Database. (2010). *Potamogeton crispus*. Retrieved July 4, 2015, from http://www.issg.org/database/species/ecology.asp? si=447&fr=1&sts=sss&lang=EN
2. Invasives Tracking System. (2012). Retrieved July 5, 2015, from http://www.invasivestrackingsystem.ca/report.php?ListType=tlkpInvSpeciesGallery&ID=23
3. Gulnaz, O., Sahmurova, A., & Kama, S. (2011). Removal of Reactive Red 198 from aqueous solution by Potamogeton crispus. Chemical Engineering Journal, 174(2), 579-585.

Common Carp (*Cyprinus carpio*)

Description

Cyprinus carpio is a fish that can grow up to 120 cm in length and weigh up to 60 kg. It may be recognised by its small eyes, thick lips, two barbells at each comer of the mouth, small scales, and strongly serrated spines in the dorsal and anal fins[1].

https://thevlm.org/common-carp/

Habitat

Cyprinus carpio is usually found in still or slowly flowing waters, lakes and permanent wetlands, commonly with silt bottoms. Although stenohaline, they are tolerant of relatively high salinities[1].

Distribution

Cyprinus carpio has a concentrated distribution in south-central Saskatchewan[2].

Introduction Pathways

Cyprinus carpio has been introduced as a food fish and ornamental fish, into temperate freshwaters, throughout the world. It has also been introduced to many places for angling/sport[1].

http://texasbestbowfishing.com/portfolio/

Impact

On every continent where *Cyprinus carpio* has been introduced it has reduced water quality and degraded aquatic habitats. The species significantly influenced benthic macroinvertebrates, outcompeting other aquatic animals. *Cyprinus carpio* is believed to simulate algal bloom formatting by increasing nutrient release from sediments and decreasing algal grazing by cladocerans[1].

Management

Physical: Control methods include electrical barriers, harvesting, traps and water level manipulation[1].

Chemical: Widespread use of pesticide is not possible in aquatic habitats because species-species poisons for carp are not available[1].

Biological: Bio-control of carp using the Spring Viraemia of Carp Virus (SVCV) has been suggested since the 1970s; however, intense scrutiny would be given to the release of viral control agents, especially those which may be water-borne[1].

1. Global Invasive Species Database. 2011. *Cyprinus carpio*. Retrieved July 4, 2015, from http://www.issg.org/database/species/ecology.asp?si=60&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy, 2013-07-01. Retrieved June 31, 2015, from http://www.gbif.org/species/4286975

European Common Reed (*Phragmites australis subsp. australis*)

Description

European common reed is a tall, warm-season, perennial, sod-forming grass. They may be nearly 2.5 cm in diameter and up to 5 m tall, terminating in a dense, 30-cm panicle. The culms are erect, rigid, smooth, and hollow[1].

Habitat

European common reed can be found in coastland, estuarine habitats, lakes, riparian zones, water courses, and wetlands. It is especially common in alkaline and brackish environments and can also thrive in highly acidic wetlands[1].

Distribution

Although the species has been confirmed to be present in Saskatchewan, there is currently limited information on its distribution in the province[2].

Introduction Pathways

European common reed may be used for wetland rehabilitation and stabilization. It is used to revegetate disturbed areas, control shore erosion, stabilize river and canal banks, and reduce wave action on watershed structure[1].

http://www.ipmimages.org/browse/detail.cfm?imgnum=5510407

http://www.shutterstock.com/video/clip-3900803-stock-footage-phragmites-european-common-reed-phragmites-australis.html

Impact

The invasive common reed can crows out native vegetation, and generally provides poor habitat and food supplies for wildlife, thus resulting in decreased biodiversity. The species grows quickly thereby causing lower water levels as water is transpired faster than it would be with native vegetation[3].

Management

Physical: Cutting has been used successfully to control P. australis. Care must be taken to remove cut shoots to prevent their sprouting and forming stolons[1].

Chemical: Rodeo, a water solution of the isopropylamine salt of glyphosate is commonly used for Phragmites control. However, it is not selective and will kill grasses and broadleaf plants alike[1].

Biological: Biological control does not appear to be an option at this time. No organisms that significantly damage common reed without feeding on other plant species have been identified[1].

