Busy Beavers in the Big City: An Analysis of Beaver Distribution, Foraging and Non-lethal Forage Management in Urban Riverine Forests

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ABSTRACT

Where human and beaver populations overlap in cities, conflicts can arise over the beavers' impact to woody vegetation and river valley infrastructure. One way that cities reduce beavers exploitation of limited shared resources is using non-lethal deterrents, like tree enclosures. Beaver foraging behaviour is well studied in natural systems, with decades of research describing their feeding behaviour and interactions with the woody vegetation community. In comparison, there is a poor understanding of beaver foraging behaviour in urban areas and effectiveness of forage deterrents. My thesis helps to address this research gap. During late summer and fall of 2017, a survey of beaver lodge distribution and an inventory of riparian woody vegetation, as impacted by beavers, were completed on two reaches of the South Saskatchewan River. One river reach (24 km) passed through the City of Saskatoon where there is active beaver management; the second river reach (29 km) was the adjacent upstream conservation area where there is no beaver management. In City parks the effectiveness of a non-lethal forage deterrent use – tree enclosures - was assessed in May 2018. Results from the beaver activity surveys show that lodge complex density is 56% lower in the city reach; lodges active at the time of the inventory had a dispersed spatial distribution. The riparian woody vegetation community along the two river reaches is markedly different, with more than twice the species richness for both trees and shrubs in the city reach. Much of the enhanced plant diversity can be attributed to introduced woody species. Beaver prefer cottonwoods (*Populus spp.*), as evidenced by high foraging of this taxa in the unmanaged reach. But, in the managed reach, cottonwood trees are protected. Thus beavers shifted their foraging efforts to Manitoba maple and green ash. The City of Saskatoon is currently using four primary materials for construction tree enclosures. Wire-mesh in various gauges and patterns have an overall 80% effectiveness in deterring further beaver foraging, but chicken wire performs poorest as it girdles trees. Overall, this research contributes to the understanding of urban beaver foraging patterns and preferences within river valley forests. In addition, this research provides land and resource managers with evidence and suggestions regarding the appropriate use of wire-wrapping as a non-lethal beaver deterrent technique.

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DEDICATION

To my Gido, Peter Paul Seniuk (1921 – 1999), born in a TP not too far from Saskatoon. You are the inspiration for much of my work ethic, and I stayed busy as a beaver through these graduate studies on them and your home river, all the while often thinking of you and Baba. Our time together was short but your influence profound.

Also, to my own little kit that I am soon to meet. When you are old enough, your mother and I will load up our “I Do Canoe” to paddle you around the wetlands and waterways we both love and hope to always share with our friends the beavers.

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1 INTRODUCTION

Humans in cities rely on urban forests for work, play, and a suite of ecosystem services (Duinker et al. 2015). But, another contemporary city dweller, the North American beaver (*Castor canadensis* Kuhl.), has increased in population in North America after near extirpation (Whitfield et al. 2015), now shares many urban areas with human populations. A close cousin of *C. canadensis* is the Eurasian beaver (*C. fiber*) – it has also been reintroduced into much of its former range following decades of protection or reestablishment efforts. European beavers frequently cohabitate with humans in Europe’s most densely populated cities (Pachinger and Hulik 1999; Dewas et al. 2012)One of the ways conflicts with beavers arise in and around cities is when the beaver conspicuously, and very much to our chagrin, chew down trees in urban forests (Destefano and Deblinger 2005; Jonker et al. 2009; Siemer et al. 2013).

Beaver actions often run opposite to that of urban land managers - beaver harvest trees that are planted or protected by the city parks to enhance riparian aesthetics (Loeb et al. 2014). To protect urban trees from being felled by beaver, cities employ lethal and non-lethal deterrents (Nolte et al. 2003). For example, there is frequent reliance on non-lethal forage access barriers, such as wire-wrapping or fencing (tree enclosures). These barriers protect woody vegetation from beaver foraging that otherwise often results in selective cutting and removal of trees and shrubs. By contrast, few anthropogenic deterrents are used in natural systems to manage beaver. In general, the body of knowledge on urban beaver foraging is relatively limited. This is in sharp contrast to what is known for natural systems; where substantive literature exists on beaver foraging and tree replacement pathways that the forest will take following selective foraging (Barnes and Dibble 1988; Johnston and Naiman 1990; Nolet et al. 1994; Terwilliger and Pastor 1999; Stringer and Gaywood 2016). Thus, it is unclear how the interactive effects of beaver tree felling in areas of tree protection will influence urban riparian forest community composition and subsequent beaver forage preference. Likewise, there is a lack of understanding on the effectiveness of various non-lethal forage deterrents placed within the urban forest and how these management efforts will affect the distribution pattern of river-dwelling beavers.

1.1 Research Purpose and Objectives

The **purpose** of my thesis is to improve the understanding of beaver foraging and forage management on woody vegetation in urban riverine forests. Using the example of the South Saskatchewan River within the City of Saskatoon where beaver and their impacts are actively being managed, my **objectives** are: 1) to assess both historic and current beaver activity in study area, primarily through lodge complex surveys, and ; 2) to compare selective foraging patterns by beavers in urban riverine forests with and without active beaver management, and ; 3) to determine the effectiveness of different non-lethal deterrents, specifically tree enclosures, to beaver foraging.

1.2 Literature Review

The purpose of this literature review is to present the state of knowledge into the themes of urban beaver foraging behaviour, beaver management, and western riparian forest vegetation community succession with emphasis on urban riparian forests. The significance of the urban component to these fields of research is that the association with a city means human management or influence on natural systems is an ever-present factor. Knowledge gained from studying beaver interactions with natural riparian forests, including foraging behaviour and forest community dynamics, will be discussed as there has been considerably less research into these phenomena in urban settings. Although academic research and broader public perceptions seem to agree that urban forests are a beneficial component of cities, there is less agreement on the presence of urban beavers. Interestingly, a body of research exists for the social science of urban wildlife and wildlife management, with management of beaver included. However, as it does not relate to the ecological so much as emotional and economic impacts of the animal, I will not consider a review of this literature in depth.

1.3 Ecosystem Impacts of Beavers

Beaver across the globe have been largely extirpated from their historic distributions for reasons ranging from over-exploitation by the fur trade to habitat destruction (Rosell et al. 2005). Re-introduction efforts have allowed for sizeable population increases in both species such that they now re-occupy much of their former ranges (Rosell et al. 2005; Whitfield et al. 2015). The North American beaver has even seen its range move beyond historical population numbers and distributions due to efforts in establishing or re-establishing beaver populations abroad, both accidentally into Eurasia (Parker et al. 2012) and intentionally in southern South America (Anderson et al. 2009). In both cases, exotic beavers are no longer wanted, and extermination campaigns are currently underway in both southern South America (Malmierca et al. 2011) and Eurasia (Parker et al. 2012). The incredible ability of the beaver to manage water and modify habitats to suit their needs (Gurnell 1998) is both their benefit to riparian ecosystems and the source of their most significant conflict with humans.

Beavers are ecosystem engineers, meaning they can create or modify ecosystems through their dam-building and foraging activities (Jones et al. 1994; Rosell et al. 2005; Stringer and Gaywood 2016). They are also considered a keystone species as a by-product of their ecosystem engineering is a diversity of positive impacts on other organisms, with everything from improved reproductive success for amphibians, increases in the density and diversity of aquatic invertebrates, establishing spawning grounds for fish, and the proliferation of preferred riparian vegetation for browsing ungulates (Wright et al. 2002; Zavyalov 2014). Although beneficial, the habitat formation activity of the beaver is not altruistic with the essential needs of beavers requiring the ongoing presence of both land and water. The land is essential for access to vegetation for forage, building supplies, and through the act of collecting the timber for the food and shelter, a means to wear down their continually growing teeth (Baker and Hill 2003). Water provides the beaver with a means of easily transporting woody materials, as well as escape and security from predators (Müller-Schwarze and Sun 2003).

If given the opportunity and access to other suitable resources, beavers exist in and subsequently impact both flowing (lotic) and still (lentic) water systems. Consequently, beavers impact the hydrology (Naiman et al. 1988; Westbrook et al. 2013), geomorphology (Butler and

Malanson 1994), and ecology (Collen and Gibson 2000; Stoffyn-Egli and Willison 2011) of aquatic and riparian ecosystems. Given their ability to create and modify environments into suitable habitats with only the requirement of some form of pre-existing water supply beavers are found in a variety of ecosystems. However, beaver make their impacts most evident when they can dam a flowing river into a largely uncontained flooded pond spilling over the banks and around the dam into the associated river valley floodplain (Gurnell 1998; Westbrook et al. 2011). In rivers that are too wide and fast-flowing for beavers to dam, often simply called 'large rivers,' beaver impacts on the adjacent river valley floodplains and forests are considerably less impressive (Breck et al. 2001; Pinto et al. 2009)

The most notable geomorphological and ecohydrological impacts of beavers on non-dammable rivers are increased sedimentation in the channel resulting from beaver canals into the banks, beaver runs into the water, and beaver lodges within the riverbanks (Butler and Malanson 1994; Meentemeyer et al. 1998; Abbott et al. 2013). The obvious visual impacts to the river valley forests bordering these beaver-infested rivers are the amputated trunks of large, beaver-felled, mature trees that represent a considerable loss of living woody biomass from the overall canopy of the riparian forest (Boczon et al. 2009; Burchsted et al. 2010). Surprisingly, given the ability of the beaver to drastically impact and influence ecosystem function, there is still a relative paucity of literature on beaver impacts to large rivers. Ecohydrologists, for example, have tended to under-examined the role of animals in altering ecohydrological processes and instead focus more attention on terrestrial plant and hydrology interactions (Westbrook et al. 2013). That is not to say that flora-centric ecohydrology is not an important topic on large rivers. Given that many of these large rivers, especially in Western North America, are flow-controlled by major upstream dams and reservoirs (Poff et al. 2007), the natural flood cycles influencing the establishment of riparian plants and rejuvenation of riparian areas have been severely impacted (Rood et al. 1999; Rood et al. 2005; Merritt and Poff 2010). The consequences of flow-control of water are shared by all plants and animals in the riverine system upstream and downstream of the dam (Bouwes et al. 2016). As described above, river-dwelling beavers are doubly affected by changes to the rivers hydrologic cycle, given their reliance on both the water in the channel and the vegetation of the riparian forest.

1.4 Beaver Biology and Tree Cutting Behaviour

When considering beaver biology, it is crucial to understand how beavers choose what to eat, find building materials, and decide where to live. Beavers are central-place foragers (Baker and Hill 2003), meaning they foray from a central point, the beaver lodge, to find suitable forage and other requirements and then return to that point with collected resources. The types and quantities of food available to the beaver is a measure of the quality of the habitat, the habitat construction or nutritional requirements of the beaver, and the risk of predation while on foraging forays (Basey and Jenkins 1995; Busher 1996; Hood and Bayley 2008; Jenkins 2016). If available, *C. canadensis* is a choosy generalist herbivore that in its historic range generally prefers a diet of aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and cottonwood trees (other *Populus* spp.), willow (*Salix* spp.) and a mix of herbaceous aquatic and riparian plants (Breck et al. 2003; Martell, Foote and Cumming, 2006; Parker et al. 2007; Hood and Bayley 2008). As for where beavers establish themselves, it is typical to operate on an establishment, abandonment, and subsequent re-establishment cycle that varies anywhere from three to ten years based on the life cycle of the animals and the suitability of the habitat (Fryxell 2001; Zavyalov 2013) . In this process, a single beaver or beaver colony uses much of the suitable resources within foraging distance of a lodge before abandoning that site and relocating to a more suitable lodge location until such time that the forage resources become abundant again (Bhat et al. 1993; Hay 2010).

The lodge is at the center of each individual beaver population and provides the beavers with shelter, security, and a storehouse for food (McNamara 1987). On non-dammable rivers, i.e. those of large size, beavers are believed to base the site selection for their lodges on several factors. These factors include the availability of suitable lodge locations in nearby tributaries, or the characteristic river banks able to sustain a beaver lodge; the latter being especially important in northern rivers that are subject to destructive ice-flows (Dieter and Mccabe 1989; Fustec et al. 2003). Beaver lodge density is useful information for land managers as along with known lodge occupancy rates by region it facilitates estimation of local beaver populations. However, issues persist with the reliability of this proxy for the population if lodge density data are improperly collected (Parker et al. 2002). Beaver management decisions are often based on knowledge of the expected beaver impacts to vegetation as a result of beaver population levels, and therefore, reliable population estimates are essential (Parker et al. 2013).

Impacts of beaver foraging on vegetation are generally predictable. Research has examined the influence of beavers on native plant community composition and the successional pathways of natural riparian forests (Barnes and Dibble 1988; C.A. Johnston and Naiman 1990; Terwilliger and Pastor 2007). As the natural successional pathways of forests have been studied, so to have the successional pathways of riparian forests that experience a disturbance agent such as beaver foraging (Pickett et al. 2009). The composition of woody plant communities that have been subjected to beaver foraging may exhibit a decreased density of the trees and shrubs that the animals preferentially removed, as well as replacement and succession with species less desirable for beaver foraging. Or in those woody plants, such as aspen or many willows, that demonstrate tolerance to beaver foraging by vegetative reproduction through coppicing then the act of beaver foraging stimulates greater regrowth and increased density of the stand (Jones et al. 2009) In many systems, removal of woody vegetation, either by foraging or flooding owing to hydrologic alteration results in a period of predominantly herbaceous plants persisting until a more advanced seral stage of the woody vegetation community establishes. The broader long-term effects of beaver occupancy of an area are often seen in the establishment of an identifiable vegetation community form known as beaver-caused meadows. These sometimes valley-wide ecosystems contain a robust and heterogeneous mix of vegetation atop former alluvial channels that infilled with sedimentation behind beaver dams (Ruedemann and Schoonmaker 1938) as well as atop riparian terraces that were impacted by beaver activity (Westbrook et al. 2011). The process described above is a mechanism of ecosystem formation known as beaver meadow formation theory (Ives 1942). Ecosystem dynamics are also impacted by changing community composition that results from the arrival of invasive species propagules. With the presence of invasive propagules in the area, beaver foraging behaviour could have the potential for the proliferation of non-native plants in the vegetation replacement cycle (Mortenson et al. 2008). The resource fluctuation brought on by a disturbance, such as beaver foraging, can be responsible for the dynamic state of vegetation communities and their ability to progress down an either natural or invaded pathway of species recruitment and replacement (Davis et al. 2000).

1.5 Management of Beavers

Given their ability to modify ecosystems and alter both terrestrial and hydrologic processes that humans rely on, management of beaver activity and so-called problem beaver is an active field of practice, but certainly not of research. At the broadest level, there are either lethal or non-lethal beaver management techniques to control beaver populations or deter beaver behaviour deemed as destructive or unwanted. The lethal management option means the animal is killed by any number of means. Most often, beaver are killed via trapping or shooting, and this is done as part of a planned or opportunistic population reduction (Novak 1987; Nolet and Rosell 1998). Beaver extermination is most common in areas with abundant beaver populations or invasions by beavers (Malmierca et al. 2011; Parker et al. 2012). The alternatives to the above lethal management options are the non-lethal methods of beaver control.

Managing beaver populations and beaver activity by non-lethal means generally fall into one of several methods. These options include forage or access barriers, dam interference, behaviour manipulation, and finally, live-trapping and relocation. The first and perhaps most common options are the use of barriers as beaver forage or riparian area access deterrents. From the literature, there appears to be only one academic publication regarding the use of fencing to deter beaver foraging behaviour (Nolte et al. 2003). Nolte et al. (2003) considered the use of chain-link fencing installed as a deterrent to beaver access to riparian areas and experimented with a fence that extended into the water to prevent beavers swimming or burrowing under it. In addition to fencing installed between a stream and riparian area, tree enclosures (wire-wrapping) are used. Additional beaver foraging barriers include surface treatments, such as sand and paint on trees (Fitch 2016), and electric currents in water or on land (Nolte et al. 2003). Guidelines for wire-wrapping trees to create the simplest, most effective means of preventing a beaver from cutting down woody plants are provided in the U.S. Fish and Wildlife Service Beaver Restoration Guidebook (Pollock et al. 2017). With proper timing, selection of correct plants or areas for protection, and correct installation of appropriate materials these physical barriers do seem to mitigate much of the destructive behaviour on protected woody plants (Nolte et al. 2003). In addition to managing for the vegetation impacts of beaver activity, flooding or changes to the hydrology of a system from beaver activity can be mitigated. This management of altered water levels as a result of beaver activity is achieved through either displacing dammed water—with a pond-leveller or similar device—or using one of a number of other mechanisms that prevent damming in the first place (Taylor and Singleton 2014). Beaver behaviour and therefore habitat use can be altered by appealing to the beaver's powerful sense of smell. There have been efforts to deter foraging by conditioned aversion to preferred foods (Harper et al. 2005), encouraged foraging on undesirable and invasive plants (Kimball and Perry 2008), and attempts to scare the animals from foraging in an area all together with the use of predatory scents (Severud et al. 2011). Unfortunately, few of these olfactory deterrents have proven effective, and the beaver's frequent association with moist areas means that reapplication of scent is necessary, a time-consuming effort that often sees an alternative deterrent selected in its place.

The final and most extreme step in non-lethal management often involves removing a percentage of the beavers from an area using live-trapping and relocation (Pollock et al. 2017). Beavers are territorial animals (Novak 1987), and so it is often difficult to forcefully relocate individuals and have the animals successfully re-establish elsewhere (McKinstry et al. 2001). However, through work done within the Methow Beaver Project (McKinstry et al. 2001) and elsewhere, has led to successful beaver relocations by relying on the introduction of paired individuals into sites that have required necessaries of life for the relocated pair are becoming more feasible (Pollock et al. 2017). Ultimately for beavers, and managers of beavers, both lethal and non-lethal beaver deterrents can and will have a role in our interactions.

In Saskatchewan, the perceptions of management for beavers have remained little changed over the past half-century. From (Symington and Ruttan 1956)

> "The status of the beaver as a fur bearer has, during the past couple of decades, passed rapidly through four distinct phases. During the first phase, the original population was reduced by over-trapping almost to extinction in most areas. During the second phase, "hard-up" trappers maintained such heavy trapping pressure on the remnants that there was no possibility of a comeback. During the third phase, a combination of legislation, public cooperation and biological research gave the beaver an opportunity for a spectacular increase. During the fourth or present phase, attention is being paid to the possibility that strong measures may be required to ensure that enough trapping is done to keep the population from increasing past the danger point. During the whole of the conservation program, a considerable number of human and natural factors had to be kept constantly in mind, and a variety of theories were put to practical test in the field."

1.6 The Riparian Area

The riparian area, as essential and beneficial as it may be to a diversity of fauna and flora (Stoffyn-Egli and Willison 2011), often lacks a clear and consistent definition both in the literature and in law (Steiner et al. 1994). Basically, the riparian area is the transitional zone that exists at the interface of two ecotones; the water of rivers, lakes, or streams and their adjacent land (Naiman et al. 1997). A more detailed description by Illhardt et al. (2000) defines the riparian area as "three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems …". The observed patterns of riparian vegetation that occur within riparian areas are a result of the streamflow and associated fluvial and sediment processes that are the result of regional patterns of topography, geomorphology, climate, and runoff (Illhardt et al. 2000). For riparian areas of moderate latitude, altitude, and a sufficiently hydric moisture regime, the development of floodplain forests with greatly increased biodiversity as compared to adjacent uplands is common (Gregory et al. 1991).

Over much of the arid and semi-arid western parts of North America, riparian forests found on the floodplains of large, meandering perennial rivers and streams are the only deciduous forest ecosystems on the landscape (Merritt and Cooper 2000). These riverine forests are dominated by cottonwoods (*Populus* spp.), and the fate of the floodplain ecosystem is therefore primarily a function of response in the cottonwoods to changes in hydrologic and fluvial geomorphic processes (Bradley and Smith 1986; Rood et al. 1999; Merritt and Cooper 2000; Lytle and Merritt 2004). These cottonwood forests are only one of several types of riparian plant assemblages and successional stages that form over the life cycle of disturbance prone meandering prairie rivers (Thompson and Hansen 2001). As all plant communities move through successional stages there tends to be a progressive increase in the complexity and diversity of the stand, the stature or size and productivity of plants, the maturity of soil, and relative stability and regularity of plant species populations; but exceptions to all these trends are possible (Whittaker 1953). In the Canadian Prairies, river riparian forest are comprised mainly of cottonwood (Rood et al. 1999).These are rejuvenated by newly formed plant community atop the alluvium of floodplain point bars and depositional bands, through to the stately cottonwood forest towards the lateral extents of the floodplain containing often century-old mature trees. The retention of the cottonwood through the successional stages through to the final dominant and persistent one in the absence of major succession resetting disturbance is indicative of a monoclimax community and therefore a known path of dynamic change to vegetation community form and function. Although a climax forest community following succession is a concept that has been long discussed in the literature by giants in the field (Clements 1916; Gleason 1927; Whittaker 1953), nearly a century since the first publication there is still a consensus lacking as to the correct application of the idea (Meiners et al. 2015).

Succession is a vegetation community ecology process driven by variations in three broad differentials: site conditions and history, species availability, and species performance (Meiners et al. 2015). Site conditions and history are more in alignment with previous understandings of successional changes in that the sites present and past disturbance regimes and resource availabilities dictate successional stages of plants from the first colonizers through to climax or persistent dis-climax stands (Meiners et al. 2015). Species availability includes the processes that describe which species are able to colonize recently disturbed sites and survive disturbance as propagules; this concept relates to Hubble's neutral theory and plant community formation based on the competitive ability of species or functional traits to establish in unexploited niche space (Hubbell 2005). Finally, species performance is a measure of the intraspecific and interspecific mechanisms that species use to interact and structure the community (Pickett et al. 2009). Further research has been called for in all classes of successional drivers (Meiners et al. 2015); which will be especially important as anthropogenic influences on riparian vegetation succession patterns even further complicate our understanding of vegetation community succession (Groffman et al. 2003).

