The Investigation and Evaluation of Riparian Management Practices within the Manitoba Landscape: Off-stream Watering Systems

By

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ABSTRACT

This study was conducted to determine the impact of off-stream waterers (OSW) and barriers on animal productivity, behaviour, and riparian health, while comparing data collected with visual observations and GPS collars. Treatment had no significant effect ($P > 0.05$) on cow and calf weights averaged over the grazing season, with the exception of calf weights at one site ($P < 0.0001$). Although cattle utilized the OSW, they continued to drink from the stream. Further, the barriers did not discourage watering at the stream. Riparian health assessments did not indicate greater improvement with OSW or barriers. Cattle location, obtained via visual observations and GPS collars, differed with respect to the number of observations at the trough or in the riparian polygon. Long term studies are required to assess the impact of pasture size and site topography on OSW usage and riparian health, as many of the criteria take over two years to regenerate.

Keywords: riparian, off-stream water, partial exclusion, cattle distribution, GPS, animal performance, visual observation, accuracy, validation

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ABBREVIATIONS

ADG	=	Average daily gain
ADT	=	Average daily temperature
ALUS	=	Alternative Land Use Services
BMP	=	Beneficial management practices
cm	=	Centimeter
CSR	=	Continuous stocking with restricted stream access
CSU	=	Continuous stocking with unrestricted stream access
DBRM	=	Deep binding root mass
ESA	=	Endangered Species Act
GPS	=	Global positioning systems
h	=	Hour
ha	=	Hectares
KAP	=	Keystone Agricultural Producers
kg	=	Kilogram
km	=	Kilometer
LWSI	=	Livestock Weather Safety Index
m	=	Meter
MAFRI	=	Manitoba Agriculture, Food and Rural Initiatives
mm	=	Millimeter
MRP	=	Molybdate-reactive phosphorus
nm	=	Nanometer
OSW	=	Off-stream waterers
RHA	=	Riparian health assessment
R	=	Rotational stocking with restricted access
RP	=	Riparian polygon
SARA	=	Species at Risk Act
SD	=	Standard deviation
P1-D1	=	Period 1 Day 1
P1-D28	=	Period 1 Day 28
P2-D1	=	Period 2 Day 1
P2-D28	=	Period 2 Day 28
P3-D1	=	Period 3 Day 1
P3-D28	=	Period 3 Day 28
SPEA	=	Streamside Protection and Enhancement Act
THI	=	Temperature-humidity index
TKN	=	Total kjedahl nitrogen
USGS	=	United States Geological Survey
VO	=	Visual observations

1CONT	=	No OSW or barrier
2BARR	=	OSW with barrier
3NOBARR	=	OSW without barrier

1. INTRODUCTION

In cow/calf operations throughout Manitoba, riparian areas are often used as a water source for grazing livestock. Cattle are attracted to riparian areas as they provide not only a water source, but abundant forage and relief from heat (Belsky et al. 1999). While grazing and watering in the riparian area, cattle contribute to the removal of vegetation, degradation of water quality, and compaction and erosion of soil (Platts 1979; Kauffman et al. 1983). New provincial legislation, such as the Water Protection Act, introduced in 2005, prohibits activities that are detrimental to water protection, aquatic ecosystems, or drinking water sources. In response to such changes in legislation, the agricultural industry must adopt beneficial management practices (BMP) that are environmentally and economically sustainable for cattle producers.

A possible BMP to protect riparian areas is exclusion fencing. Although proven to be effective in some instances, it is costly and removes a large area of pasture from use. An alternative method to exclusion fencing is the use of off-stream watering systems (OSW). With access to an alternate source of water, cattle may spend less time loitering in the riparian area, and more time in the pasture surrounding the OSW. Previous studies have shown that the use of OSW led to a reduction in the amount of time spent in the riparian area or stream (Miner et al. 1992; Clawson, 1993; Godwin and Miner, 1996; Sheffield et al. 1997; McInnis and McIver 2001), as well as greater usage of the OSW than the stream for watering (Sheffield et al. 1997; Veira and Liggins 2002). Porath et al. (2002) reported that cows and calves with access to OSW had higher average daily gains (ADG) than those without access, indicating that OSW may be a cost-effective strategy to protect riparian areas, while increasing animal productivity. Another strategy that may improve the effectiveness of OSW is the use of natural barriers, which would partially exclude livestock from entering certain areas of the stream. Evaluation of the effectiveness of this strategy is limited at this time.

To date, much of the existing research examining the use of OSW and cattle behaviour in riparian areas has been undertaken in smaller paddocks (Veira and Liggins 2002; Godwin and Miner 1996; Sheffield et al. 1997; Schwarte et al. 2011). Manitoba has an abundance of pasture land (2,046,492 hectares (ha)) for its 655,587 head of beef cattle (Statistics Canada 2006); resulting in an estimated 3.1 ha of pasture land available per head. This estimation indicates that most cattle are grazed in large scale pastures.

Furthermore, many existing studies examine the effectiveness of OSW on riparian health without consideration of the effect on animal performance (Clawson 1993; Godwin and Miner 1996; Miller et al. 2010a; Miller et al. 2010b; Miner et al. 1992; Schwarte et al. 2011; Sheffield et al. 1997). Conversely, other studies have examined animal performance but not riparian health (Veira and Liggins 2002; Stillings et al. 2003). In order to adopt BMPs such as OSW, livestock producers must be assured that the implementation these strategies will not negatively impact animal performance, while at the same time, lead to improved riparian health.

The purpose of this study was to evaluate the effectiveness of OSW and natural barriers on riparian health and the impact on animal performance in large scale pastures, characteristic of those which exist throughout Manitoba.

2. REVIEW OF THE LITERATURE

2.1. RIPARIAN AREAS

Riparian areas make up the transition area between land and water. Naiman and Décamps (1997) describe riparian areas as zones that "encompass the stream channel between the low and high water mark, towards the uplands, where vegetation may be influenced by elevated water tables and the ability of soils to hold water". Thomas et al. (1979) have described riparian areas in North America as having the following characteristics: 1) create well-defined habitat zones within the much drier surrounding areas; 2) make up a minor proportion of the overall area (between 1-5%); 3) are generally more productive in terms of total biomass than the remainder of the area; and 4) are a critical source of biological diversity. There are a variety of disturbances, both natural and human-caused, that can cause disruption to riparian areas.

2.1.1. Disturbances to riparian areas

Riparian areas can be affected by natural disturbances such as floods, fire, temperature extremes, landslides, insects, herbivory, and disease. Many of the species present in the riparian area have adapted their lifecycles to include these phenomenons (FISRWG 1998). Flooding, caused by snowmelt or high-intensity rain showers, can have a profound impact on the vegetation in the riparian area by influencing species composition or by mechanically disturbing vegetation through erosion of the streambank (Gregory et al. 1991; Naiman and Décamps 1997). Fire causes disturbance primarily in uplands, but can impact riparian areas found throughout arid climates during drought (National Research Council 2002). As herbivory influences riparian areas, large herbivores, specifically bison, are thought to have helped to develop prairie riparian ecosystems. Fitch and Adams (1998) speculate that the bison followed a grazing regime based on seasonal and climatic fluctuations, including drought and fire, where periods of grazing were followed by rest. The extent of damage and the ability to recover from natural disturbance in the riparian area depends on the health of the ecosystem.

Human disturbances, such as hydroelectric generation, urbanization, recreation, and agriculture have the potential to greatly impact the structure and function of riparian areas (FISRWG 1998). It is estimated that there are some 933 dams in Canada which are used to generate hydroelectricity (Environment Canada 2010). These structures can cause the complete loss of riparian function due to inundation of water upstream of the dam (National Research Council 2002) and can alter the flow of water, leading to increased erosion and sedimentation, subsequently changing the morphology of the stream corridor (FISRWG 1998).

Urbanization is increasing and can cause disturbance to riparian ecosystems as surrounding land is developed into parking lots, roads, rooftops, sidewalks, and other impermeable surfaces. As the level of imperviousness increases, so does the amount of runoff in a watershed. In parts of the United States, watersheds with a minimum of 10% impervious cover have been found to contribute to stream degradation, which further increases as impervious cover increases (Schueler 1994).

Riparian areas attract a large number of recreationists who have a dramatic impact due to the high concentration of human activity in small strips of land. Resulting impacts include a decline in water quality, soil compaction, a reduction in riparian vegetation, and disturbance to animal habitat (National Research Council 2002). Green (1998) studied the impact of recreation on an Arizona riparian ecosystem, where the site was accessible by vehicle and primarily used for camping. Results from this study indicate that in high-use areas, runoff from precipitation occurred sooner and at a higher rate than in light-use areas. As well, the amount of vegetation present ranged from 0 g/m^2 in the high-use areas to 364 g/m^2 in the light-use areas.

Throughout the United States, it is estimated that agriculture is a significant contributor to the decline of riparian quality and functioning (Dillaha et al. 1987). Agriculture can contribute to the decline in riparian health due to vegetative clearing, tillage, pesticide and fertilizer runoff, drainage, irrigation, and livestock grazing (FISRWG 1998; National Research Council 2002).

2.2. CATTLE AND RIPARIAN AREAS

Manitoba has approximately 11,333 beef producers, 98% of which are cow/calf operators (MAFRI 2011). In this type of production system, cow/calf pairs typically spend the summer grazing on pasture where the water source will depend on a variety of factors, including the location and topography of the pasture, the availability of power, animal requirements, available water source, and water storage capacity. In pastures which contain natural water courses, cattle are often allowed to drink at creeks, streams, rivers, or lakes within riparian areas.

2.2.1. Cattle behaviour in riparian areas

Cattle have been found to spend a disproportionate amount of time in the riparian area as compared to adjacent uplands (Kauffman and Krueger 1984; Kie and Boroski

1996). Belsky et al. (1999) report that due to the availability of water, abundant forage, and shade, cattle spend five to thirty times more time in the riparian area than would be predicted from the size of the area alone. Although riparian areas make up only a small portion of the overall grazing area (1-5%), they have the capability of providing 20-21% of forages available for grazing (Roath and Kreuger 1982a; Thompson and Hansen 2002). Many of the sedges found in riparian areas have higher protein and energy content than key forage species found in adjacent uplands (Skovlin et al. 1976). Roath and Krueger (1982a) observed that the pattern of vegetation use changed as the grazing season progressed. Early in the grazing season, cattle grazed shrubs the least when the herbaceous vegetation was lush and very palatable. Later in the grazing season, utilization of the shrubs increased, when the herbaceous vegetation was coarse and mature. Further, utilization of the riparian area may increase as the grazing season progresses. Later in the grazing season, cattle may prefer riparian vegetation as it tends to be more palatable and nutritious than vegetation in the upland area (Kauffman and Krueger 1984). Vavra and Phillips (1979) studied the intakes of fistulated heifers grazing in the riparian area from late August to early September. Their results showed improved dry matter digestibility, improved protein levels, lowered acid detergent fibre, and lowered lignin content when the heifers grazed the riparian area compared to when they were grazing the upland area.

In addition to providing a source of nutrients, the shade provided by trees in riparian areas help to cool animals and may attract cattle to these areas (Stuth 1991). Franklin et al. (2009) found that cattle in the Georgia Piedmont region spent a greater proportion of time in the riparian area and the stream when the temperature and humidity index (THI) were high (72 – 84). In pastures in the Panhandle of Oklahoma, where the average summer temperature was 25°C and little shade was available in the upland, McIlvain and Shoop (1971) found that cattle would arrive at their watering spot in the riparian area at 9:30 am and remain there until 4:30 pm. Several other studies have demonstrated that cattle will typically move to a stream or other watering location in the morning, and remain in the area until evening (Porath et al. 2002; Parsons et al. 2003; Bailey 2004). Gillen et al. (1984) found that cattle preferred to remain within 200 meters (m) of their water source. The distance that cattle must travel to water has a significant influence on their distribution patterns throughout a pasture (Roath and Krueger 1982a; Dickard 1998).

2.2.2. Strategies to monitor cattle behaviour

A variety of strategies have been utilized to monitor animal behaviour. Two possible strategies include visual observations (VO) to record animal behaviour and location, while global positioning system (GPS) collars have been used to record animal location only. Furthermore, quadrat sampling can give an indication of the amount of forage biomass available for grazing throughout the season. Knowing that cattle distribution is influenced by forage availability, combining these strategies may give an accurate picture of animal behaviour relative to their location and the availability of forages. Understanding behaviour will provide insight into strategies to limit access to riparian areas.

2.2.2.1. Visual observations

Visual observations have been utilized by researchers to record the behaviour and/or location of cattle (Gillen et al. 1984; Miner et al. 1992; Sheffield et al. 1997; Porath et al. 2002; Ballard and Krueger 2005; Bailey et al. 2008). The length of the observation period and frequency of observations varies according to the requirements of the trial. Gillen et al. (1984) drove along designated routes from dawn until dusk every three days recording cattle distribution. The number of cattle, cattle activity, and location were recorded. Porath et al. (2002) recorded VO every three hours over six days to determine the physical distribution of the cattle herd throughout the daylight hours of 0600 hour (h) and 2100 h. Large numbers were painted on each cow so they could be individually identified. Ballard and Krueger (2005) identified 13 different behaviours and seven different areas in the study site. Observers recorded cattle activity and distribution relative to the seven designations. Observations were recorded from 0700 h to 1900 h for eight of the 12 hours; six days at the start, six days in middle, and six days at end of grazing season. Results from their observations indicated that cattle spent approximately 94% of their time in terrestrial habitats during herbivory-type activities, such as travelling, resting, or grazing, and the remainder of their time (6%) was spent in stream habitats, which included gravel bar (5%) and aquatic habitat (1%). While in the aquatic habitat, cattle spent over half of the time drinking and less than 0.01% of time defecating. Further, cattle were never observed in direct contact with a salmon redd, which is the area in a stream where salmon deposit their eggs. Bailey et al. (2008) recorded VO in the morning from 0630 h to 0800 h and the evening from 1900 h to 2030 h for 12 days in 2002, 24 days in 2003 and 26 days in 2004. Observers would drive along designated routes and stop at specified locations to record the number of cattle in each pre-established grid. Results from their observations indicated that free roaming cattle spent more time (44% ± 19%) in the riparian area than herded cattle (23% ± 6%).

Visual observations are a useful tool to learn about cattle behaviour and/or location, but they may be prone to error for several reasons including observer fatigue, the physical presence of the observer on animal behaviour (Pandey et al. 2009), and physical limitations or uncontrollable factors such as weather and light (Turner et al. 2000). Due to these limitations, combining VO with other tools such as GPS collars can provide more accurate and precise information.

2.2.2.2. Global positioning system

Researchers have used GPS collars to track the movement and learn about the behaviour of free ranging animals (Ganskopp et al. 2000; Turner et al. 2000; Ganskopp 2001; Ungar et al. 2005; Tomkins and O'Reagain, 2007; Bailey et al. 2010). This technology has also been utilized specifically to track cattle movement in riparian areas (Bailey et al. 2008; Franklin et al. 2009; Pandey et al. 2009; Schwarte et al. 2011). Bailey et al. (2008) fitted cattle with Lotek GPS 2200 collars to record locations every 15 minutes for a collection period of 27 to 29 days. The GPS data was differentially corrected from a base station located near the research site to improve accuracy. Using differential correction, Moen et al. (1997) obtained values that were accurate within 5 m; while Ganskopp and Johnson (2007) reduced the mean bias of GPS positions from approximately 4 m to 2 m, where bias is defined as the difference between measured distances and distances derived from GPS coordinates. Franklin et al. (2009) examined the accuracy of Lotek GPS 2200 collars. Two collars were placed at a pre-established United States Geological Survey (USGS) benchmark. After two weeks, the collar data was differentially corrected, and after correction, 95% of the collar data was accurate to within 3 m of the USGS benchmark.

The use of GPS collars can eliminate the errors that may arise in VO; however, GPS technology is not without limitations as well. Two primary issues are location error and missed location fix. Location error is the difference between the animal's actual location and the recorded GPS location (Swain et al. 2008). Missed location fixes arise when the GPS collar is unable to acquire and record the location (D'Eon 2003). Interference from the satellite to the GPS collar by vegetative cover, topography, or atmospheric conditions increases the likelihood of location error and missed fix locations (Lewis et al. 2007).

2.2.2.3. Forage biomass

A common strategy to measure the amount of forage is through quadrat sampling (Ominski et al. 2006; Brosh et al. 2006). Quadrats are randomly placed at nine locations in an M-pattern in each area throughout the study site and the forage within the quadrat is clipped to ground level (Ominski et al. 2006). The samples are later dried to determine forage biomass on a dry matter basis.

2.3. CATTLE IMPACT TO RIPARIAN STRUCTURE AND FUNCTION

Riparian areas are highly diverse, dynamic and complex biophysical habitats (Naiman and Décamps 1997) that contribute a variety of environmental functions. A "healthy" riparian area is one that is able to perform normal functions, which includes maintaining diverse vegetation, preserving stream channel stability, slowing overland water flow, filtering nutrients and sediment, and maintaining wildlife biodiversity (Thomas et al. 1979; Kauffman and Krueger 1984).

2.3.1. Diversity of riparian vegetation

Riparian vegetation, which includes trees, shrubs, vines, grasses, and forbes, varies with the associated topography, climate, and runoff of the region (National Research Council 2002). In each region, the riparian area contains diverse species of vegetation which are specialized or have adapted to live within the unique ecosystem. The vegetation present in the riparian area may fall into one of three categories: 1) preferred species; 2) disturbance-caused undesirable species; and 3) invasive species (Alberta Riparian Habitat Management 2008). Preferred species are those that would be present in the area with natural disturbance. Some examples include cottonwood (*Populus deltoids*), willow (*Salix* species), dogwood (*Cornus sericea* subspecies *sericea*), reed canary grass (*Phalaris arundinacea*), and sedges (*Carex* species). Disturbance-caused undesirable species includes nuisance weeds and other species that increase with non-natural disturbances, such as heavy cattle usage. These species are considered undesirable as they do not perform optimal riparian functions. Some examples include foxtail barley (*Hordeum jubatum*), sweet clover (*Melilotus officinalis*), dandelion (*Taraxacum officinale*), and Kentucky bluegrass (*Poa pratensis*). Invasive species are usually considered noxious weeds. Some examples include common burdock (*Arctium* species), Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia cyparissias*), and purple loosestrife (*Lythrum salicaria*).

Through grazing in the riparian area, cattle can remove and trample vegetation. Vegetative species that decline due to grazing are commonly damaged by removal of the photosynthetic and reproductive organs, or are unable to withstand trampling (Belsky et al. 1999). Vegetative species that typically increase with grazing are usually invasive or disturbance-caused undesirable species which benefit from the disruption associated with competition between species (Green and Kauffman 1995) or by the drier soil conditions caused by grazing (Belsky et al. 1999). Although an increase in undesirable or invasive species gives the impression of increasing species richness and diversity, they have the potential to change wildlife habitat and ecosystem processes, thus reducing native biological diversity, causing homogenization of the native landscape and loss of wildlife (Bock et al. 1993). Dobson (1973) found an increase in species diversity when a riparian area in New Zealand was grazed. He reported that grazing removed some existing vegetation, creating more niches where weeds could establish themselves. Typically, any reduction in preferred riparian species is considered as negative or as an indication of a decrease in riparian health (Ohmart 1996; Thompson and Hansen 2002). Cattle also tend to selectively graze, choosing more palatable species, thus leaving the less palatable species to increase in dominance, contributing further to a reduction in species diversity (Skovlin et al. 1976).

Grazing can also have an impact on woody vegetation as cattle will graze seedlings and saplings, thus causing the woody vegetation to be of similar age with limited reproductive capacity (Carothers 1977). Marcuson (1977) found that shrub production was 13 times greater in an ungrazed area than in a severely overgrazed area.

Beyond contributing to species richness and biodiversity, riparian vegetation serves to maintain streambank stability (Smith 1976; National Research Council 2002), decrease the velocity of surface water runoff, decrease erosion, trap sediment and nutrients (Naiman and Décamps 1997; National Research Council 2002), and provide habitat and food for wildlife (Thomas et al. 1979; Kauffman and Krueger 1984). The importance of riparian vegetation is described further in the structures and functions that follow.

2.3.2. Stream channel morphology and water tables

Stream channel morphology refers to the physical confine of the stream or river which consists of a streambed and streambanks. Stream channel stability is defined by Rosgen (1996) as “the ability of a stream, over time, in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without either aggrading or degrading". Aggrading refers to the deposit of material along the stream channel, while degrading refers to the erosion of material. Stream channels within riparian areas that have not been carefully managed are prone to accelerated erosion and channel incisement, resulting in stream channel instability.

Preferred species of riparian vegetation have deep and binding root systems that bind substrate particles and reduce erosion, therefore helping to maintain stream channel stability. As a result, removal of the vegetation by cattle grazing or trampling can impact stream channel morphology and contribute to elevation of the water table (Trimble and Mendel 1995; Magner et al. 2008).

Absence of vegetation in the riparian area can greatly increase the incidence of erosion. When examining pre-flood and post-flood photos of 748 bends in four streams in British Columbia, Beeson and Doyle (1995) found that bank erosion was 30 times more prevalent on non-vegetated banks, as compared to vegetated banks. Furthermore, the non-vegetated banks were five times as likely to have been subject to major erosion as compared to vegetated banks. Smith (1976) used a specially designed erosion box which simulated natural erosion to compare vegetated banks to non-vegetated banks in Banff, Alberta. His results showed that vegetated banks were 20,000 times more resistant to erosion than non-vegetated banks.

Excess erosion due to grazing and trampling of vegetation can impact the morphology of the stream channel. Magilligan and McDowell (1997) examined the morphological changes in a stream after cattle were excluded for 14 years. They noted a 10% to 20% decrease in bankfull width (the maximum width of the stream), which they attributed to the presence of riparian vegetation. Hayes (1978) found that when the removal of riparian vegetation exceeds 60%, there is an increase in streambank erosion, resulting in a stream channel that is narrower and deeper.

Vegetation and debris in riparian areas can help to reduce the energy of overland runoff and surface water as it flows throughout the area. Plant structures, including the stem and the root mass, serve to slow the velocity of the water thereby decreasing the power of the body of water. The stem is most effective when the water level is high, while the root mass is more effective when water level is low (Naiman and Décamps

1997). Stevens et al. (1992) found that as vegetative ground cover increases, runoff decreases. The same is true in reverse; when vegetative ground cover decreases, runoff increases. Debris, such as boulders, logs and branches, also slow the movement of water across the riparian area (Gregory et al. 1991).

Riparian vegetation that is not heavily grazed or trampled by cattle may help slow the overland flow of water, thus promoting greater water infiltration into the soil (Belsky et al. 1999). A reduction in infiltration has two major impacts on riparian health. First, less infiltration may result in greater peak runoff. Trimble and Mendel (1995) estimate that peak runoff during a storm would be two to three times greater when vegetation was removed due to heavy grazing, compared to when increased vegetation remained from light grazing. Greater peak runoff can increase erosion, resulting in greater incisement of the stream bank. Secondly, a reduction in infiltration may lower the water table; subsequently leaving the roots of riparian vegetation in drier soil, a condition that some vegetative species may not survive (Belsky et al. 1999).

2.3.3. Soils in the riparian area

As cattle move throughout the riparian area, they cause pugging, rutting, and hummocking which contribute to soil compaction and erosion in the riparian area. Pugging, rutting, and hummocking can provide an indication of the extent of soil compaction and is defined in “Managing the Water’s Edge – Riparian Health Assessment for Streams and Small Rivers” (MRAC 2004). Pugging is the large tracks that animals leave in the soil, resulting in a honeycomb appearance which leaves an irregular surface that is difficult to walk on. Rutting refers to animal paths, where high animal traffic causes significant soil compaction. Hummocking describes areas of raised soil that are 15 to 60 centimeter (cm) above the surrounding soil. As the severity of pugging, rutting and hummocking increases, so does soil compaction, thus increasing the risk for erosion.

Soil compaction from hoof action causes a reduction in macro pore space (portion of soil volume which is not occupied by soil solids, but by air), resulting in reduced root growth and overall plant production (Bryant et al. 1972), as well as reduced infiltration and greater surface runoff (Magner et al. 2008). Smith (1967) found that water infiltration rates increased 60% in cattle-excluded areas, whereas infiltration rates decreased in areas where cattle grazed, regardless of grazing intensity. Kauffman et al. (1983) found that trampling had the greatest impact on vegetation where soil was saturated and prone to compaction or in loose, gravelly soils where vegetation could be easily uprooted.

Sediment, recognized as one of the most prevalent and damaging pollutants of North American streams (Waters 1995), is a result of increases in erosion and overland runoff, as well as decreases in streambank stability; all of which may occur as a result of soil compaction. As the sediment load in the stream increases, the stream morphology may be altered as the sediment settles, gradually decreasing the stream depth (Sidle and Sharma 1996). Sedimentation has been found to be significantly greater in grazed riparian areas than ungrazed riparian areas (Kauffman and Krueger 1984). White et al. (1983) found that sediment yield was 20 times higher in a grazed watershed than in an ungrazed watershed. In a study in New Zealand, Williamson et al. (1996) found sediment loads to decrease by 85% when cattle were excluded from grazing in the riparian area of perennial streams, erosion prone hills, and pockets of native forest. At locations where cattle enter and exit the stream, damage can occur to the streambank as the force from their hooves may shear off slices of bank material, thus increasing the sediment load (Trimble and Mendel 1995).

2.3.4. Water quality in riparian areas

Riparian areas have the ability to buffer nutrient discharge from surrounding agricultural practices. Two nutrients of primary concern are nitrogen, which is usually dissolved in water, and phosphorus, which is often bound to sediment (National Research Council 1992). Plant uptake is one mechanism by which this is accomplished. Nutrients are accumulated for shorter periods in non-woody plants, such as grasses, and long term in woody plants, such as trees (Naiman and Décamps 1997). Particle, carbon, nitrogen, and phosphorus retention has been found to be higher in trees than in grasses (Sovik and Syversen 2008). Nutrient uptake may be increased in riparian areas because the level of transpiration may be higher, thus facilitating nutrient flow towards the vegetative root mass (Naiman and Décamps 1997). As well, vegetative species growing in these areas are more tolerant to high water levels and have adapted such that they are able to take up nutrients in low-oxygen conditions (Naiman and Décamps 1997). A study in the coastal plains of Georgia found that the riparian forest retained 65% of the nitrogen and 30% of the phosphorus from the surrounding agricultural land (Lowrance et al. 1984).

2.3.4.1. Nitrogen and phosphorus

Although the riparian area functions to uptake and filter certain pollutants, the presence of cattle in the riparian area can contribute to a decline in water quality as they contribute to increases in nutrient concentrations, specifically nitrogen and phosphorus.

Cattle can deposit feces directly into the stream as they drink, graze, or loaf along the stream (Miner et al. 1992). Cattle can also deposit feces in the riparian area, where nutrients may enter the stream via runoff. If nitrogen and phosphorus are in excess, they stimulate algal blooms, leading to low dissolved oxygen levels which endanger aquatic organisms (Belsky et al. 1999). Schepers and Francis (1982) found the concentrations of ammonium-N, nitrate-N, total phosphorus, and soluble phosphorus in runoff to be 6%, 45%, 37%, and 48% higher, respectively, when grazing livestock were present compared to when cattle were absent. Johnson et al. (1978) found manure concentrations to be much higher in certain areas of the pasture, including water troughs, gates, fence lines, and bedding areas. Mathews et al. (1994) found that nitrogen and phosphorus from manure accumulate near shade, water sources, and supplemental feeding areas. If cattle are using the riparian area as a water source or for shade, there is the potential for increased manure to be deposited in this area (Miner et al. 1992), where the accumulation of nitrogen and phosphorus may enter the body of water via runoff.

Excess concentrations of nitrate and nitrite (compounds that contain nitrogen) in livestock water sources can cause toxicity, however nitrite is more toxic than nitrate, as nitrate must first be reduced to nitrite by rumen bacteria. Nitrite is absorbed into the bloodstream and converts haemoglobin to methaemoglobin, reducing the oxygen carrying capacity of blood (Olkowski 2009). Prolonged insufficiency of oxygen can lead to metabolic derangements, or even death.

Although cattle may contribute to increased nitrogen and phosphorus concentrations, there are also a number of naturally occurring processes that cause fluctuations in nitrogen and phosphorus concentrations throughout the season without the presence of cattle. During the winter, when temperatures decline, nutrient uptake slows or stops (Groffman et al. 1992; Naiman and Décamps 1997). Furthermore, when riparian vegetation freezes during winter, nutrients can be returned to the stream when the plant structures drop and decompose in the water (Hanson et al. 1994; Thompson and Hansen 2002, Räty et al. 2010).

The freeze-thaw cycle that commonly occurs in colder climates, such as Manitoba, can impact nutrient retention, specifically phosphorus. Excessive phosphorus is of particular concern as it contributes to the overproduction of algae in lakes, which can lead to eutrophication (Dorioz et al. 2006). In spring, snowmelt results in saturated soils in the riparian area and increases in surface runoff over the area. Schwer and Clausen (1989) found that when surface runoff increased five-fold, the retention of phosphorus decreased seven-fold. Furthermore, Pearce et al. (1997) found the efficacy of grass buffer zones is negligible when the depth of surface runoff is higher than the vegetation, which is common during periods of snowmelt. Research by Schellinger and Clausen (1992) found similar results where mass retention of suspended solids, nitrogen, and phosphorus was highest during the growing season and lowest during snowmelt. They concluded that the higher level of fast moving surface runoff from the snowmelt prevented adequate retention time for nutrient uptake.

As plant cells become damaged during freezing and drying, the plant cells lyse, accelerating the release of phosphorus, thus increasing the loss of phosphorus in surface runoff (Bechmann et al 2005). Uusi-Kämppä (2005) found the mean annual load of molybdate-reactive phosphorus (MRP) (dissolved orthophosphate phosphorus that is thought to be readily available for uptake by algae) to be 70% higher in riparian buffer zones with natural vegetation than riparian buffer zones that were annually harvested or cultivated fields without buffer zones. As well, the different physiological changes that a plant undergoes will impact the amount of MRP that is released from the plant material. Roberson et al. (2007) found that alfalfa released increasing amounts of MRP when subject to the following treatments: untreated, fresh plant $<$ frozen $\leq$ frozen/thawed $<$ dried. The MRP released from each treatment was 1%, 8%, 14% and 26% of total plant phosphorus, respectively.

2.3.4.2. Fecal coliforms

Cattle feces contains fecal coliforms, such as *Escherichia coli*, and direct fecal deposition or runoff containing coliforms can result in increases in coliform levels in water. Contamination of water with fecal coliforms increases the risk of human infection if the water is used for drinking, bathing, or watering fruits and vegetables (Hubbard et al. 2004). Larsen et al. (1994) found that when cattle feces was deposited directly into the stream, there was a greater impact to water quality than when it was deposited within 2.5 m of the stream. They concluded that a 95% reduction in bacterial loads was possible if a minimum distance of 2.5 m was maintained between the feces and the stream. However, runoff from snowmelt or rainfall can transport coliforms from feces into the stream and high coliform levels have been linked to runoff from grazed pastures (Doran and Linn 1979; Larsen et al. 1994).

As sediment binds fecal coliforms, sediments at the bottom of the stream can act as a reservoir for these organisms. *E. coli* concentrations have been found to be 100-1000 times greater in bottom sediments than in overlying waters (Van Donsel and Gelreich

1971; Stephenson and Rychert 1982). When cattle enter the stream to cross or seek relief from the heat, they can stir up the sediment, resulting in higher *E. coli* concentrations from their re-suspension (Stephenson and Rychert 1982).

Contamination of the livestock water source with *E. coli* and fecal material is of concern as it has the potential to reduce palatability, causing a decrease in water consumption and weight gain (Holechek 1980). Furthermore, a particular strain of *E. coli* (non-O157 enterohaemorrhagic *E. coli*) has been found to cause dysentery in young calves (Fairbrother and Nadeau 2006).

2.3.5. Riparian and aquatic wildlife

Despite the small proportion of land that riparian areas occupy, they play a significant role in maintaining wildlife diversity in both terrestrial and aquatic ecosystems (Naiman et al. 1993), as they are a source of food, water, and cover for wildlife (Thomas et al. 1979). As a consequence of the important role they play in maintaining species diversity, riparian areas meet the criteria of critical habitat under Canada's Species at Risk Act (SARA) and the United States Endangered Species Act (ESA) (Richardson et al. 2010). In the Great Basin of south-eastern Oregon, 299 of the 363 terrestrial species that occur in the riparian area are directly dependent on this ecosystem (Thomas et al. 1979). Of the animal and plant species listed on Wisconsin's endangered species list, 80% live in the riparian areas surrounding lakes (Korth and Cunningham 1999).

The shrubs and trees in the riparian area also provide refuge to small mammals and nesting locations for birds (Naiman and Décamps 1997). Beyond providing habitat, many species use these areas as corridors during migration (Gregory et al. 1991; Barling and Moore 1994; National Research Council 2002). A study by Beier (1993) demonstrated that the cougar population could benefit by maintaining corridors which allow for travel between different fragmented habitats.

Populations of wildlife species that are dependent on riparian areas may be reduced or completely disappear when riparian vegetation is eliminated. A study by Henke and Stone (1978) showed that where riparian vegetation was replaced by large rocks placed along the streambank, there was a 93% reduction in the bird population and a 72% reduction in the diversity of avian species. In areas previously occupied by riparian forest, there was a 95% reduction in the bird population and a 32% reduction in the diversity of avian species when changed to cultivated land.

Conversely, wildlife numbers may recuperate when heavily grazed riparian areas were fenced and given time to recover. Duff (1979) found that the usage of the riparian area by songbirds and raptors increased by 350% after eight years of rest from grazing. Van Velson (1979) found increased pheasant production and deer populations in an area excluded from cattle grazing. Furthermore, waterfowl production took place for the first time in the excluded area. When comparing a riparian area that was free from grazing for seven years to an adjacent riparian area where grazing was allowed, Crouch (1982) found an increase in ducks and upland game animals, and twice as many terrestrial birds in the rested area. However, the grazed areas had significantly more aquatic birds, and this is believed to be a result of shorter vegetation, reduced shrub cover, and increased proportions of sandbars and shallow water that are associated with grazing.

In addition to providing habitat, riparian areas are a critical food source for invertebrates from all levels of the food chain. Organic matter, such as leaves and stems, fall into the stream, providing food for aquatic invertebrates (National Research Council 2002). Riparian vegetation contributes 99% of the stream energy as material available to heterotrophs, while the remaining 1% is provided by photosynthetic algae and mosses, which are autotrophs (Cummins 1974). The vegetation in this zone also attracts insects which are a source of food to some terrestrial invertebrates or, if the insects enter the stream, to aquatic invertebrates (Barling and Moore 1994). Over 99% of energy and organic carbon in food webs of streams are provided by the surrounding riparian forests (Fisher and Likens 1973), which is critical to maintaining aquatic species. Species with semi-aquatic habits, like the water shrew, star-nosed mole, beaver, river otter, and mink, use riparian areas as it provides food sources that are critical to their survival (DeGraaf and Yamasaki 2000).

2.4. VISUAL ASSESSMENTS TO MEASURE LIVESTOCK IMPACT IN RIPARIAN AREAS

To effectively manage riparian areas, it is necessary to determine the status and condition of the area, as well as to help measure the success of different management strategies. A variety of methods can be utilized to monitor changes in riparian health including visual assessments.

Platts et al. (1983) developed “Methods for evaluating stream, riparian and biotic conditions” to measure changes in the riparian area. Streamside cover, which is considered to be all the material on or above the streambank, is given a rating of 1 to 4 based on the type of dominant vegetation (shrub, tree, grass or forb, or >50% has no vegetation) with shrubs ranking the highest. Vegetative use by animals is visually assessed and is estimated based on plant height and the amount of bare ground. Use ranges from low (0% to 25% of vegetation) to very high (76% to 100% of vegetation). Vegetative overhang measures only the plants hanging over the water body. The overhang is measured from the furthest streambank protrusion in the water to the end of the vegetation that hangs over the waterway. The streambank stability is determined, in part, by the amount and type of vegetation on the bank, with bare earth being more prone to erosion and some species of plants having greater root binding capacity than others. McInnis and McIver (2001) utilized this method to determine the efficacy of off-stream waterers (OSW) and trace mineralized salt on minimizing cattle impact to the riparian area along Milk Creek in Eastern Oregon.

Another assessment tool has been developed which provides landowners, agricultural producers, researchers, and agency staff with a means to assess riparian health called “Managing the Water’s Edge – Riparian Health Assessment for Streams and Small Rivers” (MRAC 2004). It is a Manitoba field guide which has been modified from the “Riparian Health Assessment for Streams and Small Rivers – Field Workbook” (Fitch et al. 2001). This guide, combined with classroom and field training, provides the basics for visual assessment of riparian health and to identify any issues, along with their scale and magnitude (MRAC 2004). Miller et al. (2010a; 2011) used this tool to measure the efficacy of streambank fencing on the Lower Little Bow River in Southern Alberta.

After identifying a length or reach of the stream to assess, the assessment provides six vegetation factors and five soil and hydrology factors that the user must visually assess to determine riparian health. The vegetation factors include vegetative cover of the floodplain and streambanks, the density and distribution of invasive plant species, disturbance-increaser undesirable herbaceous species, preferred tree and shrub establishment and regeneration, and the utilization of preferred trees and shrubs. The soil and hydrology factors include standing decadent and dead woody material, streambank root mass protection, human-caused bare ground, human alteration of streambanks, pugging, hummocking, and rutting, and stream channel incisement.

Each of the mentioned factors are given a score based on percent of the assessed area that is covered, influenced, or affected by vegetation and/or structural changes. The scores from each factor are totalled and the final score is placed in one of three categories: healthy (80% to 100%), healthy but with problems (60% to 79%) and unhealthy (<60%). A healthy score indicates that the riparian area is performing all functions and that these functioning areas are resilient and stable. Healthy but with problems indicates that many riparian functions are being performed, but there is some stress and the functions may not operate at their full capability. Unhealthy indicates that most functions are severely impaired or have been lost.

Lastly, the “Rangeland Health Assessment for Grassland, Forest and Tame Pasture” utilizes five rangeland health criteria (Adams et al. 2005). Ecological status compares the current plant community to the reference plant community (which is considered the potential natural community) to determine the following: 1) degree of modification due to disturbance; 2) community structure (presence of desirable plant species); 3) litter present on the soil (contributes to moisture retention); 4) site stability (potential for accelerated erosion and human caused bare ground, arising from recreational use or livestock grazing); and 5) noxious weeds (density and distribution of invasive plants). Thereafter health scores can be calculated with a score of <50%

classified as unhealthy, 50% to 75% as healthy with problems and 75% to 100% as healthy.

2.5. STRATEGIES TO MODIFY CATTLE BEHAVIOUR

To decrease negative impacts to riparian areas, strategies to modify cattle behaviour, thereby reducing the time spent in riparian areas, may include complete exclusion via fencing, partial exclusion via barriers, grazing management, culling, herding, and the use of OSW.

2.5.1. Complete exclusion via streambank fencing

Completely excluding cattle from the riparian area via streambank fencing can improve the health of the ecosystem (Mostaghimi et al. 2001), resulting in improvements such as increases in height and vigour of riparian vegetation (Kauffman et al. 1997), increased leaf litter accumulation, and decreased bare ground (Sarr 2002; Miller et al. 2010a). A variety of studies have also shown that complete exclusion via streambank fencing can significantly reduce nutrient and sediment concentrations and loading rates (Owens et al. 1996; Line et al. 2000; Meals 2001). Line (2003) found that fecal coliform and enterococci levels decreased 65.9% and 57%, respectively, after completely excluding cattle via streambank fencing.

On the Lower Little Bow River in Alberta, Miller et al. (2010a; 2010b) studied the efficacy of cattle exclusion via streambank fencing with a cattle crossing. An 800 m length of the river was fenced on both sides of the river, with one cattle crossing which allowed cattle to cross the river to access the pasture on either sides. Two OSW were located adjacent to the fence on either side of the river, and water was pumped from the river to the OSW. Using the "Riparian Health Assessment for Streams and Small Rivers – Field Workbook" (Fitch et al. 2001), the health of the riparian area was compared before the beneficial management practice (BMP) was established in 2001 (pre-BMP) and after it was established (post-BMP) in 2005. Miller et al. (2010a) found that riparian health improved from a score of 65% (healthy with problems) to 81% (healthy), thus demonstrating that exclusion fencing improves riparian health. Water samples taken upstream and downstream of the site during streambank fencing were not significantly different, indicating that cattle exclusion via streambank fencing prevented water quality from deteriorating downstream.