1. Global Invasive Species Database. (2013). *Phragmites australis*. Retrieved July 4, 2015, from http://www.issg.org/database/species/ecology.asp?si=301&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy, 2013-07-01. Retrieved June 21, 2015, from http://www.gbif.org/species/4286975

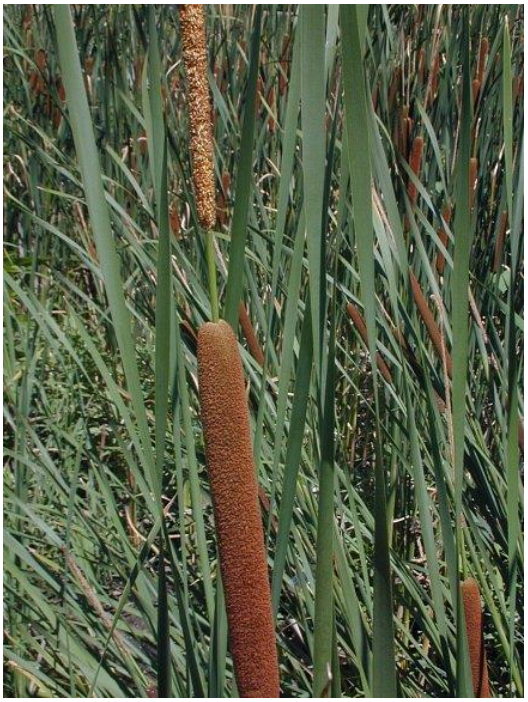
Narrow-leaved Cattail (*Typha angustifolia*)

Description
The velvety, brown flower head and long, graceful, lanceolate leaves of the cattail are a common site throughout wetlands. The flower head, shaped like an elongate cylinder, is a compact spike at the terminal end of a stem 1-3 meters tall[1].

Habitat
Stands of cattail can be found in a wide variety of wetland habitats, including marshes, lakeshores, river backwaters and roadside ditches. This prolific plant can grow in disturbed areas, as well as brackish, and polluted waters of depths nearing 3 feet[1].

Distribution
Typha angustifolia have been reported to distribute sparsely in the southern half of Saskatchewan[2].

Introduction Pathways
Typha angustifolia, similar to other cattail species, may be transported by wind, in water, in mud on the feet of birds and livestock, or by humans and machinery[3].



http://www.illinoiswildflowers.info/wetland/plants/nl_cattail.htm

http://fallingwaterdesigns.com/plants/?product=typha-angustifolia

Impact
Narrow-leaved cattails can form dense monocultures when there is a wetland disturbance. They have the ability to spread rapidly by vegetative reproduction forming dense rhizome mats and litter. This impact on species diversity by alteration of habitat[3].

Management
Physical: Control techniques of fire and physical removal (e.g. cutting) in conjunction with flooding are most appropriate. Mechanical removal of rhizomes is difficult because of their depth and volume, however, it can be used to reduce size of infestation and by following up with manual removal[3].

Chemical: Treating cattail species when flowering using herbicides has been found to cause the greatest stress. The disadvantage however of using herbicides is the large volume of decaying matter that remains which can cause water to go foul and unusable[3].

1. Nature Centre at Shaker Lakes. (n.d.). Narrow-leaved cattail. Retrieved July 4, 2015, from http://shakerlakes.org/blog/wpcontent/uploads/2010/11/narrow-leaved_cattail_factsheet.pdf
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 12, 2015, from http://www.gbif.org/species/5289461
3. Global Invasive Species Database. (2011). *Phragmites australis*. Retrieved July 4, 2015, from http://www.issg.org/database/species/ecology.asp?si=895&fr=1&sts=sss&lang=EN

Reed Canary Grass (*Phalaris arundinacea var. picta*)

Description

Reed canary grass is a robust, cool-season, sod-forming perennial grass that produces stems from creeping rhizomes. The stems grow 0.6 to 2 m tall. The leaf-blades are flat, 0.2 to 2 cm wide and up to 0.5 m long.

http://www.florum.fr/phalaris-arundinacea-var-picta/80749/7683/baldingere-faux-roseau-picta-zi.html

Habitat

Reed canary grass can be classified as growing in semi-open and open habitats. Riparian habitats are at the greatest risk of being invaded and dominated by reed canary grass, but any moist, fertile habitat provides good conditions for this species[1].