1.7 Urban Riparian Forests

Given that humans and beavers have the same requirements for land and fresh water, it is not uncommon to find our settlements established within or around riparian forests adjacent to rivers, lakes, and streams; especially until the nearby uplands are converted to production and alternative access to water is found (Thompson and Hansen 2001). For western North American cities, particularly those that overlap with historic fur-trade era beaver territory, the settlement of riverine forests and establishment of centers of commerce and population near the floodplain was commonplace (Finkel 2012). Examples of such cities in western Canada include Calgary and

Edmonton in Alberta, as well as Saskatoon in Saskatchewan and Winnipeg in Manitoba. Urban forests are often of superficially similar appearance to their natural counterparts in form and function. But these urban forests differ in the way they are formed, defined, and maintained as a stand (Sanders 1984; Blood et al. 2016). As a result, the contrast between forest plant dynamics for urban versus natural systems needs to be understood accordingly. The longstanding definition and delineation of the urban forest is the sum of all trees within a city that are both naturally occurring and planted (Rowantree 1984). The location of the tree and its underlying land ownership status are irrelevant to the suitability for inclusion in the collective sum of tall woody plants in the urban forest community (Duinker et al. 2015). Despite the apparent ease of delineation of the urban forest, understanding the dynamics of an urban forest is difficult for these complex systems with both natural and anthropogenic influence at work (Groffman et al. 2003). As with other locations where human population invades natural ecosystems, urbanization has a role in altering the ecology and hydrology of the urban forest (White and Greer 2006; Alberti et al. 2007). In sharp contrast to natural forest ecosystems, urban forests are under the extreme pressure of homogenization to their natural biodiversity (McKinney 2006). Although, there is also debate that decreasing dominance of native tree species by the introduction of non-native woody plants actually increases regional biodiversity in an ecologically valuable way (Araújo 2003). The dynamic changes present in urban and peri-urban ecosystems result in an urban forest composition that is obviously different from a natural stand, and in ways not yet fully understood.

In general, urban riparian forests are often composed of a relatively small range of tree species that are either well adapted or of sufficient genotypic plasticity (Eriksson 2014). These trees become dominant across the collective of urban ecosystems held in steady states of forest community disturbance. Unlike the natural forests discussed above, the successional pathways that an urban riparian forest can take may be restricted. It is possible to manage urban forests with an understanding of common ecological principles and the spatial and temporal dynamics that an urban ecosystem requires (Dale et al. 2000; Gaston et al. 2013). However, as Gaston et al. (2013) discuss, the successful co-management of urban forests and green spaces proves difficult if not impossible when multiple stakeholders have differing interests and still attempt to operate over the same spatial and temporal range. Many ecologists believe that conservation of any riparian forest will require in some ways the sorts of disturbances that occurred over the natural and long-term disturbance history of the site (Lorimer 2001). Specific to this belief, beavers are yet another agent of urban forest management; albeit one operating on alternate and often socially unacceptable spatial and temporal scales related to the shared use of urban riparian forests (Jonker et al. 2009).

1.8 Research Gap

As shown in the literature review, the scope of scientific information on beaver behaviour is broad and covers many of their impacts on the living and non-living environment. More specific to beaver impacts on vegetation, there is a relative wealth of scholarly knowledge on how beaver forage and their role in natural forest succession as well as relationships with native and non-native vegetation. Beaver management to reduce vegetation impacts, particularly in urban environments, is an active but understudied field. In cities, both lethal and non-lethal deterrents to beaver foraging are typically employed. Human interactions with the vegetation in urban riparian forests and the real (and perceived) value of these forest communities to people have also been examined to some extent.

With expanding beaver populations across their range as the climate changes (Jarema et al. 2009) and the increased frequency with which humans and these beaver populations overlap, there is a greater need to understand beaver foraging in the urban forests we now increasingly share. However, as beaver behaviour and beaver management relate to urban forests bordering the large rivers in cities, there are several gaps in the current extent of our knowledge reducing the ability to manage urban forests and beaver impacts within.

The first gap in our understanding of North American urban riverine beaver behaviour is that research on beavers in urban areas has focused on either the European beaver (Pachinger and Hulik 1999) or on urban beavers in wetland areas managed as parks (Nolte et al. 2003; Siemer et al. 2013; Loeb et al. 2014; McCrea 2016). Even literature that could address forage preferences of beaver in urban riverine areas presents a particular problem to prospective North American urban beaver scientists, in that it is difficult for English speakers to understand and evaluate the science written entirely in Polish (see Czyzowski et al. 2009). However, even if this one piece of urban beaver foraging literature was readily available, it is evident that several papers in a field as important as a furthered understanding of an animal with the ability, second only to our own, to modify North American ecosystems represents a real paucity of fundamental science.

To further complicate urban beaver interactions with vegetation community succession, cities often modify their river valley forests, either intentionally or by accident, to include non-native woody vegetation and these introductions have the potential to become full invasions of the riparian forest (Richardson et al. 2007; Boyce 2009). It is not well understood how natural disturbance agents like beaver foraging and woody vegetation removal interact with anthropogenic disturbances to alter resultant vegetation community composition and succession.

As such, there is a real need to gain information on beaver foraging and human beaver management in the river valley forests commonly featured across many major North American cities. Gaining this information could further contribute to the broader study of beaver foraging behaviour by including research in the novel environment of urban forest ecosystems. It may also allow for further development of methods to assess and understand beaver impacted areas in the study of urban forestry and urban greening.

2 METHODS

2.1 Study Area

The study area for this research was the banks and riparian forests of the South Saskatchewan River within the City of Saskatoon and an adjacent upstream conservation area (Figure 2.1). The South Saskatchewan River is an anastomosing sand-bed system (Conly 1990) with wide meanders (sinuosity coefficient of 1.7 in the study reach). The river has both large permanent islands as well as more transient sand flat islands within the channel. Drainage area for the river at Saskatoon (05HG001) is 1.41 x 10^5 km^2. River flow in Saskatoon is controlled by Gardiner Dam, located ~100 km upstream. The dam began operations on June 21, 1967. The dam significantly modified the runoff regime of the river in Saskatoon, with the monthly mean discharge peaking in January (301 m^3/s) and June (220 m^3/s) during the 1968-1993 flow period (Pomeroy et al. 2005).

The study area is within the Moist Mixed Grassland Ecoregion, one of seven ecoregions within the Prairie Ecozone of the Central Plains of Western Canada (Acton et al. 1998; Floate and Shorthouse 2010). The geomorphology of much of the ecoregion is a broad plain interrupted by a deep valley and subdued hilly uplands. The South Saskatchewan River valley is sunken up to 100 m or more into the plain. As a grassland ecoregion, much of the characteristic vegetation is described by grass assemblages; however, there has been characterization of the riparian forest communities (Thompson and Hansen 2001). Within the riparian forests of the Moist Mixedgrass Grassland Ecoregion woody plant communities are determined by either green ash (*Fraxinus pennsylvanica*), Manitoba maple (*Acer negundo*), trembling aspen or cottonwoods and several understory plants including chokecherry (*Prunus virginiana*), red-osier dogwood (*Cornus stolonifera*), buckbrush (*Symphoricarpos spp.*), and a variety of herbaceous species being used to define the habitat or community type.

A unique conservation strategy exists for the river valley through Saskatoon and adjacent area through a multi-agency partnership known as the Meewasin Valley Authority (MVA). The MVA is primarily a cultural and natural resource conservation organization created in 1979 through the Meewasin Valley Authority Act (Chapter 1979). In its infancy the MVA commissioned the Meewasin Valley River Resources Baseline Data Study completed by members of the University of Saskatchewan research community (FitzGibbon et al. 1982). In addition to considerable data and analysis on hydrology and water quality, the report details the riparian ecology of the Meewasin Valley. Namely, the major riparian vegetation communities are defined and mapped for the riverine forests of the South Saskatchewan River through the MVA. These detailed vegetation community descriptions and delineations allowed me to make confident surveys of the riverine forests and determine that we were sampling within all of the expected riparian community assemblages. Further detailed survey of the riverine forests through Saskatoon and surrounding area are provided by a Lineham (2000) thesis, also used by the MVA as a data source for vegetation within the river valley.

In addition to providing data and ongoing State of the Valley Reports, within the City of Saskatoon, the MVA also actively collaborates with city parks staff to manage the riverine forests, including management of introduced and invasive woody plants, as well as management of vegetation for beaver impacts primarily through exclosures to beaver by wire wrapping trees. Outside of city limits, there is little to no management of woody riverine vegetation with non-lethal forage deterrents. In fact there is little apparent management of woody vegetation at all other than the occasional removal of trees or shrubs by landowners or historical tree clearing in the riverine forest. Thus, the intentional management of woody vegetation for beaver activity in the city limits (i.e. managed study area), or the relative lack thereof outside of the city (i.e. unmanaged study area), served as the two treatments within the research design.

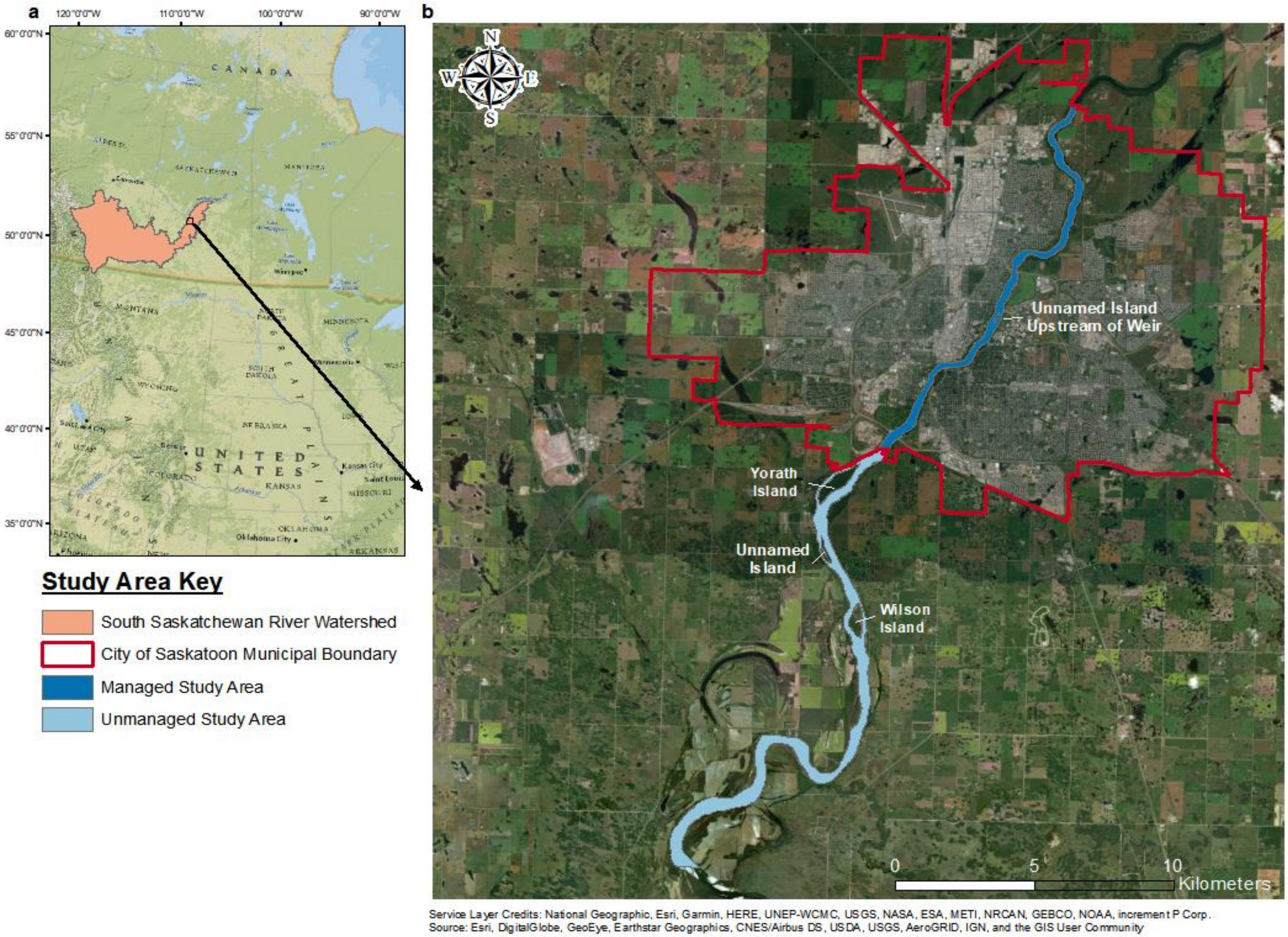

Figure 2.1 Study area overview showing; (a) our relative location within the South Saskatchewan River watershed; (b) a detailed project area map with study area sections and important river landmarks.

The most southerly portion of the MVA, located in the Rural Municipality (RM) of Corman Park, was the upstream boundary for the reach of the South Saskatchewan River studied. The intersection of the South Saskatchewan River with the City of Saskatoon northern municipal boundary was planned as the northernmost extent of the study area. However, ongoing bridge construction resulted in the formation of a water diversion structure that prevented access to the lower reaches of the river within the city limits during the study period. Given the construction, access through the channel was not possible, and thus a small portion of the managed riverine forest was excluded from the study.

2.2 Survey of River-Dwelling Beaver Activity

To understand beaver foraging patterns within the study area, the beaver lodge density and distribution patterns throughout the study area were examined. A survey of river-dwelling beaver activity occurred between 10 August and 22 September 2017 on the river and side channels within the study area, purposely coincident with a period of very low flow (Figure 2.2). Surveying at very low flow meant that a high likelihood of observing beaver activity that might otherwise have been concealed by water. That said since beavers have occupied the South Saskatchewan River and its riparian habitat through all stages of its hydrograph, a comprehensive sampling of riverine beaver activity was carried out. The primary method of survey was the use of a canoe within the wetted channel of the river. However, as beavers occupy the South Saskatchewan River through all stages of its hydrograph, surveys on-foot were also completed over the in-channel islands and oxbows that could be suitable riverine beaver habitat during periods with higher river levels.

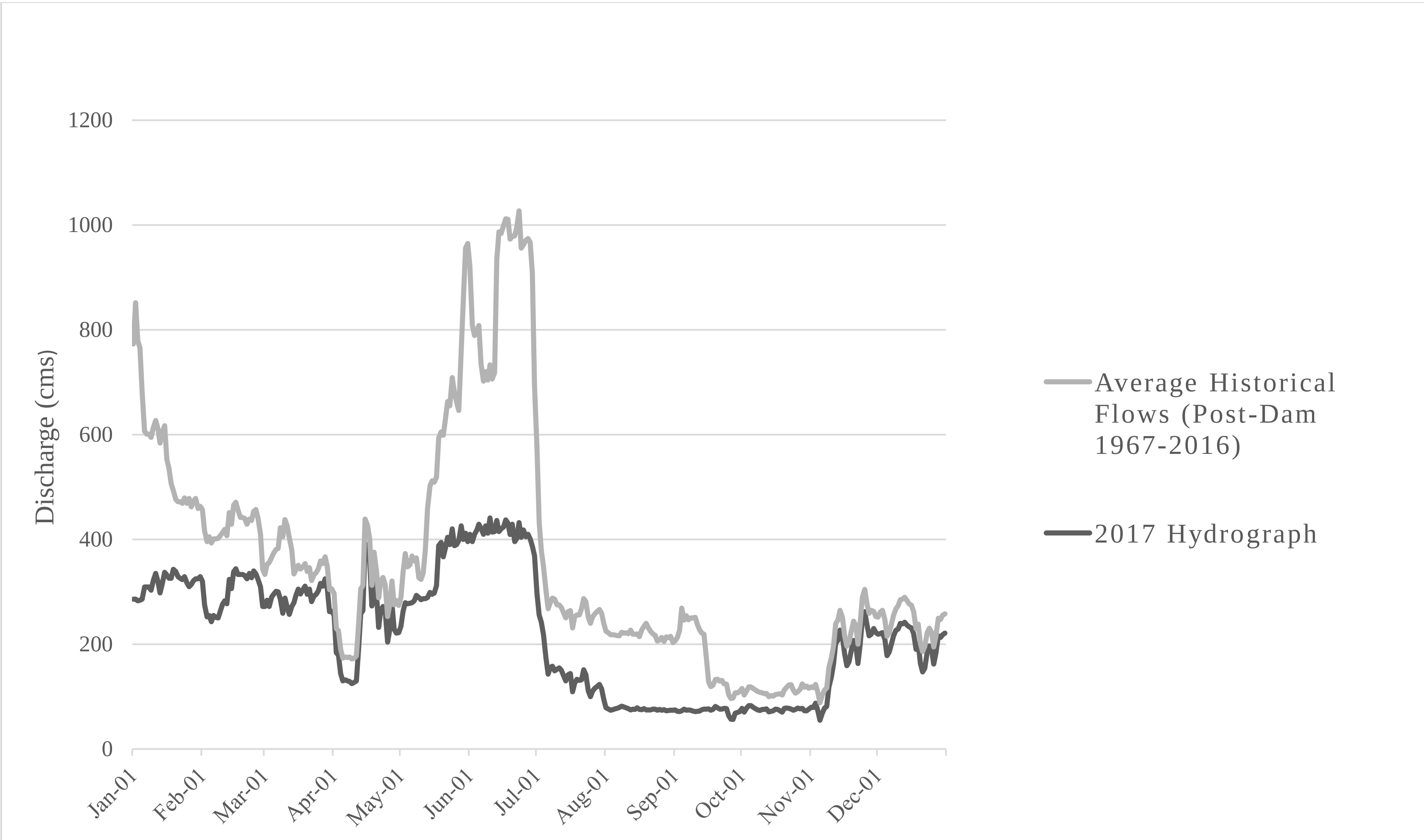

Figure 2.2 Average and 2017 hydrograph of South Saskatchewan River at Saskatoon (05HG0001).

Beaver lodge survey protocols used in other jurisdictions (Novak 1987; Parker and Rosell 2003; Dewas et al. 2012) were adapted for use here. Presence of beaver activity was based on the indicator criteria of Dewas et al. (2012). By their criteria, observation of a principal bank lodge, defined as a bank burrow with a fortified wooden structure atop, along with an active food cache, and fresh castoreum deposits (territorial scent mounds) were confirmation of an active beaver lodge complex (Figure 2.3). Presence of a principal bank lodge without the other two factors was an indicator of an inactive beaver lodge complex. With the intent of recording the location, type, and habitation status for each beaver lodge complex, each primary bank lodge structure was identified and photographed, with the data recorded in the field using an app (Fulcrum, Spatial Networks Inc.). Secondary bank lodges, meaning a less fortified or even unfortified bank dwelling adjacent to the primary lodge, as well as other indicators of beaver activity were also noted. However, the limitations of a large study area and difficult access due to very low river water levels meant that recording the indicators of primary beaver lodge complexes was prioritized.

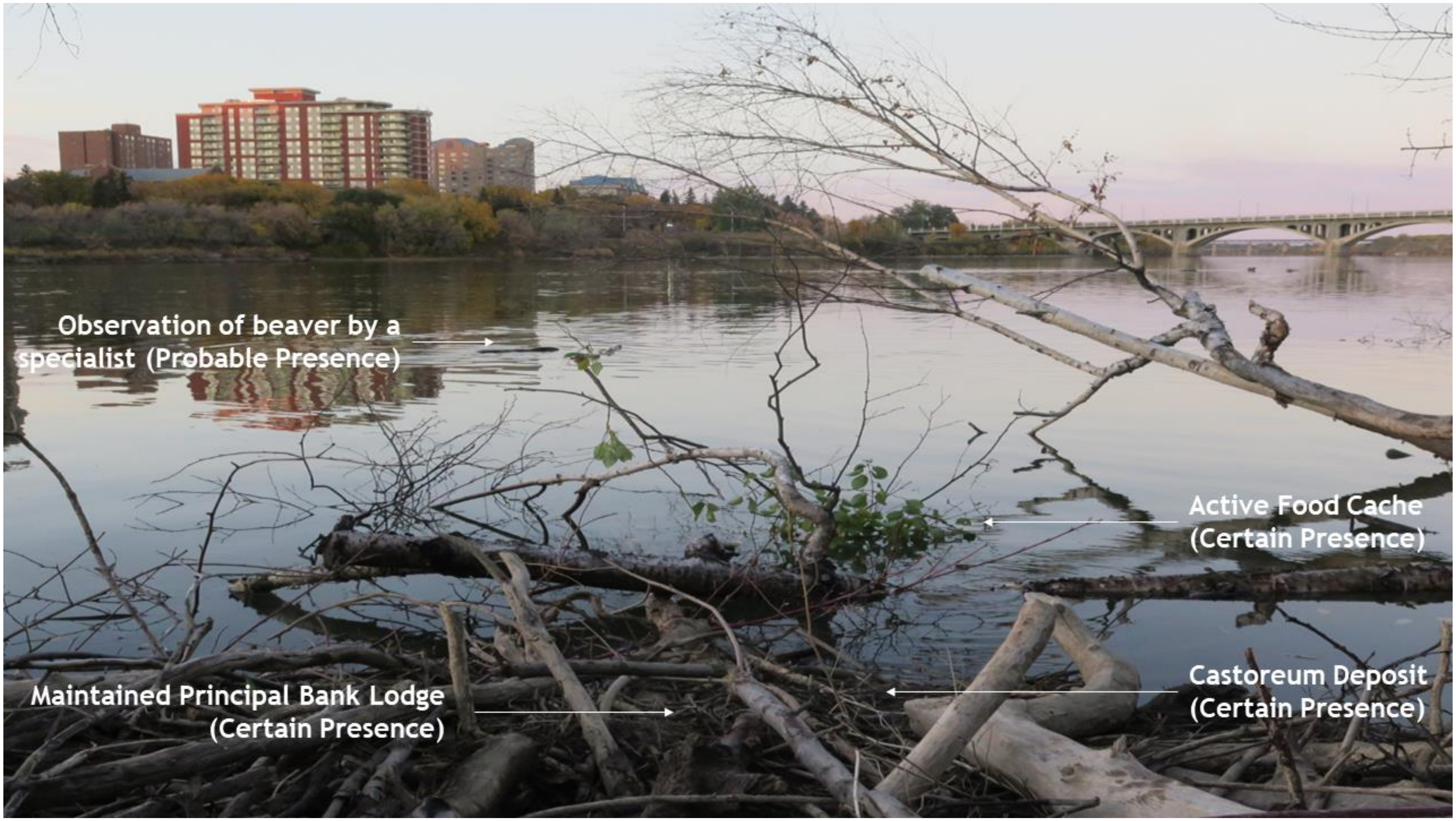

Figure 2.3 Visual indicators used to assess beaver presence and activity status of lodge complex.