Another study by Miller et al. (2010b) conducted at the same site from 2005 to 2007 hypothesized that streambank fencing would improve rangeland health and vegetative and soil properties in cattle excluded pastures, compared to adjacent grazed pastures. Further, they hypothesized that the streambank vegetation within the fenced area would act as a buffer strip, decreasing the surface depth of runoff and trapping nutrients, thereby limiting entry into the Lower Little Bow River. Using the "Rangeland Health Assessment for Grassland, Forest and Tame Pasture" (Adams et al. 2005), assessments were completed annually over the three year study. Results of the assessment indicate that streambank fencing improved the score of rangeland health, from 55% in the grazed pastures to 72% in the ungrazed pastures. Furthermore, streambank fencing significantly ($P \leq 0.10$) increased vegetative cover from 13% to 21% and standing litter from 38% to 742%. The amount of bare soil decreased from 93% to 72% and soil bulk density was reduced from 8% to 6%. Other vegetation properties, including total live basal area and fallen litter, and soil properties, including soil water and soil nutrients (carbon, nitrogen, and phosphorus) did not improve. Rainfall simulations were conducted annually to measure surface depth and nutrient concentrations from runoff. Cattle exclusion improved the ability of the fenced pasture to act as a buffer strip, as the depth of surface runoff was reduced by 32% to 21%, indicating that the buffer strip may be effective at reducing runoff into the adjacent river. Mass loads of total nitrogen were reduced by 52% to 21%, further indicating that the riparian vegetation within the fenced pasture was acting as a buffer and filtered nitrogen from the runoff. The authors speculated that the volume of runoff decreased and infiltration increased as a result of greater vegetation cover and standing litter, as well as decreased bare soil and lower soil compaction.

In some instances, cattle exclusion via streambank fencing may be the only effective management strategy and can restore riparian health rapidly (Fitch and Adams 1998). Although effective, cattle exclusion via streambank fencing is expensive and reduces access to large areas of pasture. For these reasons, streambank fencing is generally not well received by livestock producers (Swanson 1986). As well, cattle exclusion via streambank fencing gives the impression that cattle and riparian areas cannot be managed to exist harmoniously, which is ultimately the goal of landscape management (Fitch and Adams 1998).

2.5.2. Partial exclusion via strategic fencing or barriers

An alternative to completely excluding cattle from the riparian area via fencing is to partially exclude cattle by installing strategic fencing or barriers at drinking and crossing locations. When compared to fencing the entire stream, establishing fencing or barriers at these drinking points would substantially reduce the cost and allow cattle to access a greater area of pasture. Barriers, such as fallen trees or large boulders may be used to deter cattle from drinking at the stream. Planting dense or thorny hedges with low palatability, such as hawthorns or rose bushes, may deter cattle from using the riparian area (BCMAFF 2003). Further research is required to determine the efficacy of this strategy as cattle may create new access points along the stream (Veira 2007).

2.5.3. Grazing management

Alternative grazing and management strategies may also be employed as a strategy to improve riparian health, without compromising animal productivity (Thompson and Hansen 2002). Specifically, controlling the timing and duration of grazing may serve to alter cattle distribution and utilization of vegetation in the pasture. Early season grazing can be effective at reducing the amount of time cattle spend in riparian areas because: 1) there is abundant forage available upland, 2) cooler temperatures discourage cattle from riparian areas and warmer temperatures attract them to upland areas, and 3) well-drained soils will be less prone to compaction (Clary and Booth 1993). However, early grazing may impact the cover, density, and composition of the vegetation as grazing occurs during the critical growth period (DelCurto et al. 2005). As well, high soil moisture associated with spring runoff and high rainfall may leave the soil susceptible to compaction, sloughing, and erosion (Marlow and Pogacnik 1986). Midsummer grazing may provide some advantages because of lower soil moisture content, which reduces the potential for compaction, and abundant availability of palatable forages compared with upland areas (DelCurto et al. 2005). However, there are also numerous disadvantages associated with midseason grazing of riparian areas. Increased plant maturity in the upland area and increased temperatures serve to move cattle to the riparian area, leading to overgrazing of these areas (DelCurto et al. 2005). Due to variability between grazing sites, the ideal timing and duration of grazing must be determined on a per site basis in order to mitigate impact on the riparian area.

2.5.4. Culling

Cattle herds are composed of social “subherds” that can impact cattle distribution throughout the pasture. Each subherd has an area within the pasture where they prefer to remain while engaged in their usual activities and this area is known as the home range (Burt 1943). The home range of subherds tends to remain consistent from year to year (Sowell et al. 1999). Individuals within the subherd are leaders, and they often initiate an activity which the majority of the herd is not engaged in, such as grazing, travelling, or resting, causing the other animals to follow (Sowell et al. 1999). The leaders typically move towards a particular direction with a purpose in mind, such as locating resources like water and forages within the pasture (Greenwood and Rittenhouse 1997). Howery et al. (1996) studied a herd of cattle with four home ranges within the pasture. They found that individual cows occupied one of the four home ranges, and that the majority of the herd (78%) were consistently within one of the home ranges. Their results indicated that subherds from a particular home range spent more time in the riparian area than others, while another subherd preferred to spend more time in the upland pasture.

Just as livestock producers cull animals for herd improvement, it has been suggested that culling cattle that tend to frequent the riparian area could minimize impact to the area (Roath and Krueger 1982b; Howery et al. 1996). Culling animals that frequent the riparian area or herd leaders that direct the herd to the riparian area could help to develop a herd that preferred the upland pasture as their home range. However, the effectiveness of this strategy is not well understood. In the absence of a herd member who frequents the riparian area, the vacated spot may be replaced by another herd member (Sowell et al. 1999). Furthermore, Howery et al. (1998) concluded that offspring tended to use similar locations and habitats as that of their dams when environmental or social factors did not influence them otherwise. If using selective culling, producers must ensure that the replacement heifers were not raised by cows whose home range included the riparian area, as the replacement heifer will likely behave similarly to the culled mother, returning to their preferred home range (Sowell et al. 1999).

2.5.5. Herding

Herding has been used for centuries to manipulate cattle distribution across rangelands. Herding cattle may be an effective strategy to minimize the amount of time spent in the riparian area, thus mitigating the potential for damage (Butler 2000; Bailey 2004). Butler (2000) has outlined a strategy by which cattle were allowed access to the water in the morning. Once the majority of the herd had drunk, the herd was moved to an upland area where the cattle grazed or settled in a shady spot. This strategy must be used in conjunction with an OSW or the cattle will return to the stream. In absence of the herder for a couple of days, cattle will return to the riparian area.

Herding may also be used with or without the placement of minerals to further manipulate cattle behaviour. Bailey et al. (2008) utilized herders on horseback to move cattle to the upland area at midday. One upland area was supplemented with mineral and the other was not supplemented. They found that herding cattle to the upland area reduced animal usage of the riparian area. There was no difference in riparian usage when supplement minerals were placed in the pasture; however, there was an increase in forage utilization in the upland with mineral supplementation. Although research shows that herding may help to decrease cattle usage of riparian areas, its usage is limited as it requires extra labour and many producers question whether the animals will return to the stream after being moved (Bailey 2004).

2.5.6. Off-stream watering systems

To determine the impact of the location of hay placement on OSW use by cattle during the winter months, Miner et al. (1992) compared a control paddock (access to stream only) with an experimental paddock (access to OSW and stream). The source of water for the OSW was a well from a nearby homestead. For an eight-day period, from 0730 h to 1700 h, the number of cattle standing in the stream (in both the control and experimental pastures) and the number of cattle standing at OSW was recorded every 60 seconds. The OSW was placed about 90 m from the stream. During the first four days of observation, the OSW was in between the hay and the stream. During the last four days of observation, the hay was placed between the OSW and the stream. Access to the OSW resulted in a 90% reduction in the amount of time spent in the stream. When the hay was placed so the distance between the stream and the OSW was the similar, access to the

OSW was still effective in reducing the amount of time spent in the stream. Miner et al. (1992) further speculated that reducing time spent the stream by 90% would result in a reduction in fecal and nutrient loading in the stream.

Clawson (1993) utilized visual and video observations to examine the amount of time cattle spent in each of three areas: the OSW, the stream, and the spring (referred to as the bottom area) in a mountainous riparian area. The size of the pasture was 118.6 hectares (ha). The OSW, stream, and bottom were utilized as the water source for 73.5%, 23.5%, and 3% of the total number of visits, respectively. Installation of the OSW resulted in an 85% reduction in time spent in the stream and 53% in the area surrounding the stream. Clawson (1993) speculated that cattle preferred the OSW as they had to exert less effort to drink as the waterers were at a higher elevation.

Godwin and Miner (1996) studied four beef cows grazing a 1.2 ha pasture to determine the proportion of time that they spent within 4 m to 6 m of the stream when OSW was or was not available. The results of this study indicate that when the cattle were given the opportunity to drink at either the OSW or the stream, there was a 75% reduction in time spent near the stream.

Sheffield et al. (1997) compared two periods, a pre-BMP period with access to stream only and a post-BMP period with access to stream and OSW (filled with spring water). Results collected from three pastures, which were 14.2 ha, 16.6 ha, and 22.3 ha, were compiled to provide an average value from the three study sites. When given the choice, cattle were observed to water at the OSW 92% of the time, compared to observations at the stream. Further, time spent in the riparian area was reduced by 51%. These same researchers also observed a 77% reduction in stream bank erosion and a decrease of 90%, 54%, and 81% in concentrations of total suspended solids, total nitrogen, and total phosphorus, respectively. All reported changes were attributed to the use of the OSW.

In the studies by Miner et al. (1992) and Sheffield et al. (1997), the water in the OSW was from a source other than the stream. To ensure that the preference for watering at the OSW was not associated with the water source, Veira and Liggins (2002) conducted two trials in which the OSW system contained water which was pumped from the stream into an OSW. Results from VO recorded during the first trial indicated that 80% of drinking events occurred at the OSW. Results from VO recorded during the second trial also demonstrated greater preference for the OSW with 91.6% of drinking events at the OSW. Measures were taken to ensure that the water quality was similar between the two sources, so that cattle were choosing between watering location, rather than water quality. Through VO, they found that the riparian area provided cattle with crossing points, abundant forage, shade, and grooming locations. Veira and Liggins (2002) speculated that the soil where the OSW was located was dry, firm and level, thus providing better footing than the access points along the stream. Further, as the OSW was elevated, it may have been more appealing to drink from as cattle would be able to travel more easily on dry, flat ground, as opposed to the sloped orientation and unstable footing that is typical at stream access points.

Franklin et al. (2009) fitted cattle with GPS collars to record the amount of time spent in the riparian area when given access to an OSW or to stream only. They also evaluated the effect of temperature and humidity on the amount of time spent in the riparian area when OSW was available. Results indicate that when the temperature-humidity index (THI) was not stressful (<72), cattle spent 63% less time in the riparian area when OSW was available. When the THI was stressful (>72), the availability of OSW did not significantly impact the amount of time cattle spent in the riparian area.

The use of OSW in conjunction with salt/mineral placement has been studied as a strategy to modify cattle behaviour in riparian and upland areas (Ganskopp 2001; McInnis and McIver 2001; Porath et al. 2002). Results from Ganskopp (2001) showed that moving the location of the OSW had significant impact on cattle distribution as cattle appeared to follow the movement of the OSW in an effort to remain near their water source. In addition, cattle made little effort to remain close to the salt stations when they were separated from the OSW. McInnis and McIver (2001) provided cow-calf pairs with an OSW and salt in the upland area. They found that cattle were attracted to the upland area, resulting in a decrease in time spent in the riparian area. Furthermore, the incidence of uncovered and unstable streambanks decreased from 9% in pastures without OSW and salt to 3% in pastures with OSW and salt. Porath et al. (2002) compared distribution between cattle provided with OSW and trace mineral salt (off-stream cattle) to those without (no off-stream cattle). Their results indicated that the no off-stream cattle began the day the same distance or further from the stream as the off-stream cattle and then moved closer to the stream as the morning progressed. The no off-stream cattle spent the afternoon and early evening closer to the stream than off-stream cattle and moved further from the stream later in the evening. As well, the off-stream cows and calves gained an additional 0.27kg/d and 0.14kg/d, respectively, compared to the no off-stream cows and calves.

Schwarte et al. (2011) studied the effect of grazing management and OSW on cattle distribution and streambank characteristics in central Iowa. Six pastures were randomly assigned one of three treatments: continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access restricted to 4.9 m wide stabilized crossings (CSR), or rotational stocking with stream access restricted to a riparian paddock which was included in the rotation (R). Each pasture was stocked with 15 fall calving Angus cows from mid-May to mid-October. To record animal location, one or two cows from each treatment were fitted with GPS collars for two weeks of each month from May to September. Each month, the cattle in CSU and CSR had access to the OSW during the second week the cows were fitted with GPS collars. Their results indicated that OSW had no impact on cattle distribution, however cattle in CSR and R treatments spent less time in the stream zone (0 to 3 m from the center of the stream) in June and August and in the streamside zone (0 to 33 m from the stream zone) in May to August, compared to cattle in the CSU treatment. When the black globe THI measured between 50 and 100, the CSR treatment reduced the probability ($P < 0.10$) that cattle were in the riparian area (0 to 36 m from the stream center), compared to the R treatment. Presence of cattle was apparent as there was greater bare ground in the CSU treatment than in CSR and R treatments in the stream and streamside zones. As well, the streams in the CSU treatment had less stable streambanks mid- and post-stocking as compared to R or CSR treatments.

These studies demonstrate that cattle prefer to drink from OSW instead of directly drinking from the stream, and that including OSW will reduce the amount of time that cattle spend in the riparian area. However, some research has found that OSW are not effective at reducing the amount of time cattle spend in riparian areas or watering at the stream. Bagshaw et al. (2008) carried out a study where the pasture size averaged 1.1 ha to determine the effectiveness of OSW to attract cattle away from the riparian area, and the effect of diurnal and seasonal (winter, spring, summer, and fall) patterns on cattle in riparian areas. They used VO to record animal activity and location every ten minutes between 0800 h to 1730 h. Furthermore, when cattle were within 2 m of the OSW or the stream, activity was recorded every minute. Their results indicated that use of the OSW or the stream was not impacted by season. As the season progressed, the amount of forage available declined, and OSW usage increased, although cattle continued to water at the stream at the same frequency as when the OSW was not available, despite the additional usage of the OSW. Cattle did utilize the OSW, but the availability of OSW did not impact usage of the stream or the surrounding riparian area. Bagshaw et al. (2008) suggested that the OSW was unsuccessful at attracting cattle away from the stream and that the diurnal behaviour patterns of cattle cannot be changed solely by placing one resource (OSW) away from the riparian area. Furthermore, as forage availability declines, the ability of cattle to select drinking location is heavily influenced by the availability of forage.

The implementation of OSW may prove to be an economical, yet effective alternative to exclusion fencing as a means to protect riparian areas. In large pastures, location of the OSW is crucial in order to be effective, and placement of salt, mineral, back scratchers, or structures to provide shade, may help to increase usage of the OSW (Veira 2007).

2.6. LEGISLATION AND GOVERNMENT PROGRAMS

It is recognized that riparian areas contribute a number of processes that are an important part of functioning ecosystems. It is also recognized that riparian areas are sensitive to disturbances, such as cattle, if not carefully managed. This has resulted in implementation of federal, provincial, and municipal legislation and programs to promote management strategies that will protect the unique functions of riparian areas.

2.6.1. Federal

Canada's Fisheries Act is intended to preserve Canada's fisheries by protecting both fish and their habitat. The Act prohibits the deposit of any type of deleterious substance, defined as any substance that, if added to water, makes the water deleterious to fish or fish habitat, in water frequented by fish (Government of Canada 1985). The presence of cattle in riparian areas can cause declines in water quality, and in the future may be considered as non-compliance with the Act.

Canada's SARA was implemented to protect endangered species and includes a list of targeted species of plants and animals. It ensures the preservation of critical habitat, which is "habitat that is necessary for the survival or recovery of a listed wildlife species, and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (Government of Canada 2002). Riparian areas are included in the criteria for critical habitat because they provide habitat and contribute to functions that are necessary for a variety of plants, mammals, fish, and other organisms (Richardson et al. 2010). In the United States, the ESA similarly protects areas that have been deemed as critical for an endangered plant or animal species and includes riparian areas (National Research Council 2002).

In the United States, the National Environmental Policy Act requires any federal activities that may be harmful to the environment to be identified and analyzed to determine potential damage and possible alternatives (National Research Council 2002). Although not specific to riparian areas, past claims have considered riparian health, such as the impact of a hydroelectric dam on a riparian area and the habitat it provides for bald eagles (National Research Council 2002).

2.6.2. Provincial

In British Columbia, the Riparian Area Regulation requires landowners with riparian areas to conduct an assessment to determine the Streamside Protection and Enhancement Area (SPEA), prior to development. The SPEA determines the area that must be left in its natural, undisturbed state to prevent degradation of fish habitat (Anonymous 2007). In the future, other provinces may adopt similar legislation, making the implementation of like programs mandatory.

The Province of Manitoba has implemented the Water Protection Act, where members of watershed communities must develop Watershed Management Plans to protect, conserve, or restore water, aquatic ecosystems, and drinking water sources (Government of Manitoba 2010a). Further, the Act requires that the management plan must contain objectives, policies, and recommendations for activities in areas such as water quality, management zones, riparian areas, wetlands, flood areas, flood plains, and reservoir areas (Government of Manitoba 2010a). In response to this legislation, the

Government of Manitoba has introduced an incentive-based approach to encourage landowners to protect riparian areas. The Riparian Tax Credit Program provides a tax credit to producers who commit to the practice of maintaining riparian areas free from livestock or cropping for five years (Government of Manitoba 2010b).

2.6.3. Municipal

In the Rural Municipality of Blanshard, Manitoba, a voluntary, incentive-based approach to land management, including riparian areas, was explored from 2006 to 2009. The Alternative Land Use Services (ALUS) pilot project, initiated by the Keystone Agricultural Producers (KAP), compensated landowners for the environmental benefits that are created by protecting four different land types: wetlands, ecologically sensitive lands, riparian areas, and natural areas (KAP 2010). Participants were paid annually over three years with ecologically sensitive lands receiving the highest payment ($25/acre), and wetlands, riparian areas, and natural areas receiving $15/acre (Knight 2010). The pilot program in the Rural Municipality of Blanshard was the first of its kind in Canada. Since its successful implementation, similar projects have been organized in Prince Edward Island, Ontario, and Alberta.

The implementation of government regulations and land management programs across Canada and the United States to protect riparian ecosystems includes government organizations, landowners, and livestock producers. As regulations and programs become increasingly important, it is indicative that developing and implementing new strategies to protect these sensitive ecosystems is necessary in order to meet what could become mandatory standards.

2.7. SUMMARY OF LITERATURE REVIEW

In cow/calf production systems, cattle typically spend the summer on pasture. If a creek, stream, or river runs through the pasture, it is often used as a water source for grazing livestock. In addition to seeking water, cattle are attracted to the riparian area surrounding the creek, stream, or river to graze the abundant forage and to seek relief from heat. Riparian areas have a number of important functions, including filtering runoff, storing floodwater, maintaining streambanks, and providing habitat for wildlife. However, cattle presence in the riparian area has been found to negatively impact these functions through the removal of riparian vegetation, changes to stream channel morphology, compaction of riparian soils, and decline in water quality.

A number of strategies are available to monitor the behaviour of cattle grazing on pasture, as well as their impact to riparian areas. The location of cattle throughout the pasture and their behaviour can be recorded with VO. Cattle location can also be recorded with GPS collars. Quadrat sampling is an approach to monitoring forage availability over the grazing season. Further, there are a variety of visual assessments that can be completed to determine the health of the riparian area.

The importance of optimal function in riparian areas is well recognized, as are the detrimental impacts that may arise from the presence of cattle in these sensitive ecosystems. As a result, various management strategies have been explored as a means to decrease the amount of time cattle spend in the riparian area, minimizing the potential for damage. These strategies include complete exclusion fencing, partial exclusion fencing, grazing management, culling, herding, and the implementation of OSW. Research examining the usage of OSW is often focused solely on the effect on animal performance and behaviour, or the impact of OSW on the health of the riparian area. In order for BMP such as OSW to be implemented, livestock producers must be assured that in addition to improving the health of the riparian area, the productivity of their livestock will be maintained or improved. Furthermore, a number of studies examining the effectiveness of OSW were completed in smaller pastures; thus, the effectiveness of OSW in large scale pastures is not well understood, and requires further investigation.

The development of government regulations and land management programs at the federal, provincial, and municipal levels of government indicate the recognition of the importance of preserving riparian areas. Determining a BMP that maintains animal productivity and effectively reduces cattle access to riparian areas is crucial. Although cattle exclusion from riparian areas is not yet mandatory in Canada, having a viable strategy to effectively reduce cattle impact to riparian areas is crucial in the event that it becomes a compulsory standard in the future.

3. RESEARCH HYPOTHESES AND OBJECTIVES

3.1. HYPOTHESES

Two strategies, visual observations (VO) and global positioning system (GPS) collars, used to record cattle location within a pasture will produce similar results on cattle distribution. The implementation of off-stream waterers (OSW) will alter cattle distribution in the pasture as cattle will spend less time in the riparian polygon (RP), and more time in the upland pasture where the OSW is located, preferentially drinking from the OSW over the stream. Where barriers are installed at common watering locations along the stream, cattle will be further discouraged from loitering in the RP or watering from the stream. The presence of the OSW and/or barriers will not impact the productivity of cows and calves. Furthermore, the decrease in the amount of time that cattle spend in the RP will reduce the impact of cattle presence, thus improving riparian health.

3.2. OBJECTIVES

The overall objective of this research is to demonstrate that cattle can be managed in a way that optimizes animal productivity, while maintaining or restoring riparian health. Three pasture treatments, no OSW or barrier (1CONT), OSW with barrier (2BARR), and OSW without barrier (3NOBARR), were examined: 1) to compare the results of cattle location obtained with VO and GPS collars; 2) to explore the use of OSW in large-scale pastures in terms of animal productivity and riparian health; 3) to explore the effectiveness of low-cost barriers at defined crossing and watering locations; and 4) to evaluate a riparian assessment tool which producers can use to monitor the effectiveness of the BMP.

4. MANUSCRIPT I: COMPARISON OF CATTLE LOCATION ON PASTURE OBTAINED WITH VISUAL OBSERVATIONS AND GPS COLLARS

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4.1. ABSTRACT

A number of strategies have been used to monitor the distribution of cattle grazing on pasture, including visual observations (VO) and global positioning system (GPS) collars. Each strategy has limitations; therefore, using a combination of both strategies may reduce the likelihood of error due to these limitations. Our objective was to compare the similarity of results of animal location obtained with VO and GPS collars. A study examining the impact of off-stream waterers (OSW) and natural barriers on cattle distribution was conducted at two sites, Killarney and Souris, in South Western Manitoba. In each of three periods, cattle were fitted with GPS collars to record their location in the riparian polygon (RP) or at the OSW. Cattle fitted with GPS collars were also monitored via VO to record the location and behaviour of the cow. The results of cattle location, expressed as percentage of time within a three-hour time block, were compared for one randomly selected cow from each site and period, providing a total of six comparisons. Comparisons of the records obtained from both strategies indicate that the percentage of time spent in RP or at the OSW varies depending whether VO or GPS collar was used. Site topography and vegetation, observer distance from herd, and the subjectivity of the boundary size of the RP and OSW are challenges associated with VO. Some of these limitations can be addressed with the use of GPS collars; however, due to the error associated with GPS collars, some fixes may fall within the RP or OSW when they are not actually within the boundary. Each strategy seems to have an ideal application; VO may be best suited to those sites which are small, can be easily monitored visually, and when size prevents the GPS system from accurately recording cattle presence within the boundary due to associated error.

Abbreviations: BMP, beneficial management practice; **GPS**, global positioning system; **h**, hour; **ha**, hectares; **km**, kilometers; **m**, meters; **OSW**, off-stream waterers; **RP**, riparian polygon; **VO**, visual observations; **1CONT**, no OSW or barrier; **2BARR**, OSW with barrier; **3NOBARR**, OSW without barrier;

Keywords: visual observation, GPS collars, accuracy, validation, cattle distribution

4.2. INTRODUCTION

Information regarding the location of grazing cattle has been obtained using a number of strategies, including visual observations (VO) (Gillen et al. 1984; Miner et al. 1992; Sheffield et al. 1997; Porath et al. 2002; Ballard and Krueger 2005; Bailey et al. 2008), and more recently, by fitting cattle with global positioning system (GPS) collars (Ganskopp et al. 2000; Turner et al. 2000; Ganskopp 2001; Ungar et al. 2005; Tomkins and O'Reagain, 2007; Bailey et al. 2008; Franklin et al. 2009; Pandey et al. 2009; Bailey et al. 2010; Schwarte et al. 2011).

Although VO are a useful tool to learn about cattle behaviour and/or location, they may be prone to error from observer fatigue (Pandey et al. 2009) and observer proximity effects on livestock (Turner et al. 2000). Uncontrollable factors, such as weather, lighting, or site topography, contribute further to error (Turner et al. 2000). Intermittent data collection and challenges associated with large herd size or nighttime observations are just a few of the limitations associated with VO (Stobbs 1970). Due to these limitations, other tools, such as GPS collars, have been shown to provide accurate and precise information.

GPS data regarding animal location, once differentially corrected to improve accuracy, has been shown to provide values that were accurate to within 5 meters (m) (Moen et al. 1997). Ganskopp and Johnson (2007) utilized Lotek GPS 2200 collars to collect cattle location data in a pasture experiment and after differential correction, reduced the mean bias of GPS positions from approximately 4 m to 2 m, where bias is defined as the difference between measured distances and distances derived from GPS coordinates. Furthermore, Franklin et al. (2009) placed two Lotek GPS 2200 collars at established benchmarks to determine their accuracy, and after differential correction, found that 95% of the collar data was accurate to within 3 m of the established benchmark.

In addition to providing accurate location data, utilizing GPS collars can minimize some of the issues that arise from using VO to determine cattle location in the pasture. Collars alleviate the risk of introducing error from the impact of the observer on herd behaviour or the inability to maintain a clear view of the herd due to site topography, vegetation, and poor lighting, as well as inaccurate observations due to fatigue. Furthermore, GPS collars can provide continuous observations 24-hours (h) a day, while VO will likely only be recorded for a portion of the day during daylight. Despite these advantages, GPS collars are not without limitations. Depending on the site, interference from the satellite to the GPS collar can arise due to vegetative cover, topography, or atmospheric conditions (Lewis et al. 2007). This interference can increase the likelihood of location error, which is the difference between the actual location and the location recorded by the GPS collar (Swain et al. 2008), or missed location fixes, which occurs when the GPS collar is unable to acquire sufficient satellites to record the location (D'Eon 2003).

If both VO and GPS collars were used to record cattle location within a pasture, the amount of time spent in each area of the pasture should, ideally, be similar. However, due the identified limitations of VO and GPS collars, discrepancies may arise between the two strategies. The objectives of this manuscript are: 1) to compare the results of cattle location obtained with VO and GPS collars in two large scale pastures located in Southwest Manitoba.

4.3. MATERIALS AND METHODS

4.3.1. Project description

A grazing experiment in South Western Manitoba, examining the usage of off-stream waterers (OSW) as a beneficial management practice (BMP) for riparian areas, utilized VO and GPS collars to collect cattle distribution data. The trial was carried out at two locations, Killarney, on the Pembina River (Figure 8), and Souris, on the Plum Creek (Figure 9), and was divided into three, 28-day periods over the grazing season in 2009. At each site, three treatments were applied to the pastures: no OSW or barrier (1CONT), OSW with barrier (2BARR), and OSW without barrier (3NOBARR). The OSW were placed in the upland pasture on the north side of the stream in 2BARR and 3NOBARR. In 2BARR only, natural barriers were placed across common watering and crossing areas on the north side of the stream. The size of the pasture varied slightly between treatments and sites. In Killarney, 2BARR was 21.0 hectares (ha) and 3NOBARR was 25.5 ha. In Souris, 2BARR was 26.3 ha and 3NOBARR was 39.2 ha.

Twenty-five cow/calf pairs were assigned to each treatment, for a total of 75 cow/calf pairs per site. Each treatment at each site contained 25 cows, however, calf numbers varied amongst treatments (Table 2). Animal handling and care procedures in this study were carried out in accordance with the guidelines of the Canadian Council on Animal Care (CCAC 1993).

4.3.2. GPS data collection

Cattle were fitted with GPS collars to record their location in the pasture in 2BARR and 3NOBARR. Two models of collars were used: GPS3300LR Collars (Lotek

Wireless Inc., Newmarket, ON) and GPS2200 Collars (Lotek Wireless Inc., Newmarket, ON). The GPS collars were placed on different cows in each period (Table 3) and were programmed to record location fixes every five minutes with a minimum of ten days of data collection in each period.

Positions from the GPS collars were differentially corrected with N4 v.1. 2138 software (Lotek Engineering Inc., Newmarket, ON) using base-station data downloaded from the Canadian Spatial Reference System Online database station in Winnipeg, Manitoba, located 192 kilometers (km) from the Killarney site and 227 km from the Souris site. With differential correction applied to the data, Moen et al. (1997) reported the accuracy of Lotek GPS_1000 collars (Lotek Wireless Inc., Newmarket, ON) to within 5 m, while Ganskopp and Johnson (2007) reported the accuracy of Lotek GPS2200 Collars to within 2 m.

To determine when cattle were in the riparian polygon (RP) or at the OSW, buffers were created along the RP and around the OSW using ArcMap 10 (Environmental Systems Research Institute, Redlands, CA). For the RP, a buffer of 10 m was created on either side of the stream. For the OSW, a buffer of 8 m was created around the OSW. After applying the data from the GPS collars to the buffers, each fix that fell within the boundary of the RP or OSW buffer was identified (Figure 1).

4.3.3. Visual observation data collection

Visual observations were conducted to record the behaviour and location of cows fitted with GPS collars in 2BARR and 3NOBARR every five minutes from dawn until dusk for four days of each period. Individual cows were identified by coloured ribbons which were attached to their ear tags. Observation data was not collected at night, as previous research suggests that little activity occurs during the night (Stuth 1991; Miner et al. 1992). As the season progressed and the length of day shortened, observation times were adjusted to record during day light. Six cattle behaviours were identified and consisted of the following: watering, grazing, standing, laying, urinating, and defecating. Cattle behaviour was recorded when they were in any of the following locations: RP or OSW. Cattle location was recorded as RP when an animal was in the stream or within five body lengths of the stream, while cattle location was recorded as OSW when an animal was within four body lengths of the OSW. Sheffield et al. (1997) used a similar method, where animal location was recorded as riparian when they were within two body lengths of the center of the stream and as OSW when they were within two body lengths from the edge of the OSW.

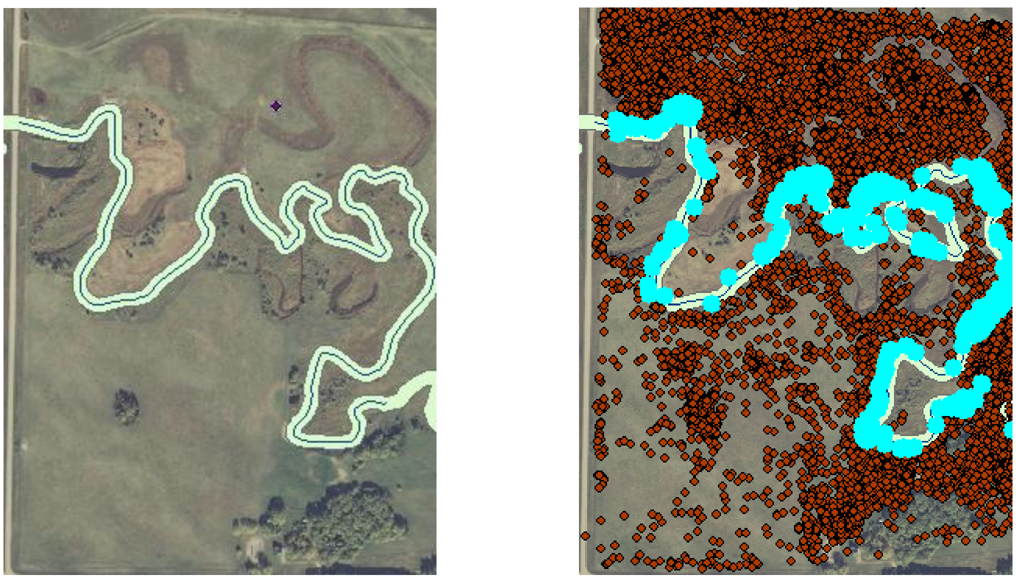

Figure 1. Example of 10m buffer in RP and 8m buffer around OSW in 3NOBARR at the Souris site (left) and GPS location fixes from Period 1 which fall within the RP buffer

4.3.4. Data analysis and comparison

Data from VO and GPS collars was compiled for each cow fitted with a GPS collar, in each site, treatment, and period. The data from VO and GPS collars was grouped into five time blocks for analysis: 0600 h to 0900 h, 0901 h to 1200 h, 1201 h to 1500 h, 1501 h to 1800 h, and 1801 h to 2100 h, as described in Porath et al. (2002). Although GPS data was collected 24-h per day, data was only used when it corresponded with the date and time that VO were carried out. Data was compared by determining the total percentage of observations in the RP or at the OSW as recorded by VO and GPS collar over the four days of each period. If, for example, 672 observations were recorded over four days and 258 of those observations were in the RP, then 38% of time over the four days was spent in the RP. Data was further compiled as the percentage of VO or GPS fixes in the RP or OSW within the three-hour time period. If, for example, 36 observations were recorded in a three-hour period and five of those observations were in the RP, then 14% of that three-hour time block was spent in the RP. If the length of time that VO were recorded was shorter, only that data from the GPS collars which corresponded to the VO data in terms of length and period of time was included for comparison. The locations obtained from the GPS collars and VO were compared by randomly choosing one collar from each site and period, providing a total of six comparisons. Furthermore, the boundaries of the RP and OSW are comparable for each strategy, as one animal length was estimated at approximately 2 m, the RP boundary of five animal lengths for VO corresponds with the 10 m boundary for the GPS collars. Similarly, the OSW boundary of four animal lengths for VO corresponds with the 8 m boundary for the GPS collars.

4.4. RESULTS AND DISCUSSION

A comparison of the location recorded by VO and GPS collars show that there is disparity between the two strategies at both Killarney and Souris, as depicted in Figures 2 to 7. In Period 1 at the Killarney site, for example, the GPS collar recorded a greater percentage of time in the RP than the VO on July 6, 7, 9, and 10 for the majority of the time blocks (Figure 2). Over the four days when VO were recorded and cattle were fitted with GPS collars, the cow spent a total of 4.17% (n=30 observations) of observed time in the RP as recorded by VO, and 17.78% (n=128 observations) of observed time as recorded by the GPS collar (Table 1). There are a number of possibilities that may account for the identified differences associated with each strategy, including site topography and vegetation, the distance between the observer and herd, the variability of the RP or OSW boundary, and the accuracy of the GPS collars within the RP or OSW boundary.

Site topography and vegetation, combined with the distance between the observer and the herd, can lead to variation in cattle location as recorded with VO and GPS collars. The Killarney site, in particular, had many trees surrounding the RP, which made it challenging to see the cattle when they were near the RP. This site also has undulating topography, with a steep hill covered in shrubs and trees which rose to a plateau on the south side of the stream. Furthermore, the observers noted that the herd had a large flight zone; therefore, the observer was required to maintain a distance that would not influence their natural behaviour. The combination of undulating topography, presence of trees, and distance from herd made it challenging for the observer to obtain accurate and continuous location recordings. As previously described and shown in Figure 2, in Period 1 at the

Killarney site the GPS collar recorded a greater percentage of time in the RP than the VO on July 6, 7, 9, and 10 for the majority of the time blocks. From 0610 h to 1845 h on July 7 and from 0700 h to1300 h on July 9, the observer could see the herd in the bush across the stream, but was unable to identify the behaviour and location of individual cows. According to the GPS collar, the cow was within the RP, but due to the presence of trees and the distance between the observer and the herd, it was difficult for the observer to accurately record the cow's location. The opposite may have occurred as well, when the cow crossed the stream and entered the bush within the RP. The cow may have left the RP, but due to the bush and distance from the herd, the observer did not see the cow leave, continuing to record her as being in the RP, when in reality, she had left the RP. This would result in a much higher percentage of time in the RP according to VO than the GPS collar.

The boundaries of the areas of interest may also account for some of the variation in the percentage of time in the RP or OSW as recorded by VO and GPS collars. The boundaries of the RP, as well as the estimation of the length of five animals, as identified by the observer are somewhat subjective. The extent of the boundaries of the RP may have been influenced by changes at the site throughout the grazing period, including the water level of the stream or the amount of forage in the RP. Conversely, the boundary of the RP or the OSW as defined by the GPS collars is static. Variation arises due to the subjectivity of the boundary for VO and the consistency of the boundary for the GPS data.

At the Killarney site during Period 2, overall, the cow is recorded as spending a greater percentage of time in the RP with VO (38.39%; n=258 observations) than with the GPS collar (17.26%; n=166 observations) over the four days (Table 1). An examination of individual days within the period demonstrates that differences occur on August 5 and August 6 (Figure 3). The behaviour data obtained via VO on August 5 indicate that from 1201 h to1500 h, the cow was grazing in the RP for 93% (n=12 observations) of the observed time and watering for the remaining 7% (n=1 observation). From 1501 h to 1800 h, the same cow was grazing in the RP for 50% (n=18 observations) of the observed time and standing for the remaining 50% (n=18 observations). From 1801 h to 2100 h, the same cow was grazing in the RP for 96% (n=27 observations) of the observed time and watering for the remaining 4% (n=1 observation). On August 6, the same cow was recorded as grazing in the RP during all of the observations. While a cow grazes, they are moving throughout the pasture at a speed up to 138 m to 238 m per hour, as observed by Brosh et al. (2006). Therefore, while grazing, the cow is moving, and thus may not remain in the RP exclusively, but be crossing back and forth across the boundary. The observer likely recorded the majority of the cow's location as RP while she was grazing near this area, while in reality she was repeatedly entering and exiting the boundary of the RP. The GPS collar would have more accurately recorded movement across the 10 m boundary, accounting for the decrease in observed time within the RP in those time blocks and days compared to VO.

The accuracy of the GPS collars within the size of the boundary for the OSW and RP may have also contributed to the observed differences between the two strategies. As previously mentioned, with differential correction, data from GPS collars is accurate to within 5 m (Moen et al. 1997) or 2 m (Ganskopp and Johnson 2007). If the accuracy of the GPS data from the collars utilized in this study is within 2 m to 5 m, there may be some instances where the cow was standing within the OSW or RP, as recorded by the observer, but because of the limitations of the accuracy of the GPS collar, the fix location had sufficient error that it fell outside of the boundary. This could be of particular importance at the OSW, where the area which was deemed to be within the OSW was small.

As the OSW were located in areas in the pasture that were flat, free from vegetation, and the cattle could be easily observed, it is anticipated that the percentage of time spent at the OSW recorded via VO and GPS collars would be similar. Although they tend to have a smaller magnitude of variation as compared to the observations in the RP, there are still some differences between the two strategies. In Period 1 at the Souris site, there are a number of observations at the OSW where the percentage of time recorded by VO and GPS collars is not consistent for the cow depicted in Figure 5. Over the four days when VO were recorded and cattle were fitted with GPS collars, the cow spent a total of 2.08% (n=12 observations) of observed time at the OSW as recorded by VO, and only 0.87% (n=5 observations) of observed time as recorded by the GPS collar (Table 1).There is a greater percentage of observed time spent at the OSW as recorded by VO compared to GPS collars on the following dates and time blocks: June 22 from 0901 h to 1200 h (VO, 11% (n=4 observations); GPS, 3% (n=1 observation)); June 23 from 0600 h to 0900 h (VO, 3% (n=1 observation); GPS, 0% (n=0 observations)); June 23 from 0910 h to 1200 h (VO, 3% (n=1 observation); GPS, 0% (n=0 observations)); and, June 23 from 1501 h to 1800 h (VO, 8% (n=3 observations); GPS, 0% (n=0 observations)). The two strategies were comparable on June 23 from 1201 h to 1500 h (VO, 6% (n=2 observations); GPS, 6% (n=2 observations)). The same cow spent a greater percentage of observed time at the OSW as recorded by the GPS collar compared to VO on June 26 from 1801 h to 2100 h (VO, 3% (n=1 observation); GPS, 6% (n=2 observations)). The accuracy of the GPS collar may be the reason for the difference in the percentage of time at the OSW as recorded by the two strategies. The observer may have recorded the cow as being within the boundaries of the OSW, however due to the error of the GPS collar, the fix was recorded as being outside of the boundary. This could also be the case when the percentage of observed time at the OSW is greater according to the GPS collar. That is, the cow is not actually within the boundaries of the OSW, but due to the error associated with the GPS collar, the location fix falls within it. A similar challenge may arise in the RP, where the cow falls within the boundary, but due to error, the location fix falls outside of the RP boundary.