Distribution

Phalaris arundinacea var. picta has been confirmed to be present across Saskatchewan and has become one of the major invasive species in the province[2].

Introduction Pathways

Farmers have planted this species it produces nutritious, palatable, succulent herbage for pasture, silage, and hay. It may be used for irrigation with pollution control sewage effluent from municipal and industrial sources as practice[1].

https://commons.wikimedia.org/wiki/File:Phalaris_arundinacea_001.jpg

Impact

Reed canary grass can from dense, persistent, monotypic stands in wetlands, moist meadows, and riparian areas that increase sedimentation, alter water circulation and ecosystem processes. These stands exclude and displace desirable native plants and animals[1].

Management

Physical: Physical removal of reed canary grass is easy and efficient early in the colonisation process before the formation of monotypic stands. Removal by hand pulling is practical only for small stands and requires a large time commitment. Hand pulling was effective if done over the entire population 2-3 times per year for five years[1].

Chemical: Several herbicides have been used to control reed canary grass, including amitrole-T, glyphosate and dalapon[1].

1. Global Invasive Species Database. (2010). *Phalaris arundinacea*. Retrieved July 13, 2015, from http://www.issg.org/database/species/ecology.asp?si=394&fr=1&sts=sss&lang=EN
2. Catling, P.M., G. Mitrow & L. Vasseur. (2014). Major invasive alien plants of natural habitats in Canada. 8. Reed Canary grass, Phalaris Roseau: Phalaris arundinacea L. CBA/ABC Bulletin 47(1): 25-34

Zebra Mussel (*Dreissena polymorpha*)

Description

Dreissena polymorpha is triangular or trigonal with a sharply pointed shell hinge end. The maximum size of Dreissena polymorpha can be 5 cm, though individuals rarly exceed 4 cm. The prominent dark and light branding pattern on the shell is the most obvious characteristic of the species[1].

https://en.wikipedia.org/wiki/Zebra_mussel

Habitat

Dreissena polymorpha colonise surface standing waters, surface running waters, the littoral zone of inland surface waterbodies, estuaries, brackish costal lagoons, large estuaries and inland waters, and hard and soft bottom habitats[1].

Distribution

Zebra mussel has not been found in Saskatchewan. The nearest populations are in Lake Winnipeg, Manitoba, and Red River, North Dakota[2].

http://www.wsabc.ca/archives/3525

Introduction Pathways

Zebra mussel adults routinely attach to boat hulls and floating objects and are thus anthropogenically transported to new locations. Larvae may be transported during fish stocking and in bait buckets[1].

Impact

As an efficient filter feeder, a high density of zebra mussels may cause major reductions in phytoplankton numbers that limits food to fish and other consumers further up the food chain. Negative economic impacts caused by zebra mussel include those caused by fouling of intake pipes, ship hulls, navigational constructions and aquaculture cages[1].

Management

Physical: Physical removal using high-pressure water jets is feasible on easily accessed industrial facilities. Larvae suffer total mortality after exposure to ultrasonic vibration (22 to 800 kHz) for three minutes, but the technical effort involved is prohibitive[1].

Chemical: Many chemicals will kill zebra mussels but the suitability of a particular chemical is determined by considerations of effect on water quality, residual concentration, by-products, cost and practicality.

Biological: Large-bodied molluscivores can limit zebra mussel numbers in coastal wetlands. Known predators include common carp, freshwater drum, channel catfish, roach, eel, sturgeon, diving ducks, crayfish and muskrats[1].

1. Global Invasive Species Database. (2009). *Dreissena polymorpha* . Retrieved July 13, 2015, from http://www.issg.org/database/species/ecology.asp?si=50&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 15, 2015, from http://www.gbif.org/species/2945830

Eurasian Water-Milfoil (*Myriophyllum spicatum*)

Description

Myriophyllum spicatum is a perennial that grows under the water surface. It has feather-like green leaves circle the stem in groups of four or five. Leaves have 12 or more thread-like segments. Flowers are tiny and reddish, growing on spikes 5 to 20 cm long that rise above the water[1].

http://www.invasive.org/weedcd/species/3055.htm

Habitat

Myriophyllum spicatum prefers shallow water 1 to 3 m deep, but can root in up to 10 m of water[1].