2.3 Beaver Foraging Vegetation Transects

The riparian woody vegetation community provides both habitat and potential forage to beavers and in the managed and unmanaged study area was further understood by a survey of riparian vegetation composition and beaver foraging. For a more complete understanding of the riparian forest composition without the influence of active beaver foraging we could have also established a number of control transects in areas outside of active beaver foraging. However, it was decided in the study design that the entire study area was likely beaver foraged at some point in the relatively recent past and that no true control exists or could be established as part of this graduate research. Thus the focus was on only active beaver foraging areas as these would be the areas also most likely under some form of non-lethal forage management in the manged study area and thus allow for comparison described in our objectives to be made. The location of active beaver lodge complexes in the managed and unmanaged portions of the study area described above served as the starting point for vegetation survey transects. Given the relatively low number of apparent active beaver colonies identified in the lodge survey within the managed treatment (n=11), it was decided to initiate sampling at these and an equal number of unmanaged colonies outside of the city limits. Given that there were more than 11 active colonies to sample from in the unmanaged river reach, 11 lodges were randomly selected using a random number generator. Upon further study during the course of completing vegetation transects it was discovered that two of the 11 beaver lodge complexes in the managed zone were not in fact occupied by beaver, bringing the number of transects sampled in the managed riverine forest to nine.

Beavers are central place foragers with an active lodge complex often serving as the centroid of their territory (Mcginley and Whitham 1985). With that assumption, appropriate locations to establish vegetation sampling transects began first by surveying the riverbanks and adjacent riverine forests for evidence of the most recent and abundant beaver foraging activity within 150 m of either the upstream or downstream side of the principal beaver lodge in the beaver lodge complex. Next identified was the most suitable beaver foraging path was that which appeared well-established and still recently active as evidenced by recent beaver tracks in the soil surface as well as maintained bank slides into the river, which are areas of cleared vegetation and mud at the soil surface made by beavers moving along as well as dragging vegetation over it (Figure 2.4). Upon identification of the most suitable beaver foraging path into the riverine forest, a transect was established for vegetation, forage deterrent, and beaver foraging sampling (Figure 2.5).

Figure 2.4 Bank slide and foraging path showing cleared vegetation and beaver tracks.

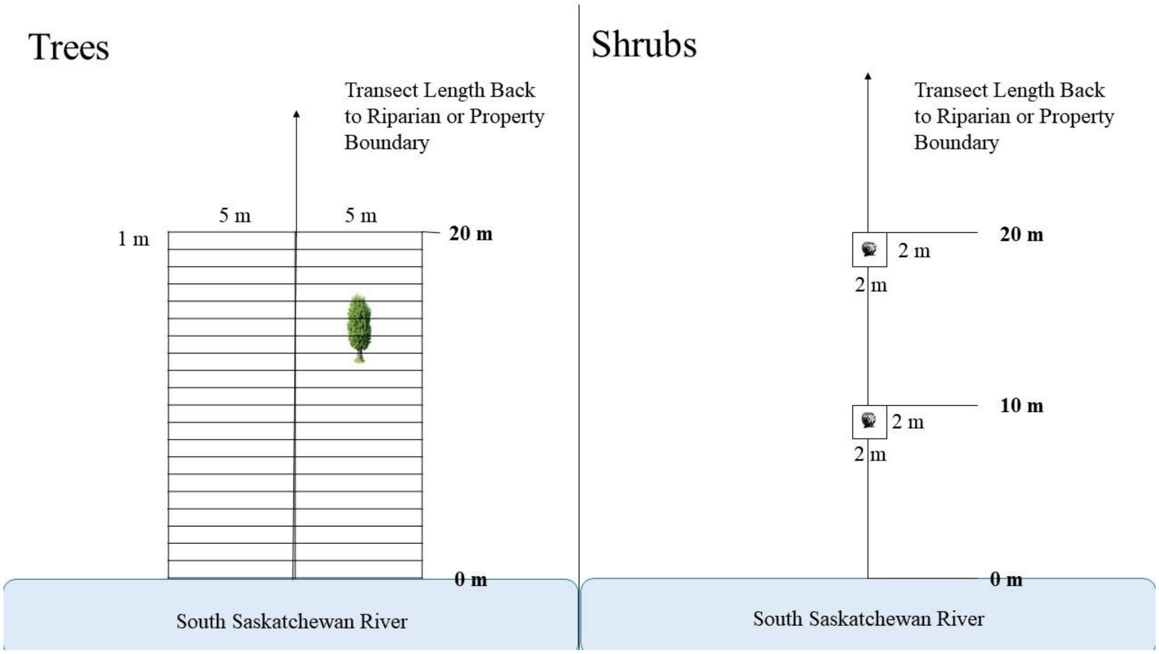

Figure 2.5 Sampling design for woody plant and beaver foraging data collection.

With both beavers and human managers treating trees and shrubs differently for their respective uses, it was appropriate to sample trees and shrubs by separate methods. Doing so has the advantage to capture differences in growth pattern and typical distribution of these plant lifeforms in the riparian forest. As for the size and configuration of transects, since there were no preconceived ideas on the ideal quadrat size to investigate any one particular ecological phenomena (Krebs 1989), the size used for inventorying woody plants in the study area was based on published research on beaver foraging (Martell et al. 2006) and the recommendations of a renowned plant ecologist (Jill Johnstone, pers. comm.). Decided on was inventorying of trees in 1 m x 10 m quadrats and shrubs in 2 m x 2 m quadrats along the length of each transect. Although the intent was originally to sample both trees and shrubs in sequential quadrats starting from the point of initiation at the water's edge back to the determined endpoint of the transect, this method did not prove feasible for the study area. Trees could be sampled in 1 m x 10 m quadrats given their low density, but shrubs often proved far too abundant and densely clustered to be sampled in a series of consecutive 2 m x 2 m quadrats over the length of the transect within a reasonable time period. With the original sampling design, shrubs took 10+ hours to inventory, just for a single, relatively short transect (80 m). Given that the riverine beaver activity survey needed to take place during low riverflows, the window of opportunity to complete vegetation surveys prior to the loss of leaves on decidous plants was too short to carry out this design. To overcome time constraints, the design of shrub quadrats sampled was modified. Shrub cover was sampled over a series of 4 m^2 quadrats at 10 m intervals from the first 8 to 10 m interval to the endpoint of the transect.

Although the quadrats had a set individual frame sampling area with the consecutive 1 m x 10 m frames for trees or the 1 m^2 frames for shrubs, transect length was not fixed and thus the total size of each overall transect was variable. Instead, transect length was dependent on identifying both riparian forest width and the maximum distance of beaver foraging away from the riverbanks. In cases where beaver foraging became unlikely as a result of significant transitions from riparian to upland habitat (as indicated by changes in the presence or absence of riparian hydrology, hydric soils, and hydrophytic vegetation), or by changes in land ownership or land use that prevented sampling further along that transect, the end distance to the nearest 10 m interval was used. By keeping sampling entirely within the riparian vegetation communities that have been described in more detail for this area and not moving into less related upland vegetation communities, I was able to make comparisons between the various quadrats and transects as well as to scale up our analysis and discuss riparian woody plant community as a whole within the respective study areas.

In each quadrat, trees with a diameter at 1.37 m, or "breast height" (DBH) of > 5 cm, were recorded. Observations included the quadrats position relative to the river, the species (or genus if species identification was not possible) of the tree, as well as tree DBH. The taxonomy and classification of each tree species were reported as described by Budd et al. (1987) and Argus et al. (2016). As well, the conservation status of the woody plant species as either native or introduced was determined based on their status in the Saskatchewan Conservation Data Centre Taxa List for Vascular Plants (http://www.biodiversity.sk.ca/SppList/vasc.pdf). For several species identified to the genus level, the status of either native or introduced is unknown as members of that genus are represented in both status categories within the province. The completeness of the vegetation sampling was verified with species-area curves, created in PC-ORD (Wild Blueberry Media) (Appendix B).

For each vegetation transect also recorded was the status of beaver foraging and change in biometric indicators such as DBH. On beaver-foraged trees, the status of each woody plant as either chewed fully or girdled (where girdled refers to partial chewing that was insufficient to separate the upper from the lower trunk) as well as the height and categorical age of a beaver foraging event (new or old) was assessed. Recent beaver foraging in contrast to older beaver foraging was identified by approximate ageing of the beaver cut based on the condition of the bark, cambium, and sapwood. Those trees with a mostly green and living cambium layer and still green wood were indicators of a recent cut. The incidence of recent beaver foraging is of principal importance to assessing the current response to non-lethal forage management as compared to old cut or girdled stems that may have been foraged prior to management barriers being in place within the study area. If an exclosure (beaver forage deterrent) was in place on a tree, its type, height, and apparent effectiveness of the deterrent in preventing further beaver foraging were recorded.

Shrub data collection was designed to reflect the often dense multi-branched growth form of these plants. Sampling methods were adapted from those of others investigating beaver foraging on shrubs (Donkor and Fryxell 1999; Herbison and Rood 2015). Recorded was the quadrat position relative to the river, as well as all the shrub species contained within each quadrat. For each species, the total number of individual plants (defined as a clump of stems sharing the same root system) of that species within a quadrat was assessed. Stem counts for two individuals of each shrub species were made. For this, the two plants nearest the center of the quadrat were selected. Moving towards the shrub centre, counted were the number of individual stem divisions from the root collar, or base of the plant nearest the root collar if not distinguishable. Also measured were the diameters of five stems at the root collar. Beaver foraging activity was determined by counting the number of cut stems present on the sub-sample of individual plants within the quadrat, as well as assessing the approximate categorical age of these cuts as either new or old, based on similar criteria as described above for trees. In subsequent analysis, all beaver cut stems were first averaged by transect and then ages of cuts combined to find the average number of cut stems for the willows and red-osier dogwood.

2.4 Non Lethal Forage Deterrent Survey

With the objective to explore the interactive effects of beaver tree-felling and urban tree protection, a survey of the non-lethal forage deterrents in place was required. A sampling of urban parks and habitat areas for non-lethal forage deterrents in place within the managed portion of the study site took place in May of 2018. Added to this dataset was information on foraged trees collected as part of the transect vegetation sampling (n=17). Although the City of Saskatoon does not maintain a database of which trees they place forage deterrent on, park managers did identify key parks where their activities had been focused (Figure 2.5). Trees in these parks were sampled in an opportunistic pattern of moving from tree to tree bearing forage deterrents until the opportunity for further sampling within that location was limited by lack of further deterrents, boundaries that prevented beaver access (fences, roads, infrastructure), or loss of daylight hours for working. More precise locations to direct sampling within Gabriel Dumont Park was further informed by conversations with City of Saskatoon parks staff on-site at the time of the inventory. Appendix C provides the location of all trees with deterrents that were inventoried.

At the time of the non-lethal forage deterrent survey there was also a limited lethal beaver management program in effect within the City of Saskatoon. A licenced trapper is contracted by the city to remove individuals from the population by means of body-gripping traps (commonly called conibear traps). However, these lethal methods of forage management were not the interest of this research and without the City Parks Department providing the record of the locations or numbers of animals removed I did not consider the role of lethal management in my analysis.

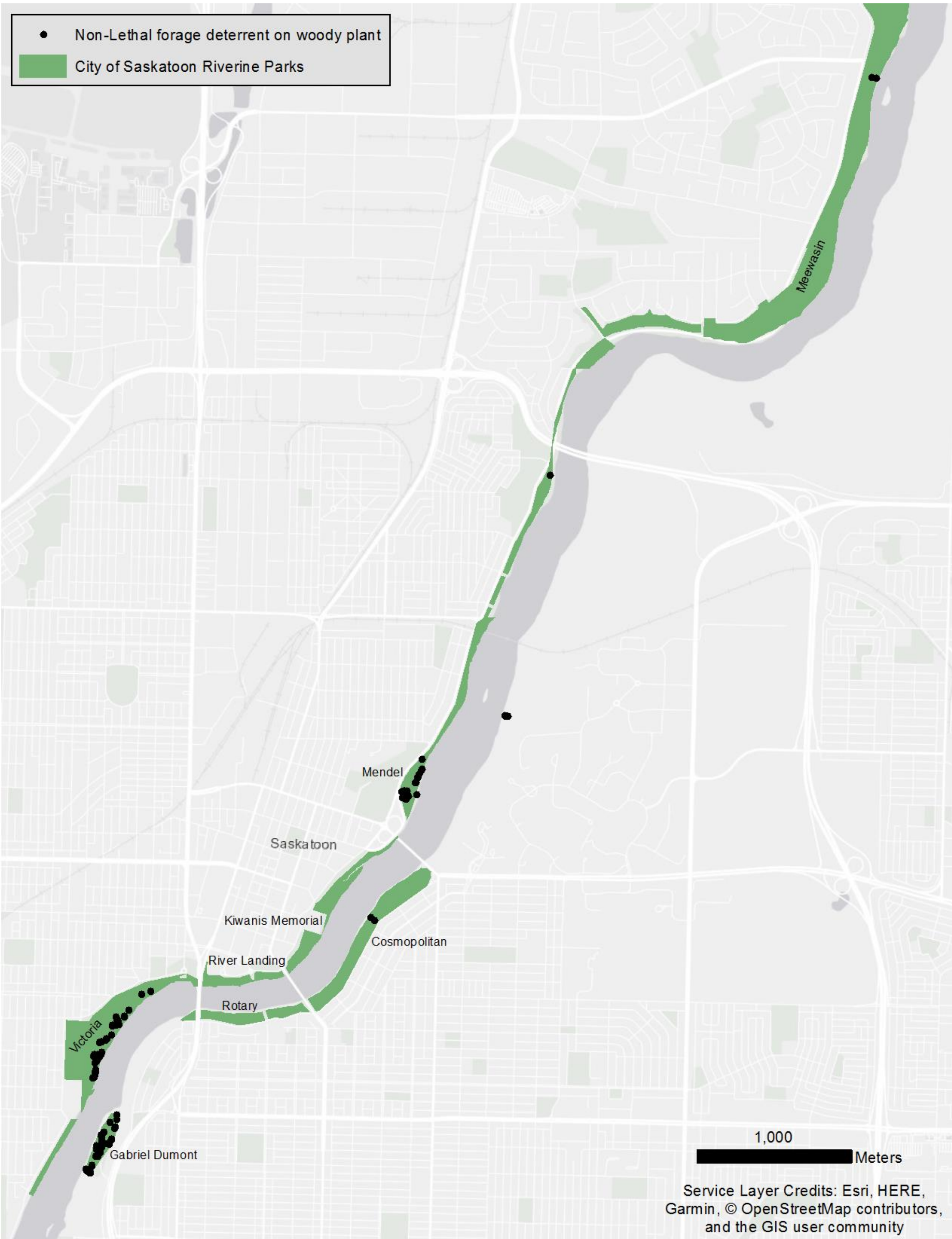

Figure 2.5 Non-lethal forage deterrent locations (n=151) within the managed study area.

2.5 Data Analysis

2.5.1 Beaver Activity and Lodge Complex Density

Analysis of beaver activity and lodge complex statistics were performed primarily using the spatial statistics toolset in ArcMap 10.5 (ESRI 2016. ArcGIS Desktop: Release 10.5 Redlands, CA: Environmental Systems Research Institute). Within that toolset, distances between active beaver lodge complexes were determined using the average nearest neighbour analysis. The average nearest neighbour analysis determines the linear Euclidean distances between features of interest, in this case, the locations of beaver lodges along the riverbanks and islands of the South Saskatchewan River. Beavers have readily colonized the islands within the channel, and these permanent islands present beaver moving directly across the channel with an obstruction to their water path. Therefore, a limitation of using the Euclidean distance solely to all lodge complexes is that it fails to account for unlikely land-based travel. To overcome this issue, further analysis in ArcMap 10.5 using least-cost pathway analysis (T. Andrew Hurly, pers. comm.) to find the water path distance between lodges was compared for the managed and unmanaged reaches.

Preliminary data analysis revealed that active lodge distribution might be more complex than captured by the simple managed/unmanaged categorization. To explore the association of beaver lodge distribution with a range of land uses, modification of the MVA Ecological Integrity or Land Use Category shapefiles used to separate portions of the riverine forest based on their respective use and therefore likelihood of human presence or development that would deter beaver use of the area. There were three categories – high, medium and low. High human influence by land use included urban (13), county residential (2), disturbed (3), industrial (7), and road and rail (12). Medium use would include agricultural production (1), golf course (4), green space (5), pasture (9), and recreational (10). The green space and golf course land use seem most indicative of a modified urban riverine forest that is being managed for aesthetics and human use. The parks layer from the City Open Data Source (http://opendata-saskatoon.cloudapp.net/) was used to identify recreational areas vs. habitat. The low category included habitat (6) and islands, the latter of which were not in the City categorization and so were digitized.

For the analysis of lodge density by study area treatment, I performed analysis to compare observed values to expected values using the chi-squared (χ^2) test in GraphPad Prism version 8.0.0 (GraphPad Software, San Diego, California USA). With multiple categories for the human land use analysis, the intent was to determine whether lodges occurred in proportion to the river lengths available, or whether human land use altered the likelihood of finding lodges by a chi-squared (χ^2) analysis. To correct for the unequal river lengths between the managed and unmanaged reach the analysis was repeated using a proportional comparison of only a 20km stretch of river; results were the same.

2.5.2 Woody Vegetation Community and Beaver Foraging

Vegetation data were analyzed to examine relationships or trends within the interactions of beaver populations, river valley forests they forage within, and non-lethal human management of available woody plants. To understand beaver forage preference, data were analyzed species by species or genus by genus comparison of woody plants present, and those removed by beavers. The selection ratio observed during beaver foraging was calculated by an Ivlev's Electivity Index (Jacobs 1974; Krebs 1989). The formula to calculate this index is:

$$E = \frac{r - p}{r + p}$$

where,

E = Ivlev's Electivity Indes

r = fraction of a given tree in the beaver's forage

p = fraction of the same tree in the environment

The index has a possible range of -1 to + 1, with negative values indicating avoidance or inaccessibility of the woody forage item, zero indicating random selection from the environment, and positive values indicating active selection for a tree species.

The ecology of the woody plant community was investigated by calculating standard measures of biodiversity, including the number of unique plants identified to the species level (or genera level if no species overlap within genus) present in the community (richness (S)), diversity via the Shannon Diversity Index (H`), and evenness (J`) of the taxa distribution in the managed and unmanaged portions of the riverine forests. In addition, descriptive statistics such as mean numbers of stems in a cluster of shrubs were calculated along with the standard error of the mean (SEM).

Beaver foraging patterns in managed and unmanaged riverine forests were then analysed using t-tests following Levene's test for equality of variance to compare foraging distances and proportions of trees foraged between the managed and unmanaged forests as well as occurrence, stem density, and beaver cutting percentages for red-osier dogwood and willows representing the major plants in the shrub community. Statistical tests were done in SPSS Version 25.0 (IBM Corp.. Armonk, New York).

2.5.3 Biomass

The foresters' understanding of the relationships between dendrometric information such as DBH, tree height, and the specific gravity of woody components has long allowed for the use of regression equations determining aboveground biomass (AGB) of woody plants (Baskerville 2010). To calculate biomass available and beaver-removed at the study site, used were allometric relationships available from a United States Department of Agriculture Forest Services online database (https://www.fs.fed.us/ne/global/pubs/books/dia_biomass/index.shtml). With climate change concerns driving a renewed interest in understanding carbon sequestration potential, fuel loads for forest fires, and the possibility of wood as a fossil-fuel alternative, an updated and more comprehensive set of generalized biomass equations have been developed for some of the woody plants surveyed (Chojnacky et al. 2014).

The allometric equations were used to calculate the woody biomass removed by the beaver for each transect. Of note, within the study area trees and shrubs both native to North America and introduced were present. Given that the database of diameter-based biomass regressions (Chojnacky et al. 2014) is primarily for native trees, there is a lack of information regarding introduced woody species. For non-native species with historical importance as shelterbelt constituents in the Canadian Prairie, there is biomass research by the federal Department of Agriculture and Agrifood Canada (Kort and Turnock 1999). For as many species and varieties as possible, biomass equations specific to these growing conditions and regional varieties of woody plants were used.

2.5.4 Non-Lethal Forage Deterrents

It is not appropriate to perform the same sorts of spatial analysis as seen on lodges with the non-lethal forage deterrents. However, the locations of spatial deterrents present within the study area are shown using a thematic map generated in ArcMap 10.5 to show the local distribution patterns of these exclosures. The effectiveness of the forage deterrents is also quantified using the Descriptive Statistics function in SPSS.

3 RESULTS

3.1 Beaver Activity and Lodge Density

The survey for river-dwelling beaver activity occurred between 10 August and 22 September 2017 on the river and side channels within the study area, coincident with a period of very low flow as seen in the 2017 hydrograph for the South Saskatchewan River at Saskatoon (Figure 2.2). The full distribution of both active and inactive principal beaver lodge complexes within the study area is shown in Figure 3.1. In addition to the spatial results of the beaver lodge survey provided in Figure 3.1, full records of lodge complex locations are available in Appendix A.

As there were different lengths of river for the managed and unmanaged reach, I compared the proportion of beaver lodge complexes per river km rather than total numbers. There is a 56% lower density of active lodges in the managed as compared to the unmanaged river reach (χ^2 =7.529, p = 0.006; Table 3.1). Beaver lodge complex distribution has been lower between the city limits and outside of them for some time, as indicated by a significant difference in the inactive lodge complex density (χ^2 = 26.51, p < 0.001).

Table 3.1 Beaver lodge survey within Meewasin Valley Authority study area in 2017.