Table 1. Total percentage of observed time spent in the riparian polygon (RP) or at the off-stream waterer (OSW) as recorded by visual observations (VO) and global positioning system (GPS) collars in Periods 1, 2, and 3 at the Killarney and Souris sites in 2009

	RP (VO)	RP (GPS)	OSW (VO)	OSW (GPS)	Total observations recorded by both VO and GPS over 4 days
Killarney Period 1 (Figure 1)	4.17% n = 30	17.78% n = 128	0.14% n = 1	0.14% n = 1	720
Killarney Period 2 (Figure 2)	38.39% n = 258	17.26% n = 116	0.30% n = 2	0.15% n = 1	672
Killarney Period 3 (Figure 3)	0.65% n = 4	0.82% n = 5	0.33% n = 2	0.16% n = 1	612
Souris Period 1 (Figure 4)	19.79% n = 114	6.94% n = 40	2.08% n = 12	0.87% n = 5	576
Souris Period 2 (Figure 5)	6.94% n = 50	2.50% n = 15	0.69% n = 5	0.28% n = 2	720
Souris Period 3 (Figure 6)	14.80% n = 87	6.46% n = 38	0.00% n = 0	0.17% n = 1	588

n = 30 number of observations recorded

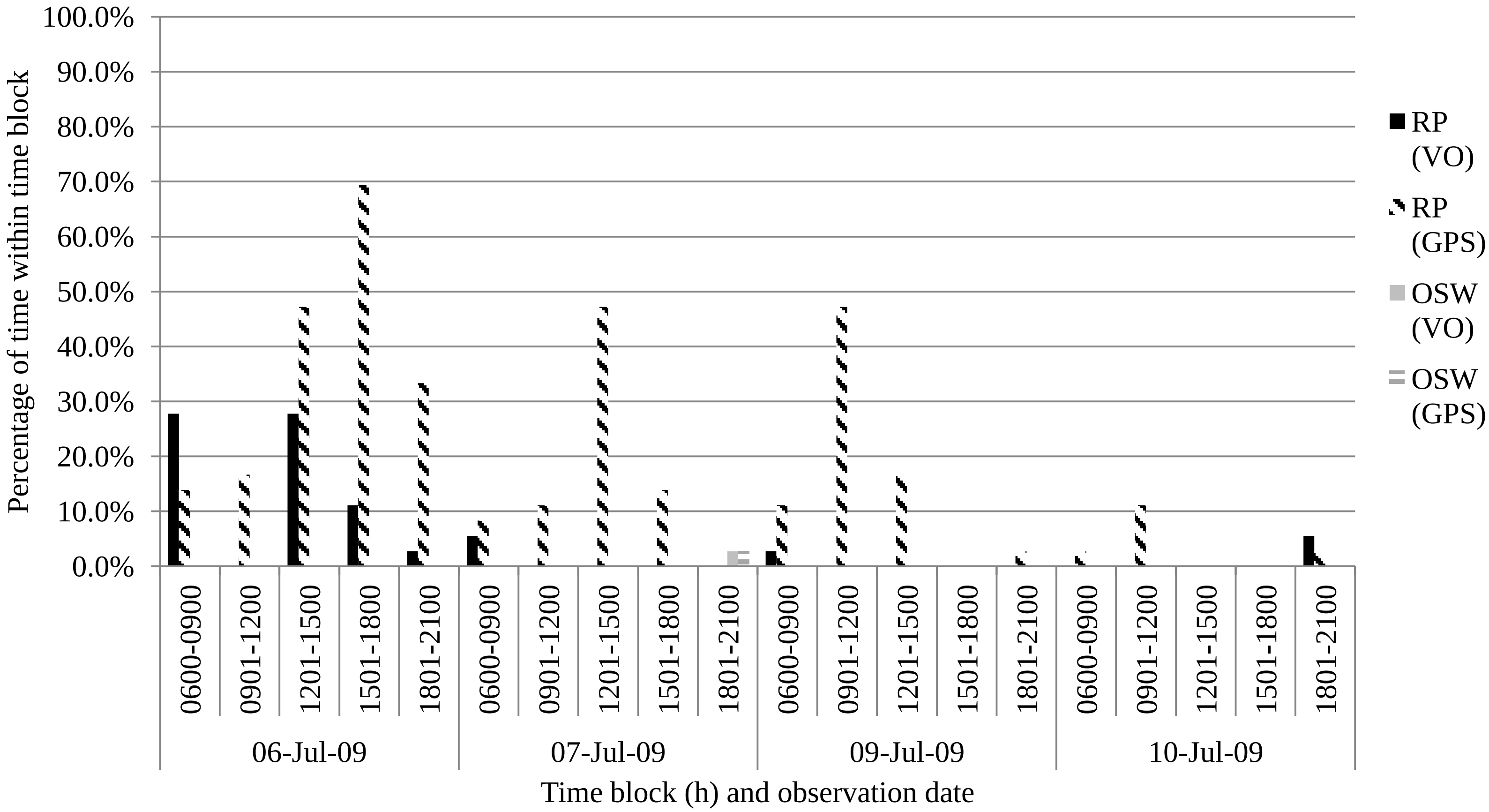

Figure 2. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 1 at the Killarney site in 2009

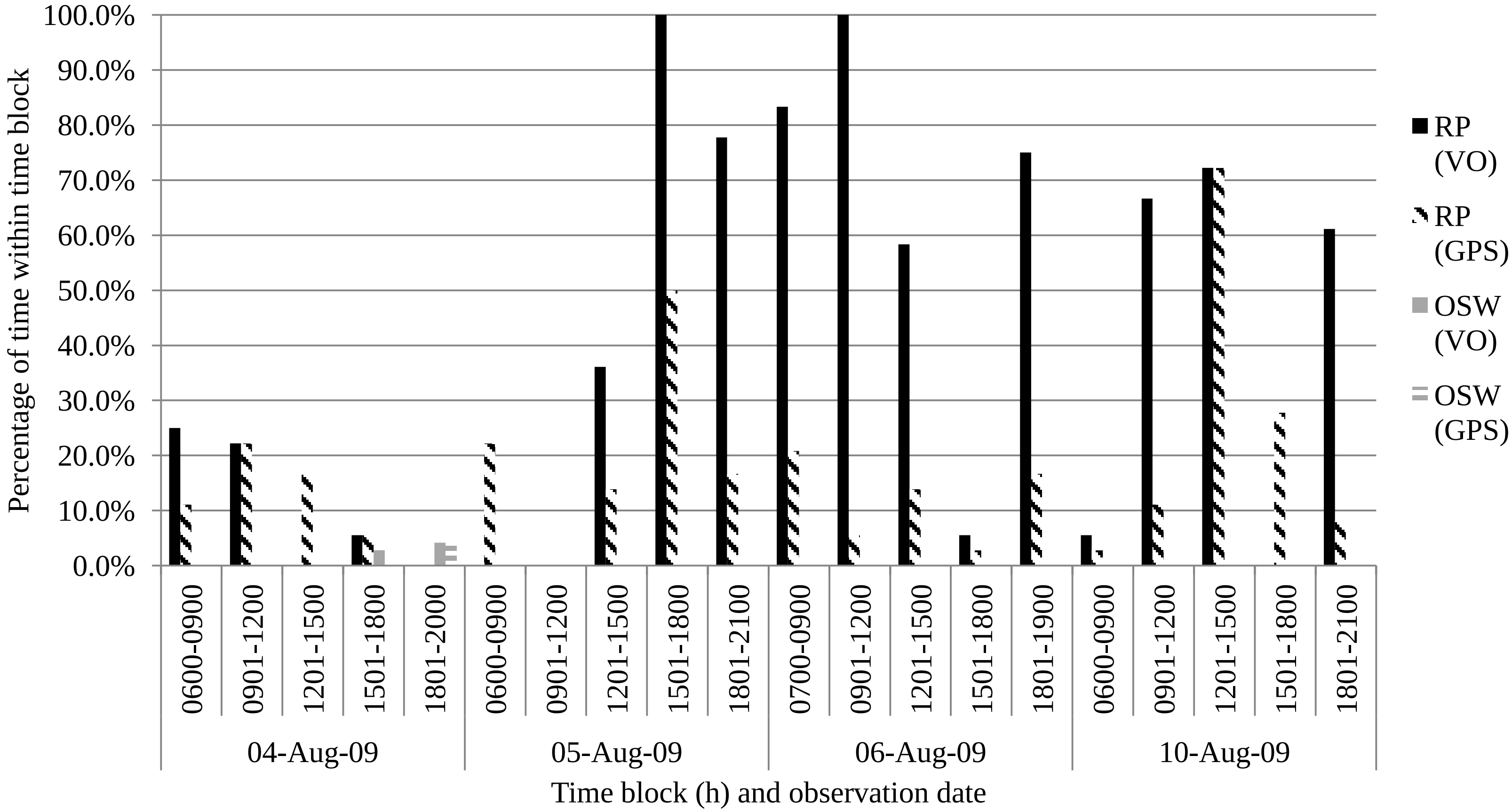

Figure 3. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 2 at the Killarney site in 2009

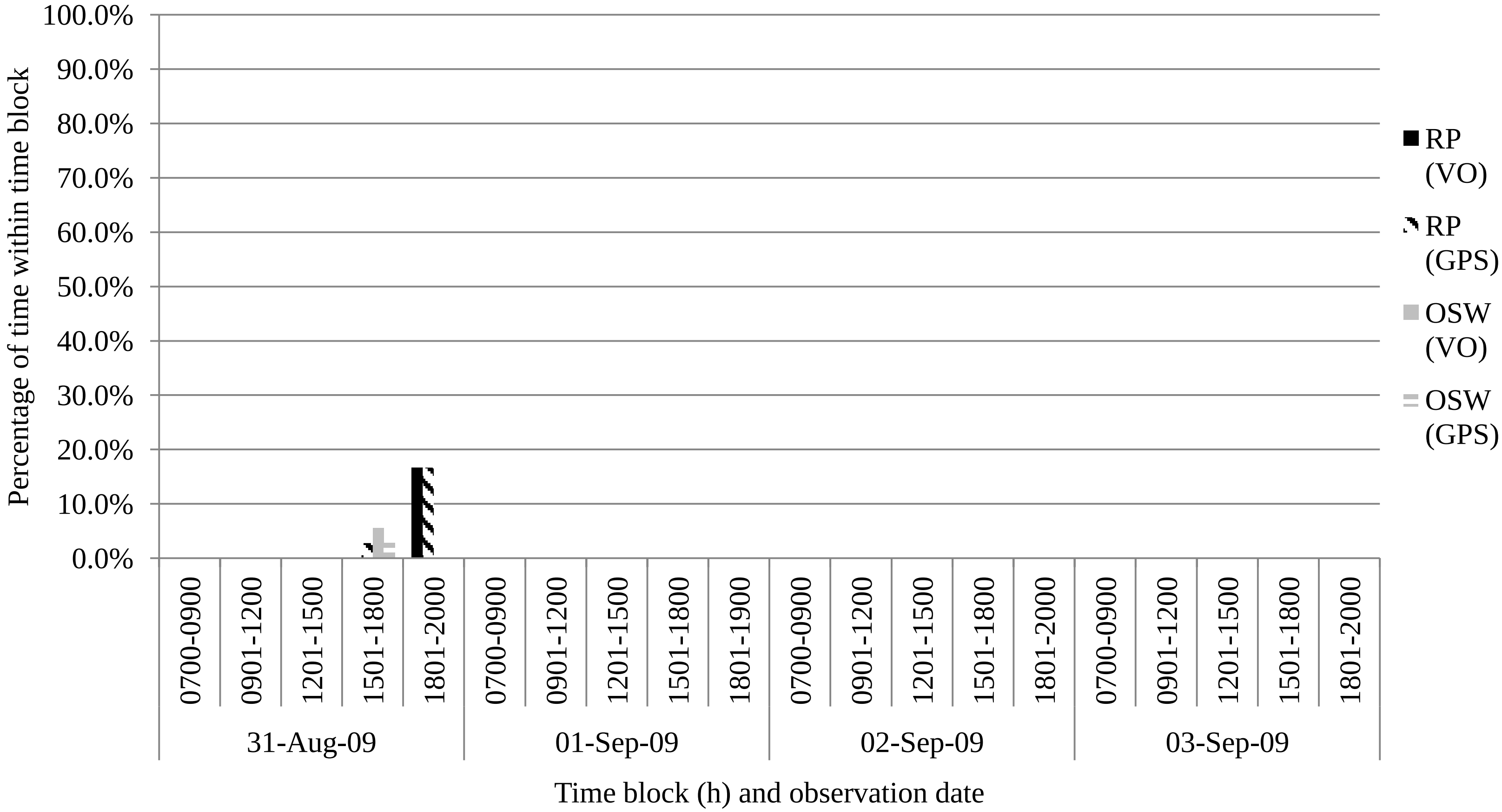

Figure 4. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 3 at the Killarney site in 2009

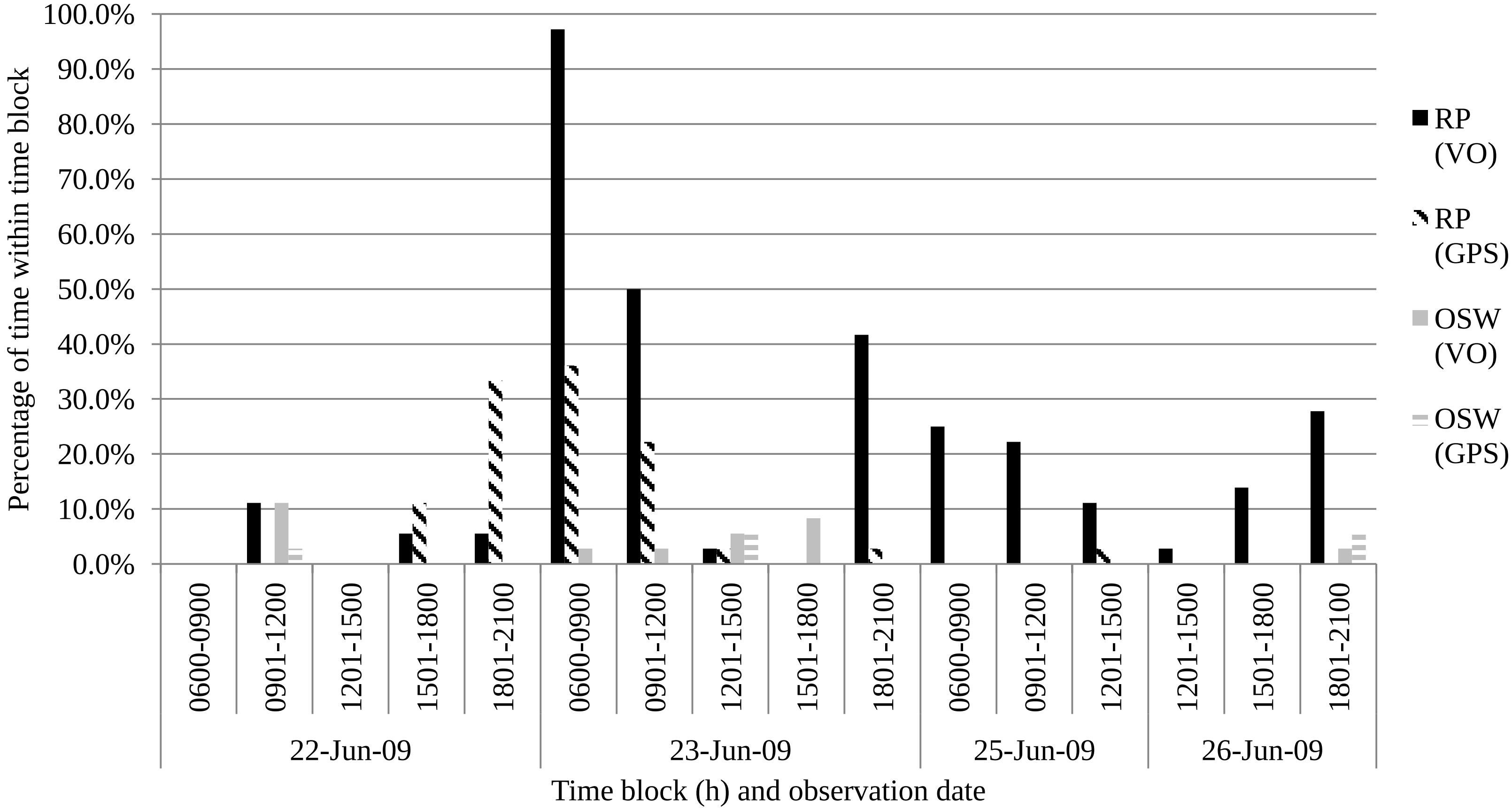

Figure 5. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 1 at the Souris site in 2009

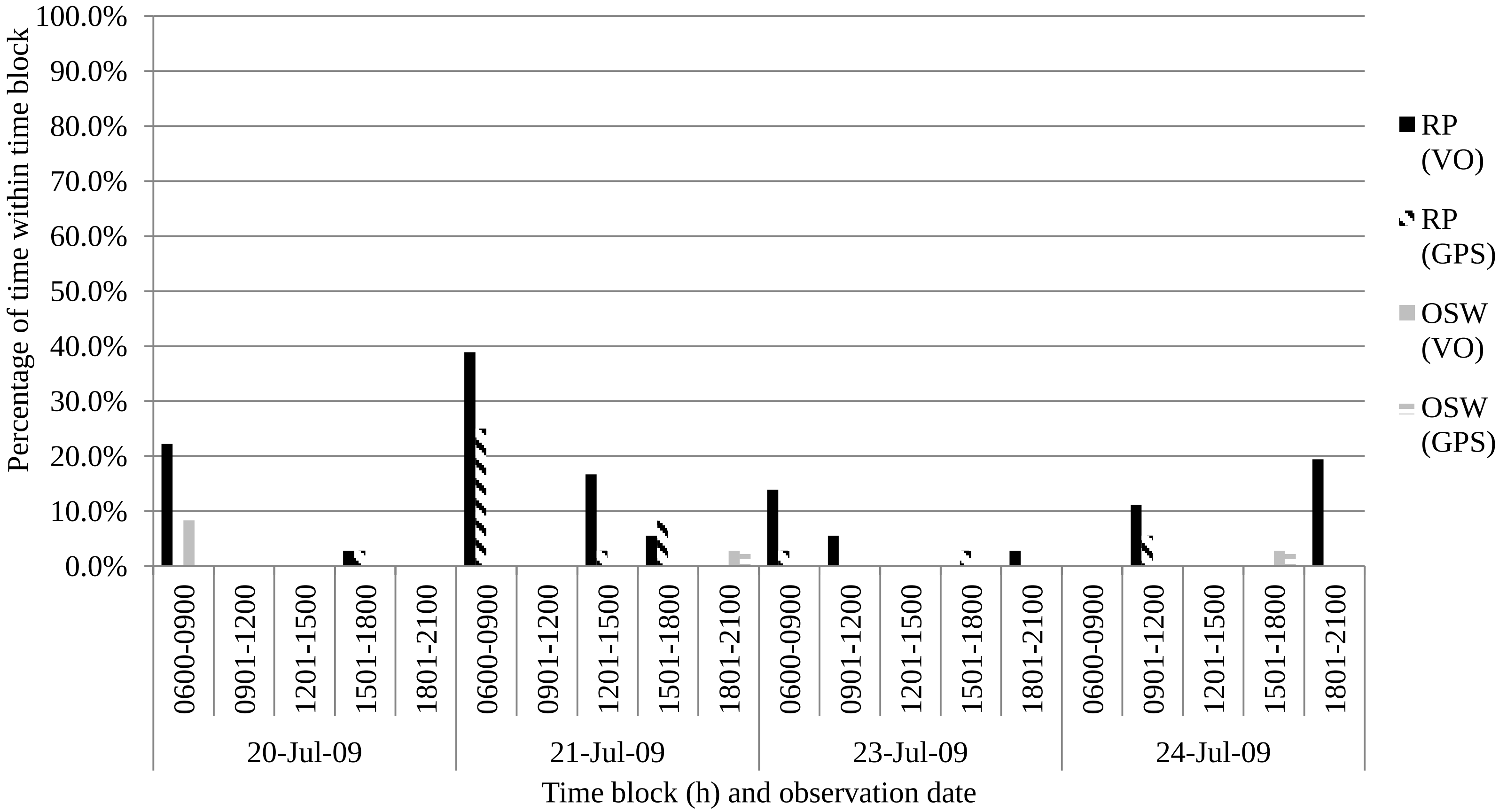

Figure 6. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 2 at the Souris site in 2009

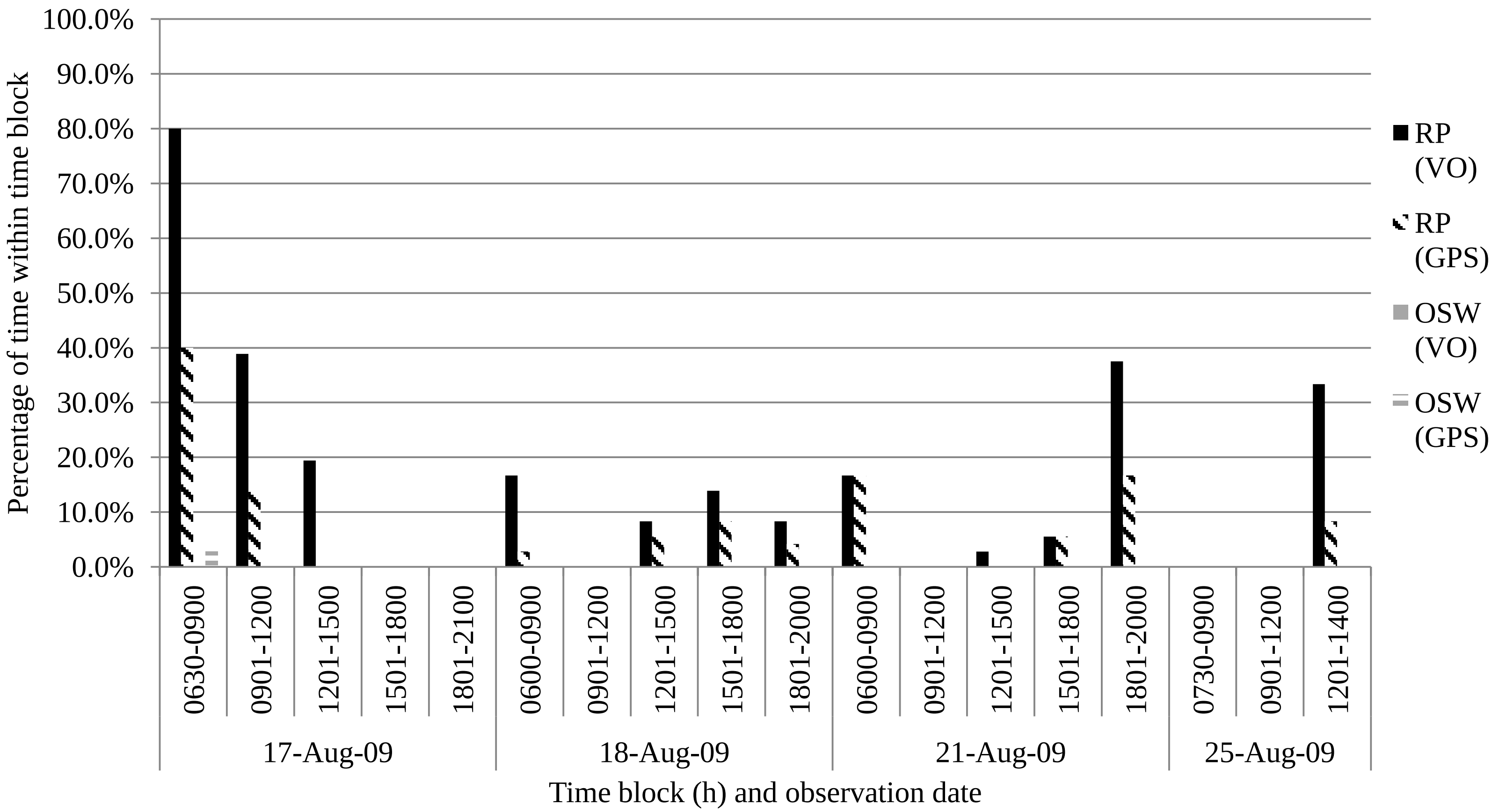

Figure 7. Comparison the percentage of observed time within each time block that an individual animal spent in the riparian polygon (RP) or at the off-stream waterer OSW as recorded by visual observation (VO) and global positioning system (GPS) in Period 3 at the Souris site in 2009

4.5. CONCLUSION

It is evident that the use of VO and GPS collars does not yield consistent results in terms of identifying cattle location at an OSW or within a RP in a large scale pasture system. Each strategy possesses challenges that limit confidence in the accuracy of the data obtained. More specifically, VO as a technique to record cattle location is limited by site topography and tree cover as it is difficult for the observer to maintain a clear view of the cattle. Furthermore, if the herd has a large flight zone, the observer has to maintain a greater distance in order to avoid influencing their behaviour. The boundary that defines the area of interest, OSW or RP, may be perceived differently based on the opinion of the observer, and is therefore subject to error. These limitations may be overcome with the use of GPS collars, which are to record fixes within the topography and tree cover of these sites. Further, the use of GPS collars does not influence cattle behaviour as does human presence. Conversely, the accuracy of the GPS collars may have recorded fixes within the RP or OSW, when according to VO, the cow was not actually within the boundary. Despite this challenge, GPS collars are preferable in large pastures with tree cover, where it is difficult for the observer to continuously monitor the herd. Visual observations may be better suited to small pastures, where the herd can be easily monitored, or if the specified area of interest is small and the GPS collar may not be able to accurately record the cow's presence within the boundary.

5. MANUSCRIPT II: OFF-STREAM WATERING SYSTEMS AND PARTIAL BARRIERS AS A STRATEGY TO MAXIMIZE CATTLE PRODUCTION AND MINIMIZE IMPACT TO RIPARIAN HEALTH

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5.1. ABSTRACT

Use of off-stream waterers (OSW) in riparian areas may serve to reduce the amount of time cattle spend in the riparian area, thus minimizing impacts such as removal of vegetation, soil compaction, and water quality deterioration. Furthermore, when used with natural barriers as a partial exclusion method, these management strategies may offer a cost-effective alternative to completely excluding cattle via streambank fencing. A study was conducted to determine the impact of OSW with or without natural barriers on the amount of time cattle spent in the riparian polygon (RP), watering location (OSW or stream), animal productivity measured as weight gain, and riparian health. The impact of water temperature and temperature-humidity index (THI) on drinking location was also explored. The study was replicated at two locations in Manitoba (Killarney and Souris), with each site replicated in two grazing seasons (2009 and 2010). At each location, the pasture was divided into three treatments: no OSW or barriers (1CONT), OSW with barriers along the stream bank to deter cattle from watering at the stream (2BARR), and OSW without barriers (3NOBARR). Cattle in 2BARR spent less time in the RP in Period 1 (P = 0.0002), 2 (P = 0.1116), and 3 (P < 0.0001) at the Killarney site in 2009 compared to cattle in 3NOBARR at the same site. In 2009, cattle in 2BARR at the Souris site spent more time in the RP in Period 1 (P < 0.0001) and 3 (P= 0.5633), while spending less time in Period 2 (P = 0.0002) compared to cattle in 3NOBARR. Cattle did use the OSW, but not exclusively, as watering at the stream was still observed. Further, usage of the OSW varied across all treatments and periods in both years and sites. Water temperature and THI did not impact the amount of time cattle spent in the RP, or their preferred drinking location. Forage biomass was greater in the riparian area

than in the pasture in most treatments at both sites. However, in Period 1 of 2010, forage biomass was greater in the pasture at Killarney, which may be the result of increased precipitation. Treatment had no significant effect ($P > 0.05$) on cow and calf weights averaged over the summer periods, with the exception the Souris site in 2010, where the weight of 3NOBARR calves was significantly less than 1CONT and 2BARR calves ($P < 0.0001$). The results from the riparian health assessment (RHA) carried out over 2009 and 2010 varied over the grazing season, however, did not indicate greater improvement in 2BARR and 3NOBARR compared to 1CONT. Improvements in the observed criteria take more time than was allotted in the two year study. Water quality results indicated that a number of samples from the stream and the trough exceeded *E. coli* levels from the guidelines for livestock drinking water. These results indicate that the presence of OSW do not create significant differences in animal performance. Although cattle used the OSW, they did not drink exclusively from them. Thus, the OSW did, for some period of time, serve to attract cattle away from the RP.

Abbreviations: ADT, average daily temperature; **BMP**, beneficial management practice; **DBRM**, deep binding root mass; **GPS**, global positioning system; **h**, hour; **kg**, kilogram; **km**, kilometers; **LWSI**, livestock weather safety index; **m**, meters; **MAFRI**, Manitoba Agriculture, Food and Rural Initiative; **mm**, millimeter; **nm**, nanometer; **P1-D1**, Period 1 Day 1; **P1-D28**, Period 1 Day 28; **P2-D1**, Period 2 Day 1; **P2-D28**, Period 2 Day 28; **P3-D1**, Period 3 Day 1; **P3-D28**, Period 3 Day 28; **OSW**, off-stream waterers; **RHA**, riparian health assessment; **RP**, riparian polygon; **SD**, standard deviation; **THI**, temperature-humidity index; **TKN**, Total Kjedhal Nitrogen; **VO**, visual observations;

1CONT, no off-stream waterer or barrier; **2BARR**, off-stream waterer with barrier; **3NOBARR**, off-stream waterer without barrier.

Keywords: riparian, off-stream water, partial exclusion, cattle distribution, GPS, animal performance

5.2. INTRODUCTION

Cow/calf operators in Manitoba may use streams within riparian areas as a water source for livestock. Cattle are attracted to riparian areas as they provide water, forage, and shade (Belsky et al. 1999). While grazing and watering in the riparian area, cattle contribute to the removal of vegetation, soil compaction and erosion, and degradation of water quality (Platts 1979; Kauffman et al. 1983). In order to minimize impacts to riparian areas, the livestock industry must adopt beneficial management practices (BMP) that are environmentally and economically sustainable for cattle producers.

Exclusion fencing is a BMP that is proven to be effective. However, it is costly, removes access to large areas of pasture, and gives the impression that cattle and riparian areas cannot be managed to exist harmoniously (Fitch and Adams 1998). Off-stream waterers (OSW) are an alternative method to exclusion fencing. Previous studies have shown reductions in the amount of time spent in the riparian area or stream when an OSW is available (Miner et al. 1992; Clawson 1993; Godwin and Miner 1996; Sheffield et al. 1997; McInnis and McIver 2001). Other studies have found that cattle will drink more frequently from the OSW than the stream (Sheffield et al. 1997; Veira and Liggins 2002). However, many of these studies were carried out in small pastures. Further research regarding the effectiveness of OSW is required in larger pastures, characterized by undulating topography, forested areas, and varying precipitation; all of which are features typical of pastureland located throughout Southern Manitoba. A possible strategy to further improve the effectiveness of OSW is the use of natural barriers, which would partially exclude livestock from accessing established crossing and watering locations. Research examining the effectiveness of this strategy is currently limited.

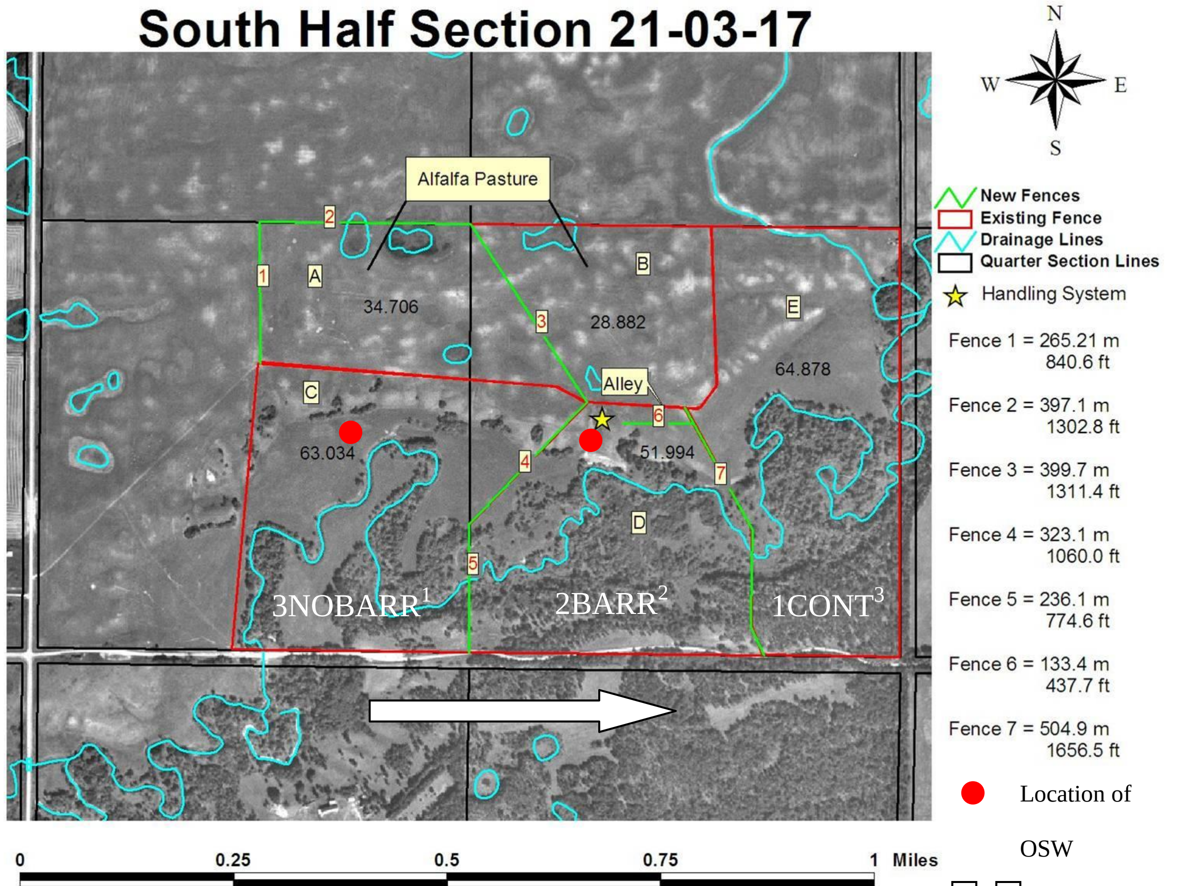
Further, many existing studies examine the effectiveness of OSW on riparian health without consideration of the impact on animal productivity or behaviour (Miner et al. 1992; Clawson 1993; Godwin and Miner 1996; Miller et al. 2010a; Miller et al. 2010b; Sheffield et al. 1997; Schwarte et al. 2011). Conversely, other studies have examined animal behaviour, but not riparian health (Veira and Liggins 2002). In order to adopt BMP such as OSW, livestock producers must be assured that the implementation of these strategies will not negatively impact animal performance. As a result, it is necessary to address both issues; evaluation of the effectiveness of OSW and natural barriers on riparian health, as well as their impact on animal productivity and behaviour.

The objectives of this research were to: 1) explore the use of OSW in large-scale pastures in terms of animal productivity and riparian health; 2) explore the effectiveness of low-cost barriers at defined crossing and watering locations; and 3) evaluate a riparian assessment tool which producers can use to monitor the effectiveness of the BMP.

5.3. MATERIALS AND METHODS

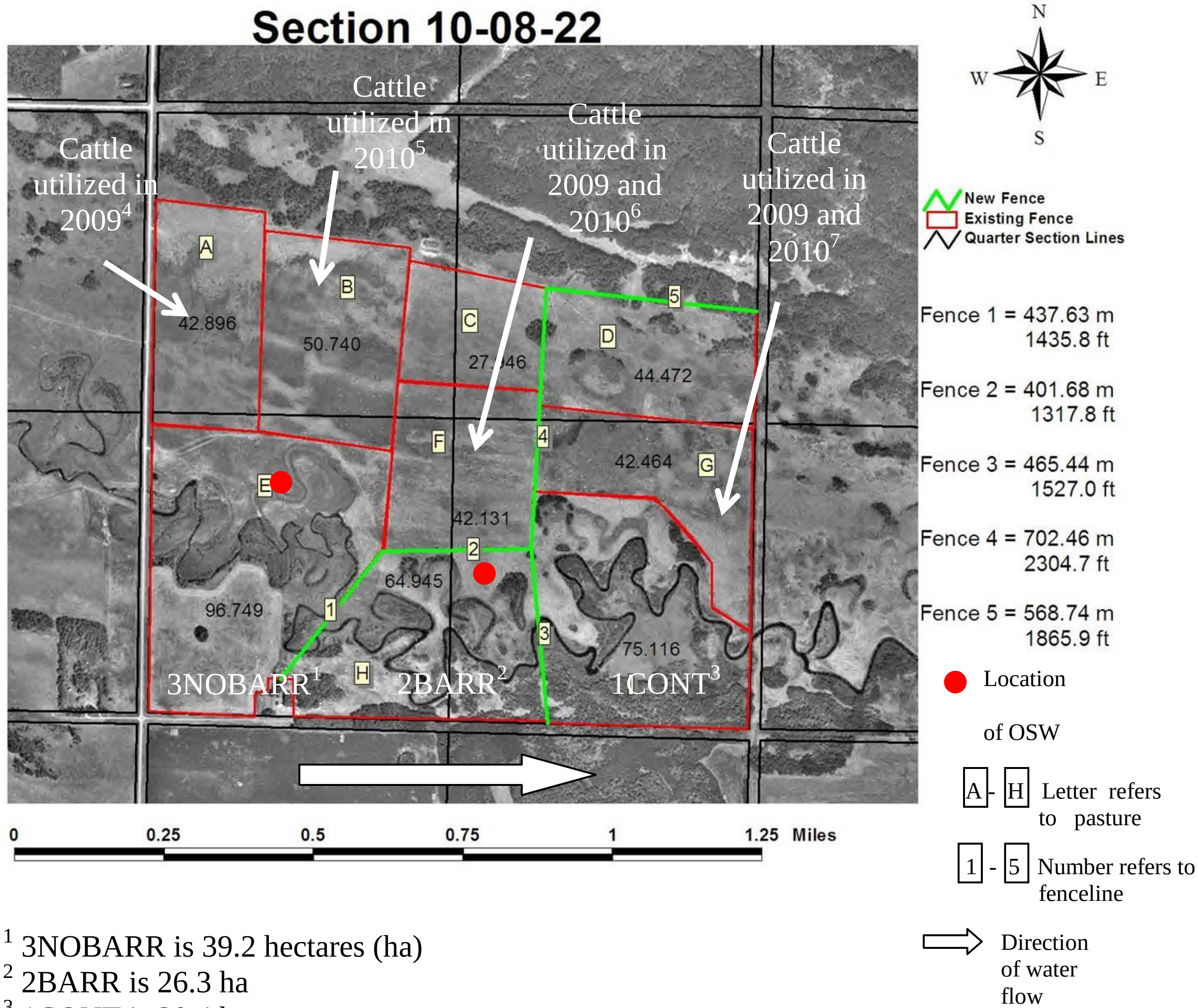
5.3.1. Site description

The study was conducted at two locations in South Western Manitoba; one site near Killarney on the Pembina River (Figure 8) and the second near Souris on Plum Creek (Figure 9). Criteria for pasture selection included: 1) continuously grazed; 2) comprised largely of native or reverted tame species, with similar forage types, carrying capacity, and stocking density of approximately 25 cow/calf pairs; and 3) adjacent to a stream, which flowed for the duration of the trial, with pre-existing fencing around the pasture, and no exclusion fencing around the stream or riparian area.



[1] 3NOBARR is 25.5 hectares (ha)
[2] 2BARR is 21.0 ha
[3] 1CONT is 26.3 ha

Figure 8. Site layout at Killarney



[1] 3NOBARR is 39.2 hectares (ha)
[2] 2BARR is 26.3 ha
[3] 1CONT is 30.4 ha
[4] Cattle in 3NOBARR utilized this 17.4 ha pasture in 2009
[5] Cattle in 3NOBARR utilized this 20.5 ha pasture in 2010
[6] Cattle in 2BARR utilized this 17.0 ha pasture in 2009 and 2010
[7] Cattle in 1CONT utilized this 17.2 ha pasture in 2009 and 2010

Figure 9. Site layout at Souris

5.3.2. Botanical composition

5.3.2.1. Killarney

The pasture in Killarney possessed the following communities based on the dominant plant species: tame flats, tame slopes and tame uplands; native slopes complex; and forested upland and forested flat and riparian (Figure 10).

Tame flats, tame slopes and tame uplands community were comprised of grasslands dominated by introduced and exotic species including various mixtures of smooth brome (*Bromus inermis*), alfalfa (*Medicago sativa*), Kentucky bluegrass (*Poa pratensis*), clovers (*Trifolium* species), dandelion (*Taraxacum officinale*), intermediate wheatgrass (*Thinopyrum intermedium*) and/or orchardgrass (*Dactylis glomerata*). Thistles (*Cirsium* species) were also frequent on the flats.

The native slopes complex community in Killarney were steep south-facing slopes comprised of complex of native grasslands with patches of brush. The native grasslands contained mixtures of green needle grass (*Nasella viridula*), porcupine grass (*Hesperostipa spartea*), blue grama grass (*Bouteloua gracilis*), june grass (*Koeleria macrantha*), little bluestem (*Schizachyrium scoparium*), prairie dropseed (*Sporobolus heterolepis*), sedges (*Carex* species), and/or sages (*Artemisia* species). The brush patches present in this pasture contained mixtures of hawthorn (*Crataegus chrysocarpa*), chokecherry (*Prunus virginiana*), and/or Manitoba maple (*Acer negundo*), usually with an understory of sweet-scented bedstraw (*Galium triflorum*), sedges (*Carex* species) and/or smooth brome (*B. inermis*).

