ASSESSMENT OF WATERSHED HEALTH ON INTERMITTENT WATERSHEDS IN SOUTHWESTERN NORTH DAKOTA

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ABSTRACT

Watersheds are complex systems that are influenced by many factors including geomorphology, climate, soil, vegetation, and land management. Due to this complexity, a watershed assessment that evaluates both the riparian and upland areas has yet to be developed. We proposed investigating a combination of plant community composition within the greenline, upland ecological site function assessment with the Interpreting Indicators of Rangeland Health (IIRH) protocol, and stream morphological parameters. Stream parameters investigated were Rosgen's classification method, bank erosion hazard index (BEHI) and bank height ratio (BHR). This research was conducted on five intermittent streams in southwestern North Dakota. We found that facultative wetland species offered the most protection to intermittent streambanks as a result of hydrology. When assessing the uplands it was determined that there is a positive correlation between rangeland health and riparian health. The stream parameter that showed the strongest relationship was the BEHI.

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GENERAL INTRODUCTION

Riparian areas are narrow corridors adjacent to bodies of water whose soil and vegetation are influenced by hydrology. River and stream riparian areas are an important part of the landscape despite making up less than two percent of terrestrial environments. These areas are important not only to fish and wildlife, but also to humans as they are a source of water. However, assessing the condition of watersheds has been difficult as methods often times focus on the immediate riparian area regardless of several researchers acknowledging the stream is influenced by its catchment. To date, there has not been a monitoring protocol developed that accurately ties the condition of the watershed catchment to the state of its stream or river. Research has recently focused on intensive small grain and row crop production and its effects on riparian function, but assessment protocols have not been developed.

The purpose of watershed assessments is to give insight into the function of the streams morphology, water quality, and biotic integrity. Current watershed assessment protocols utilize a combination of quantitative and qualitative methods that can provide opportunities for biased results. This leaves opportunities for varying results depending on the individual(s) conducting the assessment. Watershed assessments intensity varies from one protocol to the next. This allows for different protocols to investigate different functions or to focus on just one function. For example, Karr (1981) developed an assessment for investigating fish communities as they are influenced by water quality. Karr’s protocol can give great detail into the biotic integrity of the stream assuming there is flow, but it does not give insight into the land use and management issues influencing the biology of the stream. The Multiple Indicator Monitoring of stream channels and streamside vegetation protocol, oftentimes referred to as MIM, is more intensive as it investigates riparian plant communities, streambank condition, and stream channel morphology (Burton et al. 2011). However, MIM fails to look at the riparian condition at a landscape level and allows for subjective observations. Oftentimes a state will use a rapid assessment method to get detail into how a stream is functioning, but due to no quantitative data being recorded long-term monitoring can be difficult to observe.

As a result of difficulties assessing watersheds in rural areas the North Dakota Department of Health (NDoH) and Bowman-Slope County Soil Conservation District (SCD) reached out to North Dakota State University Animal Sciences Department concerning the development of a protocol for grazed watersheds that can be effective regardless of flow. The reasoning behind this project is that in remote and rural areas characterized by ephemeral and intermittent stream flow opportunities to collect water samples can be rare. Furthermore, the use of quantitative based monitoring can allow for more effective development of best management practices. In cooperation with the NDoH, Bowman Slope County SCD, and Natural Resource Conservation Service (NRCS) we proposed using a combination of the Interpreting Indicators of Rangeland Health Protocol (IIRH) and Rosgen’s classification of natural streams to interpret the ecological function of the uplands and their influence on the state and stability of the adjacent stream reaches.

CHAPTER 1: LITERATURE REVIEW

Riparian zones are dynamic portions of the landscape that contain valuable water resources, plant communities, fisheries, and wildlife (Gregory et al. 1991; Swanson et al. 1988). Riparian ecosystems are unique as they dissect terrestrial landscapes with small bands of habitat that abruptly transition into aquatic environments (Gregory et al. 1991). In uplands hydrology has minimal influence; whereas, hydrology has a significant impact on aquatic ecosystems function and formation (Gregory et al. 1991; Naiman et al. 1993; Svejcar 1997). Riparian areas are influenced by many factors including geomorphology, climate, soils, vegetation, ecological processes, and management (Gregory et al. 1991; Kovalchik and Chitwood 1990; Lytle and Poff 2004; Naiman et al. 1993; Svejcar 1997).

These diverse areas of the landscape are often interpreted by looking into riparian characteristics such as sediment load (Leopold 1994; Leopold and Wolman 1957; Magner and Steffen 2000; Simon and Rinaldi 2006; Wood and Armitage 1997), vegetative cover (Burton et al. 2011; Davies-Colley 1997; Micheli and Kirchner 2002a, b; Tufekcioglu et al. 1998), aquatic biology (Karr 1981; Wood and Armitage 1997), stream morphology (Rosgen 1985, 1994; Rosgen and Silvey 1996; Toledo and Kauffman 2001), and water quality (Magner et al. 2008; Meynendonckx et al. 2006). Recently catchment influence on water quality (Jarvie et al. 2002; Meynendonckx et al. 2006; Roberts et al. 2007; Tong and Chen 2002) and morphology (Allan 2004; Clary et al. 2000; Covino 2017; Sheppard et al. 2017; Wiens 2002) have received attention.

Due to the many factors influencing riparian areas, it has been difficult to assess watersheds at a catchment level. Furthermore, most of the research is focused on perennial streams with little research being focused on ephemeral and intermittent streams (Matthews

1988). A combination of the IIRH protocol (Pellant et al. 2005) and Rosgen's classification method (Rosgen 1985, 1994) may have potential to provide further insight into the relationship of ecological site function and local hydrology influencing rivers and streams.

Geomorphology

Landscapes that are observed in a watershed have developed over geologic time while being shaped by climate, lithology, and vegetation patterns (Rosgen and Silvey 1996). The climatic forces have carved landforms on materials supplied by geologic structure through chemical and physical weathering (Kovalchik and Chitwood 1990). The sun is critical for physical weathering as it provides energy to drive the hydrologic cycle to slowly erode away geologic structures (Hudak 2005). Kovalchik and Chitwood (1990) credit geology, climate, and time for providing the landscape's appearance and drainage pattern. The geomorphic surface is slowly created over geologic time through erosional and constructive forces from wind and water moving particles from one area to another (Ruhe 1954; Schaetzl and Anderson 2005). Erosional surfaces are those that are exposed to destructive forces such as wind and water and have sediment worn away. Constructive surfaces are those where the eroded sediment accumulates or aggrades. The drainage pattern is, therefore, a product of erosional and depositional processes (Daniels et al. 1971; Dunne 1980; Kovalchik and Chitwood 1990).