	Beaver Lodge Occupancy Status	Beaver Lodge Complex No.	Beaver Lodge Complex %	River Length (km)	Lodge Complex Density No. / km of river
Management Status					
Managed	Active	9	6.25	23.7	0.38
	Inactive	28	19.44		1.18
Unmanaged	Active	25	17.36	28.6	0.87
	Inactive	82	56.94		2.87
Total		144		52.3	2.75

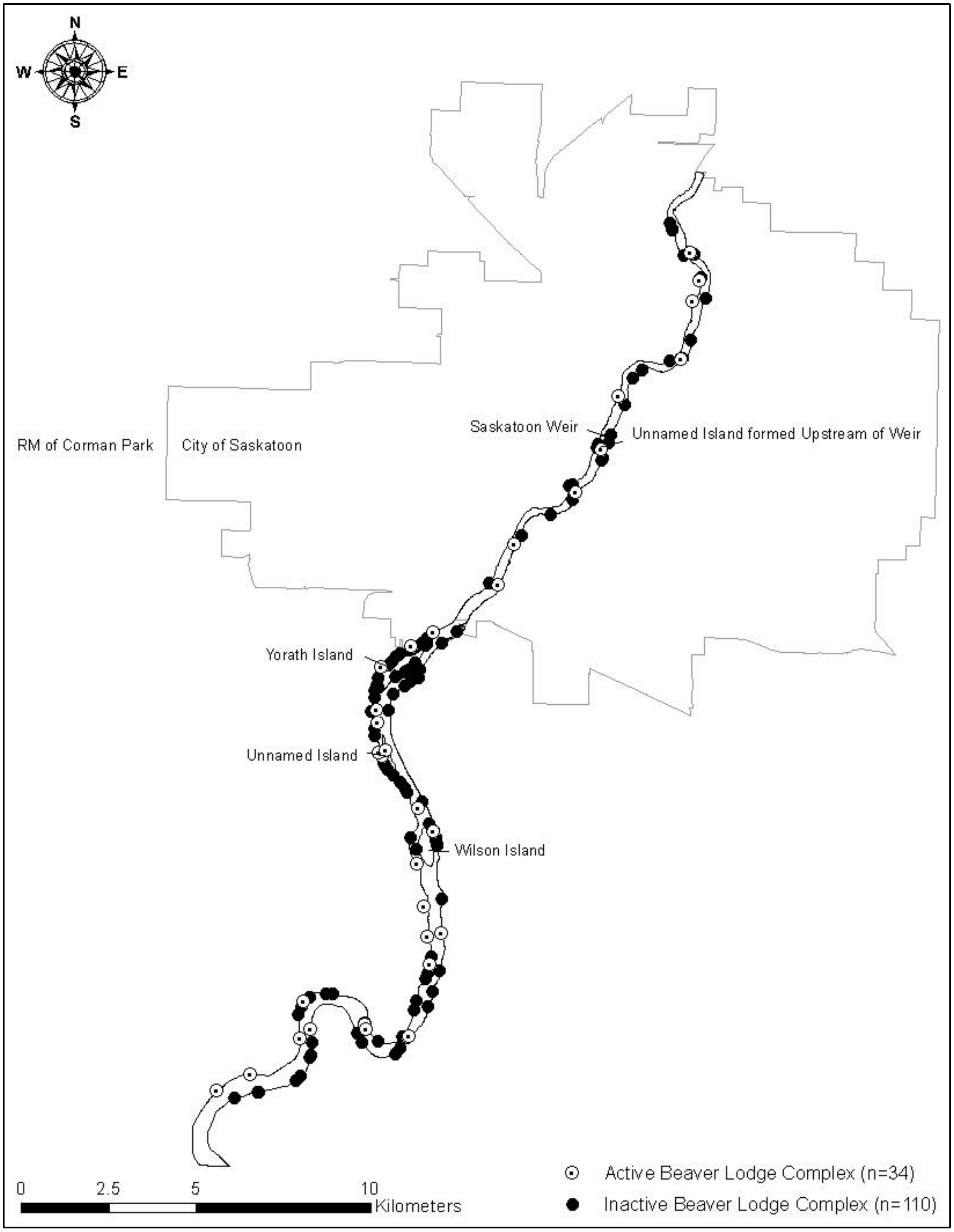

Figure 3.1 Beaver lodge complexes within the South Saskatchewan River study in 2017

Beaver were observed to live not only along the banks of the South Saskatchewan River but also along the shoreline of some islands (Figure 3.1). Of the 144 beaver lodge complexes observed in the river survey, 29 (19.9%) of the lodges were on islands. Two of these 29 lodges were active and within the managed reach. Yorath Island, a large permanent island upstream of the City of Saskatoon, appeared to be long-utilized beaver habitat with 21 inactive lodge complexes found along its shores. A further two active and two inactive lodge complexes are found on an unnamed island near the Robertson Farm, as well as two inactive lodge complexes on Wilson Island found upstream of the other two islands in the unmanaged treatment.

Beaver complexes consisted of both primary and secondary lodges as well as the associated food cache(s). A minority (44 %) of active principal lodge complexes consist of a combination of one or more principal bank dwellings as well as one or more secondary bank dens, and food caches. The slight majority of active lodges (56 %) consisted of a single principal bank-dwelling plus an established food cache. Over the long history of beaver occupancy in the South Saskatchewan River through the study area, there appears to be predominately single lodges rather than large complexes, as 88 % of inactive lodge complexes consisted of a single principal bank lodge. As noted in Appendix A, it was difficult to determine if principal lodge complexes in close proximity to other principal lodges were, in fact, individual lodges, or part of larger lodge complexes.

Beaver lodge complexes along the South Saskatchewan River trended towards dispersed distributions in the managed reach (Nearest Neighbour Ratio = 1.88, z score = 5.07, $p < 0.0001$) and clustered distributions in the unmanaged reach (Nearest Neighbour Ratio = 0.628, z score = -3.56, $p = 0.0004$). The mean Euclidean distance between active lodge complexes was 516 m; in the city, it was 1202 m. The South Saskatchewan River, however, is an anastomosing sand-bed system with wide meanders (sinuosity coefficient = 1.7: Conly, 1990) and several large, permanent islands within the channel. As noted above, beaver readily colonize islands. Beaver prefer travelling in water as it reduces the likelihood of being ambushed on land by predators cutting off beaver access to an aquatic escape route (Gable et al. 2016; Salandre et al. 2017). Therefore, a limitation of using the Euclidean distance between lodge complexes is that it accounts for unlikely land-based travel across curves in the river or over islands. To overcome this issue the water path distance between lodges was compared for the managed and unmanaged reaches. The average distance between active beaver lodge complexes, as calculated using least-cost connectivity (water-based travel), was similar ($F_{1,38} = 0.524$, $p=0.474$) between the managed reach (1308 ± 785 m SD) and unmanaged reach (1112 ± 721 m).

Interestingly, no difference between the number of active beaver lodge complexes within the three degrees of human development and land use were found (Figure 3.2; $\chi^2 = 0.7648$, $p = 0.682$) with 38% of the lodges in low intensity, 35 % of the lodges in medium intensity, and 27 % of the lodges in the high intensity human land use areas.

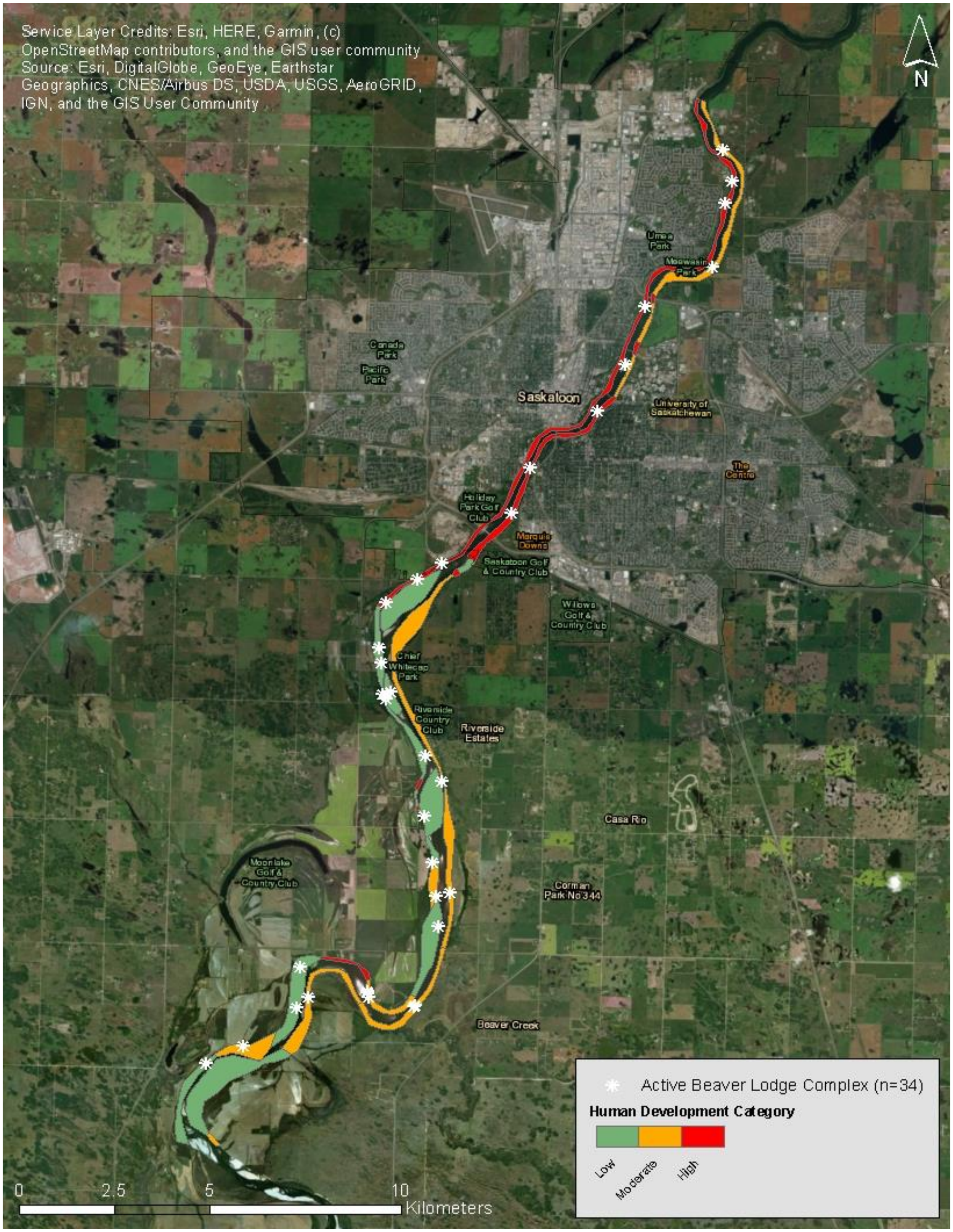

Figure 3.2 Beaver activity by land use category in 2017.

3.2 Riparian Forest Composition

Vegetation transect surveys identified of the woody plants in the study area, there are 14 unique genera of trees representing 20 unique, confirmed species. The tree community composition varies between the managed and unmanaged with 20 unique taxonomic entries for the managed study area and only 8 unique taxonomic entries for the unmanaged. The shrub community surveyed also contained 14 unique genera overall with 20 confirmed, unique species of shrubs. For the shrub community, there is one unknown species found on a single transect within the managed study area that could not be identified as it had contrasting features that prevented a positive confirmation of species. However, this unidentified shrub clearly did not overlap as part of another genera also sampled, and thus exists as a separate unique taxonomic entry (Table 3.2).

Table 3.2 Woody vegetation community sampled within study area as well as calculated ecological metrics

Trees	Plant Conservation Status	Total Number Individual Plants Observed	In Managed	In Unmanaged
*Acer negundo var. interius (*Manitoba maple)	INative – Secure (S5)	119	73	46
Acer spicatum (Mountain maple)	Native - Apparently Secure (S4)	20	20	0
Betula papyrifera (paper birch)	Native - Secure (S5)	58	30	28
Cornus alternifolia (alternate-leaved dogwood)	Introduced in SK (SNA)	2	2	0
Elaeagnus angustifolia (Russian olive)	Introduced in SK (SNA)	3	3	0
Fraxinus pennsylvanica (green ash)	Native - Apparently Secure (S4)	101	52	49
Picea spp. (Spruce Genus)	Unknown	2	2	0
Picea glauca (white spruce)	Native - Secure (S5)	1	1	0
Picea pungens (blue spruce)	Introduced in SK (SNA)	3	3	0
Pinus banksiana (Jackpine)	Native - Secure (S5)	3	3	0
Pinus spp. (Pine Genus)	Unknown	2	2	0
Pinus sylvestris (Scots pine)	Introduced in SK (SNA)	3	2	0
Populus balsamifera ssp. balsamifera (balsam poplar)	Native - Secure (S5)	7	6	1

Populus deltoides ssp. monilifera (Eastern cottonwood)	Native - Apparently Secure (S4)	25	13	12
Populus x jackii (Balm-of-gilead)	Native Species Hybrid (SNA)	51	36	15
Populus spp. (Poplar Genus)	Unknown	6	4	2
Populus tremuloides (trembling aspen)	Native - Secure (S5)	39	4	35
Prunus americana (American plum)	Native - Imperiled (S2)	3	3	0
Quercus macrocarpa (bur oak)	Native - Secure (S5)	2	2	0
Sorbus aucuparia (Rowan tree)	Introduced in SK (SNA)	3	3	0
Tilia spp. (Linden Genus)	Unknown	1	**0**	1
Tilia americana var. americana (American linden)	Introduced in SK (SNA)	10	10	0
Ulmus procera (English elm)	Introduced in SK (SNA)	4	4	0
Zelkova serrata (Japanese zelkova)	Introduced in SK (SNA)	2	2	0
	Grand Total	**470**	**280**	**193**
Tree community richness (s)		**20**	**20**	**8**
Shannon Diversity Index (**H**`)		1.89	2.25	1.68
Species Evenness (***J***`)		0.75	0.81	0.85

1. Saskatchewan Conservation Data Centre Taxa List of Vascular Plants, current as of 15-Feb-2018

2. USDA, NRCS. 2018. The PLANTS Database (http://plants.usda.gov, 25 February 2018). National Plant Data Team, Greensboro, NC 27401-4901 USA.

Shrubs	Plant Conservation Status	Total Number Individual Plants Observed	In Managed	In Unmanaged
Alnus viridis ssp. crispa (green alder)	Native - Apparently Secure (S4)	2	2	0
Amelanchier alnifolia var. alnifolia (Saskatoon)	Native - Secure (S5)	17	7	10
Betula occidentalis (river birch)	Native - Apparently Secure (S4)	2	1	1
Caragana arborescens (common caragana)	Introduced in SK (SNA)	5	5	0
Cornus sericea ssp. sericea (red-osier dogwood)	Native - Apparently Secure (S4)	51	24	27
Crataegus spp. (Hawthorn Genus)	Unknown	1	1	0
Elaeagnus commutata (Silverberry)	Native - Apparently Secure (S4)	22	7	15
Prunus virginiana var. virginiana (Chokecherry)	Native - Secure (S5)	13	9	4
Rhamnus cathartica (European buckthorn)	Introduced in SK (SNA)	21	17	4
Ribes aureum var. aureum (golden currant)	Native - Vulnerable (S3)	1	1	0
Salix bebbiana (long-beaked willow)	Native - Apparently Secure (S4)	1	1	0
Salix interior (Sandbar willow)	Native - Apparently Secure (S4)	55	11	44

Salix famelica (Yellow willow)	Native - Apparently Secure (S4)	15	7	8
Salix petiolaris (Basket willow)	Native - Apparently Secure (S4)	2	2	0
Salix pseudomonticola (False-mountain willow)	Native - Apparently Secure (S4)	5	5	0
Salix spp. (Willow Genus)	Unknown	8	1	7
Shepherdia argentea (Buffalo-berry)	Native - Apparently Secure (S4)	2	**0**	2
Shepherdia canadensis (Canada buffaloberry)	Native	1	1	0
Symphoricarpos occidentalis (western snowberry)	Native	37	16	21
Symphoricarpos spp. (snowberry genus)	Unknown	2	2	0
Viburnum opulus var. americanum (highbush cranberry)	Native	2	0	2
Unidentified	Unknown	2	2	0
Total number of shrubs		**267**	**122**	**145**
Shrub community richness (s)		**20**	**20**	**11**
Shannon Diversity Index (**H`**)		2.40	2.53	2.03
Species Evenness **(J`)**		0.80	0.84	0.85

1. Saskatchewan Conservation Data Centre Taxa List of Vascular Plants, current as of 15-Feb-2018

2. USDA, NRCS. 2018. The PLANTS Database (http://plants.usda.gov, 25 February 2018). National Plant Data Team, Greensboro, NC 27401-4901 USA.

There were 470 individual trees sampled within the study area along the beaver foraging transects; 280 of those trees are within the managed study area found along the banks of the South Saskatchewan River through the municipal boundaries of Saskatoon, and the remaining 189 trees along the banks and atop riverine islands in the adjacent unmanaged conservation area in the upstream section of the MVA. The tree community within the managed study area is different from the riverine forests of the unmanaged. In the managed study area, the most dominant tree by proportion is the Manitoba maple at 26.1 %, followed by green ash at 18.6 %, a hybrid balm-of-gilead poplar at 12.9 %, and the paper birch trees at 10.7 % of the total managed riverine forest. In the unmanaged study area the dominant tree species by proportion was green ash at 25.9 % off all trees sampled within that portion of the study area. Green ash was followed closely by Manitoba maple at 24.3 %, then trembling aspen at 18.5 % and paper birch at 14.8 %. Balsam poplar was present in both portions of the study area, although more abundant in the managed riverine forests at 2.1 % compared to the 0.5 % in the unmanaged. Interestingly, the mountain maple accounts for 7.1 % of the riparian tree composition within the managed study area and is totally absent from the unmanaged. Also of note is trembling aspen only slightly present at 1.4 % of the managed riverine tree community but a significant proportion of the unmanaged trees at 18.5 % of the trees present within that portion of the study area. There are also the several species of introduced trees that are present at less than 5 % each within the managed study area, but collectively account for approximately 10 % of the overall riverine tree community composition in the managed riverine forest.

There were 267 individual shrub form plants sampled throughout the study area. Across all species, on all quadrats, there was an average of 4.8 ± 4.2 (SE) total clusters of stems and a range of 1 to 21 total bunches or clusters of stems for any taxa. There were 123 sampled individual shrubs in the managed treatment, and 145 sampled individual shrubs within the unmanaged riverine forest transects. As is the case for the tree community, the composition of the shrub community is notably different between the managed and unmanaged riverine forests. In the managed portion of the study area the most dominant shrub species in the riverine forest was red-osier dogwood at 19.7 % of the shrub form woody plants, followed by the invasive European buckthorn at 13.9 % and western snowberry at 13. 1 %. Willows collectively account for 22.1 % of the shrubs in the managed study area with the most dominant willow being sandbar willow at 9.0 %. Contrast this shrub community with that in the unmanaged study area where the most dominant shrub is the sandbar willow at 30.3 % alone and willows collectively making up 40.7 % of the overall shrub community sampled. Red-osier dogwood in the unmanaged study area is the second most abundant species at 18.6 % followed by western snowberry at 14.5 % and silverberry at 10.3 %. The namesake shrub of the study area, the Saskatoon berry, is present in the managed study area at 5.7 % and the unmanaged at 6.9 % overall, making it a recognizable component of the shrub community. The remaining shrub species or genera are found in small quantities and do not contribute significantly to the overall woody plant community.

For the willows, as several species of *Salix* observed in the study are able to hybridize within the genus (Argus 1974), many of the individual plants recorded to one particular taxon might likely have been a combination of several varieties of willow. For this reason and the limited number of willows other than *Salix exigua*, subsequent analysis on willows treated the genus as one taxon entry.

The tree and shrub data were collected using different designs, and so they were analyzed separately. There was a greater number of tree (150 % more) and shrub (82 % more) taxa in the managed study area compared to the unmanaged study area. In both woody vegetation communities, the difference between management zones can be partially attributed to introduced species not native to Saskatchewan that are present within the city limits. The Shannon Diversity Index (**H`**) indicates diversity in the tree community was greater for the managed study area, but community composition was more equitable in the unmanaged tree community, as shown by the Evenness (***J`***) value. The Shannon Diversity Index (**H`**) indicates diversity in the shrub community was also greater within the managed riverine forests, and that shrub taxa are more equitably distributed in this reach.

3.3 Beaver Foraging of the Riparian Forest

In total, 33% of all trees sampled within the study area (n=158) were beaver chewed, with 144 entirely cut, 13 girdled, and one cut type not recorded. Beaver foraging on trees included those events that entirely severed the upper bole from the base of the tree (defined as a beaver-cut stump) as well as those foraging events where portions of the outer bark, cambium layer, and inner bark had been removed to varying degrees. This second type of foraging event did not always result in the separation of the tree trunk into multiple pieces or the death of the tree. Rather, it led to tree girdling. Of the 157 trees chewed by beaver, only 42 (27%) had signs indicating recent foraging activity. On 18 trees there were both new and old beaver cuts.

The average width of the riverine forest from the wetted river to the uplands was 44.4 ± 32.2 m. That said, the average forest width of the managed reach was significantly narrower (41.0 ± 19.6 m) than that of the unmanaged reach (49.2 ± 44.1 m) ($t= -2.72$, $p=0.007$). Beaver travelled between 2 m and 174 m from the edge of river's wetted channel to forage trees, with average foraging distance from the river similar ($t=0.132$, $df=80.1$, $p=0.895$) for the managed (29.2 m± 1.3 m) and unmanaged (28.9 m± 3.6 m) reaches (Figure 3.3). For the 42 trees that had been recently foraged (i.e. those with a healthy cambium layer still showing signs of life despite dissection by beaver foraging), foraging occurred at a maximum distance of 66 m (unmanaged) and 40 m (managed) from the river.