The main types of forest in Killarney were associated with the riparian flat and the more heavily treed uplands, which made up the forested upland, forested flat, and riparian communities. Maples (*A. negundo*) dominated the riparian woods and oaks (*Quercus macrocarpa*) dominated the uplands, though in many areas the two mixed or graded into one another. Green ash (*Fraxinus pennsylvanica*) were occasional members of either type. Density of the woody vegetation was highly variable, from open shrub lands to dense closed canopies. Both types of forest had snowberry (*Symphoricarpos occidentalis*), chokecherry (*P. virginiana*), willow (*Salix* species), and hawthorn (*C. chrysocarpa*) for shrub cover, but more so in the open canopy of the flats. Closed canopies in the flats tended to have understory communities of sedges (*Carex* species) and sweet scented bedstraw (*G. triflorum*), while those on the uplands were dominated by smooth brome (*B. inermis*). Open canopies on either the flats or uplands were dominated by smooth brome (*B. inermis*) and Kentucky bluegrass (*P. pratensis*). Burdock (*Arctium* species) and thistles (*Cirsium* species) were frequent throughout both types.

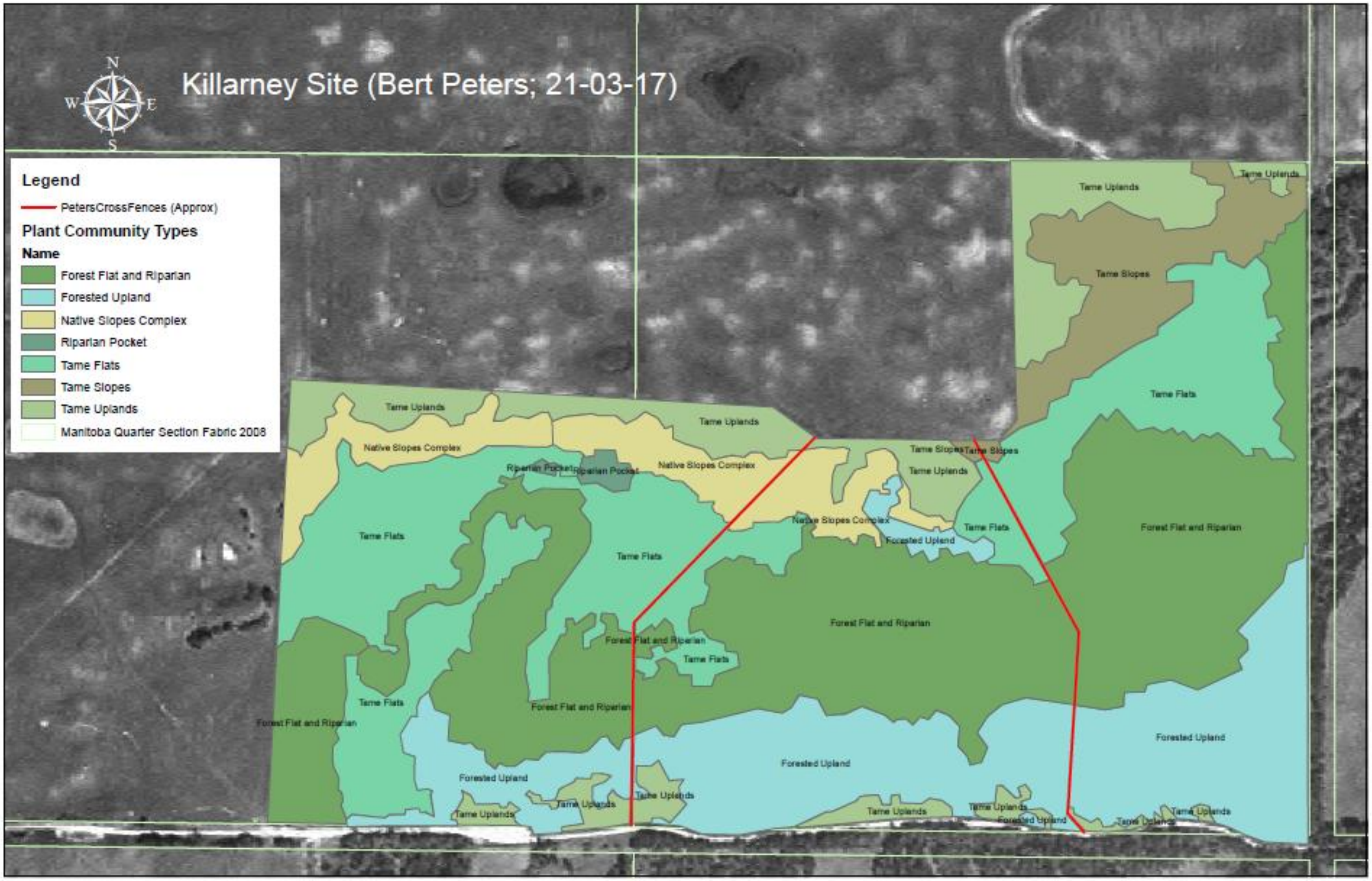


Figure 10. Plant communities present at the Killarney site

5.3.2.2. Souris

The historical management and the topography at the Souris site were far more complex than at the Killarney site, leading to a more complex mosaic of vegetative communities. The pasture in Souris was comprised of the following communities: tame hay, native grassland, and mixed upland; upland complex; open shrubby lowland; forested upland; and moist depression, and oxbow meadow and wood (Figure 11).

The south ends of each paddock were dominated by smooth brome (*B. inermis*), quackgrass (*Thinopyrum repens*), and Kentucky bluegrass (*P. pratensis*). Native grasslands in the furthest east paddock contained mixtures of Kentucky bluegrass (*P. pratensis*), smooth brome (*B. inermis*), little bluestem (*S. scoparium*), green needle grass (*Nassella viridula*), porcupine grass (*H. spartea*), and bearded wheatgrass (*Elymus trachycaulus* var. *subsecundus*). Occasional shrubs that were present on these grassland areas included western snowberry (*S. occidentalis*), meadowsweet (*Spiraea alba*), willows (*Salix* species), hawthorn (*C. chrysocarpa*), wolf willow (*Elaeagnus commutata*), and rose (*Rosa* species). The northern part of each paddock was dominated by open grassland with a mixture of exotic and native species, including smooth brome (*B. inermis*), Kentucky bluegrass (*P. pratensis*), quackgrass (*T. repens*), pasture sage (*Artemisia frigida*), sedges (*Carex* species), and silverweed (*Argentina anserina*). Occasional herbs and shrubs included licorice (*Glycyrrhiza lepidota*), marbleseed (*Onosmodium molle* var. *bejariense*), wolf willow (*E. commutata*), snowberry (*S. occidentalis*), aspen (*Populus tremuloides*), and willow (*Salix* species).

An upland complex existed in the south end of 2BARR that was a mixture of open land and shrub or tree patches. Areas of open land were dominated by smooth brome (*B. inermis*), quackgrass (*T. repens*), and Kentucky bluegrass (*P. pratensis*). Dominant shrubs were saskatoon (*Amelanchier alnifolia*), hawthorn (*C. chrysocarpa*), and chokecherry (*P. virginiana*). Dominant trees were Manitoba maple (*A. negundo*), aspen (*P. tremuloides*), and balsam poplar (*Populus balsamifera*).

The largest vegetation type was the lowland complex adjacent to the stream. The complex was a mix of open meadow, shrub land and some trees. Typical herbaceous species in the open meadows were smooth brome (*B. inermis*), Kentucky bluegrass (*P. pratensis*), quackgrass (*T. repens*), narrow reedgrass (*Calamagrostis stricta*), sedges (*Carex* species), prairie cordgrass (*Spartina pectinata*), and silverweed (*A. anserina*). Frequent shrubs were willow (*Salix* species), dogwood (*Cornus sericea* subspecies *sericea*), rose (*Rosa* species), chokecherry (*P. virginiana*), and maple (*A. negundo*). Trees included mostly Manitoba maple (*A. negundo*) and willows (*Salix* species) with occasional aspen (*P. tremuloides*) and green ash (*F. pennsylvanica*).

Older forest stands were frequent in the southern portions of the pasture. These were dominated by aspen (*P. tremuloides*), balsam poplar (*P. balsamifera*), and/or Manitoba maple (*A. negundo*). Understory shrubs included chokecherry (*P. virginiana*), saskatoon (*A. alnifolia*), dogwood (*C. sericea* ssp. *sericea*), rose (*Rosa* species), and raspberry (*Rubus idaeus*). The herbaceous understory was underutilized on the east side and likely consisted of native species, such as wild sarsaparilla (*Aralia nudicaulis*). Smooth brome and hemp nettle (*Galeopsis tetrahit*) were seen on the edge of the forest. The forested pocket in the hayfield of the western paddock was very small and more heavily used. Its understory was dominated by smooth brome (*B. inermis*), quackgrass (*T. repens*), and Kentucky bluegrass (*P. pratensis*).

A moist depression existed at the northwest portion of 3NOBARR, and was dominated by sedge (*Carex* species), Kentucky bluegrass (*P. pratensis*), and quackgrass (*T. repens*). Oxbows were common features on this landscape and transitioned from cattails in standing water to wetland grasses ringed by mature trees. Due to such variety, the oxbows were classed as one group of features. Common wetland herbs found in the depressional parts of these features were reed canary grass (*Phalaris arundinacea*), slough grass (*Beckmannia syzigachne*), sedges (*Carex* spp), cattails (*Typha latifolia*), bulrushes (*Scirpus* species), narrow reedgrass (*C. stricta*), silverweed (*A. anserina*), quackgrass (*T. repens*), and Kentucky bluegrass (*P. pratensis*). Under trees and shrubs, upland species were more likely to dominate, such as quack grass (*T. repens*), Kentucky bluegrass (*P. pratensis*), smooth brome (*B. inermis*), and thistles (*Cirsium* spp). Trees and shrubs that occurred around oxbows were willow (*Salix* species), meadowsweet (*S. alba),* western snowberry (*S. occidentalis*), rose (*Rosa* species), dogwood (*C. sericea* subspecies *sericea*), Manitoba maple (*A. negundo*), alder (*Alnus* species), raspberry (*R. idaeus*), and currant (*Ribes* species).

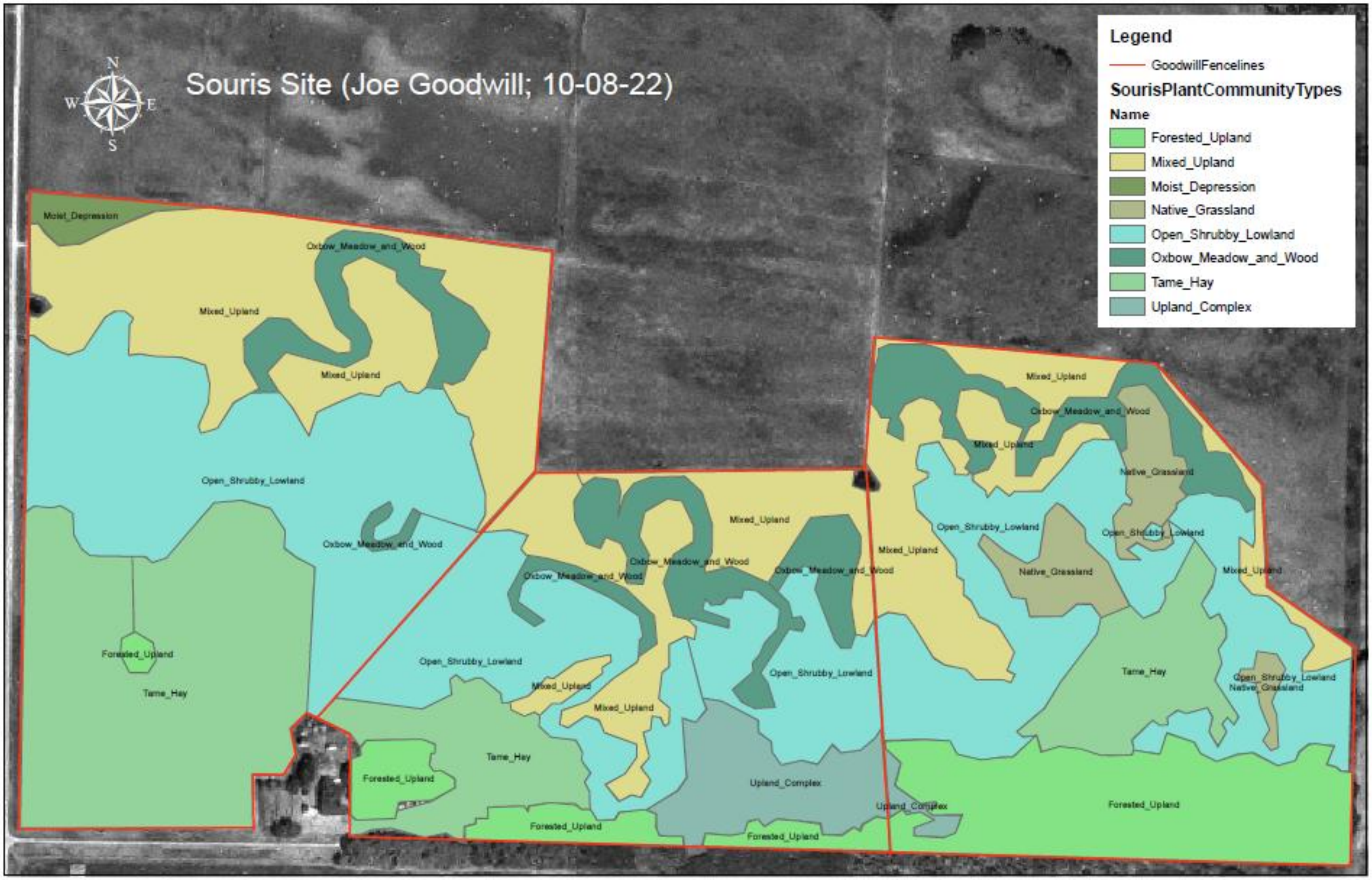


Figure 11. Plant communities present at the Souris site

5.3.3. Pasture management

The study was conducted over a two-year period from 2009 to 2010. In 2009 the grazing season was divided into three, 28-day periods. In 2010, only two, 28-day periods were observed due to excess precipitation, resulting in the accumulation of water in low lying areas of the pasture at both sites.

At each site, three treatments were examined: no OSW or barrier (1CONT), OSW with barrier (2BARR), and OSW without barrier (3NOBARR). The OSW system consisted of a submersible pump, a solar panel, battery, storage tank, and trough. Water was pumped from the stream into the storage tank, which filled the trough as the cattle drank. In 2009, the troughs were open and did not have a cover. To prevent algal build up in the trough, covers were installed in 2010. The cover had four openings where cattle could access the water. At each site, the OSW were situated north of the stream, with mineral tubs placed approximately 25 meters (m) from the OSW. At the Killarney site, the OSW was located approximately 60 m from the stream in 2BARR in 2009 and 2010, while in 3NOBARR, the OSW was located approximately 120 m and 32 m from the stream in 2009 and 2010, respectively. At the Souris site, the OSW was located approximately 95 m from the stream in 2BARR in 2009, and was relocated in 2010 so that it was approximately 232 m from the stream. In 3NOBARR, the OSW was located approximately 105 m from the stream in 2009 and 2010.

In 2BARR, natural barriers, which consisted of deadfall from the pasture, were placed across common watering and crossing areas on the north side of the stream. The locations of the barriers were determined before cattle were turned out at the beginning of the grazing season. Two established crossing points were left without barriers to allow access to the pasture on the south side of the stream. The barriers were monitored throughout the season and reinforced as required. New barriers were established if cattle appeared to be watering or crossing at new locations along the stream.

At the Killarney site, cow/calf pairs were turned out July 2, 2009 and June 16, 2010, while at the Souris site, cow/calf pairs were turned out June 18, 2009 and June 1, 2010. Cattle were allowed access to supplementary pastures to ensure sufficient forages at the Souris site. The OSW were located so that cattle would pass them en route to the supplementary pastures.

Twenty-five cow/calf pairs were assigned to each treatment, with a total of 75 cow/calf pairs per site. As a consequence of poor reproductive performance, calf numbers varied amongst treatments (Table 2). Midway through the grazing season in each year, one bull was assigned in each treatment.

To protect against horn flies, sucking lice, and biting lice, cows at both sites were treated with CyLence® (Bayer Inc, Toronto, ON). Salt (Co-op Cobalt Iodized Salt, Federated Co-operatives Ltd, Saskatoon, SK) and mineral (Co-op 3:1 Beef Cattle Mineral, Federated Co-operatives Ltd, Saskatoon, SK) were available ad libitum in each pasture. Animal handling and care procedures in this study were carried out in accordance with the guidelines of the Canadian Council on Animal Care (CCAC 1993).

Table 2. Number of cows and calves at each site and in each treatment

Site Year	Treatment	Number of cows	Number of calves
Killarney 2009	1CONT	25	18[1]
	2BARR	25	26[2]
	3NOBARR	25	22[1]
Killarney 2010	1CONT	25	23[1]
	2BARR	25	25
	3NOBARR	25	25
Souris 2009	1CONT	25	25
	2BARR	25	25
	3NOBARR	25	25
Souris 2010	1CONT	25	23[3]
	2BARR	25	25
	3NOBARR	25	24[3]

[1] Open cows resulted in lower calf numbers within the treatment
[2] One cow within the treatment had twins
[3] Delayed calving season with many of the cows calving on pasture throughout the season; a number of cows had not calved when the grazing season ended

5.3.4. Cattle location within the pasture and watering location

5.3.4.1. Cattle location within the pasture as recorded by global positioning system collars

Cattle were fitted with GPS collars to monitor their location throughout the pasture in 2BARR and 3NOBARR. Two models of collars were used: GPS3300LR Livestock GPS Collars (Lotek Wireless Inc., Newmarket, ON) and GPS2200 Collars (Lotek Wireless Inc., Newmarket, ON). The collars were programmed to record location fixes every five minutes and utilized for a minimum of ten days in each period (Table 3).

Table 3. Collar distribution between treatments and number of days of data collection at each site and in each period

Site Year	Period	Treatment	Number of Lotek collars utilized	Number of days of data obtained
Killarney 2009	Period 1	2BARR	6	12
		3NOBARR	7	12
	Period 2	2BARR	5	10
		3NOBARR	6	10
	Period 3	2BARR	4	12
		3NOBARR	7	12
Killarney 2010[1]	Period 1	2BARR	0	NA
		3NOBARR	0	NA
	Period 2a	2BARR	1	12
		3NOBARR	2	12
	Period 2b	2BARR	2	12
		3NOBARR	1	12
Souris 2009	Period 1	2BARR	7	11
		3NOBARR	5	11
	Period 2	2BARR	6	12
		3NOBARR	7	12
	Period 3	2BARR	4	13
		3NOBARR	4	13
Souris 2010	Period 1	2BARR	0	NA
		3NOBARR	0	NA
	Period 2	2BARR	5	26
		3NOBARR	4	26

[1] In 2010, Period 2 at the Killarney site was divided into Period 2a and 2b, as the GPS collars were removed so the batteries could be recharged to obtain additional data

Positions from the collars were differentially corrected with N4 v.1. 2138 software (Lotek Engineering Inc., Newmarket, ON) using base-station data downloaded from the Canadian Spatial Reference System Online database station in Winnipeg, Manitoba, located 192 kilometers (km) from the Killarney site and 227 km from the Souris site. With differential correction applied to the data, Moen et al. (1997) reported the accuracy of Lotek GPS_1000 collars (Lotek Wireless Inc., Newmarket, ON) to within 5 m, while Ganskopp and Johnson (2007) reported the accuracy of Lotek GPS2200 Collars to within 2 m.

To identify when cattle were in the RP, buffers were created along the RP and around the OSW in ArcMap 10 (Environmental Systems Research Institute, Redlands, CA). A 10 m buffer was created on either side of the stream for the RP, while an 8 m buffer was created around the OSW. Data from the GPS collars was examined to identify each fix located within the boundary of the RP buffer and the OSW buffer (Figure 1). The term “RP” is used exclusively to describe the 10 m buffer created within the riparian area for the GPS collar data and for VO data, as described below.

5.3.4.2. Watering location as recorded by visual observations

Visual observations were conducted to record the watering location of cows fitted with GPS collars in 2BARR and 3NOBARR. Observations were recorded every five minutes and took place from dawn until dusk for four days of each period. Observation data was not collected at night, as previous research suggests that little activity occurs during the night (Stuth 1991; Miner et al. 1992). Watering activity was recorded when they were in any of the following locations: stream (in stream or within one body length of the stream), RP (within five body lengths of the stream), or OSW (within four body lengths of the OSW). Sheffield et al. (1997) used a similar method, where animal location was recorded as riparian when they were two body lengths from the center of the stream and as OSW when they two body lengths from the edge of the OSW. The percentage of drinking events at the OSW or stream was calculated for each treatment and period with Excel (Microsoft, Redmond, WA).

5.3.5. Temperature, precipitation, and temperature-humidity index

Temperature, relative humidity, and precipitation were recorded hourly using HOBO U30 Cellular data loggers (Onset Computer Corporation, Bourne, MA) installed at both sites on July 15, 2009. When data from the HOBO U30 Cellular data loggers was not available (July 1 to July 15, 2009 of Period 1 in Killarney; all of Period 1 in Souris), temperature, relative humidity, and precipitation data were obtained from weather stations located near each site operated by the Manitoba Ag-Weather Program (MAFRI). Temperature and precipitation data were used to calculate the average daily temperature (ADT) and total precipitation in June, July, August, and September and compared to a 29-year average, with data from two National Climate Data and Information Archive of Environment weather stations, located at 49°25’00.000”N and 99°39’00.000”W (21.7 km from the Killarney site) and 49°39’00.000”N and 100°15’00.000”W (9.8 km from the Souris site). The temperature-humidity index (THI), which is the basis for the Livestock Weather Safety Index (LWSI) (LCI 1970), was used as a variable to analyze behaviour in livestock, based on response to weather. The THI was calculated using the following calculation:

$$THI = (0.8 \times T) + [(RH/100) \times (T-14.4)] + 46.4,$$

where T is the temperature in °C and RH is the relative humidity as a percentage (Mader 2003).

Temperature and relative humidity data recorded on days when cattle were fitted with GPS collars were used to calculate THI, averaged for each three hour block of each day in each period.

5.3.6. Water temperature

Two TidbiT v2 Water Temperature Data Loggers (Onset Computer Corporation, Bourne, MA) were utilized to obtain hourly recordings in the OSW and the stream in 2BARR and 3NOBARR at both sites. Mean water temperatures over each period were calculated with Excel (Microsoft, Redmond, WA).

More specifically, the data loggers installed at the Killarney site recorded water temperature in the stream and OSW in 2BARR and 3NOBARR from July 8 to July 15, July 30 to August 26, and August 27 to September 9 during Period 1, 2, and 3 in 2009, respectively. In 2010, the data loggers recorded water temperature in 2BARR (OSW only) and 3NOBARR (stream and OSW) from June 16 to July 12 and August 11 to September 7 during Period 1 and 2, respectively. Water temperature records from the stream in 2BARR were available for a different range of dates; from June 16 to July 1 and August 24 to September 7 during Period 1 and 2 in 2010, respectively.

The data loggers were initially installed at the Souris site on July 16, 2009; therefore, data from Period 1 is unavailable. The data loggers recorded water temperature in the stream and OSW in 2BARR and 3NOBARR from July 16 to August 11 and

August 12 to August 29 during Period 2 and 3 in 2009, respectively. In 2010, the data loggers recorded water temperature in the OSW in 2BARR and 3NOBARR from June 2 to June 30 and July 28 to August 24 during Period 1 and 2 in 2010, respectively. Water temperature records were unavailable from the data logger in the stream in 2BARR and 3NOBARR for a portion of Period 1 and all of Period 2; therefore, the data loggers in the stream in 2BARR and 3NOBARR recorded water temperature from June 2 to June 14 during Period 1.

5.3.7. Forage biomass measurements

To measure forage biomass in the pasture and riparian area, a 0.25 m^2 quadrat was randomly placed at nine locations in the riparian area and pasture, with the pasture samples collected in an M-pattern, as described in Ominski et al. 2006. Standing grasses and forbs within the quadrat were clipped to a height of 3.75 cm stubble and then placed in labelled Delnet bags (DelStar Technologies, Inc., Austin, TX). To determine dry mass content, the sample bags were weighed, dried in a forced air oven at 60°C for 48 hours to a constant mass, and weighed again. Forage availability was sampled at the beginning of each 28-day period in each grazing season of 2009 and 2010.

5.3.8. Animal performance

Cows and calves were weighed on the first day of each 28-day period and on day 28 of the last period in both 2009 and 2010. Weigh days are identified as follows in 2009: day 1 of Period 1 (P1-D1), day 1 of Period 2 (P2-D1), day 1 of Period 3 (P3-D1), and day 28 of Period 3 (P3-D28). Weight data was not available for day 28 of Period 3 in 2009.

Weigh days are identified as follows in 2010: day 1 of Period 1 (P1-D1), day 28 of Period 1 (P1-D28), day 1 of Period 2 (P2-D1), and day 28 of Period 2 (P2-D28).

5.3.9. Riparian health assessment

Riparian health assessments were conducted according to “Managing the Water’s Edge – Riparian Health Assessment for Streams and Small Rivers” (MRAC 2004). The RHA is targeted for use by landowners and producers. This tool provides a measurable outcome which allows a BMP, such as OSW, to be evaluated. Furthermore, utilization of the RHA provides an opportunity to evaluate the suitability of the assessment for producer use.

The RHA outlines six vegetation factors (Criteria 1 to 6) and five soil and hydrology factors (Criteria 7 to 11) that are visually assessed to determine riparian health. Each criterion is described in detail in the paragraphs that follow and the scoring strategy is provided in Table 4.

Criterion 1 evaluates the amount of vegetative cover within the riparian area, including plants, litter, moss, woody debris, and rocks, that help to reduce the potential for bare ground, which is prone to erosion and susceptible to the establishment of invasive species (MRAC 2004). As vegetative cover decreases, bare ground increases, resulting in a lower score.

The following criteria evaluate the canopy cover of invasive plants (Criterion 2), as well as the amount of the riparian area which is covered by disturbance increaser undesirable plants (Criterion 3). As the canopy cover of invasive plants increases, the score decreases. Similarly, as the density of plants increases from sporadic, individual plants to patches of plants to continuous occurrence, the score decreases. The score for disturbance increaser undesirable plants decreases as the percentage of cover of these species increases. Invasive plants should not be included in the evaluation of disturbance increaser undesirable plants. The presence of invasive species, while possibly contributing to some riparian function, negatively impacts the overall health of the riparian area by replacing preferred riparian species. Disturbance increaser undesirable plants may have some grazing value for livestock, but typically have shallow root systems, thus limiting their ability to bind soil and prevent erosion (MRAC 2004). An extensive list of invasive and disturbance increaser undesirable plants that may be found in the riparian area is provided in “Managing the Water’s Edge” (MRAC 2004).

Criterion 4 evaluates the canopy cover of preferred trees or shrubs with the percent cover of seedlings and saplings, which is indicative of potential for future growth of trees or shrubs. The score decreases as the percentage of seedlings and saplings within the canopy cover of mature trees decreases. Examples of preferred trees, including maple (*Acer* species), birch (*Betula* species), ash (*Fraxinus* species), cottonwoods (*Populus deltoids*), aspen (*P. tremuloides*), and elm (*Ulmus* species), and preferred shrubs, such as dogwood (*Cornus* species), chokecherry (*P. virginiana*), and willow (*Salix* species), are listed in “Managing the Water’s Edge” (MRAC 2004). It also includes a list of species that are not considered to be preferred trees or shrubs because their root systems are not as capable at stabilizing banks as the preferred species and they tend to increase under heavy grazing pressure (MRAC 2004). These species are hawthorn (*Crataegus* species), wolf willow (*Elaeagnus commutate*), rose (*Rosa* species), and snowberry (*S. occidentalis*).

Criterion 5 evaluates the extent to which livestock are browsing preferred tree and shrubs (lightly, moderately, or heavily). As in previous criteria, only the preferred species should be evaluated. Excess utilization of trees and shrubs can result in the elimination of preferred woody species, as continued removal of the above ground vegetation will impact the root system.

Criterion 6 evaluates the amount of decadent and dead woody material that comprises the total canopy cover of woody species. Large amounts of decadent and dead material may be a result of changes in hydrology, such as flood or drought conditions, chronic over use from browsing, or physical damage from trampling and/or rubbing. The score decreases as the amount of standing decadent & dead woody material increases.

Criterion 7 evaluates the species present in the riparian area, based on their deep binding root mass (DBRM) and their ability to bind soil, thus preventing soil erosion and maintaining the streambank. Along a small stream, preferred trees and shrubs, such as ash (*Fraxinus* species), cottonwoods (*Populus deltoids*), and willows (*Salix* species), provide excellent to good DBRM, while other shrubs, such as snowberry (*Symphoricarpos* species) and rose (*Rosa* species), provide fair to poor DBRM. Native grasses and forbs, such as sedges (*Carex* species) and cattails (*Typha* species), provide fair to poor DBRM, while introduced grasses, such as Kentucky Bluegrass (*P. pratensis*) or quack grass (*Agropyron repens*), disturbance-increaser undesirable species, such as foxtail barley (*Hordeum jubatum*) or dandelion (*Taraxacum offinale*), and invasive species, such as common burdock (*Arctium* species) or leafy spurge (*Euphorbia esula*), provide poor DBRM.

Criterion 8 evaluates the amount of bare ground or unprotected soil that is prone to erosion from wind, rain, or overland flooding. This includes bare ground caused by livestock grazing, cultivation, or recreation. The score decreases as the percent of bare ground caused by human activity increases.

Criterion 9 refers to bank alteration such as cracking, slumping, shearing, and the removal or reconfiguration of streambank materials due to livestock hoof shear, livestock trails or watering sites, recreational trails, bridges/culverts, or flood/erosion control methods. The score decreases as the percentage of the streambank that is altered increases.

Criterion 10 evaluates the amount of soil that is impacted by compaction through pugging, rutting, and hummocking. Pugging refers to large, individual animal tracks in soft soil. Rutting refers to deep paths in the soil resulting from regular cattle traffic, and indicates significant soil compaction. Hummocking refers to areas of soil that are elevated above the surrounding ground, usually a result of pugging and rutting. The score decreases as the percentage of the streambank that has pugging, hummocking and/or rutting increases.

Criterion 11 evaluates the vertical stability of the stream channel and the accessibility of the floodplain during high water. Incisement can arise from drainage scale changes such as dams, road construction, or culvert installation, as well as vegetation removal, extreme flooding, and beaver dams.

Scores from each criterion were summed to provide an overall score which was placed in one of three categories: healthy (80% to 100%), healthy but with problems (60% to 79%) and unhealthy (<60%). The guide states that the healthy score indicates that the riparian area is performing all functions and that these functioning areas are stable, resilient, and provide benefits and values. Healthy but with problems indicates that many riparian functions are being performed, but there is some stress and the functions may not operate at their full capability. Unhealthy indicates that most functions are severely impaired or have been lost.

In 2009, RHA were conducted twice at the Killarney site (August 12 and September 8) and twice the Souris site (August 6 and August 20). In 2010, RHA were completed at the start and end of each period at the Killarney site (Period 1, June 15 and July 7; Period 2, August 10 and September 8) and at the Souris site (Period 1, June 1 and June 29; Period 2, July 27 and August 23). In each treatment, RHA were conducted on the entire length of the stream (Table 5).

Table 4. Scoring for the 11 criteria described in "Managing the Water's Edge"

	Criteria	Scoring
1	How much of the riparian area is covered by vegetation?	6=>95% 4=85-95% 2=75-85% 0=<85%
2	How much of the riparian area is covered by invasive plant species? (Canopy cover/density)	Canopy cover: 3=no invasive species 2=<1% 1=1-15% 0=>15% Density: 3=no invasive species 2=few single plants occurring to single patch 1=several single plants to several patches 0=continuous occurrence of single plants or patches
3	How much of the riparian area is covered by disturbance-caused vegetation?	3=<5% 2=5-25% 1=25-45% 0=>45%
4	Is woody vegetation present and maintaining itself?	6=>15% 4=5-15% 2=<5% 0=absent (% of canopy that is seedlings and saplings)
5	Is woody vegetation being used?	3=0-5% 2=5-25% 1=25-50% 0=>50% (leaders browsed)
6	How much dead wood is there?	3=<5% 2=5-25% 1=25-45% 0=>45% (% of total canopy decadent/dead)
7	Are the streambanks held together with deep-rooted vegetation?	6=>85% 4=65-85% 2=35-65% 0=<35% (% of streambank with deep binding root mass)
8	How much of the riparian area has bare ground caused by human activity?	6=<1% 4=1-5% 2=5-15% 0=>15%
9	Have the streambanks been altered by human activity?	6=<5% 4=5-15% 2=15-35% 0=>35%
10	Is the reach lumpy and bumpy from use?	3=<5% 2=5-15% 1=15-25% 0=>25%
11	Can the stream access its floodplain?	9=Channel vertically stable and not incised, 6=Channel slightly incised 3=Channel moderately incised 0=Channel vertically unstable and deeply incised

(MRAC 2004)

Table 5. Approximate length of the stream in 1CONT, 2BARR, and 3NOBARR along the Killarney site and the Souris site

	Treatment[1]		
	1CONT	2BARR	3NOBARR
Killarney	1996m	961m	1378m
Souris	1972m	1478m	2150m

[1] Estimated in ArcMap.

5.3.10. Water quality sampling and analysis

In 2009, four grab samples were collected from the Pembina River (Killarney) and Plum Creek (Souris), both of which flow towards the east, at the beginning of each period; one sample at the west end of 3NOBARR , one sample between 3NOBARR and 2BARR, one sample between 2BARR and 1CONT, and one sample at the east end of 1CONT. In 2010, four grab samples were collected from the stream at similar locations, as well as one grab sample from each OSW in 2BARR and 3NOBARR. Water samples were kept in coolers with ice packs until they were delivered to the laboratory.

Water analysis for total phosphorus, total nitrogen, ammonia, and *E. coli* was completed at Cantest laboratory in 2009 and at Maxxam Analytics in 2010. The analysis used to measure the conventional and microbiological parameters based on the procedures described in Standard Methods for the Examination of Water & Wastewater 21st Edition (Eaton et al. 2005) and Method X325 in the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials (Hovrath 2005). Nitrate and nitrite in water were analyzed using Flow Injection Analysis, where nitrate was reduced to nitrite by passing the sample through a cadmium reduction column. The nitrite produced was then determined by diazotizing sulphanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride to form a reddish azo dye which was then measured colorimetrically at 540 nanometer (nm). Ammonia in water was analyzed using Flow Injection Analysis where the aqueous sample was injected into a carrier stream, which merges a sodium hydroxide stream. Gaseous ammonia was formed, which diffused through a gas permeable membrane into an indicator stream. This indicator stream was comprised of a mixture of acid-base indicators, which reacted with the ammonia gas; resulting in a colour shift which was measured photometrically at 590 nm. Total kjeldahl nitrogen (TKN) in water was determined based on Method 4500-N in Standard Methods for the Examination of Water & Wastewater 21st Edition (Eaton et al. 2005) and Method X325 in the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials (Hovrath 2005).

5.3.11. Statistical analysis

5.3.11.1. Cattle location within pasture

Data from each cow fitted with a GPS collar, in each site, treatment, and period was grouped into eight, 3-hour (h) time blocks for analysis (0001 h to 0300 h, 0301 h to 0600 h, 0601 h to 0900 h, 0901 h to 1200 h, 1201 h to 1500 h, 1501 h to 1800 h, 1801 h to 2100 h, and 2101 h to 2400 h), as described in Porath et al. (2002). The number of GPS fixes (a fix was given every five minutes) within and outside the buffer area of the RP was determined for each 3-h period for each cow.

For each location (Killarney or Souris), the number of fixes measuring time spent in the RP in 2009 (Y_{ijklm}) was examined using PROC GLIMMIX (SAS Institute Inc., Cary, NC) with the following model:

$$Y_{ijklm} = \mu + t_i + b_j + p_k + tb_{ij} + tp_{ik} + bp_{jk} + tbp_{ijk} + d_{kl} + c_{ikm} + e_{ijklm}$$

where t_i is the effect of the i'th treatment, b_j is the effect of the j'th time block, p_k is the effect of the k'th period, with their two and three-way interactions denoted with letter combinations. All parameters were considered as fixed effects. Random effects included d_{kl} as the effect of the l'th day within the k'th period, and c_{ikm} is the effect of the m'th collar (i.e. cow) within the ik'th treatment and period, and the residual error, e_{ijklm}. The interaction between treatment and time block was of particular interest since it provided an indication of whether or not cattle spent a different amount of time in the RP as the day progressed. Significance of factors was assessed using a type 1 error rate of 0.05. Using the GLIMMIX procedure, a binary distribution and a logit link function were assumed for the data. Results were presented as percentage of time in the RP relative to the total amount of time in a 3-h time block.

In 2010, data from Period 2 at the Killarney and Souris sites were analyzed together, as there were insufficient collars available to analyze the data from each site individually, with treatment, time block, and site included in the model. The impact of OSW with or without barriers on the number of GPS fixes measuring time spent in the RP was examined using PROC GLIMMIX with the following model:

$$Y_{ijklm} = \mu + t_i + b_j + s_k + tb_{ij} + ts_{ik} + bs_{jk} + tbs_{ijk} + d_{kl} + c_{ikm} + e_{ijklm}$$

where t_i is the effect of the i'th treatment, b_j is the effect of the j'th time block, s_k is the effect of the k'th site, with their two and three way interactions denoted with letter combinations. All parameters were considered as fixed effects. Random effects included d_{kl} as the effect of the l'th day within the k'th site, c_{ikm} is the effect of the m'th collar within ik'th treatment and site, and the residual error, e_{ijklm}. The interaction between treatment, time block, and site provided an indication if percentage of time in the RP varied based on time of day or site. Significance of factors was assessed using a type 1 error rate of 0.05. Using the GLIMMIX procedure, a binary distribution and a logit link function were assumed for the data. Results were presented as percentage of time in the RP relative to the total amount of time in a 3-h time block.

5.3.11.2. Temperature-humidity index

The THI data was analyzed with PROC MEANS (SAS Institute Inc., Cary, NC) to determine the mean, standard deviation (SD), minimum values, and maximum values for each period at each site and year.

5.3.11.3. Forage biomass

Forage biomass in the riparian and upland pasture areas in each treatment and period in each of two years were compared using t-tests (SAS Institute Inc., Cary, NC). Significance of differences was assessed using a type 1 error rate of 0.05.

5.3.11.4. Animal performance

Animal performance data, including cow and calf weights from each site, were analyzed separately. Repeated measures of analysis of variance were carried out in PROC

MIXED (SAS Institute Inc., Cary, NC) for cows and calves each year with treatment and period included with the following model:

$$Y_{ijk} = \mu + t_i + d_j + td_{ij} + c_{ik} + e_{ijk}$$

where t_i is the effect of the i'th treatment, d_j is the effect of the j'th weigh date, td_{ij} is the treatment*weigh date effect of the i'th treatment and the j'th weigh date. All parameters were considered as fixed effects. Random effects included c_{ik} as the effect of the k'th animal within the i'th treatment and the residual error, e_{ijk} . The interaction between treatment and period provided an indication of whether or not treatment affects animal performance differently as time passed during the grazing season. Significance of factors was assessed using a type 1 error rate of 0.05. Contrasts were developed to test hypotheses regarding treatment differences in different periods. If treatment differences were significant and positive, it may indicate that the availability of OSW was contributing to improved animal productivity. However, if the treatment differences were significant and negative, it may indicate that the availability of OSW, or other factors such as forage biomass or climate, contributed to the reduction in animal productivity.

5.4. RESULTS AND DISCUSSION

5.4.1. Cattle location within the pasture as recorded by global positioning system collars

In 2009, 2BARR cattle spent less time in the RP than 3NOBARR cattle at the Killarney site in Period 1 ($P = 0.0004$) and Period 3 ($P < 0.0001$), as indicated in Table 6. In 2009, 2BARR cattle spent more time in the RP than 3NOBARR cattle at the Souris site in Period 1 ($P < 0.0001$), while the opposite occurred in Period 2, where 2BARR cattle spent less time in the RP than 3NOBARR cattle (P <0.0001), as indicated in Table 6.

In 2010, GPS collar data from cattle in 2BARR at the Killarney site was combined with 2BARR at the Souris site and the results from the analysis indicated that the effect of the site was not significantly different (P = 0.7433). As indicated in Table 6, 2BARR cattle spent less time in the RP than 3NOBARR cattle (P = 0.0245).