The valley is a drainage basin formed between two adjacent uplands by erosional and depositional processes. The structure of the valley influences the pattern of the stream within the landscape (Dunne and Leopold 1978; Montgomery and MacDonald 2002). The structure of the valley floor is the result of basin geology, hydrology, and vegetation interacting with erosive forces over time to form various fluvial surfaces (Gregory et al. 1991; Rosgen and Silvey 1996). Fluvial surfaces that are formed by sediment movement consist of active channels, floodplains, terraces, and alluvial fans (Gregory et al. 1991; Stringham and Repp 2010). Determining river morphology is aided by understanding the geomorphology, as the geomorphology dictates the soils and plants that are found within a specific area (Rosgen and Silvey 1996; Stringham and Repp 2010). Thus, the identification of a valley type can give insight to the potential suite of stream channels that may occur, as the stream type is a function of the valley type (Rosgen 1985, 1994). According to Rosgen's classification valley type is the first level of stream classification. The valley types are defined by the dimensions, gradient of the side-slopes, and aspect (Rosgen and Silvey 1996). Rosgen has identified eleven valley types based on these criteria: 1) steep canyons, 2) colluvial, 3) alluvial fans and debris flows, 4) natural gorges, 5) glacial troughs-course materials, 6) bedrock controlled, 7) dissected-entrenched, 8) alluvial, 9) glacial outwash, 10) lacustrine, and 11) deltas (Rosgen 1994; Rosgen and Silvey 1996).

Stream types can be classified using a delineation system developed by Rosgen (1994), which groups streams based on entrenchment ratio, width to depth ratio, sinuosity, gradient, and channel materials. The entrenchment ratio is used to understand how incised the stream is, or the ease at which a stream can access its floodplain (Kellerhals et al. 1972). Entrenchment ratio can be found by dividing the flood-prone width by the surface bankfull discharge width (Rosgen 1994). As a stream's entrenchment ratio increases above 1.0, it becomes restricted laterally as it is vertically confined by its increasing bank heights (Rosgen 1997). The width to depth ratio is found by dividing the bankfull width by the average bankfull depth (Rosgen 1994; Rosgen and Silvey 1996). Streams with high width to depth ratios (>12) are wide and shallow, and as a result there is a lot of stress placed on the streambanks (Rosgen and Silvey 1996). Sinuosity is a measurement of how often a stream meander or curves, and is found by dividing the stream length by the valley length (Rosgen 1994; Rosgen and Silvey 1996). As a streams sinuosity increases the energy of the flowing water is decreased as the turning dissipates water's energy (Rosgen and Silvey 1996). The gradient, or slope, of a stream is a measurement that determines the elevation change of water's surface in a stream (Rosgen 1994). Rosgen (1994) classified streams into eight main categories: 1) A, 2) B, 3) C, 4) D, 5) Da, 6) E, 7) F, and 8) G channels. The D and Da stream channels are distinctly different from the other six as they are characterized by a "braided" stream pattern (Rosgen 1994).

Within the state of North Dakota B, C, E, F, and G channels may occur (Meehan et al. 2014; Meehan et al. 2015; Meehan et al. 2016). C and E type streams are considered slightly entrenched with an entrenchment ratio (width of the flood prone area at an elevation twice the maximum bankfull depth / mean bankfull depth) less than 2.2 (Rosgen 1994; Rosgen and Silvey 1996). These streams are considered stable as they have access to a well-developed floodplain. B channel streams have an entrenchment ratio of 1.4-2.2 and are moderately entrenched. B channel streams are characterized as having moderate gradient, stable banks, and irregularly spaced pools (Rosgen 1994; Rosgen and Silvey 1996). Within the Great Plains B channels are considered transitional despite being resistant to change (Meehan et al. 2016). The F and G channels will have an entrenchment ratio less than 1.4 and are considered entrenched (Rosgen 1994; Rosgen and Silvey 1996). F and G channels are not able to access their floodplains during high flow events because of their high banks; therefore, they are the least stable as they are unable to maintain their dimension and pattern (Rosgen 1994; Rosgen and Silvey 1996). When a stream is not able to access its floodplain the shear stress (friction) applied to the bank is increased leading to further incision and widening as the water's energy cannot be dissipated by the floodplain (Galay 1983; Schumm et al. 1984; Simon and Hupp 1986; Simon and Rinaldi 2000).

Soils

The infiltration rate is influenced by slope steepness, intensity of the rainfall, amount and type of vegetation, vegetation litter, soil moisture content, soil texture, quantity of shrink swell clays, and soil organic matter (Bagarello et al. 2004; Brooks et al. 2013; Chowdary et al. 2006; Schaetzl and Anderson 2005). Not all water that infiltrates the soil is retained and is known as excess water, which will either continue percolating down or it will move laterally when it intercepts an impermeable layer such as an argillic horizon or bedrock (Brooks et al. 2013). The water that reaches an impermeable layer will be forced to move horizontally until it reaches a wetland or stream (Brooks et al. 2013). When soil becomes saturated water will runoff, and the fate of the runoff is decided by the geomorphology of the valley (Huggett 1975, 1976).

Infiltration rate has a direct relationship with the soil particle size, or texture, as higher infiltration rates occur on soils with larger particles sizes (Fayos 1997; Hwang 2004; Schaetzl and Anderson 2005). Therefore, the infiltration rate in a soil increases as there is an increase in sand content because of the larger particle size and pore space (Hudak 2005; Mazaheri and Mahmoodabadi 2012). Soils with higher infiltration rates reduce the potential of runoff as the water infiltrates and percolates into the soil profile instead of contributing to surface flow (Brooks et al. 2013; Schaetzl and Anderson 2005). Soils that have high silt and very fine sand content are the most erodible as they have lower infiltration rates and weak aggregate stability making them susceptible to being transported by overland flow (Gardiner and Miller 2008; Wischmeier and Mannering 1969).

High aggregate stability will reduce erosion susceptibility due to its effects on water flow, erosion, and runoff (Gardiner and Miller 2008; Kodešová et al. 2009). Aggregate stability, the binding force of soil particles, can be used to determine the soil’s susceptibility to erosional processes and runoff (Barthes and Roose 2002; Bissonnais et al. 2002; Cantón et al. 2009). Because soil aggregates are exposed to moving water in fluvial areas it is important to note that erosional and depositional processes can modify the soil properties (Stavi and Lal 2011). Aggregate stability is primarily a function of organic matter (Bronick and Lal 2005; Schaetzl and Anderson 2005). Organic matter flocculates soil particles, particularly clay, acting as a cementing agent in soil aggregates reducing the risk of erosion (Abiven et al. 2009; Jakšík et al. 2015; Schaetzl and Anderson 2005). This means that soils higher in organic matter have more aggregate stability and faster infiltration rates. Aggregate stability is therefore dependent upon organic inputs (Abiven et al. 2009), and further protected by vegetative cover by reducing raindrop impact (Gardiner and Miller 2008; Kauffman and Krueger 1984; Klemmedson 1956; Schaetzl and Anderson 2005; Trimble 1994). Thus, more energy is required to disperse the soil that have high organic matter and vegetation cover to facilitate runoff and erosion (Duniway et al. 2010; Gardiner and Miller 2008; Schaetzl and Anderson 2005; Wischmeier and Mannering 1969).

Vegetation

Numerous authors have documented vegetation plays a critical role in soil retention and erosion reduction (Bilbro 1991; Butler et al. 2006; Clary and Leininger 2000; Trimble 1994; Unger and Vigil 1998). Soils with high vegetative cover cycle nutrients more effectively, have higher infiltration rates and have lower erosion rates than soils with low cover (Printz et al. 2014; Rook and Tallowin 2003; Russell and Bisinger 2015). Vegetation's influence on soil erosion and loss can be seen in both riparian areas and uplands. Un-vegetated streambanks are more likely to fail leading to mass soil wasting as plant roots are not present to bind and reinforce the soil (Beeson and Doyle 1995; Marcuson 1977; Meehan et al. 1977). Opposite of riparian areas the adjacent uplands are subject to rill and gully erosion as well as blowout formation when plant cover is reduced (Clary et al. 2000; Gardiner and Miller 2008; Stubbendieck et al. 1989). A wild card in vegetation's influence on soil enhancement is introduced vegetation, as exotic species can alter soil function and reduce cover of more desirable and beneficial species (Estes et al. 2011; Harris 1967; Knapp 1996; Melgoza et al. 1990; Morrow and Stahlman 1984; Murphy and Grant 2005; Toledo et al. 2014). In circumstances where the soil is influenced by a high water table or seep, soil salinity can have a strong influence on the available plant species (Worcester and Seelig 1976). For this reason riparian, upland, exotic, and halophytic vegetation were further researched.