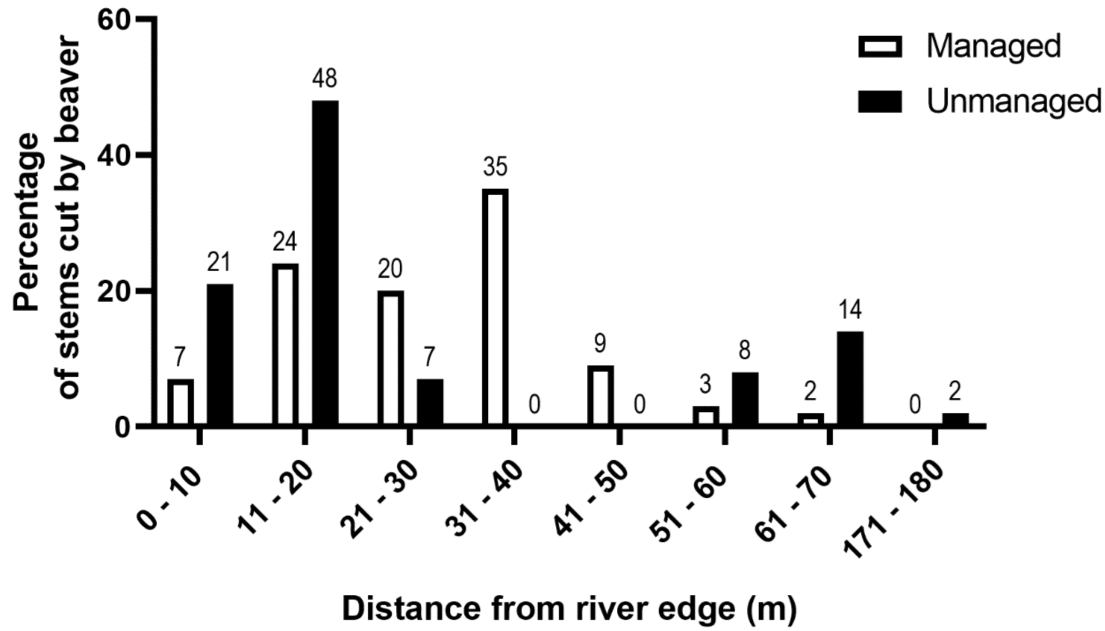

Figure 3.3 Foraging distance to trees within managed and unmanaged study area

Figure 3.5 provides the analysis of beaver foraging showing preference of woody plant species as well as these relative species abundances within the riverine forests of the South Saskatchewan River. In the study area, the most beaver selected beaver forage in relation to their overall proportion within the tree community is green ash. Manitoba maple made up only 25 % of the total trees present in the study area, and beaver foraged nearly 40 % of all available woody plants of this species. Beaver followed literature predicted forage patterns by felling a proportionally greater percentage of trees than their proportion in the forest from several members of the poplar genus including the Balm of Gilead hybrid poplar, Eastern cottonwood (*Populus deltoides ssp. monilifera*), balsam poplar (*Populus balsamifera ssp. balsamifera*), and trembling aspen. In the managed forest there were two introduced species, the Rowan tree (*Sorbus aucuparia*) and Japanese zelkova (*Zelkova serrata*), where beaver forage indicated a preference for these woody plants where available.

The forage preference of beavers in our study area was further examined by the creation of an electivity index for both the managed and unmanaged riverine tree communities (Figure 3.4).

By this index there was the strongest selection for the Rowan tree however that value is based on fewer than five incidents of beaver foraging on the species. A more accurate preference in the managed study area is indicated for green ash, followed by eastern cottonwood then balsam poplar, the hybrid poplar (*Populus x jackii*), and the American plum. In the unmanaged study area beavers select very slightly against trembling aspen, meaning the trees are foraged but almost at chance. The result for this species is in contrast to that observed in the managed study area where beavers are selecting against trembling aspen, followed by mountain maple, and then Manitoba maple as the tree species still foraged but most selected against. In the unmanaged study area beavers also appear to select against paper birch, the hybrid poplar, and a number of poplars identified only to genus as the additional specific characteristics were removed by beaver foraging. Selection values of negative one, meaning no trees were foraged for that species, were observed for all conifers (Genus *Picea* and *Pinus*), bur oak (*Quercus macrocarpa*), alternate-leaved dogwood (*Cornus alternifolia*), Russian olive (*Eleaeagnus angustifolia*), Japanese zelkova, as well as both American linden tree (*Tilia americana var. americana*) and other members of the genus identified only to that level (*Tilia spp.*). In the unmanaged there was no beaver foraging observed on a confirmed balsam poplar, but that is not to say these species were not foraged to the point of removing species characteristics and thus included in the *Populus spp.* total. The results on the remainder of the tree species showed that beavers would forage these woody plants but avoided them in relation to the trees abundance in the riparian forests of our study area.

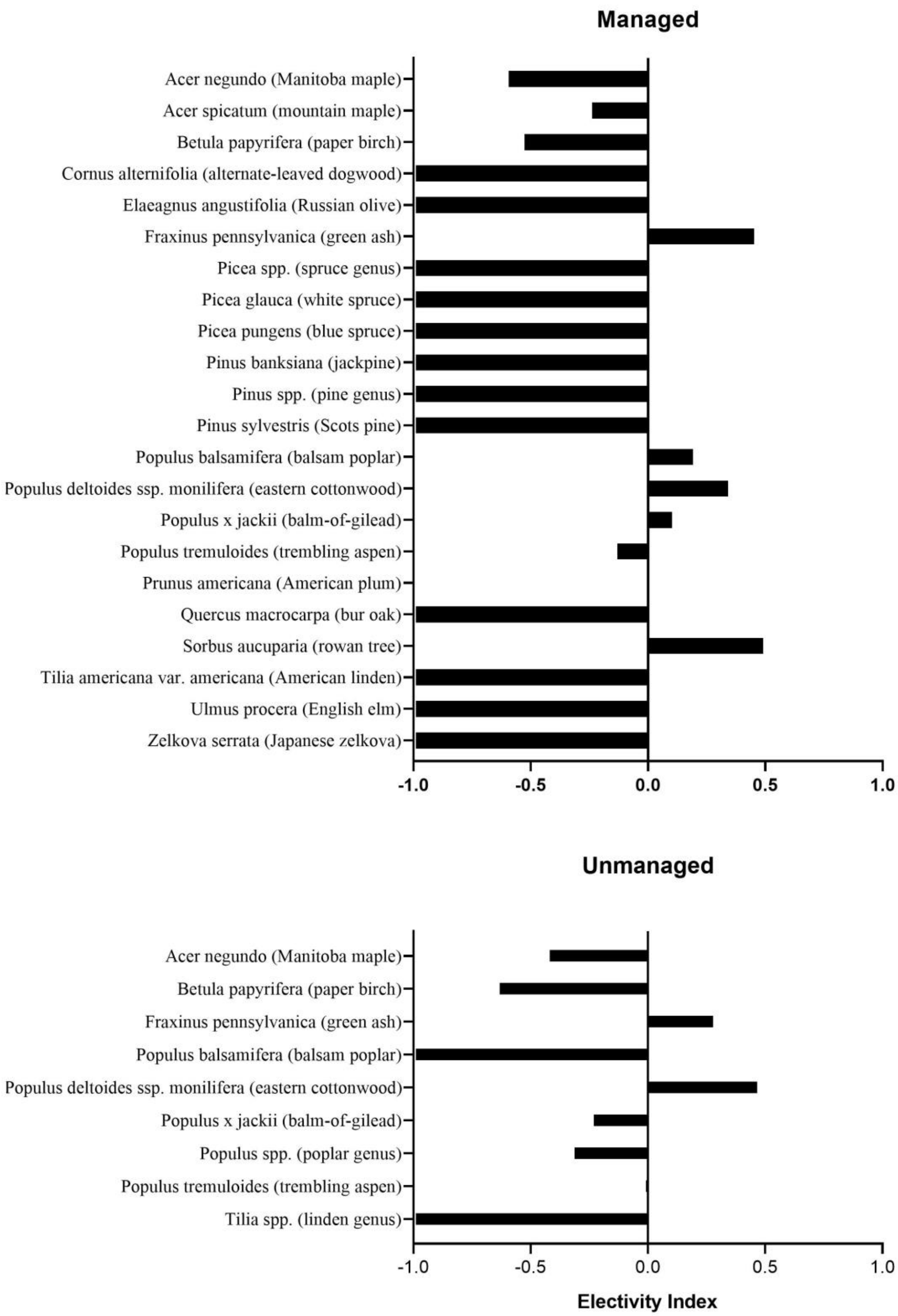

Figure 3.4 Electivity Index for beaver-foraged tree species in study area.

Results showing quantitative biomass-based relationships between the percentage of a tree species recently foraged as part of the diet in relation to the percentage of trees available in the environment is shown below (Table 3.4). Comparisons for all trees are not possible as not all tree species are found in both the managed and unmanaged study area. Further, the percent removal by beaver foraging for paper birch (*Betula papyrifera*) and trembling aspen in the unmanaged study area was only of trace amounts (< 1%) of biomass. Although these foraged trees fell outside of the established transects, it should also be noted that in the managed study area beaver foraging girdled a single trembling aspen that was subsequently wrapped before the beaver could fully cut the tree. Thus, zero biomass was removed for this species from these vegetation transects. There were noticeable but non-significant differences ($\chi^2 = 3.2$, $p = 0.074$) in percent removal of Manitoba maple with an 84% higher foraging for this species in the managed study area. For the other three tree species foraged in both the managed and unmanaged study areas, the differences between the observed and expected proportions were all significant ($p < 0.05$) in the chi-squared test. Green Ash in the managed study area had an 81% increased percent removal by beaver foraging. Eastern cottonwood was consumed at a much greater percentage (76% vs. 26%) in the unmanaged study area than within the City of Saskatoon. The hybrid poplar (*Populus x jackii)* also foraged at a higher percentage (21% vs. 9%) in the unmanaged versus managed study area.

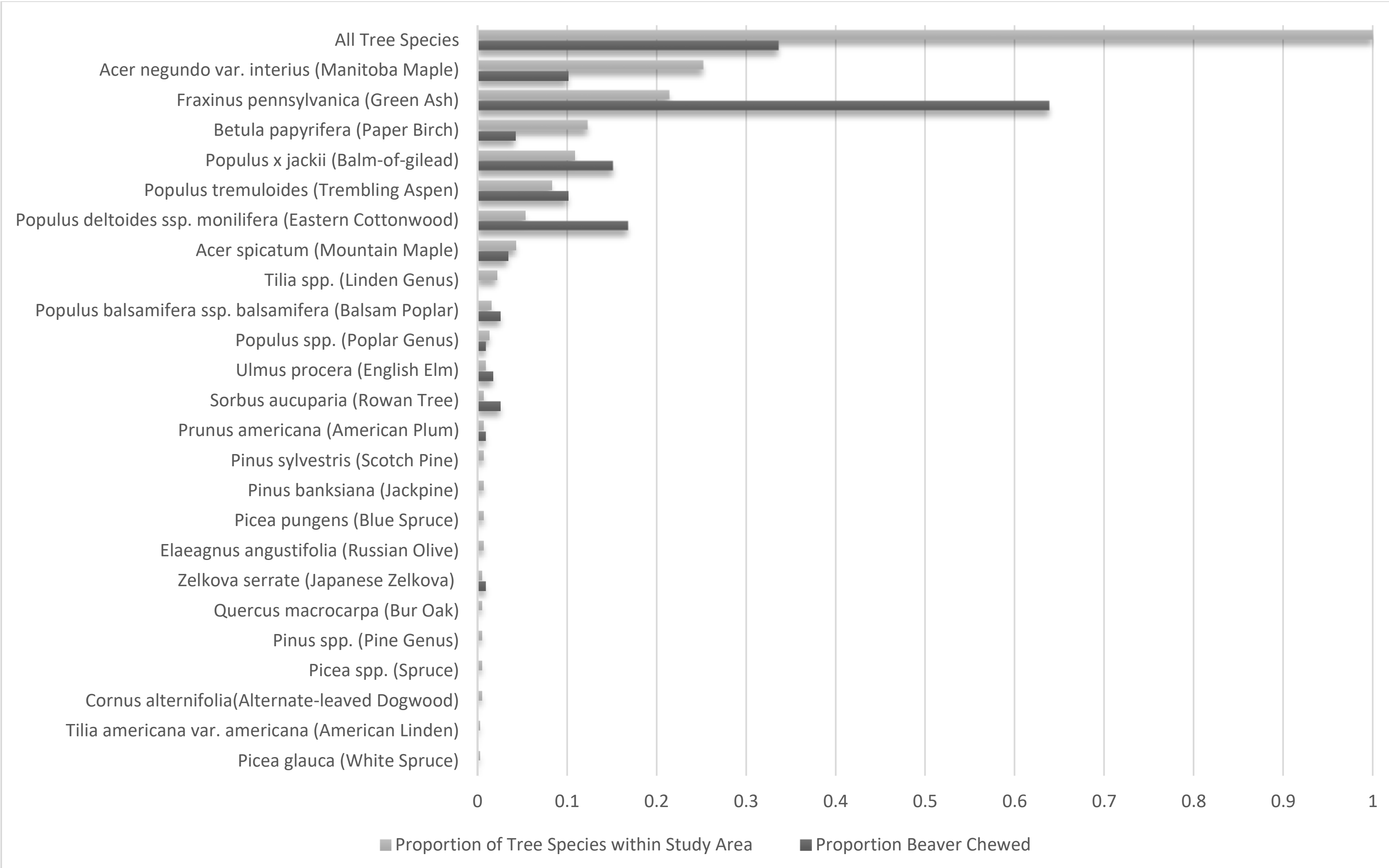

Figure 3.5 Tree proportions in riverine forest and proportions of that species removed by beaver foraging within the study area.

Table 3.3 Overall biomass and biomass recently removed for trees within the study area.

Study Area	Tree Species	Equation Form Used to Estimate Biomass for Species	Source for Equation Form	Estimated Total Biomass Available (kg)	Estimated Biomass Removed by Beaver Foraging (kg)	% of Biomass Removal by Beaver
Managed	*Acer negundo*	$ABG = 0.278 \times CSA$	i.	943.6	134.0	14.2
	Acer spicatum	$\ln biomass = a + b * dia + c * (\ln(dia^d))$	ii.	82.4	5.8	7.0
	Betula papyrifera	$biomass = a + b * dia + c * (dia ^ d)$	ii.	1583.4	5.5	0.35
	Fraxinus pennsylvanica	$ABG = 0.439 \times CSA$	i.	301.8	147.4	48.8
	Populus balsamifera ssp. balsamifera	$biomass = a + (b * dia) + c * (dia ^ 2) + d * (dia ^ 3)$	ii.	48.7	36.7	75.3
	Populus deltoides ssp. monilifera	$\log10 biomass = a + b * (\log10(dia^c))$	ii.	1627.6	412.1	25.3
	Populus x jackii	$ABG = 0.432 \times CSA$	i.	2389.8	220.0	9.2
	Populus tremuloides	$\ln biomass = a + b * dia + c * (\ln(dia^d))$	ii.	39.7	0	0
		Managed Area Total		**7017 kg**	**961.5 kg**	**13.7 %**

Unmanaged	*Acer negundo*	ABG = 0.278 × CSA	i.	1364.6	79.3	5.8
	Betula papyrifera	biomass = a + b * dia + c * (dia ^ d)	ii.	2297.4	0	0
	Fraxinus pennsylvanica	ABG = 0.439 × CSA	i.	827.2	170.4	20.6
	Populus deltoides ssp. monilifera	log10 biomass = a + b * (log10(dia^c))	ii.	494.5	376.5	76.1
	Populus x jackii	ABG = 0.432 × CSA	i.	2535.4	540.5*	21.3
	Populus spp. (Genus Poplar)	biomass = a + b * dia + c * (dia ^ d)	ii.	17.0	4.0	23.5
	Populus tremuloides	ln biomass = a + b * dia + c * (ln(dia^d))	ii.	23.2	0	0
		Unmanaged Area Total		**7559 kg**	**1171 kg**	**15.5 %**

Note that a,b,c,d are coefficients associated with the logistic biomass regression equations

ABG = Aboveground biomass in kg/tree for tree species

CSA = Cross-sectional area (cumulative for multi-stemmed trees) of the tree's stem at breast height

Equation sources:

i. (Kort and Turnock 1999) ii. (Chojnacky et al. 2014)

Although there was a diversity of shrub species present within the quadrats in both the managed and unmanaged portions of the study area, few of those taxa had any signs of beaver foraging on them – either new or old. The majority of cut stems observed were on members of genus *Salix* (willows) or red-osier dogwood. As mentioned before, several species of willows present can hybridize, and perhaps did; so, willow were collectively analyzed, with red-osier dogwood analyzed separately, for occurrence percentages, the density of stems per hectare, and beaver cutting data related to these two taxa of primarily beaver foraged shrubs. The results of the analysis are in Table 3.5. Although there were no statistically significant differences in shrub occurrence for either the willows or red-osier dogwood between the managed and unmanaged areas, willows did appear in 37 % more of the quadrats in the unmanaged forest than the managed forest. Part of this increased occurrence is likely attributed to the transects on islands in the unmanaged study area where shrubs were the dominant overstory woody plants. Red osier dogwood trended towards far greater density in the unmanaged study area. Although the difference was not significant, the mean percentage of beaver cut stems on red-osier dogwood was 67 % lower in the managed study area. For willows the opposite trend in beaver cut stems was observed with a 14 % decrease of average cut stems seen in the managed shrub community versus the adjacent unmanaged shrub community.

Table 3.4 Dominant shrub characteristics and beaver foraging results.

Characteristic	Managed	Unmanaged	t	Probability
Transects	9	11		
Occurrence (% of Quadrats)				
Red-Osier Dogwood	38.8 ± 8.7 SE	40.9 ± 10.7 SE	0.15	0.883
Willows	30.2 ± 7.3 SE	44.0 ± 10.7 SE	1.02	0.323
Density (# stems/ha)				
Red-Osier Dogwood	4650 ± 1133 SE	13549 ± 5509 SE	1.434	0.169
Willows	4873 ± 1366 SE	5993 ± 1527 SE	0.535	0.599
Beaver Cutting (% of stems)				
Red-Osier Dogwood	19.1 ± 5.5 %	11.4 ± 2.4 %	1.370	0.188
Willows	15.9 ± 5.2 %	18.4 ± 4.4 %	0.379	0.709

- Performed Levene's Test for Equality of Variances on red-osier dogwood (p=0.034) and willow (p=0.056) occurrence, red-osier dogwood (p=0.014) and willow (p=0.0351) density, and red-osier dogwood (p=0.010) and willow (p=0.884) beaver cutting percentage. As no result was significant, I did not report on the adjusted result for equal variances not assumed where that was the case.

3.4 Non-Lethal Forage Deterrents

There were 151 individual woody plants bearing a form of forage deterrent across the study site. The forage deterrent survey only included those that prevented foraging by beavers on a tree. All of the forage deterrents observed were wire-wrapping tree enclosures (beaver exclosures), with four primary materials (Table 3.5).

Table 3.6 Forage deterrent type descriptions.

Deterrent Type	**No.**	**Mean Deterrent Height (SE)**	**Mean Deterrent Diameter (SE)**	**Effectiveness**
		cm	cm	%
i. 2" x 2" wire fence	91	120 (1.5)	67 (3.1)	88
ii. 2" x 4" wire fence (unanchored)	19	148 (2.2)	69 (6.7)	17
iii. Chain link fence	23	90 (1.7)	33 (6.5)	78
iv. Chicken wire	18	67 (8.9)	17 (4.0)	89
Total	**151**	**113 (2.3)**	**56 (2.8)**	**79**

Although there was slight variation within each construction material type, the majority of non-lethal deterrent exclosures were reasonably uniform in design and deployment details (Figure 3.6). The most abundant exclosure type was the 2” x 2” wire fencing with a mean height of 1.2 m and a high percent effectiveness in preventing further foraging or manipulation of the deterrent. Of the 2” x 2” wire fence (deterrent type i), all but two were unanchored. The effectiveness was bolstered for this exclosure construction as the rest were a single cage adequately anchored to the ground by tent pegs or a bent rebar post pounded into place. Although the sample size is small, both unanchored 2” x 2” wire wrapped deterrents appeared effective. Unanchored 2” x 4” wire fence (commonly called elk or game fence) proved largely ineffective in preventing beaver foraging. This ineffectiveness was attributed to evidence of beaver being able to reach through the exclosures on trees where the wrapping was not sufficient in diameter, as well as the ability for beaver to quickly burrow under the 2” x 4” unanchored elk fence by lifting it out of the way.

For the two deterrent types (iii and iv) lacked standard measurements of the opening size of the wire wrap – this was an oversight during data collection. Nearly all chain link fence material used in the construction of non-lethal forage deterrents was the standard 2” (50.8 mm) opening size weaved of 9-gauge wire; which is the most common chain link fence material produced and used. Further, the chicken wire (deterrent type iv) also appeared to be almost exclusively the 2” mesh opening poultry netting material made of 20-gauge wire. Effectiveness of both of these types of woven deterrents is sufficient to deter further beaver foraging on many trees.

Figure 3.6 Beaver exclosure construction methods as non-lethal forage deterrents.

Table 3.6 shows that most non-lethal deterrent efforts were placed on species that are beaver preferred in the study area. The most readily wrapped tree species are the hybrid poplar with 23% of all exclosures placed on this species alone, followed by green ash with 19% of the non-lethal deterrents. For both of these species, the most abundant deterrent in place was the 2” x 2” wire fencing; unsurprising, as this deterrent type was found on 60% of all protected trees. Of note are the numbers of deterrents on conifers; this is despite the lack of observed beaver foraging on spruce or pines in the foraging transects data. However, beaver-caused damage was observed on these softwood trees in some places in the study area, and the exclosures may be in response to that beaver behaviour. In the unknown forage preference category, the American elm and especially those in Victoria Park, are being protected with the 2” x 2” and 2” x 4” wire fencing. None of these exclosures, however, were effective in preventing beaver forage access to these woody plants. Both girdling of the trees and exclosure displacement (by beavers pushing against the wrap and lifting it up) were recorded. American elm has an unknown forage preference status as a result of those taxa lacking in the vegetation transects, and thus no direct indication of beaver preference for our study area and limited reference in the literature.

Table 3.7 Woody plant species bearing non-lethal forage deterrents within study area.