Without GPS data from 1CONT, it is impossible to determine if the OSW was successful at decreasing the amount of time that cattle spent in the RP. However, the data does provide some indication of the efficacy of the natural barriers on deterring cattle from the RP. In 2009, as cattle in 3NOBARR at the Killarney site spent a greater proportion of time in the RP throughout all three periods, indicating that the implementation of the barrier was effective in deterring cattle from remaining in the RP. However, these results are inconsistent with Souris, where cattle in 2BARR were found to spend a greater proportion of time in the RP in Periods 1, while cattle in 3NOBARR spent a greater proportion of time in Period 2. In 2010, cattle in 3NOBARR at Killarney and Souris spent slightly more time in the RP.

These results indicate that low cost barriers like deadfall are insufficient to discourage cattle from spending time within the RP. The barriers may not have been large enough to deter cattle from the RP, or if the barrier did deter them from the location where it was installed, cattle may have moved further along the RP to an area without a barrier. It has been suggested that dense or thorny hedges which are unpalatable to cattle (hawthorns or rose bushes) may serve as an effective barrier (BCMAFF 2003).

Although the results of the implementation of the barrier at each site were inconsistent, there appears to be a pattern where cattle spent the lowest percentage of time in RP overnight, but spent a greater percentage of time in the RP as the day progressed, as depicted in Figures 12 to 15. In 2009, cattle in 2BARR at the Killarney site spent the greatest percentage of time within the RP from 0901 h to 1200 h, 1801 h to 2100 h, and 1201 h to 1500 h in Periods 1, 2, and 3 in 2009, respectively (Figure 12). In 2010, cattle in 2BARR spent the greatest percentage of time within the RP from 1201 h to 2100 h in Period 2 (Figure 13). In 2009, cattle in 3NOBARR spent the greatest percentage of time the RP from 0901 h to 1800 h, 1201 h to 1500 h, and 0901 h to 2100 h in Periods 1, 2, and 3, respectively (Figure 12). In 2010, cattle in 3NOBARR spent the greatest percentage of time the RP from 1201 h to 2100 h in Period 2 (Figure 13).

In 2009, cattle in 2BARR at the Souris site spent the greatest percentage of time within the RP from 1501 h to 1800 h, 1201 h to 2100 h, and 0901 h to 2100 h in Periods 1, 2, and 3 in 2009, respectively (Figure 14). In 2010, cattle in 2BARR spent the greatest percentage of time within the RP from 0601 h to 1200 h in Period 2 (Figure 15). In 2009, cattle in 3NOBARR spent the greatest percentage of time the RP from 1501 h to 2100 h, 1801 h to 2100 h, and 1201 h to 2100 h in Periods 1, 2, and 3 in 2009, respectively (Figure 14). In 2010, cattle in 3NOBARR spent the greatest percentage of time within the RP from 1201 h to 1500 h in Period 2 in 2010 (Figure 15).

Although the percentage of time in the RP in each time block fluctuated between periods, a general trend was apparent in that the percentage of time that cattle spent in the RP was limited during the night and early morning (0001 h to 0600 h), increased throughout the late morning (0901 h to 1200 h), remained high throughout the afternoon, and decreased again during the evening (2101 h to 2400 h). This trend is similar to that reported by Gillen et al. (1984) and Porath et al. (2002) and follows a similar pattern to that observed for daily temperature. As the temperature increased during the day, cattle spent an increased percentage of time in the RP. Cattle actively seek shade during the hottest part of the day (McIlvain and Shoop 1971); therefore, cattle may have spent a greater percentage of time in the RP during the afternoon as they were seeking shade for relief from heat.

In addition to the observations of time and day effects on the percentage of time cattle spent in the RP, seasonal impacts on distribution were also apparent. The percentage of time 2BARR and 3NOBARR cattle spent within the RP at the Killarney site declined as the grazing season progressed in 2009 (Table 6). Cattle in 2BARR spent a greater percentage of time within the RP early in the grazing season at the Souris site, and spent less time as the season progressed in 2009 (Table 6). Cattle at the Killarney site spent more time in the RP earlier in the season, potentially grazing riparian vegetation heavily in the earlier part of the season and moving into the upland pasture in search more vegetation as the season progressed.

A number of other studies have also found that cattle tend to spend more time near the riparian area as the grazing season progresses. Marlow and Pogacnik (1986) found that when cattle were given access to fresh pastures every two to three weeks, they grazed the riparian area more heavily in late summer and early fall. Porath et al. (2002) found that cattle with access to OSW spent more time close to the stream in the afternoon hours at the end of the grazing period compared to the beginning of the grazing period. Both researchers speculated that the forage in the riparian area may be more lush and desirable to cattle later in the grazing season compared to upland forage. In the same study, Porath et al. (2002) also found that cattle without access to the OSW stayed closer to the stream in the afternoon during the early part of the grazing season compared to the latter part of the grazing season. The authors hypothesized that due to the higher rate of forage utilization in the riparian area during the early part of the grazing season, cattle had to travel further from the stream later on in the season in order to find adequate vegetation, which is similar to the behaviour observed in 2BARR and 3NOBARR at the Killarney site, and in 2BARR at the Souris site.

Table 6. The mean percentage of time cattle fitted with GPS collars spent in the riparian polygon in Period 1, 2, and 3 throughout 2009 and 2010

	Killarney 2009			Souris 2009			Killarney + Souris 2010
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 2
2BARR	4.8 (0.8)[1]	4.3 (0.8)	0.8 (0.2)	5.4 (1.2)	1.1 (0.3)	2.1 (0.5)	1.8 (0.3)
3NOBARR	7.6 (1.3)	5.3 (1.0)	4.0 (0.7)	1.3 (0.4)	2.8 (0.6)	1.7 (0.4)	2.8 (0.5)
P-Value	0.0004	0.1324	<0.0001	<0.0001	<0.0001	0.4252	0.0237

[1]Percentage of time over 24 hours with standard error in parentheses

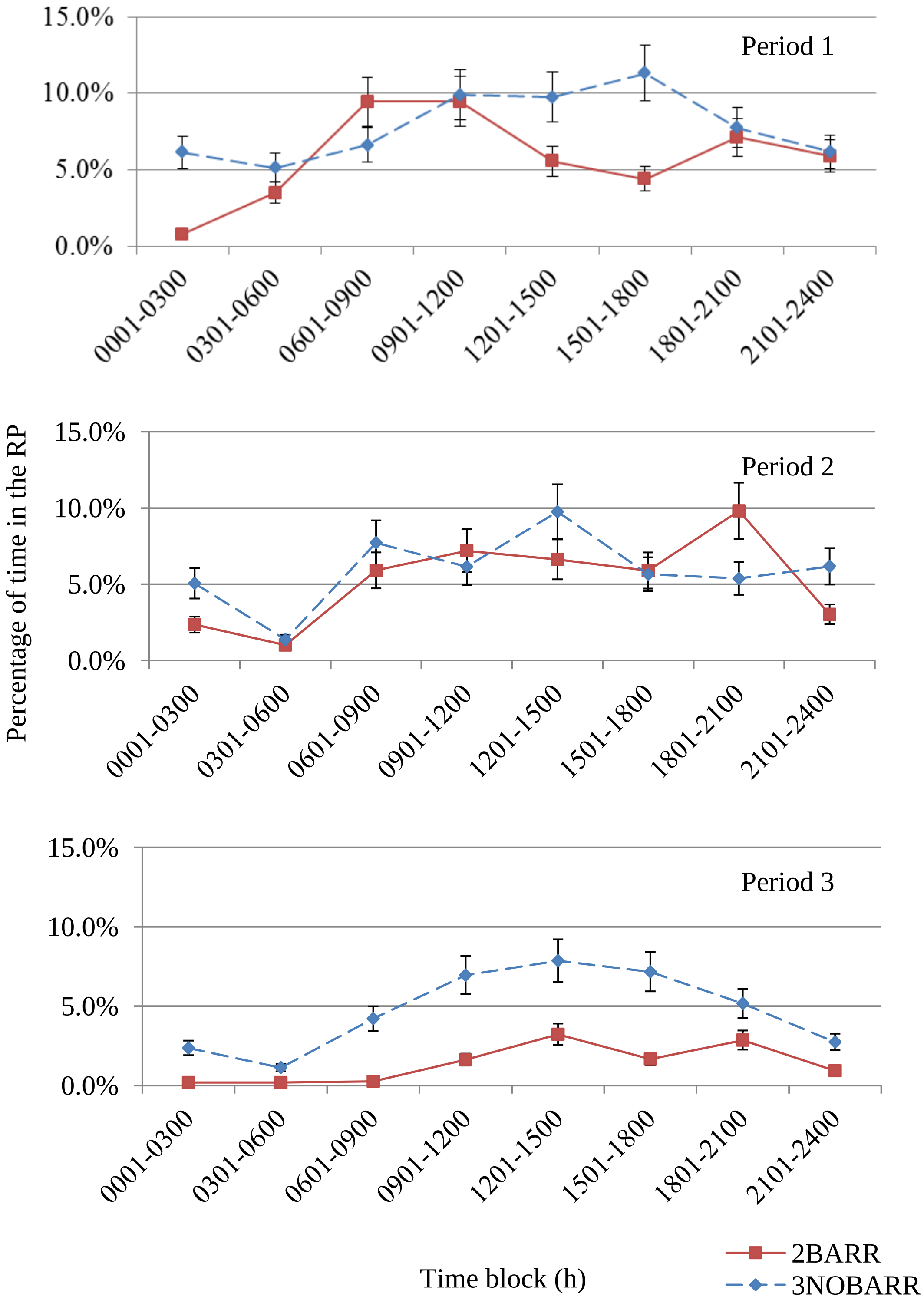


Figure 12. Percent of time cattle at the Killarney site spent in the riparian polygon for each time block during Period 1, 2, and 3 in 2009

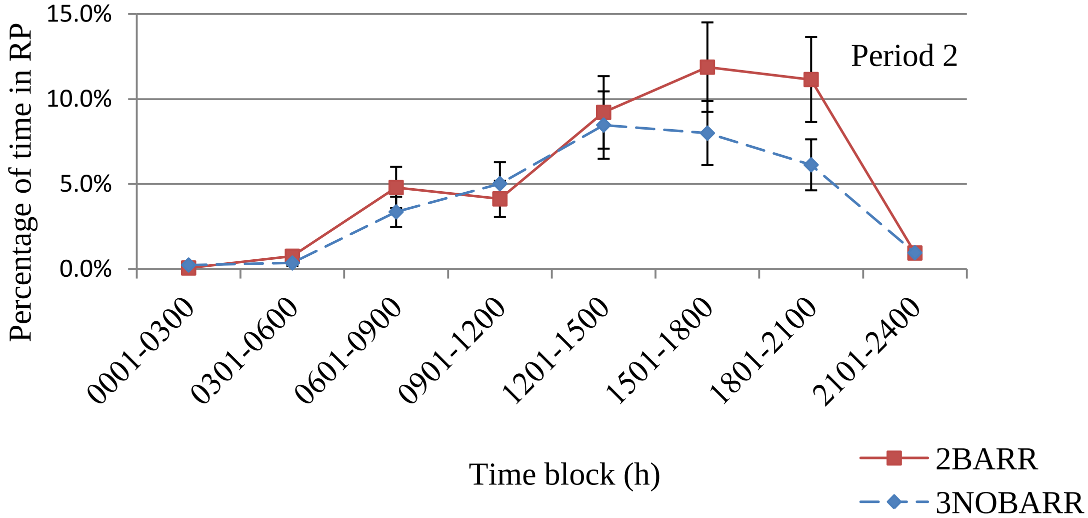


Figure 13. Percent of time cattle at the Killarney site spent in the riparian polygon for each time block during Period 2 in 2010

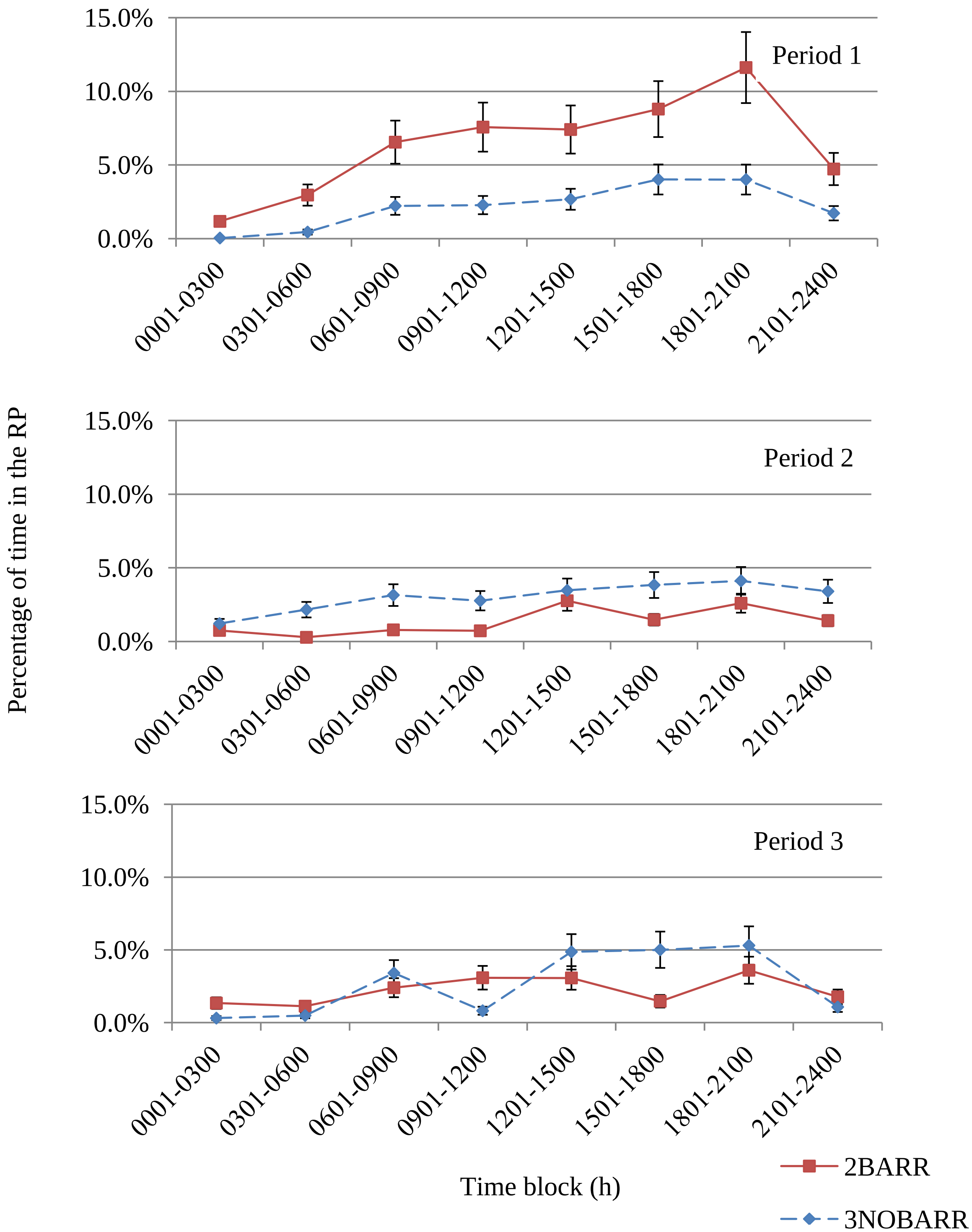


Figure 14. Percent of time cattle at the Souris site spent in the riparian polygon for each time block during Period 1, 2, and 3 in 2009

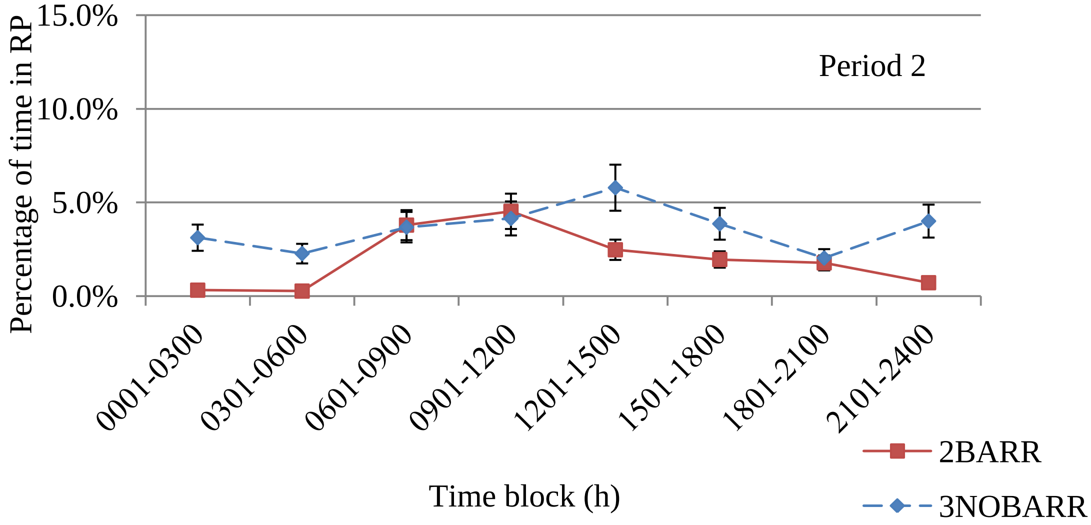


Figure 15. Percent of time cattle at the Souris site spent in the riparian polygon for each time block during Period 2 in 2010

5.4.2. Watering location as recorded by visual observations

In 2009 at the Killarney site, 100%, 93%, and 100% of observed watering events for the collared cows in 2BARR occurred at the OSW in Periods 1, 2, and 3, respectively (Figure 16). In 3NOBARR, 50%, 38%, and 40% of observed watering events for collared cows occurred at the OSW in Periods 1, 2, and 3, respectively. During 2010, 63% and 7% of observed watering events for collared cows in 2BARR occurred at the OSW in Period 1 and 2, respectively. In 3NOBARR, 0% and 52% of observed watering events for collared cows occurred at the OSW Period 1 and 2, respectively.

In 2009 at the Souris site, 85%, 31%, and 7% of observed watering events for the collared cows in 2BARR occurred at the OSW in Periods 1, 2, and 3, respectively (Figure 17). In 3NOBARR, 44%, 33%, and 0% of observed watering events for collared cows occurred at the OSW in Periods 1, 2, and 3, respectively. During 2010, 52% and 71% of observed watering events for collared cows in 2BARR occurred at the OSW in Period 1 and 2, respectively. In 3NOBARR, 83% and 0% of observed watering events for collared cows occurred at the OSW in Period 1 and 2, respectively.

Many researchers have found that cattle prefer to water at an OSW compared to a stream when an OSW is available (Clawson 1993; Sheffield et al. 1997; Veira and Liggins 2002). Our results are more similar to Bagshaw et al. (2008), who found that cattle watered at the OSW, but the availabilty of the OSW did not decrease watering at the stream or time spent in the riparain area. Our results indicate that cattle did water at the OSW, however, they did not use it exclusively. Watering at the stream continued despite the availability of OSW, with the exception of 2BARR at the Killarney site in Periods 1, 2, and 3 in 2009, where cattle were consistantly observed watering at the OSW.

The observed differences may be attributed to several factors. There may be a number of factors that influence where cattle prefer to water. The footing surrounding the watering location may play a role. Veira and Liggins (2002) suggested that dry, firm, and level soil surrounding the OSW provided better footing than watering locations along the stream. Cattle in 2BARR at the Killarney site in 2009 may have preferred the OSW as it provided better footing compared to access points along the stream.

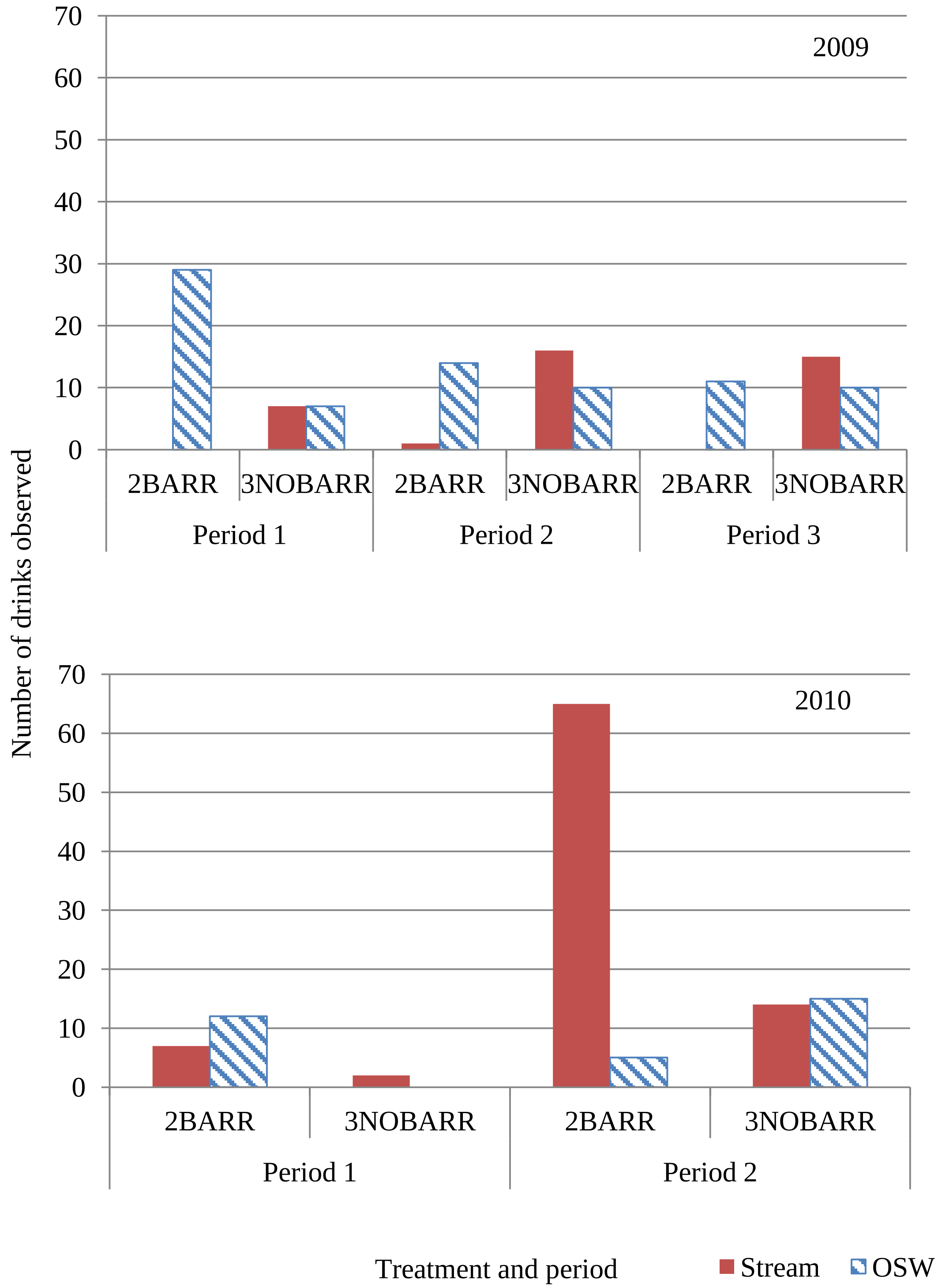


Figure 16. Watering location used by collared cows over four days at the Killarney site during Period 1, 2, and 3 in 2009 and Period 1 and 2 in 2010

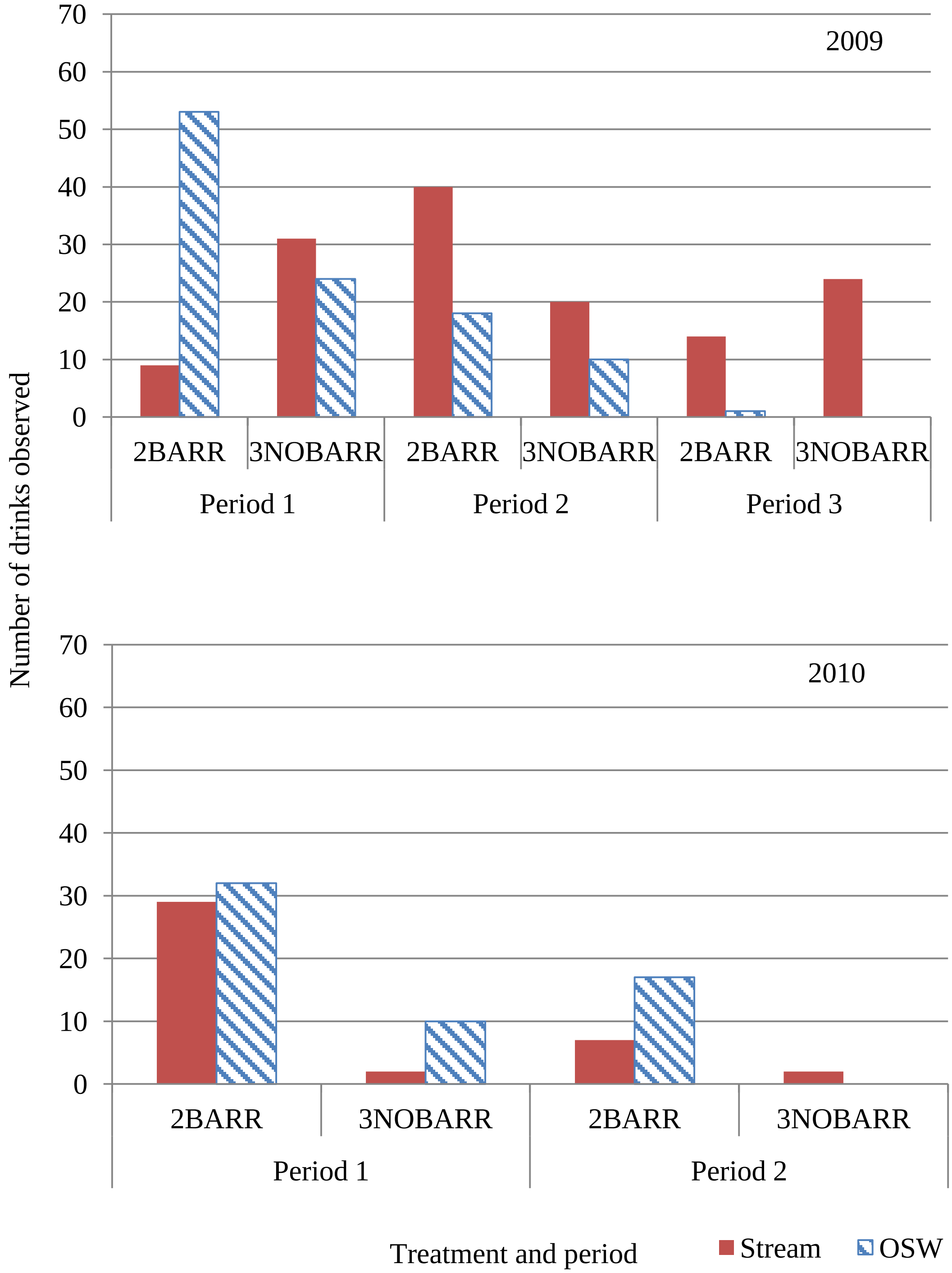


Figure 17. Watering location used by collared cows over four days at the Souris site during Period 1, 2, and 3 in 2009 and Period 1 and 2 in 2010

In addition, the location of the OSW may also be a critical factor which affects usage. Sheffield et al. (1997) compared two periods, a pre-BMP period with access to stream only and a post-BMP period with access to stream and OSW (with the OSW located adjacent to the stream), to examine OSW usage in three pastures which were 14.2 ha, 16.6 ha, and 22.3 ha in size. Their results indicated that when given the choice, cattle watered at the OSW 92% of the time, compared to the stream. Bryant (1982) examined the impact of placement of an OSW in a 344.8 ha pasture, where the OSW was located 1.5 km upslope from the stream. They observed that cattle watered exclusively from the OSW or the stream, depending on their proximity to either source within the pasture. This implies that the distance that cattle must travel to their water source will highly influence the likelihood the usage of an alternative water source, such as an OSW. Pasture size in the current study ranged 21.0 ha to 39.2 ha with an OSW located exclusively on the north side of the stream in 2BARR and 3NOBARR. Although cattle did water at the OSW, they continued to water at the stream as well. Similarly to Bryant (1982), cattle likely selected their watering location based on proximity. If cattle were a substantial distance from the OSW, such as the south side of the stream, they were likely were unmotivated to travel the distance to the OSW when they could access water from a closer source, such as the stream. Installing an OSW on both sides of the stream would ensure that cattle had easy access to the OSW, without having to travel further or cross the stream, potentially increasing usage of the OSW. However, installing two OSW within a pasture is costly, thus its feasibility is limited.

Precipitation at the sites likely influenced watering location as well. During Period 1 of 2010 at the Killarney site, there was a large accumulation of precipitation, and as a result, the Pembina River flooded. Due to the elevated water level, 2BARR cattle were restricted to the north side of the stream, and 3NOBARR cattle were restricted to the south side. In 2BARR, there was an increased frequency of watering events recorded at the OSW in Period 1 compared to Period 2. Usage of the OSW may have increased in Period 1 as the cattle were restricted on the side with the OSW. Conversely, in 3NOBARR, cattle were restricted to south side of the stream, with no access to the OSW, and as a result, there are no observations of cows watering at the OSW in Period 1. During Period 2, when they could access the north side, some use of the OSW was observed. Installing an OSW on both sides of the stream would ensure that cattle had access to the OSW, when conditions such as excess precipitation, restrict cattle to one side of the stream. However, the high cost of installing two OSW is prohibitive.

Watering events observed at the OSW and stream in Souris in 2010 decreased from Period 1 to Period 2. Between these two periods, the cattle producer allowed access to the hay pasture in the north portion of the site. Observers noted that there was standing water present in the north hay pastures and that cattle would often enter the hay pastures and remain there for most of the day. The forage in the pasture was tall, making it difficult for the observer to identify if the animal was standing in water, or if it was watering. Since cattle were allowed access to these pastures with standing water where they are presumed to be watering, this may account for the decrease in watering events recorded in Period 2 compared to Period 1.

In some periods, the total number of watering events recorded for individual cows is less than the average number of one to four drinks per day, as reported by Hafez and Bouissou (1975). Some watering events may have been missed by the observers given the topography and the amount of bush within the site. Pandey et al. (2009) found that observations may be missed due to observer fatigue, or from observer proximity effects on livestock. Increased precipitation at both sites in 2010 could have also contributed to the low number of watering events observed for several reasons. The presence of standing water allowed for cattle to water from sources other than the OSW or the stream. Furthermore, during and following rainfall, the moisture content of grasses may be greater than 80%, and as a result herbivores, such as cattle, can go for long periods without watering (King 1983).

5.4.3. Temperature, precipitation, and temperature-humidity index

Average daily temperature and precipitation over the months of June, July, August, and September in 2009 and 2010 at Killarney and Souris, as well as 29-year averages from nearby Environment Canada weather stations, are presented in Table 7. In Killarney, the 2009 ADT was slightly lower than the 29-year average ADT across June, July, and August, while in September, it was 4.7°C higher. Killarney received less precipitation in June, July, August, and September of 2009 compared to the 29-year average. The ADT in 2010 was similar to the 29-year average for each month. However, in June of 2010, Killarney received 68.5 millimeter (mm) more precipitation than the 29-year average, creating extremely wet conditions at the site (Figure 18). Thereafter, Killarney received 32 mm less precipitation in July, 17.4 mm more precipitation in August, and a similar amount of precipitation in September.

In Souris, the ADT in 2009 was comparable to the 29-year average, with the exception of September, when the ADT was 5.3°C higher. The site received less precipitation than the 29-year average in June, July, and August, while accumulating 27.8 mm more in September. In 2010, the ADT was similar to the 29-year average for June, July, August, and September. In June 2010, the site received slightly less precipitation than the 29-year average, while for July, August, and September, the site accumulated greater amounts of precipitation, at 23.2 mm, 10.4 mm, and 26.8 mm, respectively. As a result of the additional precipitation, conditions at the Souris site in 2010 were also very wet (Figure 19).

Figure 18. Killarney in June 2010 after high rainfall; overland flooding in 2BARR (left) and elevated water level along Pembina River (right)

Figure 19. Souris in June 2010 after high rainfall; elevated water level along Plum Creek in 1CONT (left) and accumulated precipitation in 3NOBARR (right)

Heat stress, as measured by THI, may be classified as follows: THI ≤ 74, normal; 74< THI < 79, alert; and 79 ≤ THI < 84, danger; and THI ≥84, emergency (LCI 1970). Other studies using cow/calf pairs have lowered the threshold for heat stress to account for the heat produced by the lactating cow, thus identifying cattle as heat stressed when the THI exceeds 72 (West 1994; Franklin et al. 2009). The mean, SD, minimum, and maximum THI values were calculated for each three-hour time block in a 24-h period when cattle were fitted with GPS collars (Table 8 and Table 9). Mean THI typically increased in the morning, remained highest between 1200 h and 1800 h, and then decreased in the evening. In the current study, the mean value does not exceed 72 at any point in the day during Period 1, 2, and 3 in 2009, or Period 2 in 2010. However, the maximum THI exceeded 72 during the three-hour block on a number of days at each site. At the Killarney site, the THI of 72 was exceeded 0 out of 12 days, 0 out of 10 days, and 7 out of 12 days in Period 1, 2, and 3 during 2009, respectively, while in Period 2 of 2010, the THI was exceeded 7 out of 24 days. At the Souris site, the THI of 72 was exceeded 5 out of 11 days, 5 out of 12 days, and 2 out of 13 days in Period 1, 2, and 3 during 2009, respectively, while in Period 2 of 2010, the THI was exceeded 15 out of 26 days.

Table 7. Average daily temperature (°C) and total precipitation at Killarney and Souris in June, July, August, and September and from 1971-2000 at nearby Environment Canada weather stations

		June		July		August		September	
		ADT (°C)	Precipitation (mm)	ADT (°C)	Precipitation (mm)	ADT (°C)	Precipitation (mm)	ADT (°C)	Precipitation (mm)
Killarney	2009	15.0[1]	53.0[1]	16.4[1]	38.0[1]	17.1	46.3	17.2[1]	20.4[1]
	2010	15.9[1]	152.0[1]	19.1	40.4	18.2	87.8	11.1[1]	48.4[1]
	Average 1971-2000[2]	16.7	83.5	19.0	72.4	18.1	70.4	12.5	48.3
Souris	2009	15.5[1]	52.4[1]	17.0[1]	74.8[1]	16.9	44.9	17.0[1]	72.2[1]
	2010	16.3	84.6	19.1	101.0	18.1[1]	67.6[1]	11.3[1]	71.2[1]
	Average 1971-2000[3]	16.3	87.1	18.4	77.8	18.0	57.2	11.7	44.4

ADT = Average daily temperature
Precip = Precipitation
[1]Portion of data obtained from the Manitoba Ag-Weather Program operated by MAFRI
[2]Data obtained from the National Climate Data and Information Archive of Environment Canada; weather station located at 49°25’00.000”N and 99°39’00.000”W which is 21.7km from the site
[3]Data obtained from the National Climate Data and Information Archive of Environment Canada; weather station located at 49°39’00.000”N and 100°15’00.000”W which is 9.8km from the site

Cattle may be attracted to riparian areas to seek relief when heat stressed (Stuth 1991; McIlvain and Shoop 1971). Franklin et al. (2009) found that cattle in the Georgia Piedmont region spent a greater proportion of time in the riparian area and the stream when the THI was high (72 – 84). The overall mean THI in the study by Franklin et al. (2009) was significantly higher (75) than that observed at Killarney and Souris, which ranged from 60-65 (Table 8 and Table 9). It is possible that the THI observed at Killarney and Souris was not consistently high enough to have a significant impact on cattle behaviour (Bagshaw et al. 2008). Furthermore, as previously mentioned, the THI increased between 1200 h and 1800 h, and then decreased the remainder of the day, indicating that cattle at both Killarney and Souris experience night cooling. Previous research has demonstrated that cattle are dependent on cooler night temperatures as it allows them to dissipate the heat they have accumulated throughout the day (Gaughan et al. 2004; Mader et al. 2006). Without night cooling as a means to dissipate heat accumulated throughout the day, cattle may be more attracted to the riparian area to seek out shade or enter the stream to find relief from heat. This is contrary to the Killarney and Souris sites where cattle experienced night cooling, so they presumably were able to dissipate the heat they accumulate throughout the day, and thus may not have relied on the riparian area for relief from heat. In locations with night cooling, cattle may not be attracted to the riparian area to seek relief from heat as strongly as in locations that do not experience night cooling.

Table 8. Temperature and humidity index (THI) by time block and period over days when cattle were fitted with GPS collars in Killarney in 2009 and 2010

	2009												2010			
	Period 1				Period 2				Period 3				Period 2			
Time Block	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
0001-0300	53	4	47	60	54	6	46	64	58	5	48	63	55	7	43	69
0301-0600	52	4	44	58	54	7	44	62	57	6	46	65	54	7	41	67
0601-0900	57	3	52	62	56	4	49	63	58	4	52	62	58	6	50	71
0901-1200	63	3	59	67	62	2	59	67	68	4	61	74	64	7	55	78
1201-1500	66	3	62	69	65	3	61	71	71	5	64	77	66	7	56	81
1501-1800	66	3	59	69	66	3	58	71	71	5	63	77	66	7	57	82
1801-2100	64	3	57	68	63	3	56	68	66	5	58	72	61	6	54	75
2101-2400	57	4	48	64	57	4	50	65	60	6	51	67	57	7	46	70
Overall mean	60	3	44	69	60	4	44	71	64	5	46	77	60	7	41	82

Table 9. Temperature and humidity index (THI) by time block and period over days when cattle were fitted with GPS collars in Souris in 2009 and 2010

	2009												2010			
	Period 1				Period 2				Period 3				Period 2			
Time Block	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
0001-0300	59	4	51	65	56	7	45	66	56	7	42	66	59	7	43	70
0301-0600	57	5	51	65	53	6	43	62	54	8	39	63	58	7	44	69
0601-0900	61	4	55	67	58	4	52	64	56	5	46	64	61	6	50	70
0901-1200	67	4	61	73	68	2	65	71	63	5	54	72	69	6	58	78
1201-1500	69	3	64	74	71	3	67	74	67	5	57	74	71	6	62	81
1501-1800	70	3	65	75	71	3	68	75	68	5	57	76	71	6	60	82
1801-2100	68	3	64	73	69	3	64	74	65	5	57	74	68	6	57	78
2101-2400	62	3	56	66	61	5	51	68	58	6	46	68	62	6	48	72
Overall mean	64	4	51	75	63	4	43	75	61	6	39	76	65	6	43	82

5.4.4. Water temperature

The difference in water temperature between the OSW and the stream ranged from 0.2°C to 3.3°C (Table 10 and Table 11), with the exception 3NOBARR in Killarney during 2009, where the difference between the OSW and the Pembina River was 8.6°C and 11.4°C in Period 2 and 3, respectively. Given that the temperature of the Pembina River in 2BARR, which was downstream of 3NOBARR, was 18.5°C and 18.0°C in Period 2 and 3, respectively, it is unlikely that the water temperatures recorded in 3NOBARR are an accurate representation. These inaccurate measurements may have been caused due to equipment malfunction.

Water temperature may have an influence on whether cattle prefer to water at the OSW or the stream. However, the small differences in temperature between the OSW and the stream observed in this study did not appear to influence drinking location. Similarly, temperature differences of 2°C (Clawson 1993), 4°C (Veira and Liggins 2002), and 5.2°C (Porath et al. 2002) between the OSW and the stream did not influence preference for either watering location. Conversely, livestock preference for water at various temperatures may depend on ambient temperature. In cold ambient temperatures, sheep (Shiga 1986), goats (Olsson and Hydbring, 1996), and cattle (Miner et al. 1992) preferred warmer water over cooler water. Furthermore, during periods of warm ambient temperature which averaged 32.7°C, Lofgreen et al. (1975) found that cattle consumed more water and had increased gains when provided water at 18.3°C compared to water at 32.2°C.