Distribution

Myriophyllum spicatum was first discovered in Canada in Lake Erie in 1961. Since then it has spared to all the Great Lakes. The species has invaded many inland lakes throughout southern and central Ontario[1].

https://gobotany.newenglandwild.org/species/myriophyllum/verticillatum/

Introduction Pathways

Dispersal by motorboats and boat trailers has been largely blamed for the spread of *Myriophyllum spicatum* in North America. Waterfowl also can facilitate the spread of the plant by eating and excreting its seeds[2].

Impact

Myriophyllum spicatum is fast-growing, it forms dense underwater mats that shade other aquatic plants, competing aggressively with native plants. Reduced oxygen levels in the water caused by decomposition of plants can kill aquatic animals[1].

Management

Physical: Drawdown can be used to control *Myriophyllum spicatum* where applicable if it is extensive enough to prevent regrowth from seeds. However, it could have a negative impact on native plants and animals[2].

Chemical: Similar to fluridon newer chemicals tend to be enzyme-specific compounds with a reduced impacts on non-target species. Diquat dibrominde and 2,4-D are currently approved for use in most states in North America. Many chemicals will kill Eurasian water-milfoil but the suitability of a particular chemical is determined by considerations of effect on water quality, residual concentration, by-products, cost and practicality[2].

Biological: The North American weevil *Euhrychiopsis lecontei* has been confirmed to have a significant impact on the survival of *Myriophyllum spicatum*[2].

1. Ontario's Invading Species Awareness Program. (n.d.). Eurasian Water-Milfoil. Retrieved July 16, 2015, from http://www.invadingspecies.com/invaders/plants-aquatic/eurasian-water-milfoil/
2. Global Invasive Species Database. (2011). *Myriophyllum spicatum*. Retrieved July 13, 2015, http://www.issg.org/database/species/ecology.asp?si=1700&fr=1&sts=sss&lang=EN

Saltcedar (*Tamarix spp.*)

Description

Saltcedar is a semi-deciduous, loosely branched shrub or small to medium-size tree. The branchlets are slender with minute, appressed scaly leaves. Flowers are whitish or pinkish and borne on slender racemes 2-5cm long on the current year's branches and are grouped together in terminal panicles[1].

http://www.greatswfurniture.com/salt-cedar-twig-

Habitat

Saltcedar can find found in a variety of habitats, including agricultural areas, coastland, desert, estuarine habitats, lakes, riparian zones, water courses and wetlands[1].

Distribution

The nearest populations of *Tamarix spp.* have been confirmed to be present in many areas of Manitoba and North Dakota[2].

Introduction Pathways

Saltcedar was introduced as ornamentals and for windbreaks in North America. The massive quantities of minute seeds are readily dispersed by wind[1].

http://www.malag.aes.oregonstate.edu/wildflowers/images.php/id-2964/fullsize-1

Impact

Saltcedar is capable of utilizing saline groundwater by excreting excess salts through glands in the leaves , causing an increase in surface soil salinity that make the habitats unsuitable for other plant species[1].

Management

Physical: Hand pulling can be used where plants are small, access is difficult, or herbicides cannot be used. Uprooting methods are effective in the short-term because uprooted trees do not resprout[1].

Chemical: Where little or no native vegetation is present, aerial application of the herbicide imazapyr, alone or in combination with glyphosate, is effective and practical for controlling saltcedar over a large area[1].

Biological: A biocontrol agent, the saltcedar leaf beetle (*Diorhabda elongate*), has been released in the United States to reduce the abundance of saltcedar[1].

1. Global Invasive Species Database. (2010). *Taramix spp.*. Retrieved July 17, 2015, from http://www.issg.org/database/species/ecology.asp?si=72&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 17, 2015, from http://www.gbif.org/species/9362931

Faucet Snail (*Bithynia tentaculata*)

Description

Bithynia tentaculata can grow up to 0.5 inch in length, but are generally smaller. They are light brown to black, with 4 to 5 whorls and a cover on the shell opening. The shell opening is on the right when the shell pointed up[1].

https://prezi.com/4xbwgcr5woau/faucet-snail/

Habitat

Bithynia tentaculata can be found on rocky shorelines, river and lake bottoms, aquatic plants, dock, and other objects placed in the water[1].