Species	Status*	No. trees with Non-lethal Forage Deterrent	Deterrent Type				No. Deterrent Effective
			i.	**ii.**	**iii.**	**iv.**	
Beaver Preferred Forage							
Fraxinus pennsylvanica (green ash)	N	29	26	2	0	1	26
Populus balsamifera ssp. Balsamifera (balsam poplar)	N	16	14	1	1	0	12
Populus deltoides ssp. monilifera (Eastern cottonwood)	N	19	6	1	9	3	17
Populus tremuloides (trembling aspen)	N	13	8	0	4	1	13
Populus x jackii (Balm-of-gilead poplar)	N	34	24	0	4	6	32
Sorbus aucuparia (Rowan tree)	I	2	1	1	0	0	1
Non-Preferred Forage							
Acer negundo var. interius (Manitoba maple)	N	5	3	0	1	1	4
Picea glauca (whitespruce)	N	4	3	0	0	1	4
Pinus sylvestris (Scots pine)	I	2	0	0	0	2	2
Pinus sp. (Pine Genus)	U	3	1	0	0	2	3
Quercus macrocarpa (bur oak)	N	5	0	3	1	1	1
Tilia spp. (Linden Genus)	I	2	2	0	0	0	2

Species	Status*	No. trees with Non-lethal Forage Deterrent	Deterrent Type				No. Deterrent Effective
			i.	ii.	iii.	iv.	
Unknown Forage Preference							
Corylus sp. (Hazelnut tree)	U	1	0	0	1	0	1
Salix alba var. (Golden weeping willow)	I	3	1	0	2	0	0
Ulmus americana (American elm)	I	13	2	11	0	0	0
Total		**151 (100%)**	**91**	**19**	**23**	**18**	**119 (79%)**

* Status: Native (N), Introduced (I), or Unknown (U)

4 DISCUSSION

4.1 Beaver Activity and Lodge Density

With both lethal, mainly body-gripping kill traps, and non-lethal deterrents in the form of wire exclosures on trees to deter beaver activity, beaver management practices in the City of Saskatoon are having the intended effect of reducing active beaver colony numbers. A similar consideration of beaver numbers through some overlapping portions of the study area was completed by other University of Saskatchewan researchers as mentioned above (FitzGibbon et al. 1982). The baseline survey by FitzGibbon et al. counted lodge complexes both in the unmanaged reach as well as within city limits and to points downstream. By using an estimated number of six beavers per lodge they reported approximately 40 beavers from Saskatoon to about eight km of river channel length from our study area boundary in the unmanaged reach. This population equates to about six lodges over approximately 20 km of river for a 0.33 lodge complex per river km density. Immediately upriver of beaver creek for a stretch of river to within a few kilometres of our upstream boundary, the colony density was closer to 2.2 lodge colony complexes per river km. In the managed reach and to a point approximately 20 km further downstream the baseline survey reported only around 40 beavers. Which, at approximately six lodges over the now almost 40 km stretch from Circle Drive bridge to the Clarksboro Ferry is a density of only 0.167 lodge complexes per river km; a much lower density in the urban area than currently observed by my research. This finding suggests that beavers that had in previous decades found refuge outside of the city limits, as evidenced by higher colony density there, are now more-so urban dwellers than their ancestors.

An overview of how the beaver lodge complex density in our study area compares with that observed elsewhere is shown below (Table 4.1).

Table 4.1 Beaver lodge densities across a number of locations (number of colonies per unit stream length)

Location	Number of beaver lodges per river km	Source
Study Area (Saskatoon, Saskatchewan, Canada)	Managed – 0.38 Unmanaged – 0.87	England 2019 Graduate Research
North American Average (in suitable habitat)	1.2	Muller-Schwarze 2011
City of Seattle, Washington, U.S.A.	2.0	Bailey et al. 2019
Green River, Colorado, U.S.A.	0.56	Breck et al. 2001
Yampa River, Colorado, U.S.A.	0.35	
New Brunswick, Canada	1.09	Nordstrom 1972
Netherlands (*C. fiber*)	0.33	Nolet and Rosell 1994
France (*C. fiber*)	0.12	Fustec et al. 2001

It is interesting to note that the now higher beaver colony density in areas under human management of beavers is consistent with that observed elsewhere in Canada (Nordstrom 1972). Lodge complex density in both the managed (0.38 colony per river km) and unmanaged (0.87 colony per river km) reaches of the South Saskatchewan River through Saskatoon is lower than the average of 1.2 colonies per km of stream reported in a review of the literature on beaver in North American across suitable habitat (Muller-Schwarze 2011). On large rivers in Colorado, bank-dwelling beaver were found at colony densities of 0.56 colonies per km on the flow-regulated Green River and 0.35 colonies per km on the free-flowing Yampa River (Breck et al. 2001). Beaver lodge complexes can occur at higher densities in urban environments than this research found. For example, urban beaver density in Seattle, Washington in the urban centre was 2.0 colonies per stream kilometre (Bailey et al. 2019). Bailey et al. attribute a recent dramatic rise in the beaver population to legislation outlawing the use of lethal beaver traps, which are still in use in Saskatoon. Beaver (*C. fiber*) are also common in European urban centres. Urban beavers are strictly protected by laws prohibiting capturing, killing, or disturbing them in most European countries unless when authorized through a formal exemption (Pillai and Heptinstall 2013). In large European rivers that pass through urban areas, colonizing *C. fiber* have been shown to have a colony density of about 0.33 lodges per river km (Nolet and Rosell 1994), which is consistent with modelled patterns of colonization and range expansion across human-dominated landscapes elsewhere in Europe (Swinnen et al. 2017). In France, colonizing beaver studied over a twenty-five year period have been shown on average to have 0.117 colonies per km of river length explored (Fustec et al. 2001). In most cases, beaver colony density in Saskatoon is similar to that in European cities, even though protections differ. Although beaver-human conflicts have received much attention (Jonker et al. 2006; Morzillo and Needham 2015), it is unlikely that human development helps explain the differences observed in lodge complex density along the South Saskatchewan River reaches. Lodge occurrence was unrelated to anthropogenic disturbance. Mumma et al. (2018)also came to a similar conclusion - that it is not the presence of human developments around potential lodge sites that appears to impact their location so much as the human influence of foraging opportunities and community tolerance of beaver (i.e. active management of beaver populations).

Country cousins of city beaver build lodge complexes generally closer to each other. There are a few places along the unmanaged river reach which had particularly high density of beaver lodges, specifically the in-channel islands Wilson and Yorath. As is consistent with the literature, side channels of the anastomosing bed of the river with less flows seem to provide more preferred beaver habitat given their greater available forage and suitable denning areas (Zadnik et al. 2009). In addition to the large permanent islands, beavers also reside on more transient sand-bed islands that are present in both the managed and unmanaged reach. These more recently established sand-bed islands lacked the large tree cover present on the Wilson and Yorath Islands, but active and inactive lodge complexes found on them indicate that they have in the past and continue to provide suitable beaver habitat. Further, island habitation likely provide beavers with protection from their main terrestrial predators – wolves (*Canis lupus*) (Gable et al. 2016; Gable et al. 2018), coyotes (*Canis latrans*) (Ozoga and Harger 1966), as well black bears (*Ursus americanus*) (Smith et al. 1994a) and cougars (*Felis concolor*) (Kertson et al. 2011) will prey on beavers. All of these predators are known to be present in the Moist Mixed Grassland Ecoregion (Acton et al. 1998), but how common they are in the MVA is not yet known. However, the South Saskatchewan River freezes over in winter allowing predators overland access to islands. Even out of the seasonal freeze-up of the river, intense predation on beaver can occur even in places where overland access to islands is limited year-round (Smith et al. 1994b). Finally, the predator with the highest mortality on beavers – humans – are notably less present on islands. Humans impact beaver populations greatly through trapping, shooting, and vehicle collisions, causing beaver death (Muller-Schwarze 2011). Without use of a river-faring watercraft there is limited access to islands for beaver trapping and shooting, and with no cars on the sand-bed islands to cause vehicle mortalities, the animals seem spared from some of their greatest threats to mortality.

Even with the reduced lodge complex density in Saskatoon and the pressures placed on the population by the threats described above, it is likely the beaver are there to stay within the city limits. As a recent review of human-wildlife interactions in urban areas, wildlife has existed in urban areas since records began and beavers are no exception (Soulsbury and White 2016). In those urban and suburban centres where human and beaver population densities are both high, the number of human-wildlife conflicts increase

(Siemer et al. 2013). The presence of beavers is a natural component of a properly functioning riparian ecosystem and there are benefits to their continued occupancy within the urban riparian forest relating to the animals role as a natural disturbance agent (Stoffyn-Egli and Willison 2011; Law et al. 2016). However, as Soulsbury and White (2016) also acknowledge, without natural predation there will always be a need to manage urban wildlife populations, including those of beaver. Management may be through lethal measures to attempt to decrease populations, or it may be a non-lethal methods, as this research set out to examine. As described by Pollock et al. (2017), rather than simply managing beaver in urban environments, in the future it may make more ecological and economic sense to integrate their presence as a form of natural habitat restoration and an integral ecosystem process. It is important to recognize that citizen opinions will differ on preferred beaver management strategies. An understanding of the actual rather than the perceived extent of beaver activity will be an important step for managers prior to developing a beaver management plan and through the adaptive application of the strategy (Hood and Yarmey 2015; Pollock et al. 2017). There are urban beaver management plans in other jurisdictions, including in some cities in the United States (Wheaton 2013). Some Canadian cities are moving away from lethal beaver management, for example, Calgary, Alberta. Instead, the City of Calgary (2019) has an adaptive beaver management strategy that relies non-lethal management techniques such as tree enclosures in riverine parks.

4.2 Riparian Forest Composition

The woody plant community from which beavers find food and the materials to build shelter is not the same between the managed and unmanaged forests along the South Saskatchewan River and its islands. Within the managed study area, there is a far greater diversity of taxa for trees and shrubs and for the latter a more equitable distribution of composition as well. Furthermore, the possibility that horticultural varieties of closely related native species are existent in the riparian forest but not easily detected by the vegetation survey could further increase the biodiversity and complexity of the riparian forest. It is known that beaver herbivory can have an effect on the overall composition of riparian forests following harvest by the rodents (Barnes and Mallik 2001; Mortenson et al. 2008; Hood and Bayley 2009) but the presence of a number of introduced species not native to Saskatchewan indicates that an anthropogenic influence is more likely to blame for the greater diversity in the managed reach. The proliferation of those non-native woody plants following colonization within the managed reach may still be partially aided by beavers as has been demonstrated elsewhere (Mortenson et al. 2008) but further experimentation in areas containing the non-natives that are both exposed to and protected from beaver foraging would be required.

Interestingly, Lineman's graduate research on the area in the late 1990's characterized a river alder (*Alnus tenufolia*) wetland community type that was not sampled during our subsequent vegetation surveys. It is possible that this species of woody plant is present in the riverine forests of the South Saskatchewan River valley but absent from our transects either by chance, or the possibility that ongoing beaver foraging has eliminated the species from the assessed study area. The latter seems somewhat unlikely as the characteristic lenticels and bark pattern on alder would lead even mostly foraged stands of the shrub to be still identifiable.

4.3 Beaver Foraging of the Riparian Forest

Interestingly, despite the differences in the woody plants present and their relative abundance within each respective treatment, beaver still foraged only ~ 30 m into the riparian forest. An average foraging distance of 30 m from the water is consistent with the trend of more than 80% of stems cut within 30 m observed around ponds in central Alberta (Hood and Bayley 2008), but shorter than the average 40 m active foraging distance seen on riverine systems in northern Ontario (Barnes and Mallik 1997). The similar foraging between the managed and unmanaged study area indicates that although the types woody plants available for utilization may differ depending on location, the beaver feeding pattern within the riverine forest differs little as a result of the surrounding management regime or forest composition. However, unlike lentic systems where beaver create canals and thus increase surface area of water through the ecosystem (Abbott et al. 2013), the river-dwelling beaver I studied appeared relegated to being content with river levels as they were and adjusting foraging paths into the forest as well as lodge complex locations to accommodate the relatively higher or lower stage of the hydrograph. This behaviour was assumed by the relative lack of beaver canals found in the riverine habitat adjacent to the river, as well as the relatively steep banks of the South Saskatchewan River (FitzGibbon et al. 1982) through the reach that may have discouraged the building of a network of beaver canals outside the channel.

Beaver prefer cottonwoods, as evidenced by high foraging of this species in the unmanaged reach, and as supported by the literature (Severud et al. 2013). But, in the managed study, cottonwood trees are protected. In the managed reach, beavers focused their foraging efforts to Manitoba maple and green ash. Importantly, while the literature suggests trembling aspen is a highly preferred forage material for beaver (Novak 1987; Gallant et al. 2004), no recent foraging on this species was found in the studied transects. It was not lack of availability that preventing foraging on aspen as it was common in both the managed and unmanaged riverine forests. So, something else is more recently steering beavers away from their suggested favourite food; called so as it has been observed in other jurisdictions. Without behavioural observations of beaver, it is difficult to determine a cause rather than just a correlation with some other possible factors for the lack of forage on aspen. Beaver have a long history in the study area (Symington and Ruttan 1956). It could be that repeated beaver foraging on trembling aspen plants have produced high levels of secondary compounds and phenolics that deters further herbivory following past foraging events (Villalba et al. 2014). However, studies of this phenomena shows that it is usually the sprouted regrowth and branches exhibiting juvenile morphological characteristics that are exhibiting the inducible defences (Basey et al. 1990). The selection for adult-form sprouts on these previously foraged plants was not observed along the study reaches, so it is unlikely that the presence of inducible defences was to blame for the beavers avoidance of trembling aspen. Aspen was not the most readily available tree as it was only around 10 % of the trees within the study area, nor was it readily protected in the managed study area and aspen was available both within and outside of the 30 m band that beaver typically foraged within. With the lack of clarity as to why beaver are not actively foraging aspen, there is needed further exploration of the reasons behind the behaviour.

The urban riverine aspect of the beaver foraging in this research provided a novel opportunity for analysis. Given that most beaver foraging research has taken place in natural settings, with primarily endemic species, there was interest in seeing how the beaver in our study area would react to the introduced species of woody plants present in the city. One of our primary research questions was how beaver foraging would interact with urban trees and urban tree protection efforts. If trees that are known beaver forage, like aspen and cottonwoods, were protected by the city would beavers switch to a shrub diet or show more interest in the introduced trees they may not be familiar with. The electivity index suggests that the most preferred beaver forage is the Rowan tree, which, interestingly, is an introduced tree species in the study area. However, the small number of Rowan trees (n=3) that all happened to be beaver foraged influenced the Electivity Index calculation. It is not clear if presented with more introduced foraging options if the beavers would continue to select those species that are not traditionally considered a beaver food. Proper determination of that trend in this study area might be accomplished through the development of cafeteria-style feeding experiments as performed for other species in other jurisdictions to determine beaver forage selection (Muller-Schwarze 2011). That is not to say that beavers elsewhere have not demonstrated a considerable ability to consume species with which they did not evolve. In southern South America, the 20 beaver introduced in 1946 to southern Patagonia (Lizarralde et al. 2004; Anderson et al. 2009; Pietrek and Fasola 2014) have since multiplied and consumed so much of the southern beech (*Nothofagus spp.*) forests that they are recognized as the largest disturbance agent to the region since the last ice age.

As it relates to the objective of comparing selective foraging patterns by beavers in both managed and unmanaged urban riverine forests I was also interested in the trees beavers are avoiding. The most negative value in the electivity index (-1) indicates avoidance or inaccessibility to a forage item. As is consistent with others research on beaver forage selection (Doucet and Fryxell 1993; Donkor and Fryxell 1999), conifers (Genus *Pinus* and *Picea;* pine and spruce, respectively) are avoided in our study area. Although not observed along vegetation transects, within the study area it was observed that there was beaver girdling on several pine trees that removed wood from the trunk but did not sever the bole. It is possible that beaver were sampling these trees for palatability (Jenkins 1978) or gnawing on the trunks as a means to wear down their ever-growing incisor teeth (Baker and Hill 2003). Bur oak also had a highly negative electivity index, although studies in Massachusetts showed initial foraging of oaks but a lack of repeated cutting during a second season of observation (Jenkins 1978). Whether this species is preferred by beaver or not is not clear - there was only a single specimen of this type and it was not beaver foraged. The complete avoidance of both *Tilia sp.* (two species assumed as one member of the genus was not able to be identified to the species level) by beaver in our study area is consistent with the foraging patterns observed elsewhere for this taxa of tree in North America (Barnes and Dibble 1988) as well as by European beaver (Czyzowski et al. 2009). Finally, although beaPollver did forage Manitoba maple in our study area, the negative selection index value indicates partial avoidance when this species is available amongst others. There appears to be little scientific research observing beaver foraging on Manitoba maple (also known as boxelder), but what is available also suggests avoidance of the species (Dieter and Mccabe 1989). It is also known that maple species elsewhere are typically avoided by beavers, especially the "hard-maples" such as *Acer saccharum* (Müller-Schwarze et al. 1994). Manitoba maple is a "soft-maple" (Farrar 1997) that beaver could rely on for forage in the managed riverine forests where their other more preferred forages may not be fully available. With only a partial selection for this species by beavers, I expect its presence in the riparian forest composition to increase over time, along with other less or non-preferred species, as models have predicted (Johnston and Naiman 1990; Donkor and Fryxell 1999; Mortenson et al. 2008). Further, beaver promoting the invasion of non-native species, as described by Lesica and Miles (2004), might also be occurring along the South Saskatchewan River in Saskatoon. Beaver tended to avoid Russian olive and that continued behaviour may promote its increase in density over time. How beavers forage, the trees they choose to eat or avoid will shape the riparian forest either towards a composition suggested by the natural path of succession or towards a modified woody plant community guided by the intentional management of the urban forest by humans and the unintentional management by beaver.

Although the forest is primarily characterized by the trees present within it, the understory woody plants are also cut by beavers, and either foraged on immediately or placed in the winter food cache. For the shrubs present in the study area, the majority of cut stems were those of willows or red-osier dogwood. Beaver foraging on both these species has been observed by others studying large river systems (Herbison and Rood

2015). There was little to no evidence of a trend (p=0.188) towards a more significant removal of red-osier stems by beaver cutting in the managed study area. Although an initial hypothesis considered during field observation was that there may have been beavers targeting this species at a slightly elevated rate when forage options are reduced by non-lethal deterrents on trees. With a burgeoning riparian shrub community of willows and red-osier dogwood in the City of Saskatoon, bolstered by the presence of invasive European buckthorn (*Rhamnus cathartica*) (Meewasin Valley Authority 2019a), the urban beaver could shift their foraging efforts to these shrub-form woody plant species and still find suitable plant material to cache for winter stores.

4.4 Non-Lethal Forage Deterrents

Of the four non-lethal forage deterrents found in City of Saskatoon parks, only one was ineffective at preventing beaver foraging – 2" x 4" wire fencing (a.k.a. elk fence). Pollock et al. (2017) provide guidance on wire cage specifications. Although the specifications vary, Pollock et al.'s general recommendation is to use a wire mesh gauge that is reasonably heavy (e.g., 6 gauge) to prevent the beaver chewing through it. The guidelines also indicate that mesh size should be 152 x 152 mm or smaller and that cages are to be 30 to 60 cm larger in diameter than the tree trunk that the wire wrap cage is enclosing. Finally, the cage should extend 90 to 120 cm above the ground, or the anticipated height of the winter snowpack in cold climates. Although the elk wire fencing falls within these suggested guidelines, it poorly functioned as a beaver deterrent. Probable reasons for its failure include being wrapped tighter than the suggested diameter gap, and without an effective anchor system around the perimeter of the cage such that beavers are able to push the wire fence up against the tree and forage through the 4" height openings. Thus, our results indicate that further guidance on installation of elk fencing, beyond what is provided by Pollock et al. (2017) is necessary to prevent beaver foraging.

The other three non-lethal forage deterrents in City parks – 2" x 2" fencing, chain link fencing, and chicken wire – were all nearly equally effective in preventing beaver foraging. That said, the use of chicken wire (20 gauge poultry fence) was concerning as it led to tree girdling. Girdling occurred when chicken wire was used because in many cases it was wrapped too tightly to the trunks of trees, and so did not provide the amount of space required for the tree to grow, based on the guidelines of Pollock et al. (2017). Distancing this type of fencing from a tree is unlikely to provide adequate protection from beaver foraging, however, as the gauge of the chicken wire is too thin to provide sufficient support to stand on its own. Due to the apparent failings of the chicken wire in protecting tree health, the City of Saskatoon abandoned the practice of using it in 2019 and started a program to replace this non-lethal deterrent on living trees that have it installed.

Proper selection of construction materials and proper methods for their installation are critical in ensuring beaver foraging deterrents will be most effective, but also important is ensuring that efforts to protect trees are primarily directed toward those species with high likelihood of being foraged by beaver. In Saskatoon, 84% of the wire wrapping deterrents were placed on beaver preferred forage. However, 14% of deterrents were found on Manitoba Maple, bur oak, and several conifers which are known to be non-preferred beaver forage in our study area and elsewhere (Doucet and Fryxell 1993). The choice to protect non-preferred forage in the urban study area is because certain trees on city property are considered of high value (Jeff Boone, pers. comm.). Regardless of whether beavers find them palatable or not, the city is unwilling to risk beaver foraging and so protect them. Also, the city collaborates with the MVA to run a memorial Plant-A-Tree program that offers citizens the sense of ownership of the shared riverine forest resources (Meewasin Valley Authority 2019b). In the program, residents can make a financial donation of $50 to $500; interestingly bur oak and conifers are at the higher end of this donation range. Although it is unlikely that beaver will fully forage some woody plants, the payoff of playing the odds towards these species is not worth the cost of a curious forager.

Finally, human presence on trails through beaver occupied habitats or strategically adding predator scents to beaver-preferred areas can serve as effective, non-lethal beaver deterrents in urban areas (Loeb et al. 2014). The literature suggests that frightening techniques, primarily audio and visual stimuli used to reduce animal desire to enter or stay in an area, towards beavers work for a very short time at best (Koehler et al. 1990) and that fencing is still an effective technique when coupled with other non-lethal methods (Nolte et al. 2003). Through this research I recommend that wire-wrapping, human-presence on trails, and predator scent be used synergistically in Saskatoon to decrease reliance on killing problem beaver. Although the efficacy may not be greatly increased as it concerns the beaver, using multiple approaches to deter beaver foraging addresses the social carrying capacity implications of living with beavers in urban environments. By having multiple non-lethal deterrents being seen by those people using the riverine forests, residents are often re-assured that a perceived beaver issue is being addressed (Jonker et al. 2006).