Table 10. Average water temperature in the stream and OSW in Killarney throughout 2009 and 2010

	2009			2010	
	Period 1[1]	Period 2[2]	Period 3[3]	Period 1[4]	Period 2[5]
2BARR Stream	20.5°C	18.5°C	18.0°C	20.8°C[6]	16.6°C[7]
2BARR OSW	21.3°C	19.5°C	20.3°C	20.4°C	18.3°C
3NOBARR Stream	21.1°C	11.0°C	8.6°C	21.5°C	18.2°C
3NOBARR OSW	19.6°C	19.6°C	20.0°C	19.2°C	18.4°C

[1] Water temperature recorded from July 8 to July 15, 2009
[2] Water temperature recorded from July 30 to August 26, 2009
[3] Water temperature recorded from August 27 to September 9, 2009
[4] Water temperature recorded from June 16 to July 12, 2010
[5] Water temperature recorded from August 11 to September 7, 2010
[6] Water temperature in 2BARR Stream recorded from June 16 to July 1, 2010
[7] Water temperature recorded in 2BARR Stream from August 24 to September 7, 2010

Table 11. Average water temperature in the stream and OSW in Souris throughout 2009 and 2010

	2009			2010	
	Period 1[1]	Period 2[2]	Period 3[3]	Period 1[4]	Period 2[5]
2BARR Stream	Not recorded	20.8°C	19.9°C	16.7°C[6]	Not recorded[7]
2BARR OSW	Not recorded	21.0°C	18.7°C	20.0°C	22.2°C
3NOBARR Stream	Not recorded	20.9°C	19.9°C	16.6°C[6]	Not recorded[7]
3NOBARR OSW	Not recorded	19.6°C	18.4°C	17.9°C	20.9°C

[1] Not recorded as data loggers were not yet installed
[2] Water temperature recorded from July 16 to August 11, 2009
[3] Water temperature recorded from August 12 to August 29, 2009
[4] Water temperature recorded from June 2 to June 30, 2010
[5] Water temperature recorded from July 28 to August 24, 2010
[6] Water temperature in 2BARR Stream and 3NOBARR Stream recorded from June 2 to June 14, 2010
[7] Not recorded due to data logger malfunction

5.4.5. Forage biomass

In 2009, forage biomass at the Killarney site was significantly greater in the riparian area than the pasture in 3NOBARR (P <0.0001) during Period 1, as well as 1CONT (P = 0.01) and 2BARR (P = 0.0002) in Period 2 (Table 12). Conversely, in 2010, forage biomass was significantly greater in the pasture than the riparian area in 1CONT (P = 0.003), 2BARR (P = 0.003), and 3NOBARR (P = 0.0004) during Period 1. The amount of forage biomass available in the pasture decreased as the grazing season progressed in 1CONT, 2BARR, and 3NOBARR in both 2009 and 2010 (Table 12). However, the amount of forage biomass in the riparian area remained consistent throughout the grazing season in 1CONT in 2009 and 2010, while forage biomass decreased in 2BARR and 3NOBARR in 2009. Conversely, forage biomass increased over the 2010 grazing season in 2BARR and 3NOBARR (Table 12).

In 2009, forage biomass at the Souris site was significantly greater in the riparian area than the pasture in 2BARR (P = 0.04) and 3NOBARR (P = 0.01) during Period 2, as well as 3NOBARR (P = 0.003) in Period 3 (Table 13). Similarly, in 2010, forage biomass was significantly greater in the riparian area than the pasture in 1CONT (P = 0.003), 2BARR (P = 0.004), and 3NOBARR (P = 0.006) in Period 1, as well as 1CONT (P = 0.05) and 2BARR (P = 0.002) in Period 2. The amount of forage biomass available in the pasture decreased as the grazing season progressed in 1CONT and 3NOBARR, while forage biomass increased in 2BARR in 2009. Conversely, forage biomass in the pasture increased in 1CONT and 3NOBARR, and decreased in 2BARR over 2010. However, the amount of forage biomass in the riparian area increased over the grazing season in 1CONT, 2BARR, and 3NOBARR in 2009 and 2010 (Table 13).

Table 12. Forage biomass (kg/ha) in the riparian upland pasture area at the Killarney site in 2009 and 2010.

			Forage Biomass (kg/ha)		
Year	Period	Treatment	Pasture	Riparian	Significance
2009	1	1CONT	1565.5	2030.8	0.29
		2BARR	1806.0	2623.6	0.09
		3NOBARR	2070.5	5124.8	<0.0001
	2	1CONT	1045.9	2198.2	0.01
		2BARR	468.9	1750.8	0.0002
		3NOBARR	1408.8	1289.7	0.70
	3	1CONT	985.2	2069.6	0.21
		2BARR	849.5	935.7	0.80
		3NOBARR	1326.8	1317.4	0.99
2010	1	1CONT	2251.9	1053.4	0.03
		2BARR	2199.0	695.6	0.03
		3NOBARR	1784.3	527.0	0.0004
	2	1CONT	924.8	1033.0	0.62
		2BARR	930.8	1004.1	0.73
		3NOBARR	1348.9	1032.4	0.14

Table 13. Forage biomass (kg/ha) in the riparian upland pasture area at the Souris site in 2009 and 2010

			Forage Biomass (kg/ha)		
Year	Period	Treatment	Pasture	Riparian	Significance
2009	1	1CONT	799.8	622.8	0.48
		2BARR	780.5	1163.4	0.22
		3NOBARR	517.7	792.8	0.13
	2	1CONT	453.5	325.4	0.42
		2BARR	589.0	1277.3	0.04
		3NOBARR	356.2	1381.6	0.01
	3	1CONT	760.0	997.0	0.42
		2BARR	845.2	1442.5	0.22
		3NOBARR	472.1	1676.4	0.003
2010	1	1CONT	398.3	975.9	0.003
		2BARR	489.8	1085.2	0.004
		3NOBARR	138.2	488.0	0.006
	2	1CONT	488.0	1287.7	0.05
		2BARR	323.0	1949.4	0.002
		3NOBARR	830.5	1664.4	0.07

Forage biomass was greater in riparian areas compared to upland pasture in the majority of observations in Killarney in 2009, and Souris in 2009 and 2010. Increased forage biomass in the pasture in Killarney in 2010 may be a result of flooding. When water levels are low in the stream, the exposed riparian area is colonized by vegetation, such as grasses and forbes, or the seedlings of shrubs and trees. However, frequent flooding within this area discourages the establishment of vegetation due to surface erosion (Gregory et al. 1991). Many species of plants within the riparian area have adapted to withstand disturbances, such as flooding; however, some may not be able to withstand periodic inundation (Naiman and Décamps 1997). Periodic inundation may have killed some of the vegetation in the riparian area, accounting for the decreased forage biomass observed in the riparian area compared to the pasture in Period 1 at the Killarney site during 2010.

5.4.6. Animal performance

As a consequence of differences in animal population, site topography, and precipitation, the weight gain of cows and calves in the two treatments with OSW (2BARR and 3NOBARR) was compared to that for cows and calves in the control treatment (1CONT) at each site and in each year. For each class of animal (calves and cows) and in each site-year, the significance of treatment, period, and the associated interaction at both the Killarney and Souris sites are provided in Table 14.

Table 14. The importance of treatment, period, and their interaction on weight of calves and cows at the Killarney and Souris sites in 2009 and 2010

Site	Year	Calves/cows	Significance		
			Treatment	Period	Treatment*Period
Killarney	2009	Calves	0.5523	<0.0001	0.1088
		Cows	0.9032	<0.0001	<0.0001
	2010	Calves	0.4003	<0.0001	0.0002
		Cows	0.4315	<0.0001	<0.0001
Souris	2009	Calves	0.1454	<0.0001	0.0177
		Cows	0.8891	<0.0001	<0.0001
	2010	Calves	<0.0001	<0.0001	0.3439
		Cows	0.2584	<0.0001	<0.0001

The initial weight of the calves and cows recorded on P1-D1 was used as a reference for treatment differences in subsequent periods, as treatment effects, if important, should appear as time passes. Treatment differences in the second and third period were compared to differences present in the first period (which may be present as a result of random chance).

In 2009, there was no change in weight gain in 2BARR calves from P1-D1 to P2-D1 (P = 0.4042) compared to weight change realized by 1CONT calves at the Killarney site (Table 15). However, significant weight change (P = 0.0242) amongst 2BARR calves did occur from P3-D1 relative to P1-D1, with lower weight gain in 2BARR compared to 1CONT calves (Figure 20). In 2009, 2BARR cows had significantly greater weight gain compared to 1CONT cows in P2-D1 relative to P1-D1 (P < 0.0001) and P3-D1 relative to P1-D1 (P = 0.0001), as indicated in Table 15. The positive differences in weight gain between 2BARR cows and 1CONT cows, and the negative differences between 3NOBARR cows and 1CONT cows may be attributed to the presence of the OSW (Table 15). However, as the variation in weights was no longer apparent as the season progressed (Figure 20), the OSW was likely not the cause of the observed differences in weight gain.

In 2010, there were no significant differences in weight gain between 2BARR calves and 1CONT calves at the Killarney site, with the exception of P2-D1 relative to P1-D1 (P = 0.0020), where 2BARR calves realized significantly greater weight gain compared to 1CONT calves, as indicated in Table 15. Changes in weight gain in 2010 were significantly lower in 2BARR cows compared to 1CONT cows in P1-D28 (P = 0.0166), P2-D1 (P < 0.0001), or P2-D28 (P < 0.0001) relative to P1-D1, as indicated in Table 15. These negative changes in weight gain may be a result of the availability of the OSW, or other factors such as climate. Conversely, 3NOBARR cows had significantly greater weight gain compared to 1CONT cows in P1-D28 ($P = 0.0210$), P2-D1 ($P = 0.0223$), or P2-D28 ($P = 0.0076$) relative to P1-D1 and these positive weight changes may be attributed to the availability of the OSW. Differences in average weights were less apparent as the grazing season progressed (Figure 21), once again indicating that the OSW was likely not the cause of the observed differences in weight gain.

In 2009, there was no change in weight gain in 2BARR calves from P1-D1 to P2-D1 ($P = 0.0937$) compared to weight change realized by 1CONT calves at the Souris site. However, significant, positive weight change ($P = 0.0183$) in 2BARR calves did occur from P3-D1 relative to P1-D1, attributed to the availability of OSW (Table 16). In 2009, 2BARR cows had significantly lower weight gain compared to 1CONT cows in P2-D1 relative to P1-D1 ($P = 0.0010$) and P3-D1 relative to P1-D1 ($P < 0.0001$), as depicted in Figure 22. Similarly, 3NOBARR cows had significantly lower weight gain compared to 1CONT cows in P2-D1 relative to P1-D1 ($P < 0.0001$) and P3-D1 relative to P1-D1 ($P < 0.0001$). The negative differences in weight gain between 2BARR and 3NOBARR cows relative to 1CONT cows were not attributed to the availability of the OSW, as indicated in Table 16.

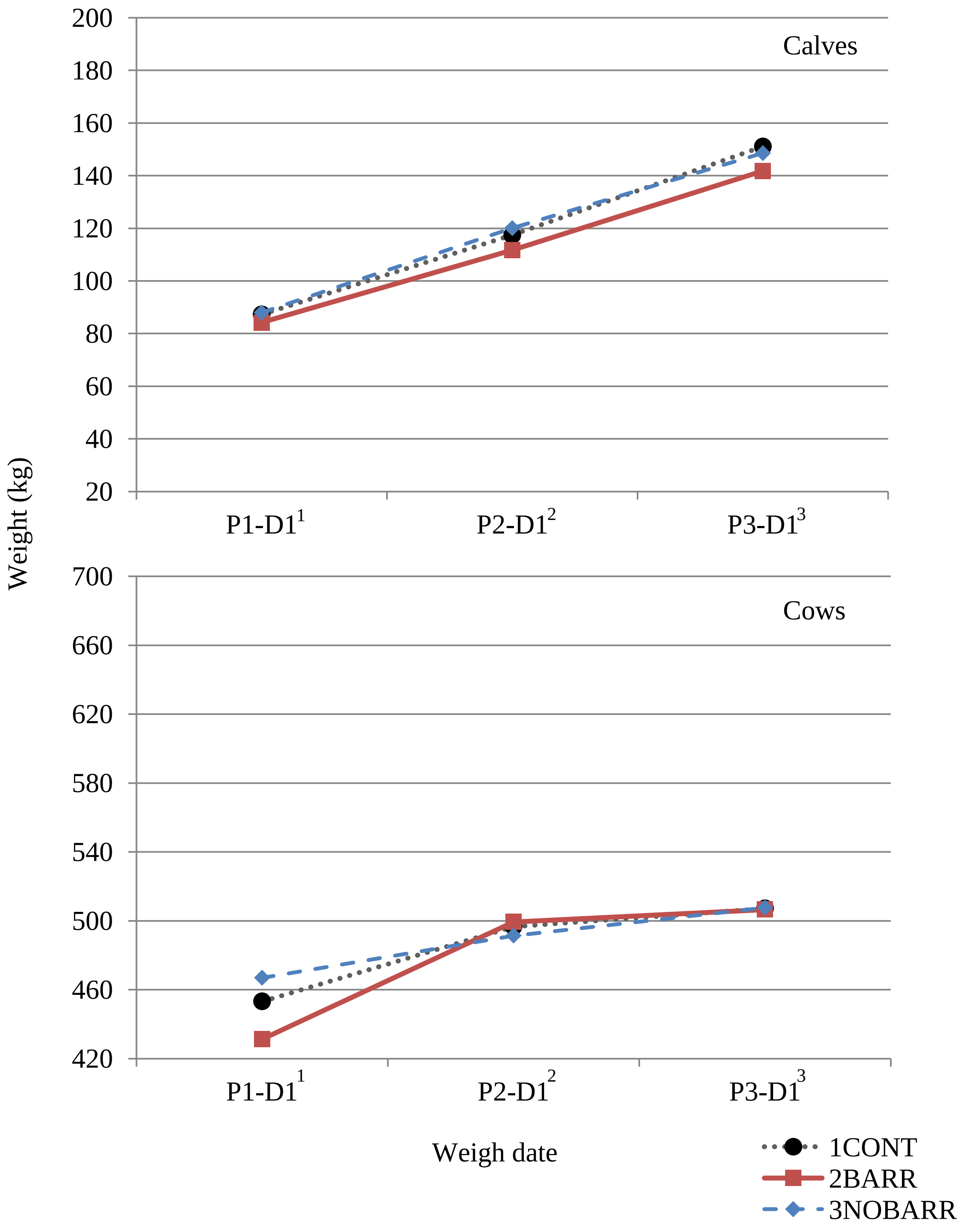
In 2010, there were no significant differences in weight gain between 2BARR calves and 1CONT calves at the Souris site. The variation in weights depicted in Figure 23, where 3NOBARR calves had lower average weights than 2BARR and 1CONT calves, may be attributed to a randomization problem caused by a lack of uniformity in the ages of the calves, as calf age was variable. The average weights of cows was significantly different in 3NOBARR compared to 1CONT in P1-D28 ($P < 0.0001$), P2-D1 ($P = 0.0002$), or P2-D28 ($P < 0.0001$) relative to P1-D1, and these negative changes in weight gain were not attributed to the availability of the OSW (Table 16). The average weight of 3NOBARR cows was greater than 1CONT and 2BARR cows (Figure 23). However, by the end of Period 3 (P3-D28), the initial difference was no longer apparent and the average weight of cows in each treatment was similar. The initial higher average weight of 3NOBARR cows was a result of an issue with randomization, as many of these cows were pregnant when they were initially weighed and subsequently calved on pasture.

Research by Porath et al. (2002) showed that access to OSW and salt improved the average daily gain (ADG) of cows and calves as compared to those animals that did not have access to OSW or salt. Our results indicated that OSW may improve gains but that improvement is not consistent throughout the grazing season. In some instances, the presence of an OSW may act in favour of animal performance; however other factors may also have an influence such as management, forage biomass, and temperature.

Table 15. Change in weight of calves and cows over the grazing season in 2009 and 2010 at the Killarney site

Year	Calves/cows	Treatment compared	Weigh dates	Significance	Weight change (kg)[1]	Weight change in favour of OSW
2009	Calves	2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.4042	-2.6 (3.1)	-
		2BARR vs. 1CONT	P3-D1 vs. P1-D1	0.0242	-6.2 (2.7)	No
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.4821	2.0 (2.8)	-
		3NOBARR vs. 1CONT	P3-D1 vs. P1-D1	0.2469	-3.2 (2.8)	-
	Cows	2BARR vs. 1CONT	P2-D1 vs. P1-D1	<0.0001	24.6 (5.7)	Yes
		2BARR vs. 1CONT	P3-D1 vs. P1-D1	0.0001	20.3 (5.1)	Yes
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.0003	-18.9 (5.1)	No
		3NOBARR vs. 1CONT	P3-D1 vs. P1-D1	0.0058	-14.2 (5.1)	No
2010	Calves	2BARR vs. 1CONT	P1-D28 vs. P1-D1	0.5048	2.3 (3.4)	-
		2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.0020	10.9 (3.5)	Yes
		2BARR vs. 1CONT	P2-D28 vs. P1-D1	0.1006	-5.7 (3.4)	-
		3NOBARR vs. 1CONT	P1-D28 vs. P1-D1	0.2127	-4.3 (3.4)	-
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.5550	2.0 (3.4)	-
		3NOBARR vs. 1CONT	P2-D28 vs. P1-D1	0.2097	-4.3 (3.4)	-
	Cows	2BARR vs. 1CONT	P1-D28 vs. P1-D1	0.0166	-20.8 (8.6)	No
		2BARR vs. 1CONT	P2-D1 vs. P1-D1	<0.0001	-43.4 (8.8)	No
		2BARR vs. 1CONT	P2-D28 vs. P1-D1	<0.0001	-79.6 (8.6)	No
		3NOBARR vs. 1CONT	P1-D28 vs. P1-D1	0.0210	20.4 (8.8)	Yes
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.0223	20.2 (8.8)	Yes
		3NOBARR vs. 1CONT	P2-D28 vs. P1-D1	0.0076	23.6 (8.8)	Yes

[1] Average weight change between weigh dates with standard error in parentheses



[1] Day 1 of Period 1
[2] Day 1 of Period 2
[3] Day 1 of Period 3

Figure 20. Average weights of calves and cows at the Killarney site in 2009

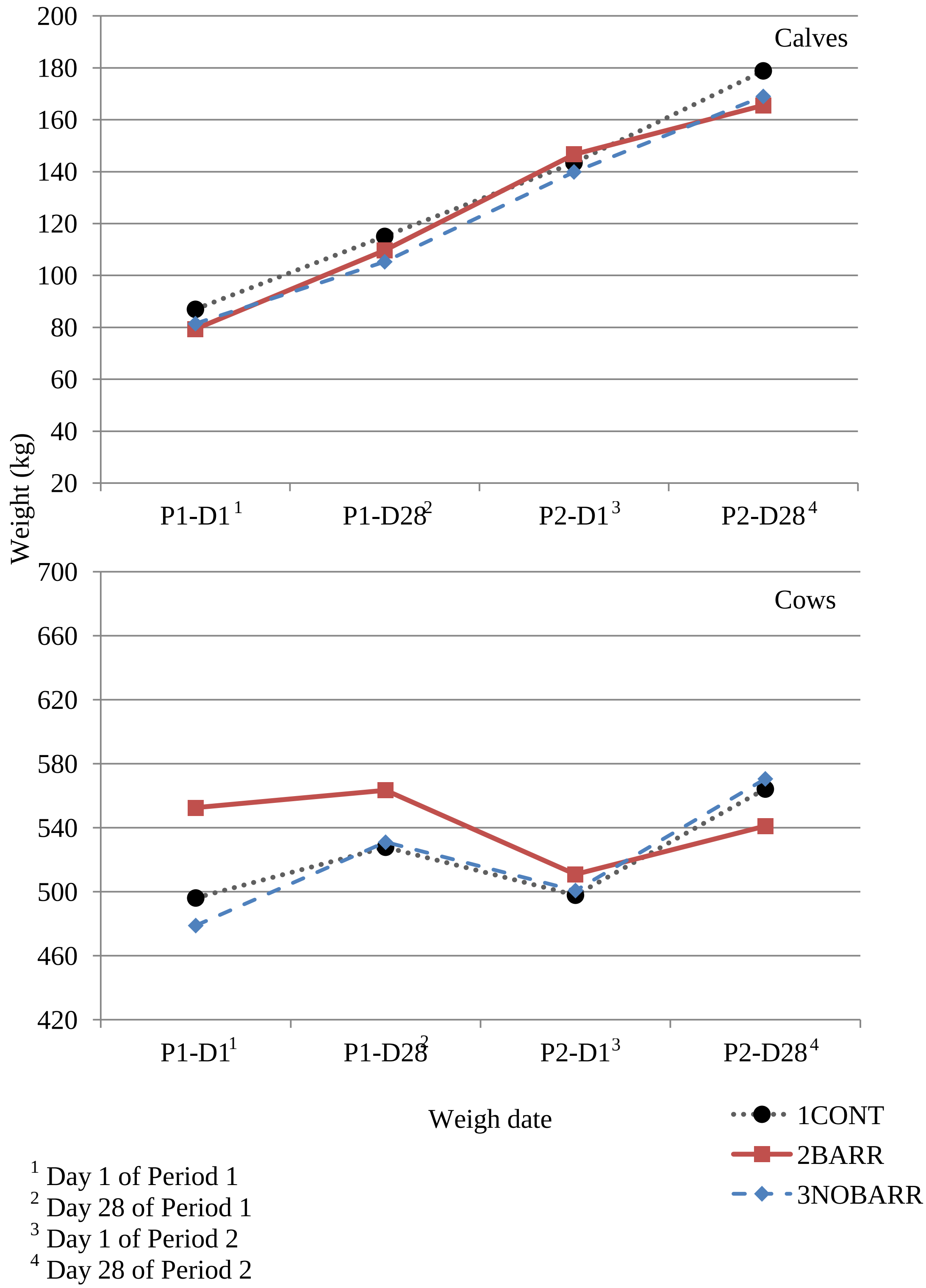
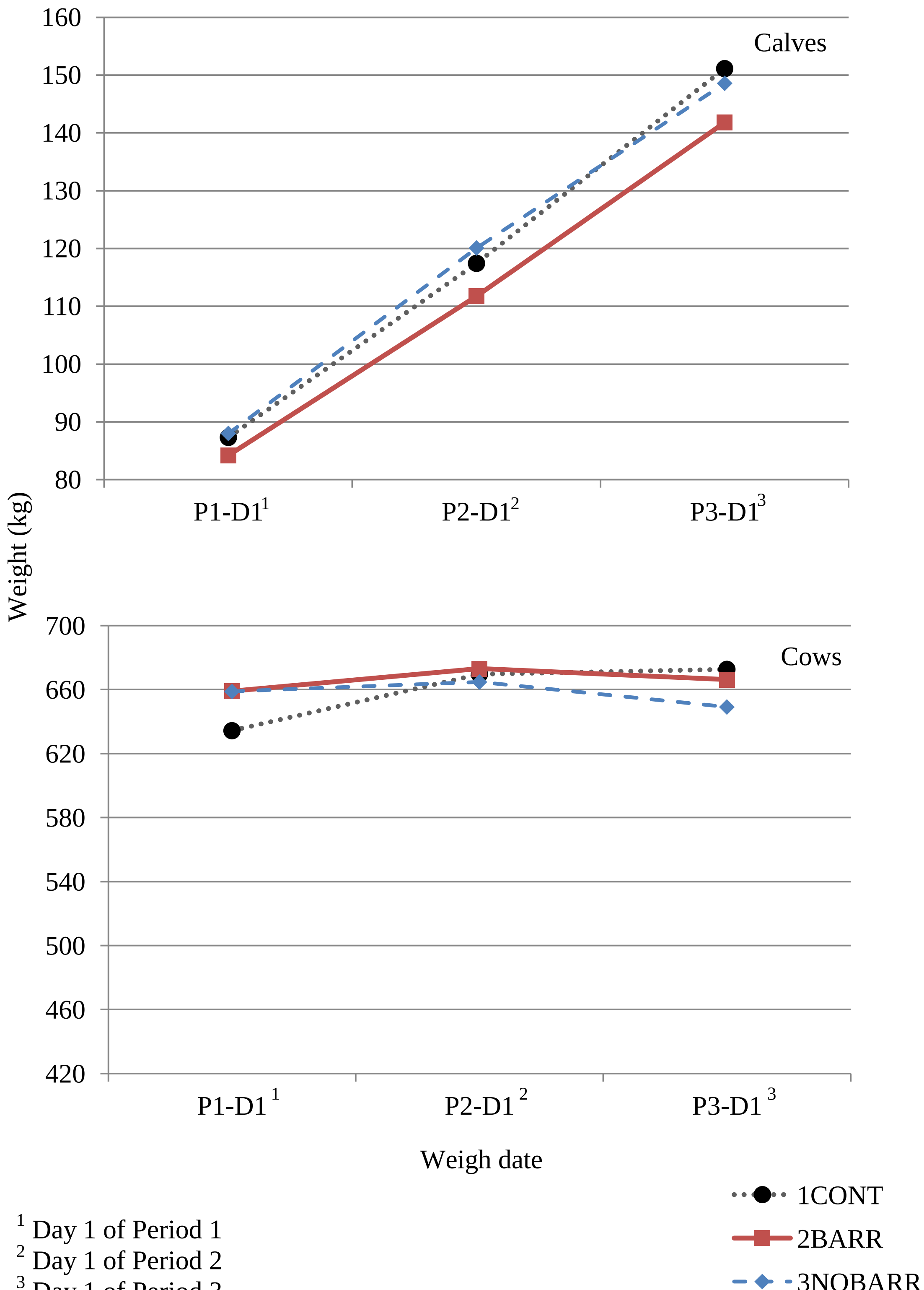


Figure 21. Average weights of calves and cows at the Killarney site in 2010

Table 16. Change in weight of calves and cows over the grazing season in 2009 and 2010 at the Souris site

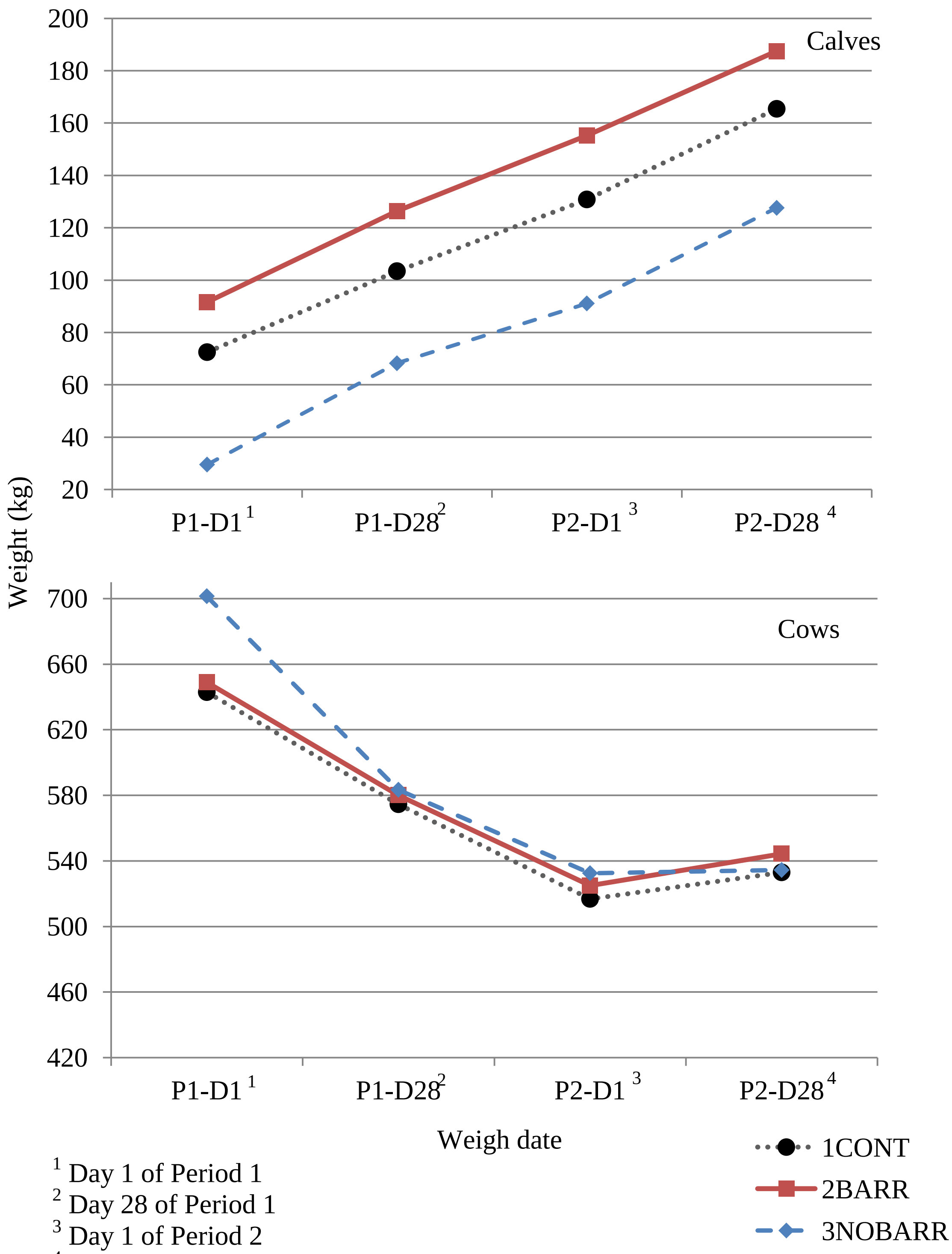
Year	Calves/cows	Treatment compared	Periods	Significance	Weight change (kg)[1]	Weight change in favour of OSW
2009	Calves	2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.0937	3.7 (2.2)	-
		2BARR vs. 1CONT	P3-D1 vs. P1-D1	0.0183	5.3 (2.2)	Yes
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.4326	-1.7 (2.2)	-
		3NOBARR vs. 1CONT	P3-D1 vs. P1-D1	0.3966	-1.9 (2.2)	-
	Cows	2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.0010	-21.3 (6.3)	No
		2BARR vs. 1CONT	P3-D1 vs. P1-D1	<0.0001	-31.2 (6.4)	No
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	<0.0001	-29.4 (6.4)	No
		3NOBARR vs. 1CONT	P3-D1 vs. P1-D1	<0.0001	-48.0 (6.4)	No
2010	Calves	2BARR vs. 1CONT	P1-D28 vs. P1-D1	0.2431	3.9 (3.3)	-
		2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.0879	5.4 (3.1)	-
		2BARR vs. 1CONT	P2-D28 vs. P1-D1	0.3444	3.0 (3.1)	-
		3NOBARR vs. 1CONT	P1-D28 vs. P1-D1	0.1154	7.7 (4.9)	-
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.4930	3.2 (4.7)	-
		3NOBARR vs. 1CONT	P2-D28 vs. P1-D1	0.2767	5.1 (4.7)	-
	Cows	2BARR vs. 1CONT	P1-D28 vs. P1-D1	0.9636	-0.5 (11.3)	-
		2BARR vs. 1CONT	P2-D1 vs. P1-D1	0.8499	2.1 (11.3)	-
		2BARR vs. 1CONT	P2-D28 vs. P1-D1	0.6366	5.3 (11.2)	-
		3NOBARR vs. 1CONT	P1-D28 vs. P1-D1	<0.0001	-49.7 (11.3)	No
		3NOBARR vs. 1CONT	P2-D1 vs. P1-D1	0.0002	-42.9 (11.4)	No
		3NOBARR vs. 1CONT	P2-D28 vs. P1-D1	<0.0001	-57.1 (11.3)	No

[1] Average weight change between weigh dates with standard error in parentheses



[1] Day 1 of Period 1
[2] Day 1 of Period 2
[3] Day 1 of Period 3

Figure 22. Average weights of calves and cows at the Souris site in 2009



[1] Day 1 of Period 1
[2] Day 28 of Period 1
[3] Day 1 of Period 2
[4] Day 28 of Period 2

Figure 23. Average weights of calves and cows at the Souris site in 2010

5.4.7. Riparian health assessment

"Managing the Water's Edge" field guide recommends completing the assessment on a reach of the stream with vegetation, cattle usage, channel characteristics, and stream gradients that are representative of the entire stream. The length of the reach should include two meander cycles, which on a small stream will usually be within a 200-m length. The width of the reach should extend to the outer edge of the riparian area. If the edge of the riparian area is difficult to determine, the area along the stream which is occupied by water that escapes the stream channel during average flood levels can be used. We carried out the RHA on the entire length of the stream in each treatment in order to determine the health of the area in the entire treatment. However, this may impact the result of our assessments as the length of the stream in each treatment varies, and is longer than the suggested reach length (Table 5). This increased length caused difficulties accurately estimating the components of various criteria, such as the percent of bare ground on a reach that is 1996-m, as is the case in 1CONT at the Killarney site.

The field guide also recommends conducting the assessment when flow conditions are close to normal. It specifically recommends that assessments should not be conducted when water levels are high, such as during spring run-off or immediately after a major storm. As a consequence of above average precipitation at both Killarney and Souris, it was necessary to conduct the assessment when the riparian area was submerged, making it difficult to complete an accurate assessment. As such, the assessment was conducted several times throughout the season, in an attempt to mitigate these challenges.

As described, assessments at both sites were completed approximately three to four weeks apart in 2009 and 2010. This timing allowed for variation in the scores of certain criteria to be observed, such as Criterion 1, while other criteria require years before changes would be detected, such as Criterion 11. Changes in Criterion 11, which measures stream channel incisement, may arise due to high water flow events that recur over several years to several decades (Gregory et al. 1991). However, the score of Criterion 1, which measures vegetative cover of the riparian area, will decline with presence of sediment deposits which can be moved and reshaped several times a year (Gregory et al. 1991).

Furthermore, the above average precipitation received in 2010 created extreme flood conditions which likely had greater impact to various criteria within the RHA than the impact associated with OSW and barriers. As a consequence of the unpredicted flooding event, the impact of the imposed management strategies may have been overshadowed by the more dramatic effects associated with flooding.

The results of the RHA for each treatment are shown for Killarney in Table 17, Table 18, and Table 19, and for Souris in Table 20, Table 21, and Table 22. As the length of time during which the experiment was conducted was not sufficient to see changes in the overall score, changes in each individual criterion were examined in greater detail. Photos taken during the RHA are also available, which allow for visualization of the changes in criterion (Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, Figure 29, Figure 30 and Figure 31).

Table 17. Riparian health assessment of 1CONT at the Killarney site

Criteria	Aug 12, 2009	Sept 8, 2009	June 15, 2010	July 6, 2010	Aug 10, 2010	Sept 8, 2010
1. Vegetative cover of Floodplain & Streambanks	6	4	6	6	6	6
2. Invasive Plant Species – cover/density	1/0	1/0	0/0	1/0	1/0	1/0
3. Disturbance-increaser Undesirable Herbaceous Species	2	2	1	2	2	2
4. Preferred Tree & Shrub Establishment	2	2	2	2	2	2
5. Utilization of Preferred Trees and Shrubs	1	2	2	2	2	2
6. Standing Decadent & Dead Woody Material	2	1	3	3	3	3
7. Streambank Root Mass Protection	6	6	0	4	4	6
8. Human-Caused Bare Ground	2	2	6	4	6	6
9. Streambank Structurally Altered by Human Activity	6	4	6	6	6	6
10. Pugging, Hummocking and/or Rutting	2	2	NA[1]	2	2	0
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	33 (58%)	29 (51%)	29 (54%)	35 (61%)	37 (65%)	37 (65%)
Overall descriptive rating	Healthy with problems	Unhealthy	Unhealthy	Healthy with problems	Healthy with problems	Healthy with problems

[1] Pasture was underwater therefore not included in calculation of overall descriptive rating

Table 18. Riparian health assessment of 2BARR the Killarney site

Criteria	Aug 12, 2009	Sept 8, 2009	June 15, 2010	July 6, 2010	Aug 10, 2010	Sept 8, 2010
1. Vegetative cover of Floodplain & Streambanks	6	6	6	4	6	6
2. Invasive Plant Species – cover/density	1/0	2/0	1/0	2/1	2/1	2/1
3. Disturbance-increaser Undesirable Herbaceous Species	2	3	1	3	2	2
4. Preferred Tree & Shrub Establishment	2	2	2	2	2	2
5. Utilization of Preferred Trees and Shrubs	2	2	3	2	2	2
6. Standing Decadent & Dead Woody Material	2	2	3	3	3	3
7. Streambank Root Mass Protection	6	6	0	4	2	4
8. Human-Caused Bare Ground	4	6	6	4	4	6
9. Streambank Structurally Altered by Human Activity	6	6	6	6	6	6
10. Pugging, Hummocking and/or Rutting	3	3	3	1	0	0
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	37 (65%)	41 (72%)	34 (60%)	35 (61%)	33 (58%)	37 (65%)
Overall descriptive rating	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems

Table 19. Riparian health assessment of 3NOBARR the Killarney site

Criteria	Aug 12, 2009	Sept 8, 2009	June 15, 2010	July 6, 2010	Aug 10, 2010	Sept 8, 2010
1. Vegetative cover of Floodplain & Streambanks	6	4	4	6	6	6
2. Invasive Plant Species – cover/density	0/0	1/0	0/0	2/1	2/1	1/1
3. Disturbance-increaser Undesirable Herbaceous Species	1	2	1	2	2	2
4. Preferred Tree & Shrub Establishment	2	2	2	2	2	2
5. Utilization of Preferred Trees and Shrubs	2	1	2	3	2	2
6. Standing Decadent & Dead Woody Material	1	1	2	2	3	3
7. Streambank Root Mass Protection	4	6	2	4	3	6
8. Human-Caused Bare Ground	2	4	4	6	6	6
9. Streambank Structurally Altered by Human Activity	6	6	6	6	6	6
10. Pugging, Hummocking and/or Rutting	3	3	3	2	1	2
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	30 (53%)	33 (58%)	29 (51%)	39 (68%)	37 (65%)	40 (70%)
Overall descriptive rating	Unhealthy	Healthy with problems	Unhealthy	Healthy with problems	Healthy with problems	Healthy with problems

Table 20. Riparian health assessment of 1CONT at the Souris site

Criteria	Aug 6, 2009	Aug 20, 2009	June 1, 2010	June 29, 2010	July 27, 2010	Aug 23, 2010
1. Vegetative cover of Floodplain & Streambanks	6	4	6	6	6	6
2. Invasive Plant Species – cover/density	1/0	1/0	2/1	2/1	2/1	2/1
3. Disturbance-increaser Undesirable Herbaceous Species	2	3	3	3	3	3
4. Preferred Tree & Shrub Establishment	4	4	6	6	6	4
5. Utilization of Preferred Trees and Shrubs	2	1	2	2	1	1
6. Standing Decadent & Dead Woody Material	2	2	1	3	2	1
7. Streambank Root Mass Protection	4	6	6	6	2	6
8. Human-Caused Bare Ground	2	4	6	6	6	6
9. Streambank Structurally Altered by Human Activity	4	6	6	6	4	6
10. Pugging, Hummocking and/or Rutting	2	2	3	3	1	1
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	32 (56%)	36 (63%)	45 (79%)	47 (82%)	37 (65%)	40 (70%)
Overall descriptive rating	Unhealthy	Healthy with problems	Healthy with problems to healthy	Healthy	Healthy with problems	Healthy with problems

Table 21. Riparian health assessment of 2BARR at the Souris site

Criteria	Aug 6, 2009	Aug 20, 2009	June 1, 2010	June 29, 2010	July 27, 2010	Aug 23, 2010
1. Vegetative cover of Floodplain & Streambanks	6	6	6	4	6	6
2. Invasive Plant Species – cover/density	1/1	2/0	2/1	2/1	1/1	1/1
3. Disturbance-increaser Undesirable Herbaceous Species	3	3	3	3	3	3
4. Preferred Tree & Shrub Establishment	6	6	6	4	6	6
5. Utilization of Preferred Trees and Shrubs	3	2	2	3	1	2
6. Standing Decadent & Dead Woody Material	3	3	3	2	3	1
7. Streambank Root Mass Protection	6	6	0	4	2	6
8. Human-Caused Bare Ground	6	4	6	2	6	6
9. Streambank Structurally Altered by Human Activity	6	6	6	6	6	6
10. Pugging, Hummocking and/or Rutting	3	3	3	1	2	1
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	47 (82%)	44 (77%)	41 (72%)	35 (61%)	40 (70%)	42 (74%)
Overall descriptive rating	Healthy	Healthy	Healthy w/problems	Healthy with problems	Healthy with problems	Healthy with problems

Table 22. Riparian health assessment of 3NOBARR at the Souris site

Criteria	Aug 6, 2009	Aug 20, 2009	June 1, 2010	June 29, 2010	July 27, 2010	Aug 23, 2010
1. Vegetative cover of Floodplain & Streambanks	6	6	6	4	6	6
2. Invasive Plant Species – cover/density	1/0	1/1	2/1	2/1	1/0	1/1
3. Disturbance-increaser Undesirable Herbaceous Species	2	2	2	2	2	3
4. Preferred Tree & Shrub Establishment	4	4	4	6	6	6
5. Utilization of Preferred Trees and Shrubs	3	1	3	2	2	2
6. Standing Decadent & Dead Woody Material	2	2	2	2	0	0
7. Streambank Root Mass Protection	6	6	2	4	4	6
8. Human-Caused Bare Ground	6	2	NA[1]	4	6	6
9. Streambank Structurally Altered by Human Activity	6	6	6	6	6	6
10. Pugging, Hummocking and/or Rutting	2	2	NA[1]	1	2	1
11. Stream Channel Incisement	3	3	3	3	3	3
Overall total/rating	41 (72%)	36 (63%)	31 (65%)	37 (65%)	38 (67%)	41 (72%)
Overall descriptive rating	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems	Healthy with problems

[1] Pasture was underwater therefore not included in calculation of overall descriptive rating