Distribution

The nearest populations of *Bithynia tentaculata* are in northwest Montana[2].

Introduction Pathways

Bithynia tentaculata can spread by attaching to aquatic plants, boats, anchors, decoy anchors, other recreational gear and equipment placed in the water. Some movement by waterbirds may also spread this invasive to new waters[1].

http://fwcb.cfans.umn.edu/courses/nresexotics3002/GradPages/Faucet_snail/

Impact

Faucet snail is an intermediate host for three intestinal trematodes, or flukes (*Sphaeridiotrema globulus, Cyathocotyle bushiensis, and Leyogonimus polyoon*) that cause mortality in ducks and coots. When waterfowl consume the infected snails, the adult trematodes attack the internal organs and cause lesions and hemorrhage[1].

Management

Physical: In an attempt to limit the number of faucet snails in the Upper Mississippi River National Wildlife and Fish Refuge, biologists experimented with covering colonies of faucet snails with sand. However, the success of this method was undocumented[3].

Chemical: There are no known chemical control methods for this species[3]

Biological: There are no known biological control methods for this species[3].

1. Minnesota Department of Natural Resources. (2015). Faucet snail. Retrieved July 17, 2015, from http://www.dnr.state.mn.us/invasives/aquaticanimals/faucet_snail/index.html
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 17, 2015, from http://www.gbif.org/species/2299854
3. Kipp, R.M., A.J. Benson, J. Larson, and A. Fusaro. 2015. *Bithynia tentaculata*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Retrieved July 16, 2015, from http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=987

New Zealand Mudsnail (*Potamopyrgus antipodarum*)

Description

Potamopyrgus antipodarum is a very small, aquatic nail whose elongate shell consists of 5 to 6 dextral, or right handed, whorls. It is often described as horn colored or light to dark brown. I has an operculum that covers its shell aperture. The average length is usually 4-6 mm in introduced locations[1].

https://en.wikipedia.org/wiki/New_Zealand_mud_snai

Habitat

Potamopyrgus antipodarum is an extremely tolerant species that is capable of inhabiting many aquatic conditions. It colonizes a wide range of habitats including rivers, lakes, streams, estuaries, reservoirs, lagoons, canals, ditches, and even water tanks[1].

Distribution

Potamopyrgus antipodarum has a widespread distribution across Montana[2].

Introduction Pathways

Commercial movement of aquaculture products, such as live fish or eggs may be an important vector for *Potamopyrgus antipodarum* spread[1].

http://www.walpa.org/waterline/march-2013/the-invasive-new-zealand-mud-snail-may-be-hitchhiking-on-your-field-gear/

Impact

Potamopyrgus antipodarum may establish very dense populations, consume large amounts of primary production, alter ecosystem dynamics, compete with and displace native invertebrates, and negatively influence higher trophic levels[1].

Management

Physical: Draining waters and allowing substrate to heat and dry completely in the summer or freeze in the winter will kill *Potamopyrgus antipodarum*[1].

Chemical: Chemicals methods used to eradicate *Potamopyrgus antipodarum* include Bayer 73 copper sulfate and 4-nitro-3-trifluoromethylphenol sodium salt (TFM). However, chemical treatment poses risks to surrounding drainages and native species[1].

Biological: Studies of the efficacy and specificity of a trematodes parasite from its native range as a biological control have demonstrated promising results. Also the parasite *Micophallus sp*. has been found to highly specific and effective in most genotypes of *Potamopyrgus antipodarum*[1].

1. Global Invasive Species Database. (2011). *Potamopyrgus antipodarum*. Retrieved July 17, 2015, from http://www.issg.org/database/species/ecology.asp?si=449&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 17, 2015, from http://www.gbif.org/species/5192470

Spiny Waterflea (*Bythotrephes longimanus*)

Description

Bythotrephes longimanus is a freshwater crustacean characterised by a well-developed abdominal region, a cauda continued into a long, thin caudal appendage, a head clearly delimited from the trunk and the ocular part of the head globular and filled with a large eye separated by a depression from the head shield. An adult spiny waterflea is between 1.5 and 5 mm in length[1].

http://www.northeastans.org/online-guide/species information.html?SpeciesID=17

Habitat

Bythotrephes longimanus has a preference for large, deep, clear lakes with relatively low summer bottom temperatures[1].