Riparian Vegetation

Riparian vegetation consists of plants typically found in hydric soils (Lichvar et al. 2012; Reed 1988; Tiner 1991). Reed (1988) classified riparian vegetation as facultative wetland and obligate wetland. Facultative wetland species are found in hydric soils 67-99 percent of time; whereas, obligate species are found in hydric soils 99 percent of the time (Lichvar et al. 2012; Reed 1988). Riparian vegetation has a significant impact on stream stability and morphology. However, the influence of the vegetation on stability varies depending on the stream types. A stream types are the least affected; whereas, E and C stream types being the most affected by riparian vegetation (Rosgen 1994). Riparian vegetation supports streambank stability with roots that bind the soil together (Abernethy and Rutherfurd 2001) and by providing canopy cover that dissipates raindrops energy (Behnke and Raleigh 1979; Gregory 1992; Naiman and Decamps 1997).

Riparian vegetation is crucial as it also acts as a filter, preventing sediments, excess nutrients, pollutants, and debris from accessing the stream (Butler et al. 2006; Clary and

Leininger 2000; Clary et al. 1996; Cooper et al. 1987; Fleming et al. 2001; Lowrance et al. 1984; Marcuson 1977; Meehan et al. 1977; Svejcar 1997; Winward 1994, 2000). The increased ability to entrap and stabilize sediment by riparian vegetation within the greenline aids in floodplain development (Clary and Leininger 2000; Winward 2000). The sediment trapping action of the riparian zone is a product of the tall vegetation as it adds roughness removing energy from flowing water, allowing for sediment to settle out (Li and Shen 1973). For this reason it is recommended to leave a stubble height of at least ten cm when grazing riparian areas (Clary et al. 1996; Schwarte et al. 2011b)

Riparian vegetation promotes infiltration, which in return stores and recharges water in the groundwater system, and replenishes aquifers during peak flows (Gardiner and Miller 2008; Hudak 2005; Stringham and Repp 2010). This lessens the impacts of spring floods and releases water back into the stream in the form of recharge, minimizing fluctuations in streamflow (Beschta et al. 1987; Svejcar 1997). Improper management of riparian areas and their surroundings can have negative impacts on riparian areas and their ecological functions (Byers et al. 2005; Fitch and Adams 1998). Improperly managed areas may suffer from shallow rooting species and soil compaction, which decreases infiltration rates promoting increased flow. The increase in stream flow has potential to move a stream reach into an unstable state as a result of the increase in energy (Magner and Steffen 2000; Poff 2002; Poff and Allan 1995).

The greenline is the plant community near the bankfull elevation that helps stabilize the streambanks. A floodplain with riparian species present will aid in bank stability as it lowers its risk of erosion by adding roughness to slow the flowing water’s velocity (Hunter 1991; Li and Shen 1973; Schumm and Meyer 1979). Beeson and Doyle (1995) found that un-vegetated streambanks were up to five times more likely to have noticeable erosion than vegetated banks.

The species occupying the greenline also need to have the appropriate rooting depth as shallow rooting species allow for erosion of the toe bank forming cut banks and causing bank failure (Micheli and Kirchner 2002a, b; Petersen 1986). Micheli and Kirchner (2002a) found that the presence of *Carex* and *Juncus* spp. can increase bank stability up to ten times more than a streambank consisting of upland and facultative upland species. Micheli and Kirchner (2002b) found that rushes are better suited for stabilizing streambanks consisting of courser textures; whereas, sedges were more efficient at stabilizing fine textured materials.

The greenline and floodplain plant communities need to be adapted to a variety of moisture regimes as periods of extended drought or flooding could lead to plant mortality (Capon 2003). When hydric species become stressed from drought they have decreased vigor, potentially decreasing their root strength (Lytle and Poff 2004; Vivian et al. 2014). Contrarily, during long durations of inundation flood intolerant species can be lost (Lytle and Poff 2004). Stromberg (2005) found that when the flow of a stream was altered from perennial to intermittent that many obligate wetland species were reduced and/or lost and facultative wet species increased. In streams that are actively incising the hydrologic disconnectivity could also replace the greenline vegetation with dry and mesic species as the water table lowers making it difficult for recolonization (Chambers et al. 2004). Oftentimes when a stream incises the greenline vegetation is lost as a result of the lowered water table leading to stream widening (Chaves et al. 2002; Meehan et al. 2014; Meehan et al. 2015).

Plants that naturally occur within greenline communities are hydrophilic, meaning they are usually found in areas of wet soil conditions. There are two primary types of plants that occur within riparian areas, herbaceous and woody plants (Lyons et al. 2000). Woody vegetation such as trees and shrubs are late successional plants in comparison to herbaceous vegetation that range from early to late successional species. Historically on the Great Plains, wooded riparian areas were uncommon as fire naturally occurred. After European settlement, fire was all but removed from the plains allowing for forested riparian areas to develop. Furthermore, in the Great Plains grassland streams, particularly intermittent streams, are typically dominated by warm season grasses (Dodds et al. 2004). Both woody and herbaceous vegetation have similar functions in riparian areas; however, the benefits of one's presence over the other can contrast (Lyons et al. 2000).

Woody Vegetation

Although canopy cover from woody vegetation is rare in headwater streams (Wiley et al. 1990) woody vegetation can enhance streambank stability (Lyons et al. 2000). Willows (*Salix spp.*) are particularly good at preventing soil erosion as they have a bushy growth form that helps slow water velocity during floods allowing for sediment trapping to occur. In comparison, more erect trees, such as cottonwoods (*Populus deltoides*) and other members in the *Populus* genus, can induce turbulence during high water events causing erosion near their trunks (Lyons et al. 2000). Furthermore, heavily wooded areas can shade out grasses leaving the soil surface exposed to flood water (Hunt 1979; Peterson 1993; White and Brynildson 1967). When larger trees die, they can increase the amount of erosion when they fall over as their roots leave a large portion of the ground damaged and vulnerable. Occasionally when taller trees fall they can sometimes damage the opposite streambank from impact (Shields and Gray 1992). Woody vegetation is recommended for tall steep banks as their deep rooting systems offer the most support for streambanks (Burckhardt and Todd 1998; Hupp 1992; Isenhart et al. 1997; Watson et al. 1997; Wynn et al. 2004).

Herbaceous Vegetation

Herbaceous vegetation increases streambank stability and reduces surface erosion by portioning their root density throughout the streambank (Wynn et al. 2004). Streambanks dominated by herbaceous vegetation oftentimes has a sod on the soil surface while having roots extend over a meter in depth (Wynn et al. 2004). Due to herbaceous vegetation in riparian areas leaving minimal areas of bare ground, erosion is minimal during heavy precipitation and flooding events (White and Brynildson 1967). Herbaceous vegetation's dense growth adds roughness to moving water during floods dissipating energy (Hughes 1997; Li and Shen 1973; Naiman and Decamps 1997) and enabling sediment trapping and floodplain development to occur (Castelle et al. 1994; Osborne and Kovacic 1993; Parsons et al. 1994; Rosgen and Silvey 1996).