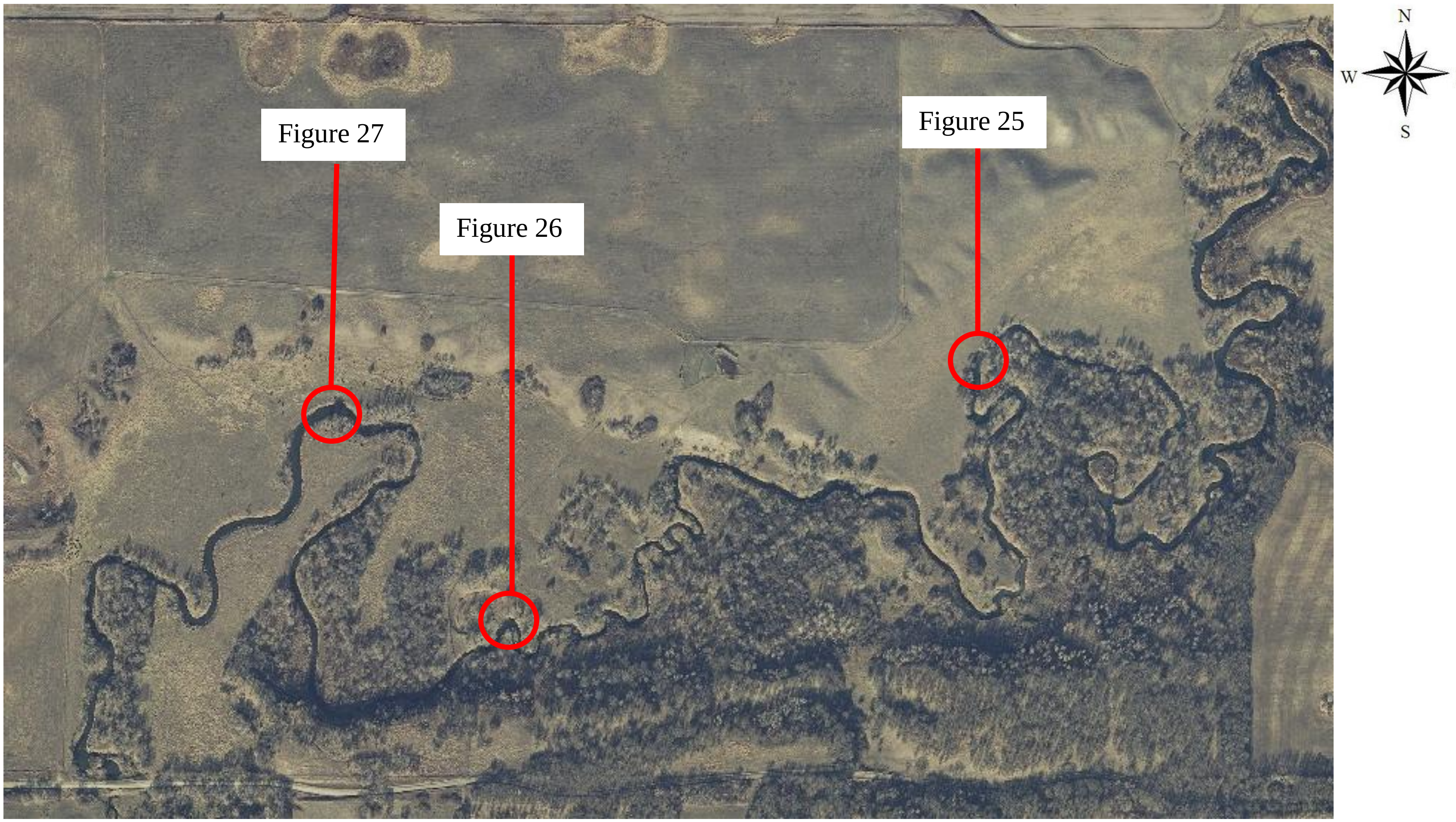


Figure 24. Location of site photos depicted in Figures 25, 26, and 27 at the Killarney site

a) August 12, 2009; view from south; low water level; bare ground with dried pugging and hummocking imprints in soil

b) September 8, 2009; view from south; low water level; bare ground with saturated soil that may be prone to pugging and hummocking

c) June 15, 2010; view from south; elevated water level; bare ground and/or vegetation underwater

d) July 7, 2010; view from north; lowered water level; little evidence of pugging and hummocking in bare ground; shearing along bank

e) August 10, 2010; view from north; low water level; some pugging and hummocking in bare ground; shearing along bank

f) September 8, 2010; view from north; low water level; pugging and hummocking in bare ground; shearing along bank

Figure 25. Crossing and watering location in riparian area in 1CONT at the Killarney site

a) September 8, 2009; view from west; low water level; some pugging and hummocking amongst vegetation and bare ground

b) June 15, 2010; view from west; elevated water level; vegetation and bare ground submerged

c) July 7, 2010; view from east; lowered water level; bare ground with pugging and hummocking; trampled and browsed vegetation

d) September 8, 2010; view from west; low water level; bare ground with pugging and hummocking; trampled and browsed vegetation

Figure 26. Barriered crossing and watering location in riparian area in 2BARR at the Killarney site

a) August 12, 2009; view from west; low water level; bare ground with pugging and hummocking

b) September 8, 2009; view from west; low water level; bare ground

c) June 15, 2010; view from west; elevated water level; regrowth of vegetation throughout bare ground

d) July 7, 2010; view from east; lowered water level; bare ground with some pugging and hummocking

e) August 10, 2010; view from west; low water level; pugging and hummocking in bare ground

f) September 8, 2010; view from east; elevated water level; bare ground with pugging and hummocking

Figure 27. Crossing and watering location in riparian area in 3NOBARR at the Killarney site

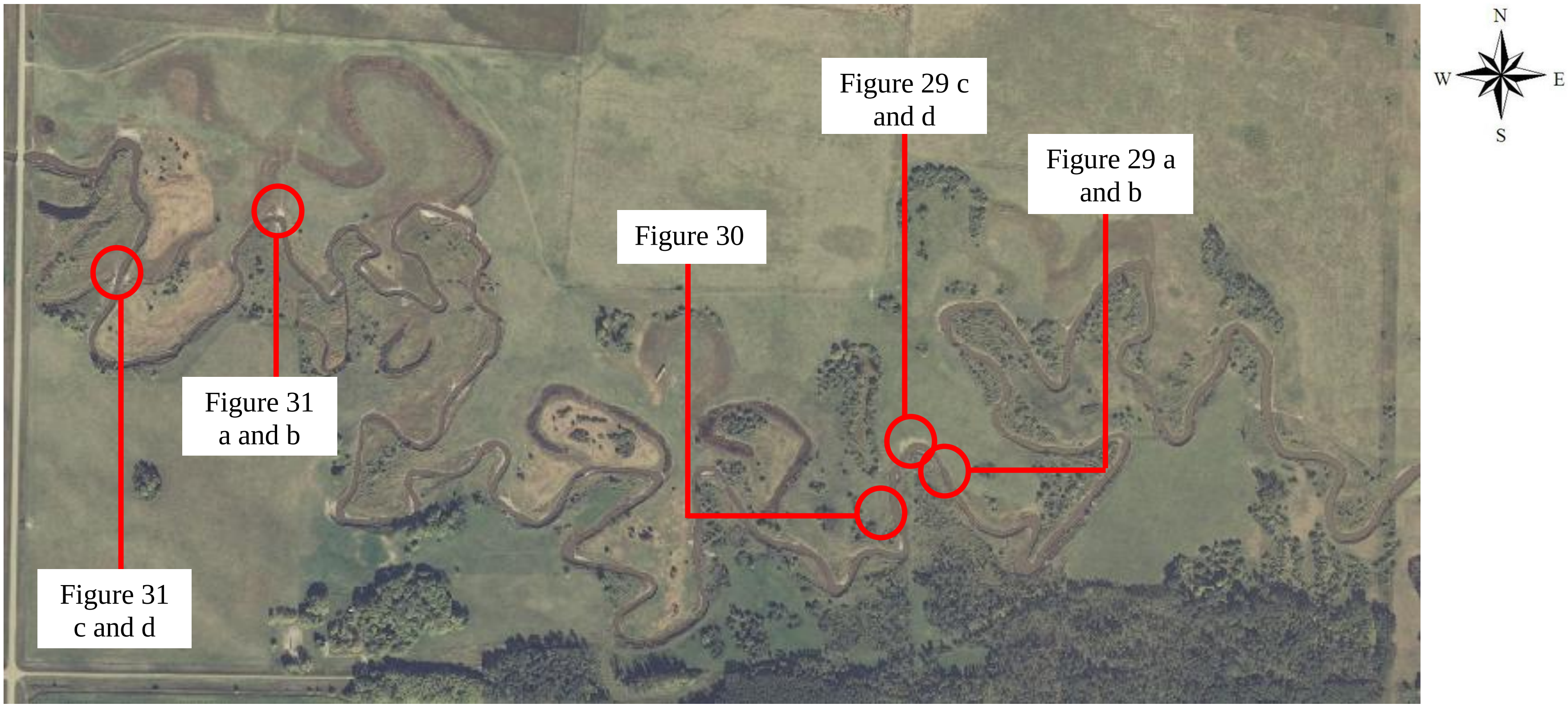


Figure 28. Location of site photos depicted in Figures 29, 30, and 31 at the Souris site

a) July 27, 2010; view from north; low water level; path with bare ground and shearing; some vegetation

b) August 23, 2010; view from north; low water level; path with bare ground and shearing; some vegetation

c) July 27, 2010; view from east; elevated water level; path with bare ground and shearing; some vegetation

d) August 23, 2010; view from east; low water level; path with bare ground and shearing; some vegetation

Figure 29. Crossing and watering locations in riparian area in 1CONT at the Souris site

a) August 6, 2009; view from south; low water level; some bare ground

b) June 1, 2010; view from south; elevated water level; bare ground and vegetation underwater

c) July 27, 2010; view from south; lowered water level; some vegetative regrowth

d) August 23, 2010; view from south; lowered water level; some vegetative regrowth

Figure 30. Barriered crossing and watering location in riparian area in 2BARR at the Souris site

a) July 27, 2010; view from east; low water level; bare ground

b) August 23, 2010; view from east; low water level; bare ground

c) July 27, 2010; view from east; low water level; bare ground

d) August 23, 2010; view from east; low water level; bare ground

Figure 31. Crossing and watering locations in riparian area in 3NOBARR at the Souris site

5.4.7.1. Criterion 1: Vegetative cover

Changes in the amount of vegetative cover within the riparian area as recorded by Criterion 1 can occur in a variety of ways. As cattle graze, trample, and remove the vegetation in the riparian area, bare ground increases. The score for Criterion 1 ranged between 4 and 6 at both the Killarney and Souris sites across all treatments. As the grazing season progressed in 2009, the score decreased from 6 to 4 in 1CONT (Table 17) and 3NOBARR (Table 19) at the Killarney site, and in 1CONT (Table 20) at the Souris site. This may be attributed to an increase in grazing pressure in the riparian area in 1CONT at the Souris site, as a consequence of increased forage biomass in the riparian area (1676.4 kg/ha) compared to the upland pasture (472.1 kg/ha), as indicated in Table 13.

The range of scores observed throughout 2010 in 2BARR (Table 18) and 3NOBARR (Table 19) in Killarney, as well as 2BARR (Table 21) in Souris 2010 are likely attributed to elevated water levels. Sediment deposits, as depicted in Figure 32, arise as a consequence of elevated water levels. As the sediment deposits did not have vegetation established, it was considered bare ground, thus causing the score to decrease. When the water level is elevated, the vegetation is submerged, making it difficult to see vegetation under the water as depicted in Figure 26 (b) and Figure 33. Furthermore, vegetation in riparian areas has often adapted to withstand flooding, although some species may not be able to withstand periodic inundation during high water levels (Naiman and Décamps 1997), leading to a loss in vegetative cover and an increase in bare ground.

Figure 32. Sediment deposit along bank in 1CONT at the Killarney site on July 7, 2010

Figure 33. Vegetation submerged in elevated water in 1CONT at the Killarney site on July 7, 2010

5.4.7.2. Criterion 2: Invasive plant species and Criterion 3: Disturbance-increaser undesirable plant species

These criteria evaluate the canopy cover of invasive plants (Criterion 2), as well as the amount of the riparian area which is covered by disturbance increaser undesirable plants (Criterion 3). In 2009 and 2010, across all periods and treatments, the following invasive plants were observed in Killarney: common burdock (*Arctium* species), Canada thistle (*Cirsuim arvense*), tall buttercup (*Ranunculus acris*), and sow thistle (*Sonchus* species). The following disturbance increaser undesirable plants were observed: quackgrass (*Agropyron repens*), absinth (*Artemisia absinthium*), canola (*Brazicca* species), smooth brome (*B. inermis*), strawberries (*Fragaria spp*), foxtail barley (*Hordeum jubatum*), black medic (*Medicago lupulina L.*), timothy (*Phleum pratense*), plantain (*Plantago* species), Kentucky Bluegrass (*P. pratensis*), Russian thistle (*Salsola kali*), dandelion (*T.officinale*), and clover (*Trifolium* species).

In 2009 and 2010, across all periods and treatments, the following invasive plants were observed in Souris: common burdock (*Arctium* species), Canada thistle (*Cirsuim arvense*), leafy spurge (*Euphorbia esula*), tall buttercup (*Ranunculus acris*), and sow thistle (*Sonchus* species). The following disturbance increaser undesirable plants were observed: absinth (*Artemisia absinthium*), wild oats (*Avena fatua*), canola (*Brazicca* species), smooth brome (*B. inermis*), gumweed (*Grindelia squarrosa*) foxtail barley (*Hordeum jubatum*), black medic (*Medicado lupulina L.*), plantain (*Plantago* species), Kentucky Bluegrass (*P. pratensis*), Russian thistle (*Salsola kali*), common chickweed (*Stellaria media*), dandelion (*T. officinale*), and clover (*Trifolium* species).

It takes many years before significant changes in the canopy cover of the vegetation in the riparian area, including preferred plants, invasive plants, and disturbance increaser undesirable plants are realized at the levels outlined by the RHA (Mae Elsinger, personal communication, April 23, 2012). The score varied frequently for Criterion 2 for both canopy cover and distribution at both sites and in all treatments. There is some variation in scores for Criterion 3 between assessments dates, but the scores do not fluctuate as frequently as those observed for Criterion 2. It is unlikely that changes in canopy cover and density occurred in the time allotted between assessments. It is, however, possible that changes observed were a result of invasive or disturbance increaser undesirable plants which are established in the riparian area were growing and getting a larger canopy over the season (Mae Elsinger, personal communication, April 23, 2012).

5.4.7.3. Criterion 4: Preferred Tree and Shrub Establishment

Criterion 4 evaluates the canopy cover of preferred trees or shrubs with the percent cover of seedlings and saplings, which is indicative of the potential for future growth of trees or shrubs. A score of 2 was assigned to Criterion 4 for each RHA and all treatments at the Killarney site (Table 17, Table 18, and Table 19). The establishment of some preferred trees and shrubs was recorded, including maple (*Acer* species), dogwood (*Cornus* species), ash (*Fraxinus* species), chokecherry (*P. virginiana*), and willow (*Salix* species), however, the less preferred species, including hawthorn (*Crataegus* species), rose (*Rosa* species), and snowberry (*S. occidentalis*) were also observed as being well established at the site.

The score for Criterion 4 ranged between 4 and 6 (Table 20, Table 21, and Table 22). The increase in the score at the end of the grazing season may have occurred as the seedlings and saplings increased in size and accounted for a greater percentage of the canopy cover. The establishment of some preferred trees and shrubs was recorded, including maple (*Acer* species), dogwood (*Cornus* species), and willow (*Salix* species), however, the less preferred species, including hawthorn (*Crataegus* species), wolf willow (*E. commutata*), rose (*Rosa* species), and snowberry (*S. occidentalis*) were also observed as being well established at the site.

5.4.7.4. Criterion 5: Utilization of preferred trees and shrubs

Criterion 5 evaluates the extent to which livestock are browsing on preferred tree and shrubs (lightly, moderately, or heavily). The score for Criterion 5 ranged from 1 to 3 throughout the RHA in most treatments and at both sites. In 2010, the overall score declined over the grazing season in 2BARR (Table 21) the Souris site. This may have occurred as cattle moved into the riparian area and increasingly browsed the preferred trees and shrubs as the forage biomass in the upland pasture decreased. At both sites, it was observed that willows were often browsed which could have a detrimental impact on the regeneration of this preferred shrub.

5.4.7.5. Criterion 6: Standing decadent & dead woody material

Criterion 6 evaluates the amount of decadent and dead woody material that comprises the total canopy cover of woody species. This score is unlikely to vary substantially over the period of time which the RHA were carried out. The trees would have to be subject to stress for a long period of time before they would become increasingly decadent, and eventually die. However, the scores for this criterion vary throughout the grazing season at both sites. Scores at the Killarney site for Criterion 6 improved as the grazing season progressed in 1CONT (Table 17), 2BARR (Table 18), and 3NOBARR (Table 19). Conversely, scores at the Souris site decreased as the grazing season progressed in 1CONT (Table 20), 2BARR (Table 21), and 3NOBARR (Table 22). In Souris in 2BARR, the score was 3 in 2009, and then decreased overall from 3 to 1 in 2010 (Table 21). With the increased precipitation received throughout 2010, perhaps some of the woody species were unable to withstand inundation, resulting in more dead and decadent material at the Souris site.

5.4.7.6. Criterion 7: Streambank root mass protection

Criterion 7 evaluates the species present in the riparian area, based on their deep binding root mass (DBRM) and their ability to bind soil, thus preventing soil erosion and maintaining the streambank. Similarly to Criterion 1, changes in the species composition from trees, shrubs, and native grasses with high DBRM to those with poor DBRM could arise from accelerated invasion by disturbance-increaser undesirable and invasive species in areas with bare ground. However, as with Criteria 2 and 3, substantial changes in species composition would take more time than the length of the assessment period. The scores for this criterion ranged from 4 to 6 in 2009, while in 2010, the scores decreased early in the grazing season and fluctuated as the season progressed, ranging from 0 to 6 at both the Killarney site (Table 17, Table 18, and Table 19) and the Souris site (Table 20, Table 21, and Table 22). The excess precipitation received in 2010 may account for the decreased score. As the riparian area was flooded, preferred species may have been inundated and died, or were not easily visible due to the high water level depicted in Figure 33.

5.4.7.7. Criterion 8: Human caused bare ground

Criterion 8 evaluates the amount of bare ground which is caused by livestock grazing, cultivation, or recreation. In Killarney and Souris, although the scores for Criterion 8 fluctuated between RHA, there was an overall increase. In 2BARR and 3NOBARR, it may have been a result of the OSW attracting cattle away from the riparian area, thus reducing the amount of bare ground caused by their presence at the Killarney site (Table 18 and Table 19) and the Souris site (Table 21 and Table 22). However, a similar response occurred in 1CONT, indicating that the reduction in bare ground is not attributed solely to the presence of the OSW at the Killarney site (Table 17) and the Souris site (Table 20). Furthermore, due to the high level of precipitation received, the score for bare ground may have fluctuated as the water level changed, making the bare ground more or less visible.

5.4.7.8. Criterion 9: Streambank structurally altered by human activity

Criterion 9 refers to bank alteration such as cracking, slumping, shearing, and the removal or reconfiguration of streambank materials due to livestock hoof shear, trails, or watering sites. In Killarney and Souris, the overall score remained the same, indicating that less that 5% of the bank is structurally altered. Areas with hoof shearing and slumping were observed during the assessments, but the frequency and severity did not change substantially as depicted in Figure 25 and Figure 27 at the Killarney site and Figure 29 at the Souris site.

Sheffield et al. (1997) compared two, seven month periods, a pre-BMP period with access to the stream only and a post-BMP with access to the stream and OSW to determine the impact of OSW on streambank erosion. Nine cross-sections were established along the stream, and the distance between the streambank and the stream edge was measured to estimate streambank erosion. These measurements were taken prior to the beginning of the study and every two months during the pre-BMP and post-BMP periods. Their results indicated that streambank erosion decreased by 77% after the implementation of the OSW.

Changes in streambank structure are influenced by the severity of streambank erosion. As previously described, Sheffield et al. (1997) measured streambank erosion over each seven month period, for a total of 14 months. In the current study, RHA were repeated over a similar period of time. The impact of the OSW on riparian health was not reflected in the RHA as it did not show changes in streambank structure; however, Sheffield et al. (1997) did observe reductions in streambank erosion with the implementation of OSW. The difference in results is likely due to the type of measurement used and the associated precision. The RHA was a visual assessment where a substantial amount of erosion is required to notice changes in streambank structure, while Sheffield et al. (1997) installed reference stakes, allowing for precise, quantitative measurements which were repeated at the same location, allowing any erosion that took place to be more easily observed and recorded.

5.4.7.9. Criterion 10: Pugging, hummocking, and/or rutting

Criterion 10 evaluates the amount of soil that is impacted by compaction, referred to as pugging, hummocking, and rutting. In Killarney and Souris, the scores decreased as the grazing season progressed in 2010. This is likely a result of the high precipitation received at both sites. Observers noted that the soil remained saturated throughout the first half of the season, making the soil softer and more prone to pugging, rutting, and hummocking (Figure 25). Furthermore, as the soil dried, the areas of compaction and raised soil that resulted from pugging, rutting, and hummocking, would harden and remain for the rest of the season (Figure 27; a), unless overland flooding occurred which would redistribute the soil.

5.4.7.10. Criterion 11: Stream channel incisement

Criterion 11 evaluates the vertical stability of the stream channel and the accessibility of the floodplain during high water. The score remained the same for Killarney and Souris throughout the RHA, and it is unlikely to change over the time between assessments as changes in stream channel incisement occurs over several years or even decades (Gregory et al. 1991). The stages of incisement are categorized by Rosgen (1996) and a score of 3 indicates that the channel is moderately incised and that higher flows can access the floodplain, as was observed in 2010 during Period 1.

5.4.7.11. Overall descriptive ratings

The overall descriptive rating for each treatment at each site is inconsistent. The overall health trend at the Souris site increased in 1CONT (Table 20), while the overall score decreased in 2BARR (Table 21) and 3NOBARR (Table 22) between the first and last RHA. It was hypothesized that the overall health score would improve in 2BARR and 3NOBARR and decrease in 1CONT, as the OSW would serve to attract cattle away from the riparian area. Impact from flood conditions at each site in 2010 likely had a greater influence on the various criterion and overall score measured in the RHA, compared to the imposed management strategy of OSW and barriers.

Furthermore, there is limited research that utilizes an assessment similar to the "Managing the Water's Edge" RHA to determine the efficacy of OSW as the sole BMP. However, Miller et al. (2010a) used a similar RHA to measure the efficacy of stream bank fencing with a cattle crossing and OSW. Two RHA were completed; one before the implementation of the BMP (pre-BMP) in 2001, and one after the BMP was established (post-BMP) in 2005. The results from their RHA showed an increase in the overall improvement for riparian health from 65% (healthy with problems) to 81% (healthy). A four-year period between RHA may have allowed some criterion more time to recover in the current study, possibly resulting in more dramatic improvements in the overall scores, as seen in the study by Miller et al. (2010a).

5.4.8. Water quality

Water samples were specifically collected to determine if nitrate, nitrite, and *E. coli* concentrations were within the values outlined for livestock water quality guidelines (CCME 2005). Results from the water samples indicate that the concentrations of nitrate and nitrite did not exceed the livestock guidelines for water quality in the Pembina River and OSW (Table 23 and Table 24), or in Plum Creek and OSW (Table 25 and Table 26).

Nitrate concentrations are present in surface water at concentrations below 5 mg/L throughout Canada (Health Canada 2012), while nitrite concentrations are present at less than 3.3 mg/L throughout the United States (WHO 2011). The results for nitrate and nitrite from the samples in the current are consistently lower than 5 mg/L and 3.3 mg/L for nitrate and nitrite, respectively.

Cattle may deposit feces directly into the stream as they drink, graze, or loaf along the stream (Miner et al. 1992), contributing to increased nutrient concentrations in the stream. Furthermore, runoff from the surrounding pasture containing cattle manure may also contribute to increased nutrient concentrations. Land management other than OSW, such as non-point source pollution from fertilizer use on the surrounding land, can also contribute excess nutrients to surface water. Nutrient concentrations in streams, including nitrate and nitrite, will vary throughout the year and are typically elevated during periods of high stream flow, such as snowmelt in spring or following excess precipitation (USGS 1999). However, the results of nitrate and nitrite concentrations had minor fluctuations over the grazing season, indicating little contribution from direct deposition of cattle manure or non-point source pollution.

Conversely, *E. coli* concentrations exceeded the livestock water quality guidelines in a number of stream and OSW samples. One would expect that if *E. coli* concentrations were elevated in the stream, they would also be elevated in the OSW, as the stream is the source of water for the OSW. This was the case in the Pembina River for the August 10, 2010 samples, where concentrations exceeded the guidelines in both the stream and the OSW samples (Table 24). However, this is not the case at Plum Creek, where the July 27, 2010 samples had elevated concentrations in the stream samples, but not the OSW samples (Table 26). *E. coli* contaminates streams when cattle defecate directly into the water or via runoff from surrounding cattle pastures. *E. coli* then binds to sediment and as a result, concentrations have been found to be 100-1000 times greater in bottom sediments than in overlying waters (Van Donsel and Gelreich 1971; Stephenson and Rychert 1982). *E. coli* concentrations may have been higher in the stream compared to the OSW if the sediment had been re-suspended prior to sampling, which may arise when stream flow increases and supplies sufficient energy to disturb the bottom sediment (Stephenson and Rychert 1982).

Although the *E. coli* concentrations in a number of samples results exceeded the livestock water quality guidelines, it is difficult to draw conclusions for a number of reasons. The number of samples taken from the stream, as well as the frequency of sampling, is insufficient to provide any real indication for the changes in nutrient or *E. coli* concentrations. Treatment order may have had an impact on water quality results. The treatment which is hypothesized to have the least impact from cattle should be furthest upstream so that the presence of cattle is not reflected in the samples taken further downstream. As both the Pembina River and Plum Creek flow from west to east, the treatments should have in the following order 2BARR, 3NOBARR, and 1CONT, instead of 3NOBARR, 2BARR, and 1CONT. Finally, to improve accuracy of the *E. coli* results, a minimum of five duplicates should ideally have been analyzed (Justin Shead, personal communication, November 3, 2011).

Table 23. Nutrient and E. coli concentrations in water samples collected from the Pembina River at the Killarney site in 2009

	Sample location								
	Stream 1[1]		Stream 2[2]		Stream 3[3]		Stream 4[4]		
	July 30	Aug 27	July 30	Aug 27	July 30	Aug 27	July 30	Aug 27	Livestock guidelines (CCME 2005)
Nitrate and nitrite (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<	<0.01	-
Nitrate (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<	<0.01	100
Ammonia nitrogen (mg/L)	0.12	0.06	0.07	0.03	0.06	0.04	0.09	0.04	-
Nitrite (mg/L)	0.004	0.004	<0.01	0.002	0.004	0.033	0.003	<0.002	10
E. coli (MPN/100 mL)	790*	12	79	49	49	79	23	49	100
Total kjedahl nitrogen (mg/L)	1.0	1.2	0.9	1.3	0.9	1.1	1.0	1.1	-
Total nitrogen (mg/L)	1.0	1.2	0.9	1.3	1.2	1.8	1.0	1.1	-
Total phosphorus (mg/L as P)	0.158	0.144	0.224	0.138	0.185	0.089	0.165	0.128	-
Total particulate phosphorus (mg/L as P)	0.025	0.046	0.079	0.031	0.087	0.028	0.095	0.076	-
Total soluble phosphorus (mg/L as P)	0.133	0.098	0.145	0.107	0.098	0.061	0.07	0.052	-

[1] Sample location of Stream 1 is at the west end of 3NOBARR
[2] Sample location of Stream 2 is between 3NOBARR and 2BARR
[3] Sample location of Stream 3 is between 2BARR and 1CONT
[4] Sample location of Stream 4 is at the east end of 1CONT
* exceeds livestock guideline
< = Less than reporting limit
mg/L = milligrams per liter
MPN/100mL = Most probable number/100mL

Table 24. Nutrient and *E. coli* concentrations in water samples collected from the Pembina River and off-stream waterer (OSW) at the Killarney site in 2010

	Sample locations												
	Stream 1[1]		Stream 2[2]		Stream 3[3]		Stream 4[4]		OSW 2BARR		OSW 3NOBARR		
	June 16	Aug 10	June 16	Aug 10	June 16	Aug 10	June 16	Aug 10	June 16	Aug 10	June 16	Aug 10	Livestock guidelines (CCME 2005)
Nitrate and nitrite (mg/L)	<0.02	-	<0.02	-	<0.02	-	<0.02	-	<0.02	-	<0.02	-	-
Nitrate (mg/L)	<0.02	0.14	<0.02	0.1	<0.02	0.11	<0.02	0.09	<0.02	0.05	<0.02	0.06	100
Ammonia nitrogen (mg/L)	0.18	0.23	0.23	0.10	0.21	0.05	0.21	0.06	0.11	0.39	0.10	0.28	-
Nitrite (mg/L)	0.002	0.009	<0.002	0.009	<0.002	0.009	<0.002	0.011	<0.002	0.011	<0.002	0.008	10
E. coli (MPN/100 mL)	1100*	210*	210*	430*	43	230*	<3	430*	23	930*	<3	1500*	100
Total kjedahl nitrogen (mg/L)	1.00	1.50	1.06	1.90	1.05	1.60	1.07	2.10	1.08	1.70	1.23	1.50	-
Total nitrogen (mg/L)	1.00	1.60	1.06	2.00	1.05	1.7	1.07	2.20	1.08	1.80	1.23	1.60	-
Total phosphorus (mg/L as P)	0.247	0.336	0.231	0.335	0.247	0.336	0.243	0.337	0.235	0.409	0.160	0.408	-
Total particulate phosphorus (mg/L as P)	<0.002	-	0.019	-	0.034	-	0.023	-	0.026	-	0.038	-	-
Total soluble phosphorus (mg/L as P)	0.247	0.262	0.213	0.262	0.213	0.262	0.22	0.265	0.209	0.404	0.122	0.403	-

[1] Sample location of Stream 1 is at the west end of 3NOBARR
[2] Sample location of Stream 2 is between 3NOBARR and 2BARR

[3] Sample location of Stream 3 is between 2BARR and 1CONT
[4] Sample location of Stream 4 is at the east end of 1CONT
* exceeds livestock guideline
< = Less than reporting limit
mg/L = milligrams per liter
MPN/100mL = Most probable number/100mL

Table 25. Nutrient and E. coli concentrations in water samples collected from the Plum Creek at the Souris site in 2009

	Sample locations								
	Stream 1[1]		Stream 2[2]		Stream 3[3]		Stream 4[4]		
	July 16	Aug 12	July 16	Aug 12	July 16	Aug 12	July 16	Aug 12	Livestock guidelines (CCME 2005)
Nitrate and nitrite (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
Nitrate (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	100
Ammonia nitrogen (mg/L)	0.04	0.06	0.02	0.06	0.02	0.07	0.04	0.11	-
Nitrite (mg/L)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	10
E. coli (MPN/100 mL)	110*	790*	490*	230*	130*	49	170*	49	100
Total kjedahl nitrogen (mg/L)	1.5	2.1	1.2	2.3	1.7	2.2	1.6	2.2	-
Total nitrogen (mg/L)	1.5	2.1	1.2	2.3	1.7	2.2	1.6	2.2	-
Total phosphorus (mg/L as P)	0.035	0.104	0.034	0.152	0.024	0.083	0.06	0.136	-
Total particulate phosphorus (mg/L as P)	0.012	0.070	0.023	0.091	0.004	0.016	0.017	0.091	-
Total soluble phosphorus (mg/L as P)	0.023	0.034	0.011	0.061	0.020	0.067	0.043	0.045	-

[1] Sample location of Stream 1 is at the west end of 3NOBARR
[2] Sample location of Stream 2 is between 3NOBARR and 2BARR
[3] Sample location of Stream 3 is between 2BARR and 1CONT
[4] Sample location of Stream 4 is at the east end of 1CONT
* exceeds livestock guideline
< = Less than reporting limit
mg/L = milligrams per liter
MPN/100mL = Most probable number/100mL

Table 26. Nutrient and *E. coli* concentrations in water samples collected from the Plum Creek and off-stream waterer (OSW) at the Souris site in 2010

	Sample location												
	Stream 1[1]		Stream 2[2]		Stream 3[3]		Stream 4[4]		OSW 2BARR		OSW 3NOBARR		
	June 1	July 27	June 1	July 27	June 1	July 27	June 1	July 27	June 1	July 27	June 1	July 27	Livestock guidelines (CCME 2005)
Nitrate and nitrite (mg/L)	0.07	-	0.07	-	0.08	-	0.08	-	0.12	-	0.07	-	-
Nitrate (mg/L)	0.05	<0.02	0.06	<0.02	0.06	<0.02	0.07	0.04	0.11	0.06	0.06	0.1	100
Ammonia nitrogen (mg/L)	0.03	<0.05	0.01	<0.05	0.03	<0.05	0.04	<0.05	0.15	<0.05	0.04	0.29	-
Nitrite (mg/L)	0.013	-	0.014	-	0.013	-	0.013	-	0.014	-	0.015	-	10
E. coli (MPN/100 mL)	93	4300*	93	4300*	93	430*	93	2300*	23	4	38	9	100
Total kjedahl nitrogen (mg/L)	1.14	1.28	1.38	1.51	1.24	1.45	1.26	1.29	1.60	1.35	1.39	1.59	-
Total nitrogen (mg/L)	1.24	1.28	1.45	1.51	1.32	1.44	1.35	1.33	1.72	1.41	1.47	1.71	-
Total phosphorus (mg/L as P)	0.082	0.091	0.072	0.090	0.080	0.083	0.082	0.260	0.049	0.109	0.078	0.098	-
Total particulate phosphorus (mg/L as P)	0.013	0.019	0.021	0.017	0.018	0.013	0.022	0.193	0.021	0.047	0.024	0.027	-
Total soluble phosphorus (mg/L as P)	0.068	0.071	0.051	0.073	0.062	0.071	0.060	0.067	0.028	0.061	0.055	0.071	-

[1] Sample location of Stream 1 is at the west end of 3NOBARR
[2] Sample location of Stream 2 is between 3NOBARR and 2BARR
[3] Sample location of Stream 3 is between 2BARR and 1CONT

[4] Sample location of Stream 4 is at the east end of 1CONT
* exceeds livestock guideline
< = Less than reporting limit
mg/L = milligrams per liter
MPN/100mL = Most probable number/100ml

5.4.9. Overall impact of off-stream waterers with or without barriers in large scale pastures

The results from this study indicate that cattle used the OSW, although they did not use it exclusively. Further, partial exclusion via natural barriers was not effective at deterring cattle from watering at the stream or loitering in the riparian area. Reductions in watering at the stream or time spent in the riparian area were not observed to the same magnitude as reported by Godwin and Miner (1996), Sheffield et al. (1997), and Veira and Liggins (2002) when access to OSW was provided. This potentially may be due to the larger pasture size utilized in the current study, ranging from 21.0 ha to 39.2 ha, as compared to the size used in the previously mentioned studies, ranging from 1.1 ha to 22.3 ha. Perhaps in the larger pastures, cattle are not motivated to travel further to use the OSW if the stream is closer. Furthermore, the accumulation of precipitation at the sites in 2010 likely deterred cattle from watering at the OSW as standing water was available throughout the site. In large scale pastures, the installation of additional OSW throughout the site may increase usage as cattle would not have to travel as far to utilize. However, the considerable cost of the OSW system would likely prevent producers from installing more than one system per pasture.

5.5. CONCLUSION

Results from this study examining the effectiveness of OSW with or without barriers in large scale pastures indicate that cattle watered at the OSW when available, but they did not use the OSW exclusively. Excess precipitation accumulated during the grazing season also allowed cattle to water at locations other than the OSW or the stream.

Furthermore, when comparing the percentage of time that cattle spent in the riparian area with or without barriers, the presence of the barriers did not consistently deter cattle from watering at the stream or remaining in the RP. There was a difference in animal performance in 3NOBARR calves in Souris in 2010; however, this difference appeared to be associated with challenges with randomization as opposed to the presence of the OSW. The RHA assessed a number of criteria throughout the two grazing seasons, but overall improvements in riparian health were not consistently observed with the presence of the OSW with or without barriers in the time allotted for this study and as a consequence of extreme precipitation.

Overall, this study demonstrates the continued need for multidisciplinary research approaches to determining the effectiveness of the use of OSW as a recommended BMP. Both the impact on livestock behaviour and productivity, as well as to environmental sustainability, must be considered and evaluated as the effectiveness of OSW depends on a number of factors such as the site location, site topography, climate, and the prior experience of cattle within the site. Further research is necessary to determine complementary management strategies, such as the implementation of shade structures adjacent to the OSW, that will increase cattle usage. Finally, as riparian areas may take multiple years to regenerate, the effectiveness of OSW on riparian health must be studied further over a longer period of time.

6. GENERAL DISCUSSION

This study examined the use of OSW and partial barriers to deter cattle from the riparian area, and the impact of the OSW on cattle productivity and riparian health, both of which are important considerations that will greatly influence adoption of the BMP by producers. The overall effectiveness of OSW and barriers at discouraging cattle from the watering and loitering in the riparian area, the usefulness of the RHA as a tool for producers, strategies to improve visual observation records, the importance of multi-disciplinary research, and suggestions for future research that would help us to learn more about cattle behaviour in riparian areas will be discussed.

6.1. OVERALL EFFECTIVENESS OF OFF-STREAM WATERERS

Although cattle did water at the OSW at both Souris and Killarney, frequency of OSW usage by cattle in this study was less than that reported in a number of other studies (Sheffield et al. 1997; Veira and Liggins 2002), as was a reduction in time spent in the riparian area (Miner et al. 1992; Clawson 1993; Godwin and Miner 1996; Sheffield et al. 1997; McInnis and McIver 2001). There are a number of possibilities that may explain why we did not see greater usage of the OSW. Firstly, the topography of the site may have an influence on watering location. It has been suggested that cattle may prefer to water at the OSW when the soil surrounding the OSW is dry, level, and firm, as opposed to watering at access points along the stream, which may have a steep slope or soft ground. If cattle are at risk of being preyed upon, it would be easier for them to flee from their position around the OSW where they have good footing on flat ground, as opposed to the streambank, where they may be facing downward on a slope with soft ground, making it more difficult for them to quickly escape the predator. At both the Souris and Killarney sites, many of the access points along the stream were gently sloped, making it easy for cattle to enter the stream to water or cross. The footing of the access points was typically firm enough that cattle did not sink too deeply into the soil. Had the riparian area been more severely sloped or had softer footing; cattle may have been more motivated to water at the OSW as it would offer a more attractive location to water as opposed to the stream. The installation of a concrete pad surrounding the OSW may further improve footing, making the OSW more appealing.

The herds' home range, defined as an area within the pasture where cattle prefer to remain while engaged in their usual activities, has been found to have an influence on the amount of time that cattle spend in the riparian area. Herding and culling have both been suggested as strategies to alter the home range of cattle, minimizing the amount of time spent in the riparian area. When turned out to a new pasture, herding combined with OSW, appears to be most effective when the herder remains with the cattle until they have settled in their new location near the OSW to ensure that they do not return to their former location in the riparian area, a task that requires approximately 30 minutes to two hours (Sowell et al. 1999). This task may have to be repeated for a period of time to ensure that the cattle become accustomed to their new location. This task could be quite time consuming for a producer, thus its suitability is limited. Selective culling has been suggested to remove cattle that do not respond well to herding, or to remove cattle that frequent the riparian area (Roath and Krueger 1982b; Howery et al. 1996). Culling as a riparian management strategy should be used cautiously as its effectiveness is not yet known. Furthermore, the success of culling will greatly be impacted based on the source of replacement animals. Outside animals that are introduced into the herd may occupy the habitat vacated by the culled animal, while replacement heifers raised by culled cows will establish a home range similar to that of their mothers (Sowell et al. 1999). Herding and selective culling have the potential to alter cattle distribution, decreasing the amount of time cattle spend in riparian areas, but should be managed carefully to ensure that the intended objective is achieved.

Cattle are attracted to the riparian area not only as a water source, but to seek shade, relief from heat, and graze the abundant forages. As cattle tend to remain closer to their water source, perhaps implementing items of interest to cattle in the pasture near the OSW would serve to better attract them away from the riparian area. For example, if cattle are attracted to the riparian area for shade, installing a low cost shade structure in the upland pasture near the OSW may serve to draw them out of the riparian area. If cattle are entering the stream in the riparian area to escape insect pressure, placing a cattle oiler near the OSW may attract them to the area with the oiler, as opposed to the stream. The implementation of these attractants may provide some of the same services as the riparian area, but cattle will not have to remain in the sensitive area in order to take advantage of these services.