5 CONCLUSIONS

5.1 Summary of Findings

The purpose of my thesis was to improve the understanding of beaver foraging and forage management on woody vegetation in urban riverine forests. To understand that relationship between beavers and the riverine forests I also sought to put the urban beavers distribution in context with an overall lodge density survey. Urban beaver colony density is more than halved within the City of Saskatoon and that these lodges complexes are dispersed rather than the clustered distribution of beaver colonies found in the unmanaged reach. Also, nearly 20% of all beaver lodge complexes are on in-channel islands, both within the managed and unmanaged sections of the study area. A combination of active and inactive lodges on these islands shows that beavers have long sought habitat on these relatively less disturbed banks within the channel. Further analysis for lodge density influenced by degree of human development found no significant differences between colony numbers between areas of relative low, medium, and high human development and activity. These results gave further support to the hypothesis that it is vegetation availability and the opportunities for foraging that define beaver distributions more so than the human development in and around the riverine forests of the South Saskatchewan River.

As for beaver foraging, it was observed both by biomass removed and forage selection indices that cottonwoods are the preferred diet of riverine beavers. However, in the urban riparian forests where these types of trees are protected, the foraging beaver shift their attention to another native riparian species, green ash as well as the occasional exotic taxa such as the Rowan tree which are not a species the North American beaver would have evolved eating. Within the non-lethal forage deterrent protected urban forests there was also evidence of a slightly elevated beaver removal of red-osier dogwood, a high forage value shrub that may serve as a replacement option to fill food caches when other preferred tree species are protected.

Finally, I sought to understand the role and efficacy of forage management efforts in place within the urban forest. It was observed that four primary methods were used to construct beaver exclosures around select trees. Overall, these wire wrapping forage deterrents appeared 80% effective with the most effective and appropriate installations being a 2” x 2” welded wire fence averaging 1.2 m in height and anchored to the ground around its perimeter with tent pegs or a similar method. By the numbers, chicken wire (20 ga poultry fence) did appear to be effective in preventing further beaver forage but it was clear that it is not a viable solution for the ongoing health of the tree as the lack of structural support necessitating the need for a close wrap often girdled the growing trunk and caused premature death of the woody plant. With 84% of non-lethal deterrents in the form of wire-wrapping placed on appropriate tree species beaver are likely to forage, it is apparent that in most cases members of the urban forest deserving protection from beaver foraging are receiving it. The forage protection of beaver preferred species which are also the community forming species along major prairie rivers, such as cottonwood and green ash, may shift the vegetation community into an alternate state that is further altered by the anthropogenic influences and introductions of taxa in the urban forest. However, our results show that beavers will continue to interact with these modified riparian forests and also act as agents of change through their selection behaviour on woody plants, native or otherwise.

5.2 Limitations of Study

The principal limitations of this study and its ability to address the objectives of the work are related to issues with the study design. Namely, to investigate beaver activity in response to management activity I am making assumptions about the spatial and temporal scale of the management efforts in place within the City of Saskatoon. There are three primary issues that the design failed to include: 1) a control area of the riparian forest that is not subject to active beaver foraging to determine the riparian forest composition in the absence of foraging beavers; and, 2) the lethal management component that is present within the study area, and the role that beaver removal has had on foraging patterns and distribution of active beaver colonies; 3) relates to the timing of installation of the non-lethal deterrents and how this affects the apparent effectiveness. Without a record of the state of beaver foraging on trees prior to wire-wrapping it is possible that some deterrents deemed ineffective might have been installed after the fact. In most cases, but not all, there were chips of beaver foraged wood within the ineffective cages to remove the above possibility of a post hoc deterrent treatment. Another limitation related to issues with defining the spatial boundaries of one active colony from another as little is known for this study area, or any urban study area for that matter, about the home range delineation of a large river beaver colony. However, the trend is apparent that beaver colony density is significantly impacted within the City of Saskatoon and a small error of colony overlap would not influence those results. Finally, the native and introduced woody plant species present provided a diversity for beavers to forage within the study area. But the relatively limited number of occurrences along the vegetation transects meant that for many of these species there were only a few opportunities for beaver-foraging events and thus the selection index as it relates to trees in the urban riparian forest is not in our opinion a sufficiently representative sampling. An alternative to overcome this limitation in future research may be to develop and use a rank-preference index to better quantify the most to least preferred forage of beavers without being influenced by a less abundant and overall rarely foraged species.

5.3 Research Implications and Future Work

The implications of our research relate primarily to the ongoing management of beaver activity and foraging behaviour within urban forests and the riverine habitat. It is clear that if given the opportunity beaver will continue to forage on cottonwoods and other preferred native species such as green ash. Non-lethal protection on these species is a viable and cost-effective option if these deterrents are of a correct material, that is a wire wrap fence of 2” x 2” or smaller and that cages are to be 30 to 60 cm larger in diameter than the tree trunk that the wire wrap cage is enclosing. Finally, the cage should extend 90 to 120 cm above the ground, or the anticipated height of the winter snowpack in cold climates. For some species with a multi-trunked growth pattern, such as the Eastern cottonwood, there will result in several metres of wire wrap needed to fully enclose the shared trunks of larger diameter specimens and still give them room to grow. However, that one large wire wrap properly anchored, then properly recorded and stored in a database of non-lethal forage deterrent installations is our recommendation. This system will allow for a more thorough understanding of ongoing non-lethal beaver management efforts

As part of the social benefits of this research I will remind managers of urban forests that beavers are a natural disturbance agent and mechanism of renewal in the riverine forest community that should not be eliminated completely by wire wrapping all trees of preferred beaver forage. In the unmanaged portion of our study area, beavers removed around 30 % of the available trees and less than 20 % of the preferred shrubs. These values are certainly not in line with the occasional public perception that beavers are clearing out the forest and our research provides evidence that is not the case. It was observed that at the time of our study beaver colony density both in the managed and unmanaged sections are well below colony densities observed elsewhere and thus beaver are certainly not overruning the South Saskatchewan River valley either. Our recommendation is that colony density and distribution continue to be monitored and if efforts are made to further reduce colony density along riverbanks that the in-channel islands be recognized as suitable, even desireable, habitat for riverine beavers offering an opportunity for co-existence alongside the human population that has relatively little influence on these islands. Further studies to determine beaver colony establishment patterns in the context of human activity and development will also contribute to the scholarship on available beaver habitat and opportunities for sustainable co-existence elsewhere.

Finally, the relatively limited but still present beaver interactions with introduced and exotic woody plants in the riparian forest are likely to be a source of interesting and relevant further research. As vegetation communities continue to change and shift under human influence and the ongoing proliferation of invasive species, it is of great interest how an animal with an ability to modify woody vegetation communities second only to our own will interact with the shifting mosaic of plant communities and influence them accordingly. Research elsewhere has shown that beaver may promote the proliferation of invasive species by avoiding these non-native and often relatively unpalatable species. However, in riparian areas such as the urban forest where forage availability can be modified before the beaver has an opportunity to preferentially select woody plants it may be possible to use the animals need to find and forage woody plants to manage introduced and invasive species. In cities such as Saskatoon with a considerable invasive shrub problem, the role that beavers could potentially play as partners in riparian forest restoration is yet to be seen.

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APPENDIX A: S. SASKATCHEWAN RIVER BEAVER SURVEY ACTIVITY LOCATIONS

Beaver Activity Status (2017)	**Latitude**	**Longitude**	**Beaver Activity Record**	**Activity Part of Beaver Lodge Complex (Yes/No)**	**Notes**
Active	51.9706892	-106.7967904	Principal Bank Lodge	Yes	Fresh wood in food cache, secondary bank burrow as part of complex
Active	51.9748754	-106.7828852	Principal Bank Lodge	No	Feeding transect above lodge
Active	51.9843472	-106.7629406	Principal Bank Lodge	No	Fresh mud, many cached cut stems.
Active	51.9853831	-106.7181419	Principal Bank Lodge	Yes	Foraging runs into bank above. Large mature birch cut. Active food cache at base.

Active	51.9856134	-106.7177826	Principal Bank Lodge	Yes	Several entrances into bank around dam
Active	51.9869007	-106.758632	Principal Bank Lodge	No	Slides are abundant on Sandy bank just upstream. Food caching in bank. Bank appears unstable.
Active	51.9872691	-106.7354857	Principal Bank Lodge	Yes	
Active	51.9883607	-106.7359081	Principal Bank Lodge	Yes	Two secondary bank lodges adjacent to each other
Active	51.9886792	-106.735835	Principal Bank Lodge	Yes	Dragged material onto bank. Some may be from a collapsed tree from the bank.
Active	51.9938888	-106.7618351	Principal Bank Lodge	Yes	Three lodges and food caches adjacent to each other. No visible fresh cached wood, but an active castoreum deposit is observed between lodge 1 and lodge 2. Mink was observed using beaver lodge.
Active	52.0042246	-106.7094238	Principal Bank Lodge	No	Large active lodge. Fresh mud

Active	52.0113494	-106.7107441	Principal Bank Lodge	No	
Active	52.012394	-106.7053022	Principal Bank Lodge	No	Fresh wood on top of lodge
Active	52.0191523	-106.7123837	Principal Bank Lodge	Yes	Huge! many bank lodges around in hillside
Active	52.0301794	-106.715926	Principal Bank Lodge	No	Active mud on lodge and banks
Active	52.03857	-106.7093377	Principal Bank Lodge	No	Slide down top of lodge. Fresh mud
Active	52.0443273	-106.7161755	Principal Bank Lodge	No	Beaver foraging runs just D/S would be worth inventory
Active	52.0574932 3	-106.7315759	Principal Bank Lodge	Yes	Recently established. Active forage run into bank behind lodge

Active	52.0585132	-106.7330547	Principal Bank Lodge	Yes	Hole into lodge at water level on upstream bank
Active	52.0591279 8	-106.729973	Principal Bank Lodge	No	Large active runs near lodge. Across an unnamed island from other active lodges that may form a complex.
Active	52.0661422	-106.7335573	Principal Bank Lodge	No	Lodge appears old and perhaps recolonized Many chewed stems of small shrubs in bank.
Active	52.0694814	-106.7345173	Principal Bank Lodge	No	Large bank slide just upstream
Active	52.0803515	-106.732606	Principal Bank Lodge	Yes	Large secondary lodge hole in bank about 5 m upstream
Active	52.0859332	-106.7205871	Principal Bank Lodge	Yes	Large active food cache, secondary lodges
Active	52.0897434	-106.7115585	Principal Bank Lodge	No	Active by red osier dogwoods cuts and mud

Active	52.1020530 7	-106.6850808	Principal Bank Lodge	No	Large active lodge at upstream point of island, fresh cut wood
Active	52.1128269	-106.6785897	Principal Bank Lodge	No	Fresh food cached along sticks at water. Lodge is just upstream of confluence with a small trib. Could be storm water
Active	52.126462	-106.6533538	Principal Bank Lodge	No	Below a large slump in the riverbank
Active	52.1375411	-106.6429668	Principal Bank Lodge	No	Lodge is within the east bank of the island just upstream of the weir. Fresh cut wood and mud on the lodge
Active	52.1514579	-106.6362304	Principal Bank Lodge	Yes	Active lodge is in channel. Less active primary lodge on shore. Secondary lodge in bank
Active	52.161176	-106.6106953	Principal Bank Lodge	No	Beaver on lodge as we arrived. Fresh cut wood and new mud.
Active	52.1760875	-106.6062339	Principal Bank Lodge	Yes	A series of inactive lodges flanking the large active one. Mud on lodges and banks.

Active	52.1815078	-106.6035869	Principal Bank Lodge	Yes	Another lodge with both a bank and an over the water portion
Active	52.1887209	-106.6075724	Principal Bank Lodge	No	
Inactive	51.9689348	-106.7898115	Principal Bank Lodge	No	Lots of racoon tracks on shore. No sign of beaver.
Inactive	51.9703999	-106.7801771	Principal Bank Lodge	No	Most wood has been lost from food cache
Inactive	51.9705292	-106.7793394	Principal Bank Lodge	No	Inactive. Again, racoon tracks around
Inactive	51.9737375	-106.7641285	Principal Bank Lodge	Yes*	With secondary lodge adjacent and trails in the mud leading into beaver lodge at base of bank
Inactive	51.9749585	-106.7621802	Principal Bank Lodge	No	On oxbow

Inactive	51.9799393	-106.7585251	Principal Bank Lodge	No	
Inactive	51.9802712	-106.7584312	Principal Bank Lodge	No	
Inactive	51.9812351	-106.7233623	Principal Bank Lodge	Yes*	Inactive secondary lodge near confluence with South Saskatchewan River
Inactive	51.9827851	-106.7215107	Principal Bank Lodge	Yes*	Secondary bank dens upstream of primary lodge.
Inactive	51.983657	-106.7579919	Principal Bank Lodge	No	Standing cut wood. Bank slides 20 m upstream
Inactive	51.9840255	-106.7370572	Principal Bank Lodge	No	Very old, but cavity in bank apparent behind cut sticks
Inactive	51.9842507	-106.7306171	Principal Bank Lodge	No	

Inactive	51.9857471	-106.7206606	Principal Bank Lodge	No	Active feeding area adjacent
Inactive	51.9862798	-106.7390829	Principal Bank Lodge	Yes*	Small burrow next to old lodge. Canine activity abundant.
Inactive	51.9906079	-106.7640271	Principal Bank Lodge	No	Long abandoned. Pooled water is about 3 m away.
Inactive	51.9925585	-106.7159658	Principal Bank Lodge	No	
Inactive	51.992724	-106.7628631	Principal Bank Lodge	No	
Inactive	51.993737	-106.7099847	Principal Bank Lodge	No	Foraging runs just upstream
Inactive	51.995008	-106.7149121	Principal Bank Lodge	No	

Inactive	51.9952721	-106.7595824	Principal Bank Lodge	No	Old food cache within banks
Inactive	51.9953373	-106.7595214	Principal Bank Lodge	No	Many cut sticks in bank. Debris caught in lodge. No signs of repair in many years.
Inactive	51.9961543	-106.7499671	Principal Bank Lodge	No	
Inactive	51.9962323	-106.7528825	Principal Bank Lodge	No	
Inactive	51.9973331	-106.7084969	Principal Bank Lodge	Yes*	Several large secondary bank lodges upstream near a spring
Inactive	52.0007607	-106.7112281	Principal Bank Lodge	No	Old foraging runs into adjacent poplar forest
Inactive	52.002141	-106.7102487	Principal Bank Lodge	No	

Inactive	52.0030052	-106.705873	Principal Bank Lodge	No	
Inactive	52.0065414	-106.7090416	Principal Bank Lodge	Yes*	Inactive lodge also just upstream
Inactive	52.0213874	-106.7055683	Principal Bank Lodge	No	
Inactive	52.0338705	-106.7165633	Principal Bank Lodge	No	
Inactive	52.0349979	-106.7079922	Principal Bank Lodge	No	Very old Bank lodge. Little signs of recent activity
Inactive	52.0353424	-106.708067	Principal Bank Lodge	Yes*	Larger than adjacent lodges
Inactive	52.0361127	-106.7081921	Principal Bank Lodge	No	Caved in back towards bank

Inactive	52.0362041	-106.7082733	Principal Bank Lodge	Yes*	Complex of lodges. Up to three within a 10m stretch and possibly sharing entrances
Inactive	52.0369648	-106.7188372	Principal Bank Lodge	No	Sandy deposits below old lodge site
Inactive	52.0370258	-106.7085157	Principal Bank Lodge	No	Feeding trail on Sandy Beach across the channel
Inactive	52.0388852	-106.7095722	Principal Bank Lodge	No	Large lodge still mostly intact. No signs of recent activity.
Inactive	52.0406061	-106.7114596	Principal Bank Lodge	No	Chewed CORNSTO banks is more recent
Inactive	52.0462014	-106.7146335	Principal Bank Lodge	No	Lodge extends out over water.
Inactive	52.0485053	-106.720935	Principal Bank Lodge	No	Water entrance exposed. Feeding area within collapsed main chamber

Inactive	52.0495139	-106.7217831	Principal Bank Lodge	No	Feeding area at base of lodge
Inactive	52.0511621	-106.7238379	Principal Bank Lodge	No	Large hole in side of lodge could have been predation.
Inactive	52.0528263	-106.7267172	Principal Bank Lodge	No	
Inactive	52.0542714	-106.7294024	Principal Bank Lodge	Yes*	Wood caches on either side
Inactive	52.055197	-106.7304741	Principal Bank Lodge	No	Inactive lodge in bank with deep pool below
Inactive	52.0556938	-106.7309531	Principal Bank Lodge	No	
Inactive	52.055871	-106.7306254	Principal Bank Lodge	No	

Inactive	52.0584749	-106.7322456	Principal Bank Lodge	No	old food cache has been mostly washed away
Inactive	52.0629108	-106.7348457	Principal Bank Lodge	No	Long inactive
Inactive	52.0646457	-106.7350311	Principal Bank Lodge	No	Old lodge beneath a mature Manitoba Maple
Inactive	52.0690566	-106.7366724	Principal Bank Lodge	No	No geomorphic remainder of lodge. Mostly just piled sticks
Inactive	52.0694153	-106.7296157	Principal Bank Lodge	No	Trailing by rec access has wrecked much of the signs of beaver activity.
Inactive	52.0727672	-106.7351965	Principal Bank Lodge	No	Little wood remaining on bank
Inactive	52.073598	-106.7279259	Principal Bank Lodge	No	Lots of dog activity has likely driven beavers from this lodge

Inactive	52.0744763	-106.7353195	Principal Bank Lodge	Yes*	Complex of abandoned primary and secondary lodges. Mostly destroyed
Inactive	52.0753164	-106.734072	Principal Bank Lodge	No	Paddle within
Inactive	52.0757671	-106.7343658	Principal Bank Lodge	Yes*	Could have been a larger lodge complex. Little remaining on the surface of the upstream portion but deep pool and food cache below
Inactive	52.075906	-106.7231603	Principal Bank Lodge	No	No wood cache around base. May have been lost during previous floods
Inactive	52.0769327	-106.7207595	Principal Bank Lodge	No	Long inactive
Inactive	52.0777182	-106.7342586	Principal Bank Lodge	No	
Inactive	52.0779622	-106.717472	Principal Bank Lodge	Yes*	Two holes into bank lodges at base of valley slope banks on oxbow

Inactive	52.0779754	-106.727089	Principal Bank Lodge	No	Large dead POPUBAL over lodge
Inactive	52.0792712	-106.7232323	Principal Bank Lodge	No	Steep run up hillside behind lodge
Inactive	52.0797174	-106.7221936	Principal Bank Lodge	No	Large lodge. Not active and muskrats are using the area.
Inactive	52.0799249	-106.7213515	Principal Bank Lodge	No	Nothing above waterline remaining on the bank
Inactive	52.0800084	-106.7166559	Principal Bank Lodge	No	Pooled water in front of old lodge
Inactive	52.0811538	-106.7299087	Principal Bank Lodge	No	Lodges along a narrow side channel on west side of Yorath Island
Inactive	52.0818059	-106.7287016	Principal Bank Lodge	No	Lodges along a narrow side channel on west side of Yorath Island

Inactive	52.0818619	-106.7186352	Principal Bank Lodge	No	On bank is grassed over
Inactive	52.0830251	-106.7268624	Principal Bank Lodge	No	Lodges along a narrow side channel on west side of Yorath Island
Inactive	52.0836529	-106.7257412	Principal Bank Lodge	No	Lodges along a narrow side channel on west side of Yorath Island
Inactive	52.0842098	-106.7250459	Principal Bank Lodge	No	Wood in piles adjacent may be debris from this lodge
Inactive	52.0851184	-106.7215492	Principal Bank Lodge	No	Lodges along a narrow side channel on west side of Yorath Island
Inactive	52.0854785	-106.7201205	Principal Bank Lodge	No	
Inactive	52.0858291	-106.718535	Principal Bank Lodge	No	Mostly destroyed second entrance

Inactive	52.0862715	-106.7144733	Principal Bank Lodge	No	Adjacent to large sandbar on Yorath Island
Inactive	52.0866229	-106.7139676	Principal Bank Lodge	No	Near the north tip of sandbar.
Inactive	52.0869728	-106.7078649	Principal Bank Lodge	No	Sandy blocks of soil adjacent
Inactive	52.0869803	-106.7162945	Principal Bank Lodge	No	Small ponded water below old lodge
Inactive	52.0880522	-106.7141053	Principal Bank Lodge	No	No wood remaining above bank
Inactive	52.0880644	-106.7141462	Principal Bank Lodge	No	A fire has been built atop The old lodge. Made the call based on pattern of wood and sediment within the structure.
Inactive	52.0900617	-106.7016278	Principal Bank Lodge	No	

Inactive	52.102671	-106.6887486	Principal Bank Lodge	No	
Inactive	52.1150504	-106.6758868	Principal Bank Lodge	No	Large canal through bulrushes dug to lodge.
Inactive	52.1207745	-106.6637144	Principal Bank Lodge	No	
Inactive	52.1246704	-106.654591	Principal Bank Lodge	No	Old chewed stems
Inactive	52.1279733	-106.6554654	Principal Bank Lodge	No	
Inactive	52.1280375	-106.6554987	Principal Bank Lodge	No	Cattails cut within lodge. No more recent activity
Inactive	52.1281337	-106.6551107	Principal Bank Lodge	No	Small hole in bank above wood cache

Inactive	52.1282454	-106.6563863	Principal Bank Lodge	No	Wire wrapped trees above, 20 m south of old lodge
Inactive	52.128405	-106.6547118	Principal Bank Lodge	No	Dead beaver just d/s may have belonged to this lodge.
Inactive	52.1349284	-106.643089	Principal Bank Lodge	No	Just beyond cable buoys for weir
Inactive	52.1354779	-106.6425275	Principal Bank Lodge	No	Forest of non-native shrubs in behind
Inactive	52.1381157	-106.6453314	Principal Bank Lodge	No	Large hole in bank left
Inactive	52.1389921	-106.6444987	Principal Bank Lodge	No	Very old it appears
Inactive	52.1394193	-106.6403293	Principal Bank Lodge	No	No wood cache on bank