Distribution

Bythotrephes longimanus has a widespread distribution in the Great Lakes region. The nearest populations have been confirmed in Manitoba[2].

http://www.lakegeorge.com/lakefriendlyliving/2012/08/spiny-water-flea-is-now-in-lake-george.html

Introduction Pathways

Bythotrephes longimanus has spread to almost 50 inland lakes in Ontario, most likely moved there from the Great Lakes by anglers and recreational boaters[1].

Impact

The invasion of *Bythotrephes longimanus* into the Great Lakes has resulted in substantial and sustained decreases in the populations of a number of native zooplankton species, directly competing with small fish for food[1].

Management

To date, the only effective strategy for controlling spiny waterflea is to prevent its introduction into new bodies of water. Preventative measures include: 1) inspecting requirement upon leaving a lake, 2) removing all visible plants and animals from your boat, trailer, and accessory equipment before leaving the access area, 3) draining live wells and bilge water before leaving the access site, 4) emptying all water from bait buckets onto the land, 5) drying all boats and equipment for at least 5 days before entering another body of water[1].

1. Global Invasive Species Database. (2011). *Bythotrephes longimanus*. Retrieved July 17, 2015, from http://www.issg.org/database/species/ecology.asp?si=151&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 17, 2015, from http://www.gbif.org/species/2234644

Round Goby (*Neogobius melanostomus*)

Description

Neogobius melanostomus is a small, soft-bodied fish. It is most readily distinguished from all other freshwater fish in North America by the presence of a fused pelvic fin that forms a suction disk on the ventral surface. The body is brownish gray with dark brown lateral spots[1].

http://www.lakescientist.com/ecological-impacts-invasive-round-goby-neogobius-melanostomus-laurentian-great-lakes-beyond-summary-presentations-iaglr-2014/

Habitat

Neogobius melanostomus is a bottom dweller in the nearshore region of lakes and rivers, and prefers rocky habitat that provides lots of hiding opportunities[1].

Distribution

Neogobius melanostomus has a widespread distribution across the Great Lakes region. The nearest population is situated in the inland lakes of Manitoba[2].

https://www.tum.de/en/about-tum/news/press-releases/short/article/31047/

Introduction Pathways

Neogobius melanostomus was probably deposited in the Great Lakes during ballast water exchange[1].

Impact

The number of native fish species have declined in areas where *Neogobius melanostomus* has become abundant. This species has been found to prey on darter, other small fish, and lake trout eggs and fry in laboratory experiments. They also may feed on eggs and fry of sculpins, darters and logperch[1].

Management

Physical: Using electrical barriers to deter movement of *Neogobius melanostomus* has been reported to be successful[3].

Chemical: In addition to electrical barriers, scientists suggested that a chemical piscicide (e.g. rotenone) could be applied between electrical barriers. However, the effectiveness was not documented[3].

Biological: There are no known biological control methods for *Neogobius melanostomus*[1].

1. Global Invasive Species Database. (2011). *Neogobius melanostomus*. Retrieved July 18, 2015, from http://www.issg.org/database/species/ecology.asp?si=151&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 18, 2015, from http://www.gbif.org/species/2379089
3. Kornis, M. S., Mercado-Silva, N., & Vander Zanden, M. J. (2012). Twenty years of invasion: a review of round goby Neogobius melanostomus biology, spread and ecological implications. *Journal of Fish Biology*, *80*(2), 235-285.

Rusty Crayfish (*Orconectes rusticus*)

Description

Orconectes rusticus is a relatively large crayfish that may reach 10 cm in length and has robust claws and dark, rusty spots on either side of its carapace[1].

http://www.invadingspecies.com/invaders/invertebrates/rusty-crayfish/

Habitat

Orconectes rusticus is inhabits permanent lotic and lentic environments of lakes, ponds, and streams that provide suitable water quality year-round. Suitable substrate include clay, silt, sand, gravel, or rock[1].