6.2. OVERALL EFFECTIVENESS OF BARRIERS

The presence of barriers did not ensure that the majority of watering events were consistently from the OSW versus the stream. At both sites in 2BARR, barriers were installed only on the north side of the stream. The barriers were effective at some locations, as cattle abandoned or decreased usage of these watering or crossing locations, and vegetative regrowth was evident (Figure 34). At locations where the barriers seemed to be most effective, usage of thorny barrier material from trees such as hawthorns did appear most effective at deterring cattle. Observers also noted that if cattle entered the stream to cross on the south side, they would cross the stream and break through the barriers located on the north side (Figure 35). Thus at cattle crossings, it may be more effective to install barriers on both sides of the stream, to further discourage cattle from entering the stream at these locations. It was difficult to maintain barriers at large access points and they did not appear to be effective at reducing cattle access to the stream, as cattle would walk through and around the barrier material (Figure 36). It was also observed that when the barrier did prove effective at discouraging cattle from entering the stream at a particular location, cattle would travel along the riparian area looking for an alternate access point. This does not serve to minimize impact to the riparian area as intended because as travel in the riparian area increases, so does the likelihood of soil compaction, pugging, hummocking, and bare ground.

As water levels fluctuated with increased precipitation throughout the grazing season, the barriers had a tendency to be washed away after a period of high precipitation. There is also speculation that beavers would remove barrier material. As a result, barriers had to be checked regularly to ensure they were intact. Checking the barriers was very time consuming, as was acquiring new barrier material to replace what had been lost. As such, non-permanent barriers are not practical in a real life production scenario, as the majority of livestock producers would not have time to check and reinforce the barrier material on a regular basis.

As the barriers did not consistently reduce watering at the stream or discourage cattle from accessing the stream, and are also time-consuming to check and maintain, use of barriers is not an effective strategy to effectively reduce the frequency of watering at the stream or the time spent in the riparian area. Use of a more permanent barrier, such as dense hedges with low palatability including hawthorns or rosebushes, may be a better alternative to discourage cattle from the spending time in the riparian area. Hedges, however, would take a number of years to establish in order to be effective at deterring cattle. Although there is currently no literature to support this, installing fencing at specific access points may be effective immediately compared to hedges, and would not require the same amount of maintenance as the barriers. Although partial fencing at access points would not be as costly as complete exclusion fencing, it would still have a higher cost associated compared to deadfall barriers. Hedges or partial fencing may have a similar issue as the barriers, where cattle may establish a different access point at a different location along the stream.

Figure 34. Vegetative regrowth with use of barrier in 2BARR at the Souris site. Photo on left shows a barriered watering area in 2009. Photo on right shows the same area with vegetative regrowth in 2010.

Figure 35. Cattle crossing through barriers in 2BARR at the Souris site

Figure 36. Barriered crossing in 2BARR at the Souris site

6.3. IMPACT ON ANIMAL PERFORMANCE

Results from the analysis of cow and calf weights indicate some differences in performance based on the presence of the OSW. During a number of periods, the OSW seemed to have a positive influence on animal performance, while in some periods, changes in weight gain were not attributed to the presence of the OSW. Porath et al. (2002) found that cattle with access to OSW and trace-mineral salt had increased weight gain compared to cattle with access to trace-mineral salt only. They attributed the increased weight gain to increased forage production in OSW pastures, intake of higher quality forage as a result of reduced patch grazing, and more uniform cattle distribution. Similarly, the variation in weight gain in the current study may be the result of a number of factors, such as forage quality and biomass, management, and climate, rather than the availability of OSW.

As the water source for the OSW was from the stream, this would likely not impact animal performance. Often, if cattle are offered clean water as opposed to a lower water quality source, such as a dugout, animal performance will improve with access to cleaner water. Water quality within the OSW may be a concern if the frequency of use is low; therefore, fresh water is not being pumped to the OSW on a regular basis. *E. coli* contaminated OSW have been found to act as long-term reservoirs for the bacteria, remaining a persistent source of cattle exposure to the bacteria (Lejeune et al. 2001). A particular strain of *E. coli* (non-O157 enterohaemorrhagic *E. coli*) has been found to cause dysentery in young calves (Fairbrother and Nadeau 2006). Prolonged dysentery may lead to production losses as calves become dull, anorexic, and lethargic, or even die.

6.4. EFFICACY OF RIPARIAN HEALTH ASSESSMENT

"Managing the Water's Edge" is intended as an educational tool to teach land owners and producers about the health of their riparian area and to help them identify any adjustments that need to be made to their management strategy. Furthermore, if they have implemented a BMP, they can utilize the assessment to determine if riparian health is in fact improving. The assessment, designed based on sound science, relies on visual observations instead of technical methods or measurements, with the intention that it can easily be used by anyone to carry out a rapid and repeatable assessment once they attend classroom and field training, as suggested in "Managing the Water's Edge".

Although the RHA is intended to be easily used by anyone, those that carried out the RHA in this study found it to be challenging, despite having attended a training session. They completed the RHA multiple times per year, which gave them many opportunities to put the skills they learned to use, as opposed to a producer, who may only complete the RHA once a year. Despite completing the RHA multiple times, the users did not report that the RHA became easier to complete. The RHA has numerous criteria to evaluate, and the scores assigned to each are subjective, and thus may vary from day to day. Furthermore, the RHA is very time consuming to complete and a producer may not have time to complete the assessment regularly. Due to the subjectivity of the criteria and the significant time required to complete an assessment, it may be challenging for a producer to carry out a representative RHA if they are only utilizing the theory and skills once a year.

If using the RHA for future research, it would likely be more effective to carry out the assessment on a 200 m reach as the RHA instructs, instead of the entire stream length within the treatment. Those carrying out the assessments found it difficult to accurately estimate the percent cover of the various criteria and found that they could easily be influenced by what they saw towards the end the treatment, which may skew the assigned scores. By repeating the assessment on the same 200 m reach in each treatment, it would be easier to more accurately interpret the health of the area within that reach. Furthermore, by completing the assessment once before the installation of the BMP and once after a number of years of use of the BMP, one may be better able to account for changes in the riparian area that are a result of the BMP, rather than changes that result from seasonal weather, including fluctuating stream levels.

6.5. STRENGTHENING THE ACCURACY AND UTILITY OF VISUAL OBSERVATIONS

A comparison of the time spent in the RP as recorded by VO to that recorded by GPS collars revealed discrepancies between the two techniques. Inaccuracies arising from VO have been associated with observer fatigue, effect on animal behaviour, physical limitations, and factors such as weather and light which may make it difficult to see animals continuously. Inaccuracy was also associated with the subjectivity of various observers regarding the boundaries of the RP or the area surrounding the OSW. Inaccuracy may also be due to the undulating site topography, making it difficult to maintain continuous observations on the herd. A number of adaptations could be made to improve the accuracy of VO. Firstly, by measuring and marking the boundaries of the RP or the area around the OSW, the subjectivity of the area could be avoided. The boundaries of the area would no longer be impacted by changes at the site such as vegetation or water level, or between different observers. However, this strategy may be time consuming, given the length of the stream within each treatment. An alternative to physically sitting in the pasture to obtain VO could be utilizing high quality video cameras at strategic locations that would begin recording when cattle entered the area. One camera could be placed at the OSW to monitor usage and behaviour at the OSW. For the riparian area, cameras could be established along one or two of the most common access points along the stream to monitor the amount of time spent in the area, as well as behaviour. This would allow for monitoring without the observer influencing cattle behaviour. However, there are a number of limitations associated with the use of video cameras. Observations are limited to the location where the camera is installed and can only be carried out when cattle are within the range of the video camera. In large scale pastures similar to the current study, cattle may not enter the camera field of vision often enough to provide sufficient information about cattle behaviour.

6.6. IMPORTANCE OF MULTI-DISCIPLINARY APPROACHES TO RESEARCH

Multi-disciplinary research is crucial as real-life production scenarios have numerous dimensions that contribute to their success or failure. Taking a mono-disciplinary approach to the challenges facing the agricultural industry will not provide optimal outcomes that consider long-term economic and environmental sustainability. Consideration of economic and environmental sustainability is of particular importance when considering BMP. A producer is unlikely to adopt a BMP unless they can be certain that it will not impact the productivity of his or her farm. Furthermore, producers will be reluctant to implement a particular BMP if the effectiveness of the BMP on the intended ecosystem has not been proven. Thus, in the current study, a multi-disciplinary approach was taken to determine both the impact of OSW with or without barriers on the weight gain of cows and calves, as well as riparian health.

Taking a multi-disciplinary approach requires bringing researchers and experts from a variety of backgrounds together in order to effectively develop a plan for the research trial and to ensure all important aspects are considered. The current study would have been impossible to complete without the input of a variety of scientists including range biologists, animal scientists, riparian specialists, and GPS technologists. As each individual comes from a variety of backgrounds, skilled leadership and co-operation among team members was required in order to effectively meet the research objectives. Challenging, yet rewarding, combining the knowledge of various scientists was integral to better address the suitability of OSW with or without barriers to livestock production in the Manitoba landscape.

6.7. FUTURE RESEARCH

Riparian areas take time to respond to BMP such as OSW systems. As such, the length of time that the treatments were surveyed in this study may not have been long enough to have a substantial effect on the riparian area. In order to obtain accurate results on the effectiveness of OSW on riparian health, a long term study should be established. If using the RHA, it would be ideal to complete an assessment before the OSW was installed, and then repeat the assessment after the OSW has been installed for a minimum of four years, as was the length of time in Miller et al. (2010a). Some criterion, such as pugging and hummocking, will fluctuate throughout the grazing season, while other criterion, such as invasive or disturbance-caused plant species, will take a number of years before improvements in plant communities will be observed.

As this study was carried out in large scale pastures, representative of the pasture size that many herds graze over the summer, perhaps cattle require more attractants to draw them out of the riparian area and closer to the OSW. Further research should be conducted to explore if implementing shade structures or oilers would allow cattle to cool off or seek relief from insects without having to move into the riparian area, potentially increasing watering at the OSW and decreasing the amount of time spent in the riparian area. As ease of access to the stream seems to influence where cattle prefer to water, research should be completed on OSW usage and ease of stream access. Further investigation regarding the factors that attract cattle to OSW and away from the riparian area could help to improve the functionality of BMP for riparian management.

The use of partial barriers merits further research. Using natural deadfall was not consistently successful as the barriers were time consuming to maintain and cattle seemed to maneuver through the barrier if they entered the stream from the opposite side. Examining the effectiveness of different types of barrier material, such as hedges or strategic fences, may prove to be more effective at deterring cattle from watering at the stream, thus encouraging usage of the OSW.

Multi-disciplinary research regarding the usage of OSW on cattle behaviour and riparian health is complex. There are numerous aspects to study, including the effect on animal behaviour and performance and the impact to riparian health, as well as a number of interactions to examine, such as the impact of climate and precipitation on animal distribution. Although the scope of this research has been challenging, it is integral to continue the multi-disciplinary approach to ensure that the impacts of BMP on livestock behaviour, animal productivity, and the surrounding environment are fully understood.

7. REFERENCES

Adams, B.W., Ehlert, G., Stone C., Alexander, M., Lawrance, D., Willoughby, M., Moisey, D., Hincz, C. and Burkinshaw, A. 2005. Range health assessment for grassland, forest and tame pasture. Alberta Sustainable Resource Development Publication T/044.

Alberta Riparian Habitat Management. 2008. Invasive and disturbance-caused plants in riparian areas. Alberta Riparian Habitat Management, Calgary, AB.

Anonymous. 2007. The technical basis of zone of sensitivity determinations under the detailed assessment procedure of the riparian areas regulation. B.C. Ministry of Environment and Fisheries and Oceans Canada, Pacific Region. 55 pp.

Bagshaw, C.S., Thorrold, B., Davison, M., Duncan, I.J.H. and Matthews, L.R. 2008. The influence of season and of providing a water trough on stream use by beef cattle grazing hill-country in New Zealand. App. Anim. Behav. Sci. **109**:155-166.

Bailey, D. W. 2004. Management strategies for optimal grazing distribution and use of arid rangelands. J. Anim. Sci. **82**:E147-E153.

Bailey, D.W., Van Wagoner, H.C., Weinmeister, R. and Jensen, D. 2008. Evaluation of low-stress herding and supplement placement for managing cattle grazing in riparian and upland areas. Rangeland Ecol. Manag. **61**:26-37.

Bailey, D.W., Thomas, M. G., Walker, J. W., Witmore, B. K., and Tolleson, D. 2010. Effect of previous experience on grazing patterns and diet selection of Brangus cows in the Chihuahuan Desert. Rangeland Ecol. Manag. **63**:223-232.

Ballard, T.M. and W.C. Krueger. 2005. Cattle and salmon I: Cattle distribution and behavior in a Northeastern Oregon riparian ecosystem. Rangeland Ecol. Manage. **58**: 267-273.

Barling, R.D. and Moore, I.D. 1994. Role of buffer strips in management of waterway pollution - a review. Environ. Manage. **18**:543-558.

Bechmann, M.E., Kleinman, P.J.A., Sharpley, A.N. and Saporito, L.S. 2005. Freeze-thaw effects on phosphorus loss in runoff from manured and catch-cropped soils. J. Environ. Qual. **34**:2301-2309.

Beeson, C.E. and Doyle, P.F. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. J. Am. Water Resour. As. **31**:983-990.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conserv. Biol. **7**: 94-108.

Belsky, A.J., and Matzke, A. and Uselman, S. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. J. Soil Water Conserv. **54**:419-431.

Bock, C.E., Saab, V.A., Rich, T.D. and Dobkin, D.S. 1993. Effects of livestock grazing on neotropical migratory landbirds in western North America. Pages 296-309 *in* D.M.

Finch and P.W. Stangel, eds. Status and management of neotropical migratory birds: September 21-25, 1992, Estes Park, Colorado. USDA Forest Serv. Gen. Tech. Rep. RM-229. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

British Columbia Ministry of Agriculture, Food and Fisheries (BCMAFF). 2003. Riparian factsheet: livestock distribution in riparian areas. [Online] Available: http://www.agf.gov.bc.ca/range/publications/documents/riparian.pdf [29 April 2011].

Brosh, A., Henkin, Z.,Ungar, E.D., Dolev, A., Orlov, A., Yehuda, Y. and Aharoni, Y. 2006. Energy cost of cows' grazing activity: Use of the heart rate method and the Global Positioning System for direct field estimation. J. Anim. Sci. **84**:1951-1967.

Bryant, L.D. 1982. Response of livestock to stream zone exclusion. J. Range Manage. **35**:780-785.

Bryant, H.T., Blaser, R.E. and Peterson, J.R. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a meadowville loam. Agron. J. **64**:331-334.

Burt, W. 1943. Territoriality and home range concepts as applied to mammals. J. Mammal. 66:346-352.

Butler, P. J. 2000. Cattle distribution under intensive herded management. Rangelands **22**:21-23.

Canadian Council on Animal Care (CCAC). 1993. Guide to the care and use of experimental animals. 2nd ed. Vol. 1. E. D. Olfert, B.M. Cross and A.A. McWilliam, ed. Canadian Council on Animal Care, Ottawa, Canada.

Canadian Council of Ministers of the Environment (CCME). 2005. Canadian water quality guidelines for the protection of agricultural water uses: Summary table. *In* Canadian environmental quality guidelines, Canadian Council of Ministers of the Environment, Winnipeg, MB.

Carothers, S. W. 1977. Importance, preservation and management of riparian habitat: an overview. Pages 2-4 *in* Importance, preservation and management of riparian habitat: a symposium July 9, 1977, Tucson, Arizona. USDA Forest Serv. Gen. Tech. Rep. RM-43. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Clary, W.P. and Booth, G.D. 1993. Early season utilization of mountain meadow riparian pastures. J. Range Manage. **46**:493-497.

Clawson, J.E. 1993. The use of off-stream water developments and various water gap configurations to modify the behaviour of grazing cattle. M. Sc. Thesis. Department of Rangeland Resources, Oregon State University, Corvallis, OR.

Crouch, G. L. 1982. Wildlife on ungrazed and grazed bottomlands on the South Platte River in northeastern Colorado. Pages 186-197 *in* Wildlife-livestock relationship symposium. University of Idaho, Moscow, ID.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience. **24**:631-641.

D'Eon, R.G. 2003. Effects of a stationary GPS fix-rate bias on habitat-selection analyzes. J. Wildlife Manage. **67**:858-863.

DelCurto, T., Porath, M., Parsons, C. T. and Morrison, J. A. 2005. Management strategies for sustainable beef cattle grazing on forested rangelands in the Pacific Northwest. Rangeland Ecol. Manag. **58**:119-127.

DeGraaf, R.M. and Yamasaki, M. 2000. Bird and mammal habitat in riparian areas. In Riparian management in forests of the continental eastern United States, E.S. Verry, J.W. Hornbeck and C.A. Dolloff (eds.). Lewis Publishers, Bocca Raton, FL. Pages 139-156.

Dickard, M.L. 1998. Offstream water and salt as management strategies for improved cattle distribution and subsequent riparian health. M.S. Thesis, Univ. Idaho, Moscow, Ida.

Dillaha, T. A., Reneau, R.B., Mostaghini, S., Shanholtz, V.O. and Magette, W.L. 1987. Evaluating nutrient and sediment losses from agricultural lands: vegetative filter strips. U.S. Environmental Protection Agency, Report No. CBP/TRS 4/87, Washington, D.C.

Dobson, A. T. 1973. Changes in the structure of riparian community as the result of grazing. Proc. New Zealand Ecol. Soc. **20**:58-64.

Dorioz, J. M., Wang, D., Poulenard, J. and Trévisan, D. 2006. The effect of grass buffer strips on phosphorus dynamics - a critical review and synthesis as a basis for application in agricultural landscapes in France. Agr. Ecosyst. Environ. **117**:4-21.

Doran, J.W. and Linn, D. M. 1979. Bacteriological quality of runoff water from pastureland. Appl. Environ. Microbiol. **37**:985-991.

Duff, D. A. 1979. Riparian habitat recovery on Big Creek, Rich County, Utah. Pages 91-92 *in* O.B. Cope, ed. Proceedings of the forum-grazing and riparian/stream ecosystems. Trout Unlimited, Denver, CO.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E. and Franson, M.H, eds. 2005. Standard methods for the examination of water & wastewater, 21st edition. American Public Health Association, Washington, D.C.

Environment Canada. 2010. Dams and diversions. [Online] Available: http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=9D404A01-1 [15 April 2011].

Fairbrother, J.M. and Nadeau, E. 2006. *Escherichia coli*: on-farm contamination of animals. Rev. sci. tech. Off. Int. Epiz. **25**:555-569.

Fisher, S.G. and Likens, G.E. 1973. Energy flow in bear brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. **43**:421-439.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream corridor restoration: principals, processes, and practices. Federal Interagency Stream Restoration Working Group. GPO Item No. 0120-A, SuDocs No. A 57.6/2:EN3/PT.653.

Fitch, L. and Adams, B.W. 1998. Can cows and fish co-exist? Can. J. Plant Science. **78**:191-198.

Fitch, L., Adams, B.W. and Hale, G. 2001. Riparian health assessment for streams and small rivers - field workbook. Cows and Fish Program, Lethbridge, AB.

Franklin, D.H., Cabrera, M. L., Byers, H. L., Matthews, M.K., Andrae, J.G., Radcliffe, D.E., McCann, M.A., Kuykendall, H.A., Hoveland, C.S. and Calvert II, V.H. 2009. Impact of water troughs on cattle use of riparian zones in the Georgia Piedmont in the United States. J. Anim. Sci. **87**:2151-2159.

Ganskopp, D., Cruz, R. and Johnson, D.E. 2000. Least-effort pathways?: a GIS analysis of livestock trails in rugged terrain. Appl. Anim. Behav. Sci. **68**:179-190.

Ganskopp, D. 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Appl. Anim. Behav. Sci. **73**:251-262.

Ganskopp, D. C. and Johnson, D. D. 2007. GPS error in studies addressing animal movements and activities. Rangeland Ecol. Manage. **60**:350-358.

Gaughan, J. B., Davis, M.S. and Mader, T.L. 2004. Wetting and the physiological responses of grain-fed cattle in a heated environment. Aust. J. Agric. Res. **55**:253-260.

Gillen, R.L., Krueger, W.C. and Miller, R.F. 1984. Cattle distribution on mountain rangeland in Northeastern Oregon. J. Range Manage. **37**:549-553.

Godwin, D. C. and Miner, J.R. 1996. The potential of off-stream livestock watering to reduce water quality impacts. Bioresource Technol. **58**:285-290.

Government of Canada. 1985. Fisheries act. c. F-14.

Government of Canada. 2002. Species at risk act. c. 29.

Government of Manitoba. 2010a. The water protection act. C.C.S.M. c. W65.

Government of Manitoba. 2010b. The riparian tax credit: information for tax payers. [Online] Available: http://www.gov.mb.ca.proxy2.lib.umanitoba.ca/finance/tao/pdf/riparian/info_for_taxpayers.pdf [01 March 2011].

Green, D.M and Kauffman, J.B. 1995. Succession and livestock grazing in a Northeastern Oregon riparian ecosystem. J. Range Manage. **48**:307-313.

Green, D. M. 1998. Recreational impacts on erosion and runoff in a central Arizona riparian area. J. Soil Water Conserv. **53**:38-42.

Greenwood, P.T. and Rittenhouse, L.R. 1997. Feeding area selection: the leader follower phenomena. Proc. West. Sect. Am. Soc. Anim. Sci. 48:267-269.

Gregory, S.V., Swanson, F.J., McKee, W.A. and Cummins, K.W. 1991. An ecosystem perspective of riparian zones. Bioscience **41**:540-551.

Groffman, P. M., Gold, A. J. and Simmons, R. C. 1992. Nitrate dynamics in riparian forests - microbial studies. J. Environ. Qual. **21**:666-671.

Hafez, E.S.E. and Bouissou, M.F. 1975. The behaviour of cattle. Pages 203-245 *in* E.S.E. Hafez ed. The behaviour of domestic animals (3rd edition). Balliere Tindall, London, UK.

Hanson, G.C., Groffman, P.M. and Gold, A.J. 1994. Denitrification in riparian wetlands receiving high and low groundwater nitrate inputs. J. Environ. Qual. **23**:917-922.

Hayes, F.A. 1978. Streambank and meadow condition in relation to livestock grazing in mountain meadows of central Idaho. M.S. Thesis, University of Idaho.

Health Canada. 2012. Nitrate and nitrite in drinking water. Government of Canada. [Online] Available: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/pdf/consult/_2012/nitrite-nitrite/nitrite-nitrite-eng.pdf [06 February 2013].

Henke, M. and Stone, C.P. 1978. Value of riparian vegetation to avian populations along the Sacramento River system. Pages 228-235 *in* R.R. Johnson and D.A. Jones, eds. Importance, preservation and management of riparian habitat: a symposium. USDA Forest Service General Technical Report RM-166, Fort Collins, CO.

Holechek, J.L. 1980. The effects of vegetation type and grazing system on the performance, diet and intake of yearling cattle. Ph. D. Thesis, Oregon State Univ., Corvallis, OR.

Howery, L.D., Provenza, F.D., Banner, R.E. and Scott, C.B. 1996. Differences in home range and habitat use among individuals in a cattle herd. Appl. Anim. Behav. Sci. 49:305-320.

Howery, L.D., Provenza, F.D., Banner, R.E. and Scott, C.B. 1998. Social and environmental factors influence cattle distribution on rangeland. Appl. Anim. Behav. Sci. 55:231-244.

Hovrath, S. (ed). 2005. British Columbia environmental laboratory manual. Water and Air Monitoring and Reporting; Water, Air and Climate Change Branch; Ministry of Environment, Victoria, BC.

Hubbard, R.K., Newton, G.L. and Hill, G.M. 2004. Water quality and the grazing animal. J. Anim. Sci. **82**: E255-E263.

Johnson S.R., Gary, H.L. and Ponce, S.L. 1978. Range cattle impacts on stream water quality in the Colorado front range. USDA Forest Service. Research Note RM-359, Fort Collins, CO.

Kauffman, J.B., Krueger, W.C. and Vavra, M. 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. **36**:685-391.

Kauffman, J.B. and Krueger, W.C. 1984. Livestock impacts on riparian ecosystems and streamside management implications... a review. J. Range Manage. **37**:430-438.

Kauffman, J.B., Beschta, R.L., Otting, N.and Lytjen, D.1997. An ecological perspective of riparian and stream restoration in the Western United States. Fisheries. **22**:12-24.

Keystone Agricultural Producers (KAP). 2010. Alternative land use services (ALUS): The farmer's conservation program for Canada. [Online] Available: http://www.kap.mb.ca/alus/aboutALUS.pdf [01 March 2011].

Kie, J.G. and Boroski, B.B. 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. J. Range Manage. **49**:482-488.

King, J.M. 1983. Livestock water needs in pastoral Africa in relation to climate and forage. International Livestock Centre for Africa, ILCA Research Report No. 7.

Knight, T. 2010. Enhancing the flow of ecological goods and services to society: Key principals for the design of marginal and ecologically significant agricultural land retirement programs in Canada. Canadian Institute for Environmental Law and Policy, Toronto, ON.

Korth, R. and Cunningham, P. 1999. Margin of error? Human influences on Wisconsin shores. [Online] Available: http://www.uwsp.edu/cnr/uwexlakes/humanimpact/marginoferror.pdf [15 February 2011]. Wisconsin Lakes Partnership, Stevens Point WI.

Larsen, R.E., Miner, J.R., Buckhouse, J.C. and Moore, J.A. 1994. Water-quality benefits of having cattle manure deposited away from streams. Bioresource Technol. **48**:113-118.

Lejeune, J.T., Besser, T.E., and Hancock, D.D. 2001. Cattle water troughs as reservoirs of *Escherichia coli* O157. Appl. Environ. Microbiol. **67**:3053-3057.

Lewis, J.S., Rachlow, J.L., Garton, E.O. and Vierling, L.A. 2007. Effects of habitat on GPS collar performance: using data screening to reduce location error. J. Appl. Ecol. **44**:663-671.

Line, D.E., Harman, W.A., Jennings, G.D., Thompson, E.J. and Osmond, D.L. 2000. Nonpoint-source pollutant load reductions associated with livestock exclusion. J. Environ. Qual. **29**:1882-1890.

Line, D.E. 2003. Changes in a stream's physical and biological conditions following livestock exclusion. Trans. ASAE **46**: 287-293.

Livestock Conservations Inc. (LCI). 1970. Patterns of transit losses. Livestock Conservations Inc., Omaha, NE.

Lofgreen, G.P., Givens, R.L., Morrison, S.R. and Bond, T.E. 1975. Effect of drinking water temperature on beef cattle performance. J. Anim. Sci. **40**:223-229.

Lowrance, R., Todd, R., Fail, J., Hendrickson, O., Leonard, R. and Asmussen, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience **34**:374-377.

Mader, T.L. 2003. Environmental stress in confined beef cattle. J. Anim. Sci.: **81**: E110-E119.

Mader, T.L., Davis, M.S. and Brown-Brandl, T. 2006. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. **64**:712-719.

Magilligan, F.J. and McDowell, P.F. 1997. Stream channel adjustments following elimination of cattle grazing. J. Am. Water Resour. As. **33**:867-878.

Magner, J.A., Vondracek, B. and Brooks, K.N. 2008. Grazed riparian management and stream channel response in Southeastern Minnesota (USA) streams. Environ. Manage. **42**:377-390.

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2011. Livestock: Beef. [Online] Available: http://www.gov.mb.ca.proxy2.lib.umanitoba.ca/trade/globaltrade/agrifood/po_livestock/beef.html [07 February 2011].

Manitoba Rural Adaptation Council (MRAC). 2004. Managing the water's edge - riparian health assessment for streams and small rivers. 1st ed. Winnipeg, MB.

Marcuson, P. E. 1977. Overgrazed streambanks depress fishery production in Rock Creek, Montana. Pages 143-156 *in* Proc. of the workshop on livestock and wildlife-fisheries relationships in the Great Basin. University of California, Agricultural Station, Sci. Spec. Publ. 3301, Berkeley, CA.

Marlow, C.B. and Pogacnik, T.M. 1986. Cattle feeding and resting patterns in a foothills riparian zone. J. Range Manage. **39**:212-217.

Mathews, B.W., Sollenberger, L.E., Nair, V.D. and Staples, C.R. 1994. Impact of grazing management on soil-nitrogen, phosphorus, potassium, and sulfur distribution. J. Environ. Qual. **23**:1006-1013.

McIlvain, E.H. and Shoop, M.C. 1971. Shade for improving cattle gains and rangeland use. J. Range Manage. **24**:181-184.

McInnis, M. and McIver, J. 2001. Influence of off-stream supplements on streambanks of riparian pastures. J. Range Manage. **54**:648-652.

Meals, D. W. 2001. Water quality response to riparian restoration in an agricultural watershed in Vermont, USA. Water Sci. Tech. **43**:175-182.

Miller, J., Chanasyk, D., Curtis, T., Entz, T. and Willms, W. 2010a. Influence of streambank fencing with a cattle crossing on riparian health and water quality of the lower Little Bow River in southern Alberta, Canada. Agr. Water Manage. **97**:247-258.

Miller, J.J., Chanasyk, D.S., Curtis, T. and Willms, W.D. 2010b. Influence of streambank fencing on the environmental quality of cattle-excluded pastures. J. Environ. Qual. **39**:991-1000.

Miller, J., Chanasyk, D., Curtis, T., Entz, T. and Willms, W. 2011. Environmental quality of Lower Little Bow River and riparian zone along unfenced reach with off-stream watering. Agr. Water Manage. **98**:1505-1515.

Miner, J.R., Buckhouse, J.C. and Moore, J.A. 1992. Will a water trough reduce the amount of time hay-fed livestock spend in the stream (and therefore improve water quality)? Rangelands **14**:35-38.

Moen, R., Pastor, J. and Cohen, Y. 1997. Accuracy of GPS telemetry collar locations with differential correction. J. Wildlife Manage. **61**:530-539.

Mostaghimi, S., Brannan, K. M., Dillaha III, T. A. and Bruggeman, A. C. 2001. Best management practices for nonpoint source pollution control: selection and assessment.

Pages 257-304 *in* A. Shirmohammadi and W. F. Ritter, eds. Agricultural nonpoint source pollution: watershed management and hydrology. Lewis Publishers, Boca Raton, FL.

Naiman, R.J., Décamps, H. and Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. **3**:209-212.

Naiman, R.J. and Décamps, H. 1997. The ecology of interfaces: riparian zones. Annu. Rev. Ecol. Syst. **28**:621-658.

National Research Council. 2002. Riparian areas: functions and strategies for management. National Academy Press, Washington, D.C.

Ohmart, R. D. 1996. Historical and present impacts of livestock grazing on fish and wildlife resources in western riparian habitats. Pages 245-279 *in* Rangeland wildlife. P.R. Krausman, ed. Society for Range Management, Denver, CO.

Olkowski, A. A. 2009. Livestock water quality: A field guide for cattle, horses, poultry, and swine. Agriculture and Agri-Food Canada.

Olsson, K. and Hydbring, E. 1996. The preference for warm drinking water induces hyperhydration in heat stressed lactating goats. Acta Physiol. Scand. **157**:109-114.

Ominski, K.H., Boadi, D.A. and Wittenberg, K.M. 2006. Enteric methane emissions from backgrounded cattle consuming all-forage diets. Can. J Anim. Sci. **86**:393-400.

Owens, L.B., Edwards, W.M. and VanKeuren, R.W. 1996. Sediment losses from a pastured watershed before and after stream fencing. J. Soil Water Conserv. **51**:90-94.

Pandey, V., Kiker, G.A., Campbell, K.L., Williams, M.J. and Coleman, S.W. 2009. GPS monitoring of cattle location near water features in South Florida. Appl. Eng. Agric. **25**:551-562.

Parsons, C.T., Momont, P.A., DelCurto, T., McInnis, M. and Porath, M.L. 2003. Cattle distribution patterns and vegetation use in mountain riparian areas. J. Range Manage. **56**:334-341.

Pearce, R. A., Trlica, M. J., Leininger, W. C., Smith, J. L. and Frasier, G. W. 1997. Efficiency of grass buffer strips and vegetation height on sediment filtration in laboratory rainfall simulations. J. of Environ. Qual. **26**:139-144.

Platts, W.S. 1979. Livestock grazing and riparian/stream ecosystems: An overview. Pages 39-45 in Cope, O.B., ed. Proceedings from the forum on grazing and riparian/stream ecosystems. Trout Unlimited, Inc. 94 pp.

Platts, W.S., Megahan, W.F. and Minshall, G. 1983. Methods for evaluating stream, riparian and biotic conditions. Gen. Tech. Rep. INT-138. Ogden, UT. 70 pp.

Porath, M.L., Momont, P.A., DelCurto, T., Rimbey, N.R., Tanaka, J. and McInnis, M. 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. J. Anim. Sci. **80**:346-356.

Räty, M., Uusi-Kämppä, J., Yli-Halla, M., Rasa, K. and Pietola, L. 2010. Phosphorus and nitrogen cycles in the vegetation of differently managed buffer zones. Nutr. Cycl. Agroecosyst. **86**:121-132.

Richardson, J.S., Taylor, E., Schluter, D., Pearson, M. and Hatfield, T. 2010. Do riparian zones qualify as critical habitat for endangered freshwater fishes? Can. J. Fish. Aquat. Sci. **67**:1197-1204.

Roath, L.R. and Kreuger, W.C. 1982a. Cattle grazing influence on a mountain riparian zone. J. Range. Mgmt. 35:100-103.

Roath, L.R. and Kreuger, W.C. 1982b. Cattle grazing and behavior on a forested range. J. Range. Mgmt. 35:332-338.

Roberson, T., Bundy, L. G. and Andraski, T. W. 2007. Freezing and drying effects on potential plant contributions to phosphorus in runoff. J. Environ. Qual. **36**:532-539.

Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO.

Sarr, D. A. 2002. Riparian livestock exclosure research in the western United States: a critique and some recommendations. Environ. Manage. **30**:516-526.

Schellinger, G. R., and Clausen, J. C. 1992. Vegetative filter treatment of dairy barnyard runoff in cold regions. J. Environ. Qual. **21**: 40-45.

Schepers, J. S. and Francis, D.D. 1982. Chemical water quality of runoff from grazing land in Nebraska II: influence of grazing livestock. J. Environ. Qual. **11**:351-354.

Schueler, T. 1994. The importance of imperviousness. Watershed Protection Techniques. **1**:100-111.

Schwarte, K.A., Russell, J. R. and Morrical, D. G. 2011. Effects of pasture management and off-stream water on temporal/spatial distribution of cattle and stream bank characteristics in cool-season grass pastures. J. Anim. Sci. doi: 10.2527/jas.2010-3594.

Schwer, C. B. and Clausen, J. C. 1989. Vegetative filter treatment of dairy milkhouse wastewater. J. Environ. Qual. **18**:446-451.

Sheffield, R.E., Mostaghimi, S., Vaughan, D.H., Collins, Jr., E.R. and Allen, V.G. 1997. Off-stream water sources for grazing cattle as a stream bank stabilization and water quality BMP. T. ASAE **40**:595-604.

Shiga, A. 1986. The effect of drinking water temperature in winter on water, magnesium and calcium metabolism in ewes. Jpn. J. Vet. Sci. **48**:893-899.

Sidle, R.C. and Sharma, A. 1996. Stream channel changes associated with mining and grazing in the great basin. J. Environ. Qual. **25**:1111-1121.

Skovlin, J. M., Harris, R. W., Strickler, G. S. and Garrison, G. A. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. USDA Forest Serv. Tech. Bull. 1531.

Smith, D.R. 1967. Effects of cattle grazing on a ponderosa pine-bunchgrass range in Colorado. Tech. Bul. 1371. Forest Serv. U.S.D.A., Washington, D.C. 65 pp.

Smith, D. G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. GSA Bull. **87**:857-860.

Sovik, A.K. and Syversen, N. 2008. Retention of particles and nutrients in the root zone of a vegetative buffer zone - effect of vegetation and season. Boreal Env. Res. **13**:223-230.

Sowell, B.F., Mosley, J.C. and Bowman, J.G.P. 1999. Social behavior of grazing beef cattle: Implications for management. Proceedings of the American Society of Animal Science.

Statistics Canada. 2006. Census of Agriculture. [Online] Available: http://www.statcan.ca/english/agcensus2006/index.htm [22 September 2011].

Stephenson, G.R.and Rychert, R.C. 1982. Bottom sediment: a reservoir of Escherichia coli in rangeland streams. J. Range Manage. **35**:119-123.

Stevens, R., McArthur, E., Durant, E. and Davis, J.N. 1992. Reevaluation of vegetative cover changes, erosion, and sedimentation of two watersheds - 1912-1983. Pages 123-128 *in* W.P. Clary, E.D. McArthur, D. Bedunah, and C.L. Wambolt (compilers), ed. Proceedings-symposium of ecology and management of riparian shrub communities; May 29-31, 1991; Sun Valley, ID. USDA Forest Serv. Gen. Tech. Rep. INT-289. Ogden, UT.

Stillings, A. M., J.A. Tanaka, N.R. Rimbey, T. DeCurto, P.A. Momont, and M.L. Porath. 2003. Economic implications of off-stream water developments to improve riparian grazing. J. Rand Manage. **56**:418-424.

Stobbs, T.H. 1970. Automatic measurement of grazing times by dairy cows on tropical grass and legume pastures. Tropical Grasslands **4**:237- 244.

Stuth, J. W. 1991. Foraging behaviour. Pages 65-83 *in* R.K. Heitschmidt and J.W. Stuth, eds. Grazing management: an ecological perspective. Timer Press, Portland, OR.

Swain, D. L., Wark, T. and Bishop-Hurley, G. J. 2008. Using high fix rate GPS data to determine the relationships between fix rate, prediction errors and patch selection. Ecol. Model. **212**:273-279.

Swanson, S. 1986. Options for riparian grazing management. Fact sheet 86-77. Nevada Cooperative Extension, University of Nevada-Reno, Reno, NV.

Thomas, J.W., Maser, C. and. Rodiek, J.E. 1979. Wildlife habitat in managed rangelands - the Great Basin of southeastern Oregon: riparian zones. Gen. Tech. Rep. PNW 80, USDA Northwest Forest and Range Experiment Station, Portland, OR. 19 pp.

Thompson, W.H. and Hansen, P.L. 2002. Classification and management of riparian and wetland sites of the Alberta Grassland Natural Region and adjacent subregions. Bitterroot Restoration, Inc. Prepared for the Alberta Riparian Habitat Management Program – Cows and Fish, Lethbridge, AB. 416 pp.

Tomkins, N. and O'Reagain, P. 2007. Global positioning systems indicate landscape preferences of cattle in the subtropical savannas. Rangeland J. **29**:217-222.

Trimble, S.W. and Mendel, A.C. 1995. The cow as a geomorphic agent — a critical review. Geomorphology **13**:233-253.

Turner, L.W., Udal, M.C., Larson, B.T. and Shearer, S.A. 2000. Monitoring cattle behaviour and pasture use with GPS and GIS. Can. J. Anim. Sci. **80**:405-413.

Ungar, E.D., Henkin, Z., Gutman, M., Dolev, A., Genizi, A. and Ganskopp, D. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. Rangeland Ecol. Manag. **58**:256-266.

U.S. Geological Survey (USGS). 1999. The quality of our nation's waters – nutrients and pesticides. U.S. Geological Survey Circular 1225, 82 p.

Uusi-Kämppä, J. 2005. Phosphorus purification in buffer zones in cold climates. Ecol. Eng. **24**:491-502.

Van Donsel, D.J. and Gelreich, E.E. 1971. Relationships of salmonellae to fecal coliforms in bottom sediments. Water Res. **5**:1079-1087.

Van Velson, R. 1979. Effects of livestock grazing upon rainbow trout in Otter Creek, Nebraska. Pages 53-56 *in* Grazing and riparian/stream ecosystems. Trout Unlimited Inc., Vienna, VA.

Vavra, M., and Phillips, R.L. 1979. Diet quality and cattle performance on forested rangeland in northeast Oregon *in* Proc. West. Sec. Soc. Anim. Sci. 30: 170-173.

Veira, D.M. and Liggins, L. 2002. Do cattle need to be fenced out of riparian areas? Beef Cattle Industry Development Fund – Project #95. Agriculture and Agri-Food Canada, Kamloops, B.C.

Veira, D.M. 2007. Meeting water requirements of cattle on the Canadian prairies. Rangeland J. **29**: 79-86.

Waters, T. F. 1995. Sediment in streams, sources, biological effects and control. American Fisheries Society Monograph. 249 pp.

West, J.W. 1994. Interactions of energy and bovine somatotropin with heat stress. J. Dairy Sci. **77**: 2091-2102.

White, R. K., Van Keuren, R. W., Owens, L. B., Edwards, W. M. and Miller, R. H. 1983. Effects of livestock pasturing on non-point surface runoff. Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, OK.

Williamson, R. B., Smith, C. M. and Cooper, A. B. 1996. Watershed riparian management and its benefits to a eutrophic lake. J. Water Resour. Plann. Manage. **122**:24-32.

World Health Organization (WHO). 2011. Nitrate and nitrite in drinking-water. WHO Press, Geneva, Switzerland. 31 p.