The silt capturing ability of grassy riparian zones can be reduced by idle land management in cases when trees become established and take over (Magner and Brooks 2007). When the trees are allowed to take over the trapped sediments from the herbaceous vegetation's time of occupancy can be released back into the stream (Lyons et al. 2000). However, on steeper streambanks many of the benefits of herbaceous vegetation are reduced as the rooting depths is unable to reach the appropriate depth where flowing water is exerting the most stress (Medina 1996; Petersen 1986). With the exception of high steep streambanks, herbaceous and woody vegetation are equally as useful in providing ecosystem services and bank stabilization (Davies-Colley 1997; Trimble 1997).

The Cyperaceae family is traditionally associated with increased stability as sedges (*Carex* spp.), rushes (*Juncus* spp.), spike rushes (*Eleocharis* spp.), and bulrushes (*Schoenoplectus* spp.) are within the family (Ball et al. 2003; Micheli and Kirchner 2002b).

Several hydrophytic grasses, such as those in the belonging to the *Spartina* genus may also increase bank stability as they are deep rooted and tolerant to flooding (Blom and Voesenek 1996; Vande Kamp et al. 2013; Weaver 1960). Micheli and Kirchner (2002b) found that streambanks consisting of dry meadow, or upland species were more likely to fail than those consisting of riparian species. It was determined that *Carex* spp. can increase bank stability up to five times the amount of upland species (Micheli and Kirchner 2002b).

Upland Vegetation

Upland vegetation, or dry meadow species are found away from riparian areas on the adjacent uplands. This vegetation is not depended on a high water table, and may not survive on a hydric soil. Reed (1988) broke upland vegetation into two groups, 1) upland and 2) facultative upland, as some species are rarely found if at all on hydric soils and some occasional are found within hydric soils. Upland plants are found less than one percent of the time on hydric soils; whereas, facultative upland species are found on a hydric soil 1-33 percent of the time (Lichvar et al. 2012; Reed 1988). Upland vegetation has potential to influence hydrology by influencing overland flow and sediment supply (Rosgen and Silvey 1996; Stringham et al. 2003). For this reason researchers attempt to include the entire catchment in order to determine the state of watersheds and streams when investigating water quality (Jarvie et al. 2002; Meynendonckx et al. 2006; Roberts et al. 2007; Tong and Chen 2002) and morphology (Allan 2004; Clary et al. 2000; Covino 2017; Sheppard et al. 2017; Wiens 2002).

The state of upland vegetation that has been altered through disturbance or invasion (Westoby et al. 1989) has the potential to alter local hydrology which in turn can influence the stream (Stringham et al. 2003). In circumstances where the local hydrology is altered and there is increased overland flow streams may show rapid increases in the amount of flow in comparison to proper functioning uplands capable of buffering high precipitation rates (Clary et al. 2000; Hudak 2005). Schilling and Libra (2003) and Schilling et al. (2008) found this to be true within grassland systems when native vegetation is converted to annual crops. The pulses of increased stream energy over time has potential to increase erosion on streambanks (Brooks et al. 2013). In circumstances when high amounts of sediment are being added from a lack of upland vegetation and erosion (Butler et al. 2006) point bars may form and concentrate flow into streambanks facilitating erosion (Howard and Knutson 1984).

Exotic Vegetation

Exotic or introduced vegetation can have a variety of effects on the landscape depending on their life history and phenology. Many exotic species are considered desirable for reasons such as rapid growth (D'Antonio and Vitousek 1992; Thompson and Harper 1988), aesthetic value (Pejchar and Mooney 2009), improved forage for livestock (Caldwell et al. 1981), and erosion control (Forman 2000; Huff and Bara 1993). Several exotic species are used as erosion control for road ditches, hill slopes, and other areas of concern as they grow rapidly, are competitive, and from thick sods (Forman 2000; Huff and Bara 1993; Larson 2003; Orr 1970). Unfortunately, due to their competitive nature native species can be displaced (Caldwell et al. 1981; Dillemuth et al. 2009). Plant communities consisting of introduced species may not have the same ecological benefits as the native communities they displaced (Estes et al. 2011).

Introduced cool season grasses, particularly smooth bromegrass and Kentucky bluegrass, have greatly reduced diversity within the Northern Great Plains (DeKeyser et al. 2013; Grant et al. 2009; Murphy and Grant 2005; Toledo et al. 2014). Cheatgrass (*Bromus tectorum* L.) is most known for its invasion and dominance within the Great Basin ecosystem, but it also occurs within the Great Plains ecosystem (Mack 2011). Kentucky bluegrass and smooth bromegrass are perennial sod-forming grasses introduced from Europe; whereas, cheatgrass is a winter annual introduced from Eurasia (Stubbendieck et al. 2003). These three grasses have been documented to negatively alter plant communities (Harris 1967; Morrow and Stahlman 1984; Murphy and Grant 2005; Toledo et al. 2014), nutrient cycling (Printz et al. 2014), soil structure and biota (Angers and Caron 1998; Jordan et al. 2008; Printz et al. 2014), and infiltration (Boxell and Drohan 2009; Pierson et al. 2002; Taylor and Blake 1982). Cheatgrass may be an exception in regards to infiltration as Gasch et al. (2013) found cheatgrass to increase infiltration on certain soils. Furthermore, all three species are associated with increased litter amounts that aide in their success through increased fire intervals (Ogle et al. 2003; Whisenant 1990) or shading native species (DeKeyser et al. 2009; Facelli and Pickett 1991; Printz et al. 2014; Suding and Goldberg 1999).

Sinkins and Otfinowski (2012) investigated the ability of introduced species to remain on the landscape when disturbances are removed. They found that many exotic species densities decreased with the exception of Kentucky bluegrass and smooth bromegrass. It was determined that the only time Kentucky bluegrass's density decreased was when smooth bromegrass invaded the same site (Sinkins and Otfinowski 2012). Kentucky bluegrass has been documented to increase across the landscape at all grazing intensities (DeKeyser et al. 2009; Sinkins and Otfinowski 2012; Uchytil 1993). Grazing has been more useful at reducing smooth bromegrass on prairies as it is highly palatable and has a high growing point (Briske 1991; Howard 1996; Milchunas and Vandever 2014). Grazing may be able to control cheatgrass infestations during a small window when native perennial vegetation is dormant (Vallentine and Stevens 1994). Often times a variety of different management practices are needed to effectively control aggressive exotic invaders (Travnicek et al. 2005).

Halophytic Vegetation

Plants that survive in saline soils are considered halophytic vegetation or halophytes (Jefferies 1981; Ungar 1974). Halophytic vegetation is important as their salt tolerance enables them to colonize land other vegetation cannot (Flowers and Colmer 2008). Soils that have salt crust formation are susceptible to overland flow and consequently rill erosion as their infiltration rate and aggregate stability is low (Bissonnais 1996; Mamedov et al. 2002). The ability of halophytes to survive and stabilize saline soils is crucial due to the poor hydrology and aggregate stability (Caravaca et al. 2005; Cooke et al. 1993). This is especially true for soils suffering from high sodium amounts as sodium facilitates dispersion (Schaetzl and Anderson 2005).