Distribution

Orconectes rusticus has been established in Ontario since the first occurrence reported in the late 1980s. The nearest populations are present in Manitoba[2].

Introduction Pathways

Orconectes rusticus is a commonly used live fishing bait. The majority of its introductions are believed to be the result of their intentional or unintentional release as such[1].

http://yeboyidoit.wikispaces.com/

Impact

Orconectes rusticus has a range of ecological impacts on introduced environments that include competition and displacement of native crayfish, increased predation on snails, native and threatened bivalves, reduction of macrophyte abundance, reduction of fish abundance, increase in periphyton activity, and other cascading trophic interactions[1].

Management

Physical: Intensive harvest will not eradicate or control crayfish, but may help reduce adult populations and minize some impacts. The use of electric fences along with hand removal in experimental plots was also found to reduce densities of *Orconectes rusticus* and may have implications for macrophyte restoration efforts[1].

Chemical: There are means of chemical control for *Orconectes rusticus*. However, none currently registered have been found to selectively kill *Orconectes rusticus* without affecting other species of crayfish[1].

Biological: There are no known biological control methods for *Neogobius melanostomus*[1].

1. Global Invasive Species Database. (2010). *Orconectes rusticus*. Retrieved July 18, 2015, from http://www.issg.org/database/species/ecology.asp?si=217&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 18, 2015, from http://www.gbif.org/species/397183

Silver Carp (*Hypophthalmichthys molitrix*)

Description

Hypophthalmichthys molitrix are large, laterally compressed cyprinids with a uniform silver colouration. The mouth is relatively large, upturned and toothless. *Hypophthalmichthys molitrix* is an active species well known for its habit of leaping clear of the water when disturbed[1].

http://nas.er.usgs.gov/queries/factsheet.aspx?speciesID=549

Habitat

Hypophthalmichthys molitrix is a freshwater species and is not found in saline water. While the species can inhabit lakes and ponds, for spawning to occur it requires moving water with sufficient current to allow proper egg development, which occurs in swift channels of large rivers[1].

Distribution

Hypophthalmichthys molitrix has widespread distributions across the United States. The nearest populations are in the waterways of North Dakota[2].

Introduction Pathways

Hypophthalmichthys molitrix was imported to U.S. for phytoplankton control in eutrophic water and as a food fish. This invasive species was initially introduced to U.S. waterways through their unintentional escape from southern aquaculture facilities[1].

https://encrypted-tbn1.gstatic.com/

Impact

Hypophthalmichthys molitrix has the potential to cause enormous damage to native species because it feeds on plankton required by larval fish and native mussels. This species would also be a potential competitor with adults of some native fishes, for instance, gizzard shad, which also rely on plankton for food[1].

Management

Physical: Many types of physical barriers are being examined for potential to stop the dispersal of *Hypophthalmichthys molitrix.* These include earth berms, fences, electric barriers, bubble curtains, strobe lights and high pressure sodium lights[1].

Biological: Safe and effective biological control of *Hypophthalmichthys molitrix* is not yet feasible. Several potential technologies are being explored including release of sterile male fish, triploid carp, transgenic alternatives, pheromones, disease agents, parasites, predators[1].

1. Global Invasive Species Database. (2006). *Hypophthalmichthys molitrix is*. Retrieved July 18, 2015, from http://www.issg.org/database/species/ecology.asp?si=774&fr=1&sts=sss&lang=EN
2. Global Biodiversity Information Facility Secretariat: GBIF Backbone Taxonomy (2013). Retrieved July 18, 2015, from http://www.gbif.org/species/952965

Appendix H

Invasive Species Data Collection Sheet

Date_____ **Observer**_____ **Location**_____

Species		Category	Habitat	Area	Density	Waypoint ID	Coordinate		Comments
Common Name	Scientific Name						Latitude	Longitude	

Location

County

(Please provide location information as specific as possible, town, address, directions, etc.)

Distance

Category

Plant, insect, mollusk, fish, reptile, crustacean, arachnid, bird, amphibian, mammal

Habitat

Describe where you found the species (e.g. lake, river, pond, roadside ditch, woodland, etc.)

Density

Sparse (scattered individual stems or very small stands)

Patchy (a mixed of sparse and dense area)

Dense (greater than 40% of the area)