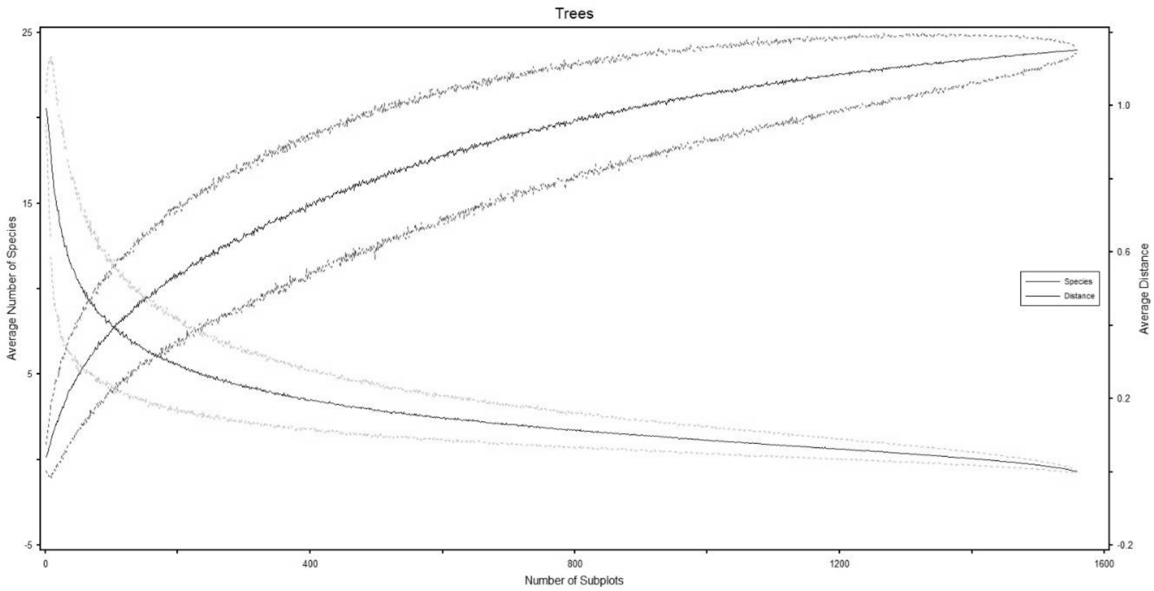
Inactive	52.1414388	-106.6395464	Principal Bank Lodge	Yes*	Secondary lodge below in the banks
Inactive	52.1492839	-106.6338635	Principal Bank Lodge	No	
Inactive	52.1561058	-106.6309999	Principal Bank Lodge	No	Recreational trail next to lodge
Inactive	52.1582009	-106.6268526	Principal Bank Lodge	No	On back oxbow of river. alluvial bar of SALIEXI and POPUBAL Between here and the river.
Inactive	52.1607849	-106.6155708	Principal Bank Lodge	Yes*	Secondary lodge in bank just upstream
Inactive	52.1615382	-106.6100987	Principal Bank Lodge	No	
Inactive	52.1662688	-106.6069016	Principal Bank Lodge	No	

Inactive	52.1737891	-106.9632018	Principal Bank Lodge	No	Chewed standing wood. Slide about 10 m upstream.
Inactive	52.1771299	-106.6010872	Principal Bank Lodge	No	Slumping bank near lodge
Inactive	52.1823093	-106.6033712	Principal Bank Lodge	No	Directly adjacent to sewage pipe in water
Inactive	52.1880534	-106.6109021	Principal Bank Lodge	No	
Inactive	52.1883112	-106.6065359	Principal Bank Lodge	No	Signs of a possible lodge, but the topography doesn't fit with an old Bank lodge. The standing cut wood is native plants and the replacement has been to non-native species
Inactive	52.1943357	-106.6158324	Principal Bank Lodge	No	Inactive lodge in dry ox bow
Inactive	52.1948891	-106.6159661	Principal Bank Lodge	No	The lodge is about 2 m above the current water level in the tributary stream to the river

Inactive	52.1961333	-106.6169629	Principal Bank Lodge	No	Very tall lodge

* For inactive beaver lodges that appeared near enough to other principal lodges in the past it is possible that these lodges in an apparent complex occurred at different periods of colonization over the temporal history of the lodge complex location. For this reason we considered these inactive lodges as individual lodge complexes for the analysis of beaver activity.

APPENDIX B: SPECIES AREA CURVES Of WOODY VEGETATION SURVEYS



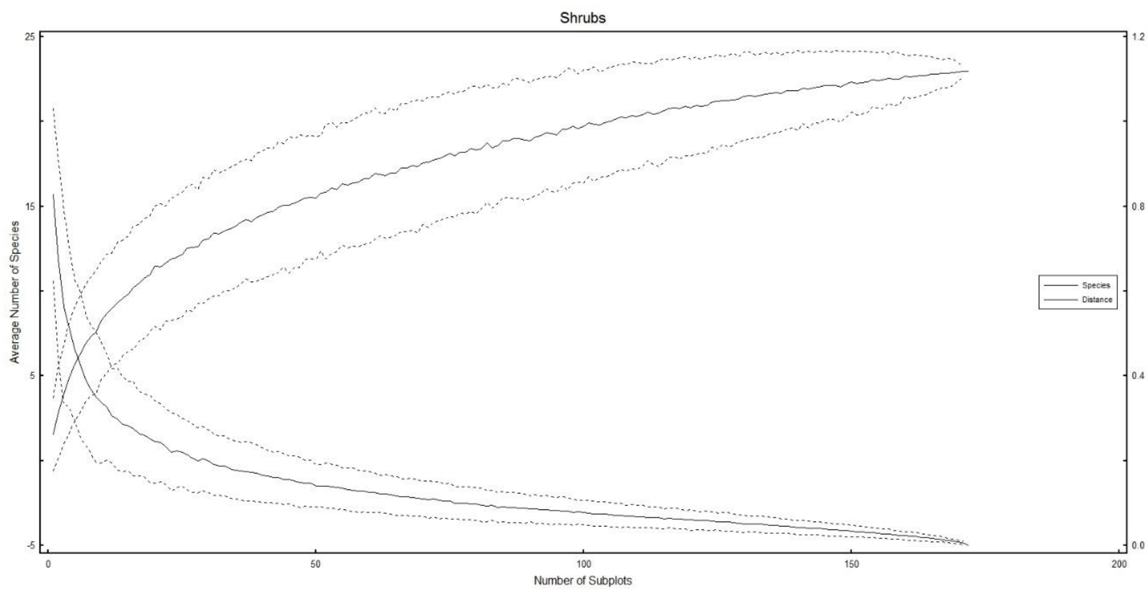


Figure B.1. Species area curves created using pcORD software showing sampling effort is sufficient to justify subsequent analysis of woody vegetation community composition and forage selection.

APPENDIX C: CITY OF SASKATOON NON-LETHAL FORAGE DETERRENTS RECORDS

Deterrent Latitude	Deterrent Longitude	Tree Species	Deterrent Type	Deterrent Height	Notes
52.1197613	-106.6763486	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	125	One of only a couple trees wrapped between river and trail. Extensive beaver foraging around this tree.
52.1202194	-106.6758723	Fraxinus pennsylvanica (Green Ash)	2" x 4" wire fence	150	Wire is nearly girdling tree at base
52.1202582	-106.6758335	Sorbus aucuparia (Rowan Tree)	2" x 2" wire fence	65	Forage deterrent is in poor shape. Sawn trunk at base may have been old beaver chewed. DBH based on three trunks added and averaged.
52.1206072	-106.6754595	Sorbus aucuparia (Rowan Tree)	2" x 4" wire fence	116	Beaver foraging near base appears very old. Forage deterrent has prevented further damage.
52.1215571	-106.6742469	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	135	Wire wrap is beginning to girdle tree. It has also left small portions (<10 cm height) of the roots and base of trunk exposed. Wire is heavily damaged possibly by beavers attempting to forage.
52.1201263	-106.6765509	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	122	
52.1201977	-106.6766433	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 4" wire fence	155	
52.1200629	-106.6765555	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	138	
52.1200463	-106.6765485	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	110	Three Boles growing from one large shared trunk. Wire is nearly girdling tree at base.

52.1200403	-106.6765728	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	110	Three Boles growing from one large shared trunk. Wire is nearly girdling base of tree
52.1200676	-106.6765887	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	110	Three Boles growing from one large shared trunk. Wire is nearly girdling base of tree.
52.1199381	-106.6764324	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	133	
52.119892	-106.6764272	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	135	
52.1198856	-106.6765475	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	135	
52.1198258	-106.6765579	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	100	Beaver has collapsed fence into tree and girdled bark near base/roots
52.119723	-106.6766384	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	140	Bottom of trunk/roots exposed as forage cage doesn't start until nearly 15 cm up the tree
52.1197247	-106.6770048	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	120	
52.119672	-106.6769654	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	155	
52.1196836	-106.6769952	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	1.5	
52.119169	-106.6770274	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	140	Beaver girdling at base of tree appears old and forage barrier has prevented further damage
52.1189321	-106.6774608	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	127	
52.1189146	-106.6774777	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	124	

52.1188651	-106.6775673	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	145	
52.118744	-106.677923	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	120	
52.1187349	-106.6779475	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	125	
52.1187721	-106.6780067	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	130	Bottom of trunk/roots are exposed for girdling. Wire has been bent on bottom.
52.1187239	-106.6781154	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	125	
52.1337444	-106.6496653	Populus x jackii (Balm-of-gilead)	Chain link fence	90	Tree in meridian of parking lot
52.1334207	-106.649511	Acer negundo var. interius (Manitoba Maple)	Chain link fence	80	Fence is girdling tree tightly
52.1333699	-106.6496426	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	121	Tree near the end of the meridian in parking lot
52.1333407	-106.6496815	Populus x jackii (Balm-of-gilead)	Chain link fence	90	Forage deterrent is enclosing multiple trunks
52.1333287	-106.6496774	Populus x jackii (Balm-of-gilead)	Chain link fence	90	Bottom of trunk and roots are exposed as fence is just wrapped around tree trunks
52.1332736	-106.6497448	Populus tremuloides (Trembling Aspen)	Chain link fence	100	
52.1333217	-106.649787	Populus tremuloides (Trembling Aspen)	Chain link fence	105	
52.1333669	-106.6497748	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	95	
52.1333094	-106.6498722	Populus tremuloides (Trembling Aspen)	Chain link fence	95	

52.1333033	-106.6498679	Populus balsamifera ssp. balsamifera (Balsam Poplar)	Chain link fence	100	
52.133303	-106.6498274	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	120	Two poplars in one cage
52.1332823	-106.6498808	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	120	Two poplars wrapped in one forage deterrent cage. Cut branches/trunks on one poplar may be old chews
52.1333593	-106.6500663	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	120	Branches cut at bottom with chainsaw may have originally been beaver chewed
52.1333688	-106.6496866	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	115	
52.133482	-106.6496818	Populus tremuloides (Trembling Aspen)	Chain link fence	90	Tree in meridian of parking lot
52.1336841	-106.6498125	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	120	
52.1336801	-106.6498178	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	130	
52.1337465	-106.6498818	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	127	
52.1337186	-106.6499807	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	118	
52.1336414	-106.6499766	Populus tremuloides (Trembling Aspen)	2" x 2" wire fence	120	
52.1337067	-106.6501454	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	124	Cage easily lifted but not on slope
52.1342367	-106.648901	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	130	Nearly touching Meewasin trail
52.1342408	-106.6488114	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	130	Roots of tree are exposed for beaver girdling

52.1344894	-106.6486941	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	120	Tree is on a well worn foraging trail
52.1345542	-106.6486715	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	125	
52.1347314	-106.6485392	Tilia spp. (Linden Genus)	2" x 2" wire fence	120	
52.1349196	-106.6483801	Acer negundo var. interius (Manitoba Maple)	Thin gauge chicken wire	90	
52.1350284	-106.6483173	Tilia spp. (Linden Genus)	2" x 2" wire fence	120	
52.1355777	-106.6483193	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	125	
52.133521	-106.6487176	Corylus sp. (Hazelnut Tree)	Chain link fence	100	Slow growing tree but fence wire may girdle eventually
52.1131138	-106.6767854	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence anchored with tent pegs	120	Beaver foraged trees in area have been chainsawed level/flat
52.11306528	-106.6768223	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	120	ACERNEG seedling in exclusion cage
52.1130141	-106.6768431	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	120	Branches cut off tree by saw
52.1127996	-106.6769764	Salix alba var. (Golden Weeping Willow)	2" x 2" wire fence	115	Tree appears damaged by branch cutting not beaver foraging.
52.1128399	-106.6774347	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	120	
52.1126348	-106.6777298	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	115	
52.1126999	-106.6777039	Acer negundo var. interius (Manitoba Maple)	2" x 2" wire fence	123	
52.1127064	-106.6777119	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	115	

52.1126476	-106.6778138	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 2" wire fence	100	Wire is pulled up at bottom and beggining to girdle tree
52.1126585	-106.6778073	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	115	
52.1125906	-106.6780034	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	140	Bottom of tree is not wrapped and wire starts at 50 cm off the ground. Beaver actively foraging Boles on shared trunk.
52.1125346	-106.6781847	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	100	Cage collapsed near base. Likely from children rather than beavers.
52.1125006	-106.6782159	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence with T bar anchors	100	
52.1125016	-106.6781476	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	118	Directly adjacent to playground.
52.1124745	-106.6778794	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	123	
52.1123364	-106.6778448	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	125	Saskatoon shrubs (Amelanchier alnifolia) coming up within forage exclusion cage.
52.1123322	-106.6778328	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	118	
52.1122836	-106.6778928	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	125	
52.1123196	-106.6779348	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	115	
52.1123634	-106.6779966	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	111	
52.1123125	-106.6780389	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	125	
52.112284	-106.6780773	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	121	
52.1120806	-106.6780405	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	118	

52.1111448	-106.6787471	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	122	Cage easily lifted up/moved
52.1111116	-106.6787801	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	100	Shared trunk with two other boles
52.11112571	-106.6787605	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	100	Shared trunk with two other boles
52.1111228	-106.6787482	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	100	Shared trunk with two other boles
52.1112486	-106.679066	Picea glauca (White Spruce)	2" x 2" wire fence	118	
52.1113262	-106.6791386	Picea glauca (White Spruce)	2" x 2" wire fence	114	
52.11152969	-106.6786224	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	125	Old beaver chewed trunk. Deterrent seems to have prevented further foraging.
52.1115566	-106.6786028	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	94	Branches sawn off towards trail
52.1120824	-106.6782704	Quercus macrocarpa (Bur Oak)	Chain link fence	87	Chain link fence is already nearly girdling tree. Sagging in places
52.1126996	-106.6781864	Pinus spp. (Pine Genus)	2" x 2" wire fence	70	Pine adjacent to playground. Tree appears to be dying as all North and many West facing branches are already dead
52.1126722	-106.6777836	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	120	
52.1127312	-106.677725	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	110	
52.1128352	-106.6777097	Acer negundo var. interius (Manitoba Maple)	2" x 2" wire fence	120	
52.1127951	-106.6777075	Acer negundo var. interius (Manitoba Maple)	2" x 2" wire fence	120	Three ACERNEG wrapped within one forage deterrent enclosure. One appears foraged prior to wrapping.
52.113036	-106.6776912	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	119	

52.1131916	-106.6777042	Salix alba var. (Golden Weeping Willow)	Chain link fence	65	The beaver deterrent chain link has already girdled and grown into the tree. The height is right where previous beaver foraging has taken place. There is remnants of old chicken wire wrap on the tree as well
52.1133277	-106.6777673	Salix alba var. (Golden Weeping Willow)	Chain link fence	84	This multi trunk Willow has beaver foraging on one of four boles with the deterrent at the height of the foraging and perhaps present prior to the beaver foraging event. The DBH of the four trunks are (37.8/15.6/17.0/45.0) cm
52.1134673	-106.6775817	Picea glauca (White Spruce)	2" x 2" wire fence	126	
52.1135017	-106.6775197	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	120	Acer negundo sapling also growing with the protection of the cage
52.113508	-106.6775367	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	125	Trees adjacent that are not protected are thoroughly and repeatedly foraged.
52.1137305	-106.6765232	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	93	
52.1138276	-106.676435	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	125	Missing bark at base is not clearly beaver foraging. Therefore no beaver inflicted recorded.
52.114255	-106.6763433	Populus x jackii (Balm-of-gilead)	Chain link fence	85	
52.1145333	-106.6763549	Populus x jackii (Balm-of-gilead)	2" x 2" wire fence	122	Tree has been partially cut by beaver, apparently before the installation of the deterrent. Much (>50%) of the canopy appears dead.
52.1140938	-106.6770062	Populus deltoides ssp. monilifera (Eastern Cottonwood)	2" x 2" wire fence	140	The base of the this cottonwood has already been foraged and the wrapping done on the upright bole after the fact. Beaver foraging on regrowing leaders outside of cage appears recent.

52.1178131	-106.6782563	Quercus macrocarpa (Bur Oak)	2" x 4" wire fence	155	Deterrent not anchored
52.1178247	-106.6782403	Quercus macrocarpa (Bur Oak)	2" x 4" wire fence	155	Deterrent not anchored
52.11788	-106.6781648	Ulmus americana	2" x 4" wire fence	155	
52.1178872	-106.6782064	Ulmus americana	2" x 4" wire fence	150	
52.1179017	-106.6786646	Ulmus americana	2" x 2" wire fence	135	
52.1179103	-106.678675	Ulmus americana	2" x 2" wire fence	145	Roots exposed
52.118014	-106.678624	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	130	
52.1179957	-106.6785422	Fraxinus pennsylvanica (Green Ash)	2" x 2" wire fence	134	
52.1179817	-106.6783557	Ulmus americana	2" x 4" wire fence	145	Starting to girdle at base.
52.1178888	-106.6781133	Ulmus americana	2" x 4" wire fence	146	
52.11801	-106.6779668	Ulmus americana	2" x 2" wire fence	155	
52.1181194	-106.6779453	Fraxinus pennsylvanica (Green Ash)	2" x 4" wire fence	137	
52.1178703	-106.6783058	Quercus macrocarpa (Bur Oak)	2" x 4" wire fence	150	Deterrent not anchored. Double check species id.
52.1178641	-106.6782566	Ulmus americana	2" x 4" wire fence	150	Wire not anchored
52.1178512	-106.6784316	Ulmus americana	2" x 4" wire fence	140	Deterrent not anchored
52.1178233	-106.6783874	Ulmus americana	2" x 4" wire fence	154	Deterrent not anchored
52.1176956	-106.6783166	Ulmus americana	2" x 4" wire fence	150	Wire not anchored
52.1176577	-106.6784019	Ulmus americana	2" x 4" wire fence	150	Deterrent loose (can move around)
52.1175988	-106.6784181	Ulmus americana	2" x 4" wire fence	150	Deterrent is loose
52.1175121	-106.6785054	Populus balsamifera ssp. balsamifera (Balsam Poplar)	2" x 4" wire fence	152	Deterrent is loose (can pick up and move around)
52.1171171	-106.6784112	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	86	Chain link anchored by rebar. Principal leader cut, but tree has continued to grow.

52.117049	-106.6784214	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	85	Dbh of tree not actually at DBH, taken at beaver chewed height 80 cm. Appears damage was after wrapping rather than prior. No rebar anchoring it.
52.1170026	-106.6784295	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link anchored by rebar. Possible deer nibbling on one branch
52.1170018	-106.6784899	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link anchored by rebar
52.1169264	-106.6784725	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link fence anchored by rebar. Anchors not sufficiently spaced
52.1168757	-106.6784706	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link anchored by rebar
52.1168259	-106.6785315	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link fence anchored by rebar.
52.116705	-106.6785736	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	80	Chain link fence anchored by rebar. Beaver chewed stems on neighbouring Salix that have no deterrents.
52.1166353	-106.6786873	Populus deltoides ssp. monilifera (Eastern Cottonwood)	Chain link fence	90	Chain link anchor with rebar. Tree supports tied to rebar as well
52.13827345	-106.640732	Pinus spp. (Pine Genus)*	Thin gauge chicken wire	100	Twoneedled pine with no cones
52.13827345	-106.640732	Pinus spp. (Pine Genus)*	Thin gauge chicken wire		Twoneedled pine with no cones
52.13827345	-106.640732	Quercus macrocarpa (Bur Oak)*	Thin gauge chicken wire		
52.1264302	-106.6530507	Picea glauca (White Spruce)*	Thin gauge chicken wire		

52.13827345	-106.640732	Populus tremuloides (Trembling Aspen)*	Thin gauge chicken wire		
52.13827345	-106.640732	Pinus sylvestris (Scotch Pine)*	Thin gauge chicken wire	110	Protected after cut [girdling]
52.1264302	-106.6530507	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire	110	
52.1264302	-106.6530507	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire	90	
52.13827345	-106.640732	Pinus sylvestris (Scotch Pine)*	Thin gauge chicken wire	80	Chicken wire is girdling the tree
52.13827345	-106.640732	Fraxinus pennsylvanica (Green Ash)*	Thin gauge chicken wire	60	
52.15227423	-106.6361452	Populus deltoides ssp. monilifera (Eastern Cottonwood)*	Thin gauge chicken wire	80	Chicken wire only partially intact
52.15227423	-106.6361452	Populus deltoides ssp. monilifera (Eastern Cottonwood)*	Thin gauge chicken wire		Chicken wire only partially intact
52.15227423	-106.6361452	Populus deltoides ssp. monilifera (Eastern Cottonwood)*	Thin gauge chicken wire		Chicken wire only partially intact
52.17572785	-106.6064535	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire	31	
52.17572785	-106.6064535	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire	28	Thin gauge chicken wire does not extend above base
52.17572785	-106.6064535	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire	41	Shared trunk with dead stump up middle
52.17572785	-106.6064535	Populus x jackii (Balm-of-gilead)*	Thin gauge chicken wire		

* For these non-lethal forage deterrent protected trees, the locations are approximations as they were collected during the vegetation transects and the latitidue/longitude corresponds with the start points of those