Soils may be influenced by salinity if a high water table is present leading to evaporation on the soil surface where the salt minerals are left behind (Timpson et al. 1986; Worcester and Seelig 1976). Observations of plant communities can be used to determine if a soil is influenced by salinity as not all plant species can tolerate saline soils (Worcester and Seelig 1976). As a result, the more saline a soil is the steeper the competition gradient favors halophytic vegetation (Ungar 1974). In some circumstances, soil salinity can lead to the death of all vegetation present as they are stressed osmotically and metabolically (Parida and Das 2005).

Management

Factors influencing riparian stability include land use, vegetation cover, topography, bank material, and watershed area (Hagerty et al. 1981; Hooke 1980). There is not much that can be done in regards to the geography and landscape of a watershed, but land use can be managed. Land management influences water quality, habitat, erosion rates, and sediment and nutrient transport (Allan et al. 1997; Smeck 1985). Intensive land use can lead to increased sediment loads (Brooks et al. 2013) as the adjacent land use is related to streambank erosion rates (Zaimes et al. 2004). When land use is changed from native perennial vegetation there can be an increase in soil erosion (Hooke 2000; Ursic and Dendy 1965; Wolman 1967) and overland flow (Naef et al. 2002). Land use that reduces overland flow; therefore, reduces the potential of flood flows (Naef et al. 2002).

The two broad categories of land utilization within grasslands include perennial vegetation and annual vegetation. Idle, grazed, and hay production management practices are all characterized by perennial vegetation; whereas, crop production is annual vegetation. There are many benefits to perennial vegetation, and the benefits are improved with diversity. Perennial vegetation provide services such as hydrologic regulation (Gerla 2007; McLaughlin and Walsh 1998), water filtration (Duchemin and Hogue 2009), improved soil structure and quality (Entz et al. 2002; Johnson et al. 2005; McLaughlin and Walsh 1998; Moonen and Barberi 2008), canopy cover protection (Gardiner and Miller 2008; Hofmann and Ries 1991; Pearce et al. 1998), lower soil temperatures (Bremer et al. 1998), and decreased runoff and erosion (Gard et al. 1943; Power 2010). When the attributes of perennial vegetation are lost, or diminished water quality (Allan et al. 1997; Jaynes et al. 1999) and flood control are reduced (Group 1998; Knox 2001). Large vegetation conversions to annual crops have led to changes in hydrology such as decreased infiltration rates (Bharati et al. 2002; Duniway et al. 2010; McLaughlin and Walsh 1998) and higher runoff rates (McLaughlin and Walsh 1998), leading to increased baseflow (Schilling and Libra 2003) and sediment loads (Brooks et al. 2013; David et al. 2009) of streams. Stream erosion is a natural process (Henderson 1986), but if the sediment load is too high bed aggradation occurs and the stream can lose its equilibrium and transition to a less stable stream type (Schumm 1977).

The Northern Great Plains have been largely altered as grasslands have, and are currently being replaced by croplands (Claassen et al. 2011; Claassen 2011; Samson et al. 1998; Turner et al. 2014). Many of the conversions have taken place on marginal lands, or lands whose climate and soil characteristics are not highly suited for crop production (Wright and Wimberly 2013). This conversion leads to reduced soil qualities as the canopy cover and organic matter inputs are reduced (Gilley et al. 1997b; Gregorich et al. 1998; McLaughlin and Walsh 1998). These land use changes can affect the hydrology of a system and increase the peak flow of streams (Villarini et al. 2011). By replacing natural vegetation with annual crops and intensifying the land use increases in erosion and sediment transport rates can be observed (Abernethy 1990; Walling).

Several authors showed concern as vast amounts of land are suffering from erosion (Kendall and Pimentel 1994; Lal 1994; Pimentel et al. 1995). This concern is due to large amounts of agricultural land being abandoned worldwide (Kendall and Pimentel 1994; Lal 1990, 1994) as the productivity is lost with the eroded soils (Faeth 1994). Speth (1994) determined that roughly 90 percent of Earth's land used for agriculture have deteriorated due to erosion with 80 percent experiencing moderate to severe erosion and 10 percent experiencing slight to moderate erosion. Land use of the past and today can contribute to a legacy effect that inhibits future beneficial land management changes from achieving the full potential of their goals (Riley et al. 2003). Management of land can vary based on region, common land uses include no use (idle), grazing, hay production, and crop production.

Idle

Idle land management is taking a passive approach without actively utilizing the land. The Conservation Reserve Program (CRP) is a commonly enrolled in for landowners operating on highly erodible lands (Hanson and Schmidt 2017). CRP is generally used on uplands;

however, other practices exist with the purpose of enhancing wildlife, pollinators, and water quality (Agapoff et al. 2016). These initiatives include upland bird habitat and nesting, prairie pothole duck habitat, bottomland hardwood, non-floodplain wetland restoration, floodplain wetland restoration, state acres for wildlife enhancement, longleaf pine, highly erodible lands initiative, and the pollinator habitat initiative (Agapoff et al. 2016).

The CRP is effective at reducing soil erosion on highly erodible lands (Davie and Lant 1994). By maintaining perennial forage raindrops are intercepted by plants before making impact with the soil (Pearce et al. 1998) and improved soil traits such as porosity (Angers et al. 1987; Duley and Domingo 1949), air permeability (Jarrett and Hoover 1985), organic C, and aggregate stability occur (Angers 1992; Perfect et al. 1990). However, CRP has also been effective in the past at introducing species that can become invasive as the majority of CRP plantings in North Dakota utilized smooth bromegrass (*Bromus inermis* Leyss.), alfalfa (*Medicago sativa* L.), and sweet clover (*Melilotus spp.*) in the past (Asbjornsen et al. 2014; Reynolds et al. 1994). Kentucky bluegrass (*Poa pratensis* L.) often invades idle land and co-dominates with smooth bromegrass making land management difficult (Murphy and Grant 2005). These shallow-rooted upland species' root systems are not sufficient to maintain the streambanks when they are present, and as a result there is decreased bank stability and accelerated erosion (Winward 1994).

Another option to idle management is resting grazed land or livestock exclusion. Numerous authors have documented livestock exclusion being beneficial to riparian health as it functions as passive restoration (Belsky et al. 1999; Coles-Ritchie et al. 2007; Green and Kauffman 1995). Researchers have found grazing tolerant plant communities switch back to hydrophytic communities as time passes following livestock exclusion within the riparian areas within the Great Basin (Batchelor et al. 2015; Martin and Chambers 2001) and Great Plains

(Vande Kamp et al. 2013). Livestock exclusion has been successful as cattle (*Bos taurus)* seek riparian areas for a source of forage during summer months as most of the upland cool-season vegetation goes dormant (Vande Kamp et al. 2013). By removing grazing, soil compaction (Brooks et al. 2013; Magner et al. 2008) is reduced; whereas, water holding capacity and infiltration rates are increased (Severson and Boldt 1978). This change in soil function in return benefits the hydrophytic plants as they are adapted to hydric soil conditions (Dwire et al. 2006).

Grazing

Riparian areas attract livestock as they offer water, shade, thermal cover and high forage quality (Ames 1977; Reid and Pickford 1946; Severson and Boldt 1978), making them vulnerable to overutilization by livestock, particularly cattle (Fleischner 1994). Overuse is more of an issue in the summer months when there are warmer temperatures as C_3 upland species begin to senesce while riparian vegetation is maintained or gaining biomass (Vande Kamp et al. 2013). Livestock, particularly cattle, are also attracted to riparian areas as they are largely dependent on streams and water bodies to reduce their body temperature to avoid heat stress (McArthur and Clark 1988). When the riparian area is over utilized by livestock they have a deleterious effect as they can change plant composition and/or reduce, or eliminate the vegetation that borders the stream (Ames 1977; Behnke and Raleigh 1979; Belsky et al. 1999; Kolvalchik 1987; Platts 1979).

Livestock can trample the protective vegetation reducing the streambanks stability (Belsky et al. 1999; Meehan and Platts 1978) while compacting the soil (Kleinfelder et al. 1992; Winward 1994). When the vegetative canopy protection is removed from utilization the soil is exposed, and soil temperatures increase leading to higher evapotranspiration and reduced moisture content (Bremer et al. 1998; Burke et al. 1998; Savadogo et al. 2007; Severson and

Boldt 1978; Winward 1994). While the vegetation communities are being altered overhanging banks can begin to slump, eventually breaking off and get washed away by the stream (Duff 1979). Overutilization by cattle can then cause increased sedimentation, nutrient loading, and possible pathogen introduction into streams (Grudzinski et al. 2016; Schwarte et al. 2011a). As streambanks become further altered the stream may widen and/or incise as the vegetative community and soil degrade (Platts 1991; Rosgen and Silvey 1996).

Due to livestock exclusion not always being a feasible solution for land managers, changes in management has shown to be an effective solution. Development of off-stream water sources and salt placement can reduce the amount of time livestock spend in a riparian area and increase livestock gains (Miner et al. 1992; Porath et al. 2002; Stillings et al. 2003). Salt can be placed in locations within the paddock that are receiving little to no utilization as livestock are attracted to it (Williams 1954). Cross fencing and specialized grazing systems have also been developed to improve grazing distribution and improve riparian conditions (Kauffman and Krueger 1984). The grazing systems generally use a rotation scheme to move livestock from one paddock to the next throughout the growing season (Kauffman and Krueger 1984; Sampson 1913). Sovell et al. (2000) found rotational systems in the Midwest to offer benefits to stream restoration in comparison to season-long grazing. Haan et al. (2010) found reducing the number of stream crossings and implementing a rotational grazing system was effective at lowering sediment and phosphorus in loads in streams.

Hay Production

Perennial cover also allows grasslands to add carbon to the soil, but harvesting hay can prevent, or greatly reduce grasslands from acting as a carbon sink (Skinner 2008). When high amounts of litter and biomass are removed the temperature of the soil is increased and the soil moisture becomes reduced leading to an increase in the decomposition of soil organic matter (Bremer et al. 1998; Burke and Nol 1998; Savadogo et al. 2007). Mechanically harvested forage can significantly increase runoff and erosion (Alderfer and Robinson 1947; Converse et al. 1976; Gallagher et al. 1996; Gilley et al. 1996; Knoll and Hopkins 1959; Thomas et al. 1992; Van Doren et al. 1940; Young and Mutchler 1976), as the canopy cover is no longer sufficient, and during rain events raindrops can dislodge soil particles (Gardiner and Miller 2008; Hofmann and Ries 1991; Pearce et al. 1998; Speth 1994; Thurow et al. 1986) that eventually get deposited in surface pores and cracks by overland flow forming a seal that reduces infiltration (Brooks et al. 2013; Ela et al. 1992; Zemenchik et al. 1996). Rills, or small channels that form from overland flow, can then form during intense rainstorms and snowmelts as the soil is left vulnerable to overland flow (Converse et al. 1976; Hensler et al. 1970; Young and Mutchler 1976).

Crop Production

Crop production is essential for food stability; however, tillage practice used on land has great implications for soil stability. No-till, or reduced tillage has similar erosion rates of CRP (Gilley et al. 1997a; Gilley et al. 1997b). Whereas, conventional tillage can result in large amounts of soil loss (Gilley et al. 1997a; Gilley et al. 1997b; Johnston 2013), up to 200 times greater than grasslands (Browning 1973) during intense wind, precipitation, and snowmelt events (Blanco-Canqui et al. 2009; Browning 1973; Low 1972). Tillage destroys soil structure (Gilley et al. 1997b), decreases aggregate stability (Kasper et al. 2009; Low 1972), eliminates surface residue (Zheng et al. 2004), and depletes the soils organic carbon (Blanco-Canqui et al. 2010; Franzluebbers 2005; Gilley et al. 1997b; Peterson et al. 1998; Sherrod et al. 2003), which degrades the health of the soil (Pagliai et al. 2004).

The loss of soil is not only detrimental to crop yields (Pimentel et al. 1995) and soil stability (Low 1972; Speth 1994; Zheng et al. 2004). When high amounts of soil are eroded in the uplands the riparian area's filtration ability can be overwhelmed (Clary et al. 1996) allowing for the soil to be added to the sediment load of streams (Allan et al. 1997; Dissmeyer 2000). The increased sediment load has the potential to alter stream morphology, as the stream may be unable to transport the excess sediment (Bridge 2009; Byers et al. 2005; Church 2006; Fitch and Adams 1998; Rosgen and Silvey 1996; Schumm 2005; Stringham and Repp 2010). The increased sediment load and nutrient input also reduces water quality, reduce dissolved oxygen (Carpenter et al. 1998; Miltner 1998) degrading aquatic life, increases turbidity, and increases the risk of flooding (Group 1998).

Assessments and Monitoring

Interpreting Indicators of Rangeland Health

The IIRH protocol allows an investigator to evaluate ecological sites using qualitative assessments described by Pellant et al. (2005) to evaluate soil/site stability, hydrologic function, and biotic integrity at the ecological level. This protocol is effective at determining the state of a site; however, it is not used to identify and determine the cause of degradation (Pellant et al. 2005). IIRH utilizes 17 indicators that assess and determine the functional status of three attributes: 1) soil and site stability, 2) hydrologic function, and 3) biotic integrity (Table 1.1). IIRH is focused on assessing and evaluating the soil and vegetation condition of a site as its evaluation is based on ecological site concepts and expert knowledge of soil and vegetation in order to determine departures in accordance of the 17 indicators in comparison to a reference state of the site. Each of the 17 indicators is evaluated and scored on a scale of departures of none-to-slight, slight-to-moderate, moderate, moderate-to-extreme, and extreme-to-total. The three attributes are then rated in accordance with the indicators that influence them (Pellant et al. 2005). IIRH gives researchers insight on how an ecological site is functioning in relation to what is believed to be the site’s full potential (Carter et al. 2017; Toledo et al. 2016).

Table 1.1. Rangeland Health Indicators and Associated Attributes

Indicator	**Description**	**Soil & Site Stability**	**Hydrologic Function**	**Biotic Integrity**
1	Number and extent of rills	X	X	
2	Presence of water flow patterns	X	X	
3	Number and height of erosional pedestals or terracettes	X	X	
4	Bare ground	X	X	
5	Number of gullies and erosion associated with gullies	X	X	
6	Extent of wind scour, blowouts, and/or depositional areas	X		
7	Amount of litter movement	X		
8	Soil surface (top few mm) resistance to erosion	X	X	X
9	Soil surface structure and soil organic matter content	X	X	X
10	Effect of plant community composition and spatial distribution on infiltration and runoff		X	
11	Presence and thickness of compaction layer	X	X	X
12	Functional/structural groups			X
13	Amount of plant mortality and decadence			X
14	Average percent litter cover		X	X
15	Expected annual production			X
16	Potential invasive (including noxious) species (native and non-native)			X
17	Perennial plant reproductive capability			X

The 17 indicators allow researchers and land managers to observe changes within an ecological site that would not be expected from its reference condition. The indicators allow for monitoring of soil and site stability (rills, water flow patterns, terracettes, bare ground, gullies, wind-scourers, blowout, and or depositional areas, litter movement, soil surface resistance to erosion, soil surface loss or degradation, and compaction layer), hydrologic function (rills, water flow patterns, terracettes, gullies, bare ground, soil surface resistance to erosion, soil surface loss or degradation, relative infiltration and runoff based on vegetation, soil compaction, and litter amount), and plant community alterations (soil surface resistance to erosion, soil surface loss or degradation, compaction layer, relative infiltration and runoff based on vegetation, functional/structural groups, plant mortality and/or decadence, litter amount, annual biomass production, presence of invasive plants, and reproductive capabilities of perennial plants) (Pellant et al. 2005; Pyke et al. 2002).

Soil and Site Stability

Pellant et al. (2005) described soil and site stability as “the capacity of an area to limit redistribution and loss of soil resources by wind and water.” Based on this definition and its associated indicators the soil and site stability attribute is strongly related to erosional processes. The presence of rills, water flow patterns, pedestals and/or terracettes, increased amounts of bare ground, and blowouts can influence riparian areas through increased sediment loads from active erosion in the uplands (Hunter 1991). Presence of rills indicate small amounts of soil loss; whereas, the presence of a gully indicate large amounts of soil loss and low opportunity for the site to recover (DeBano and Schmidt 1989; Langdale et al. 1992; Pellant et al. 2005; Shainberg et al. 1992). Presence of water flow patterns on a site indicate past erosion and lack of vegetation establishment and cover (Pellant et al. 2005). Over time, or during an extreme precipitation event a water flow pattern on the landscape could transition into numerous rills or a gully (Gardiner and Miller 2008). The soil surface resistance to erosion is an important indicator as soils with high aggregate stability are less likely to be dispersed and eroded away (Gardiner and Miller

2008; Schaetzl and Anderson 2005). Soil surface loss or degradation has implications on the productivity of the site as a degraded A horizon will influence the biotic community of the site (Pimentel et al. 1995). The final indicator of the soil and site stability attribute is the compaction layer. The compaction layer has potential to increase soil erosion, runoff, and limit plant rooting depth (Pellant et al. 2005; Rosgen and Silvey 1996; Unger and Kaspar 1994).

Hydrologic Function

Pellant et al. (2005) described hydrologic function as “the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity when a reduction does occur.” Essentially, hydrologic function is the ability of an ecological site to handle snowmelt, precipitation, and runoff events without degradation occurring. The presence of rills, water flow patterns, and gullies indicate overland flow is occurring and becoming concentrated within natural drainage areas (DeBano and Schmidt 1989). This occurrence may be the result of reduced infiltration rates (Gardiner and Miller 2008); however, during high-intensity precipitation events the amount of rainfall can exceed the infiltration rate of the soil (Huggett 1975, 1976). The presence of pedestals and/or terracettes indicate that wind and water have eroded soil away from areas unprotected by vegetation or rocks (Anderson 1974). The interspaces of pedestals may function as a water flow pattern increasing erosion and potentially erasing evidence of pedestals as they are eroded away from their sides (Anderson 1974). The soil surface resistance to erosion is an important indicator as soils with high aggregate stability are less likely to be dispersed and eroded away (Gardiner and Miller 2008; Schaetzl and Anderson 2005). Areas of bare ground, particularly those with low aggregate stability, are susceptible to splash erosion (Printz et al. 2014; Thurow et al. 1986). Splash erosion has the potential to plug soil pores reducing infiltration and increasing overland flow which increases the opportunity of soil loss (Ela et al. 1992). Litter on the soil surface not only reduces the amount of bare ground (Pearce et al. 1998), but it also acts as a buffer holding water in place longer allowing for increased infiltration (Brooks et al. 2013; Naeth et al. 1991a). The presence of a compaction layer impedes vertical water movement forcing it to move laterally in the soil profile increasing flow in streams (Haigh and Sansom 1999).

Biotic Integrity

Pellant et al. (2005) described biotic integrity as "the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur." The biotic integrity of a site indicates its resilience to disturbance and its potential to recover. Soils covered by vegetation generally have increased aggregate stability, as the vegetation roots bind to soil particles and add organic matter to the soil (Brady and Weil 2002; Tufekcioglu et al. 1998). Soils with high aggregate stability require more energy to disperse soil particles making them resistant to erosion (Wischmeier and Mannering 1969). In situations where the A horizon is degraded or lost establishing vegetation becomes difficult as the A horizon has the highest amounts of nutrients and soil organic matter (Brady and Weil 2002; Follett and Reed 2010). The presence of a compaction layer, an area of high bulk density, at a site has the potential to impede root penetration of plants limiting which species may occur (Orr 1960; Unger and Kaspar 1994).

The functional/structural group indicator provides insight into what the historical plant composition was based on the morphology and dominance of the species present in the reference condition (Pellant et al. 2005; Tilman et al. 1997). When groups are removed or a change in dominance occurs the ecologic function of the site may be altered into comparison of the loss of one species (Estes et al. 2011; Tilman et al. 1997). Invasive species result in a loss of biodiversity (DeKeyser et al. 2009), functional structural groups (Tilman et al. 1997), and ecological services and functions (Estes et al. 2011) as they tend to form monocultures over time.

Annual production of an ecological site allows for interpreting if the site is producing at its potential (Pellant et al. 2005). Invasion by an introduced species, or a species composition change can alter the annual production of an ecological site (Pellant et al. 2005). Sites consisting of low diversity often times have reduced annual production when a year has unusual climate or the site is exposed to hail and/or fire as species adapted to the various disturbances may have been removed (Tilman and Downing 1994). For this reason, diverse plant communities can have higher biomass production as they may have positive interactions with each other, and the mixture of cool and warm season plants allows for the entire growing season to be utilized (Fornara and Tilman 2008).

The amount of litter can have various effects on the biotic integrity of an ecological site. Low amounts of litter may result in increased soil loss (Clary and Leininger 2000), higher soil temperatures (Bremer et al. 1998; Savadogo et al. 2007), and higher evaporation rates (Savadogo et al. 2007). High amounts of litter can increase infiltration rates (Brooks et al. 2013; Naeth et al. 1991a), harm warm season grasses (Printz et al. 2014), and give a competitive advantage to exotic species (Suding and Goldberg 1999). For this reason a moderate amount of litter may be ideal as it will not harm warm season plants or give advantages to undesirable species (Suding and Goldberg 1999), retain soil moisture (Naeth et al. 1991a), and improve plant vigor (Naeth et al. 1991b).

Plant mortality/decadence allows for management decisions based on the age class distribution and vigor of native perennial reproducing plant species (Pyke 1995). The reproductive capability of perennial plants is important for species dispersion and establishment of new age classes (Pellant et al. 2005; Pyke 1995). Investigation of perennial plant health and their reproductive capabilities give managers insight into how resilient an ecological site is to disturbances (Printz et al. 2014).

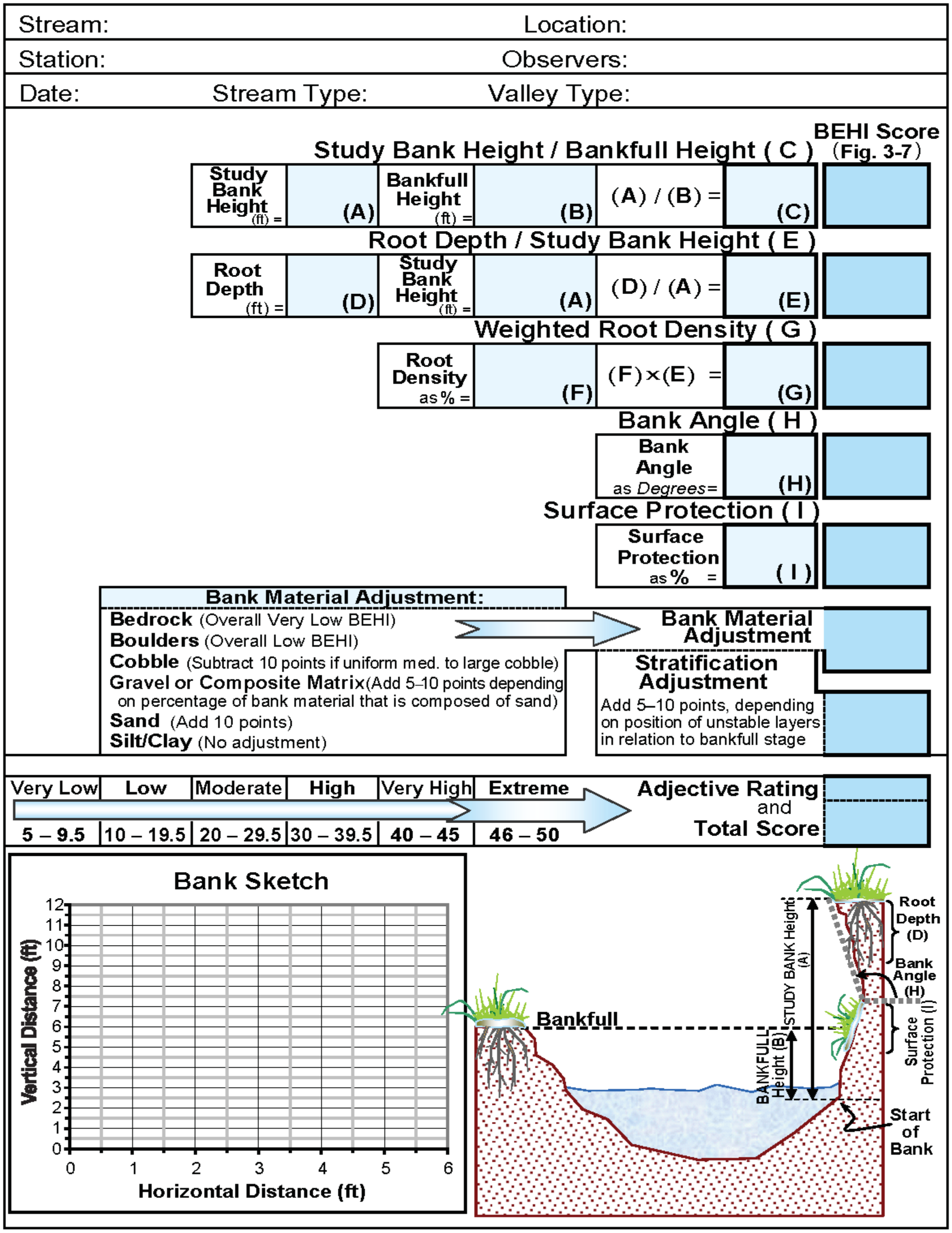
Riparian Assessments

Classification of Natural Rivers

Stream types can be determined using Rosgen's classification method (NRCS 2007; Rosgen 1985, 1994; Rosgen and Silvey 1996). Rosgen's classification methods involves assessing a cross-section, longitudinal profile, and planform features on each streams sampling site. Important features such as water's edge, bankfull discharge, floodplain edge, and terraces should be noted while recording elevations for accurate classifications. The longitudinal data is collected with a survey rod and laser level by determining the water's surface elevation at the cross-section, and a minimal of ten bankfull widths up and downstream of the cross-section (Rosgen 1994; Rosgen and Silvey 1996). The cross-sectional and profile data can be analyzed using software programs such as RiverMorph (RiverMorph 2011) or version 4.3L of the Reference Reach Spreadsheet (Mecklenburg 2006). This data is used to determine channel form, entrenchment ratio, width to depth ratio, and slope of the water's surface of the reaches surveyed. Channel sinuosity is determined using ArcMap by dividing the stream length of the meander by the valley length (Rosgen and Silvey 1996).

Bank Erosion Hazard Index

The bank erosion hazard index (BEHI) was developed by Rosgen (2001; 2006) to model the amount of sediment introduced from streambanks as a result of erosion. Rosgen's (2006) BEHI is useful for determining the susceptibility of erosion of a streambank by interpreting five variables associated with increased streambank erosion. BEHI evaluates seven erosional processes to determine the erosion risk or BEHI rating. The seven variables used to calculate the BEHI are 1) study bank height divided by bankfull height, 2) root depth divided by study bank height, 3) weighted root density, 4) Bank angle (measured in degrees), 5) surface protection (canopy cover), 6) bank material adjustment, and 7) stratification of bank material adjustment. The first five indicators are assessed by doing field measurements and finding the relationship on a graph to get their rating or score (Figures 1.1 and 1.2). The bank material adjustments can then increase or decrease the score depending on the dominant particle size of the bank. The seven scores are then added p to determine if the BEHI is rated very low (5-9.5), low (10-19.5), moderate (20-29.5), high (30-39.5) very high (40-45), or extreme (46-50) (Rosgen 2006).



Stream: Location:

Station: Observers:

Date: Stream Type: Valley Type:

BEHI Score (**Fig. 3-7**)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) = **(A)** **Bankfull Height** (ft) = **(B)** (A) / (B) = **(C)**

Root Depth / Study Bank Height (E)

Root Depth (ft) = **(D)** **Study Bank Height** (ft) = **(A)** (D) / (A) = **(E)**

Weighted Root Density (G)

Root Density as % = **(F)** (F)×(E) = **(G)**

Bank Angle (H)

Bank Angle as *Degrees*= **(H)**

Surface Protection (I)

Surface Protection as % = **(I)**

Bank Material Adjustment:

- **Bedrock** (Overall Very Low BEHI)
- **Boulders** (Overall Low BEHI)
- **Cobble** (Subtract 10 points if uniform med. to large cobble)
- **Gravel or Composite Matrix** (Add 5–10 points depending on percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt/Clay** (No adjustment)

Bank Material Adjustment

Stratification Adjustment

Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	**10 – 19.5**	**20 – 29.5**	**30 – 39.5**	**40 – 45**	**46 – 50**

Adjective Rating and **Total Score**

Bank Sketch

Figure 1.1. Bank Erosion Hazard Index (BEHI) Worksheet (1st page) (Rosgen 2006)

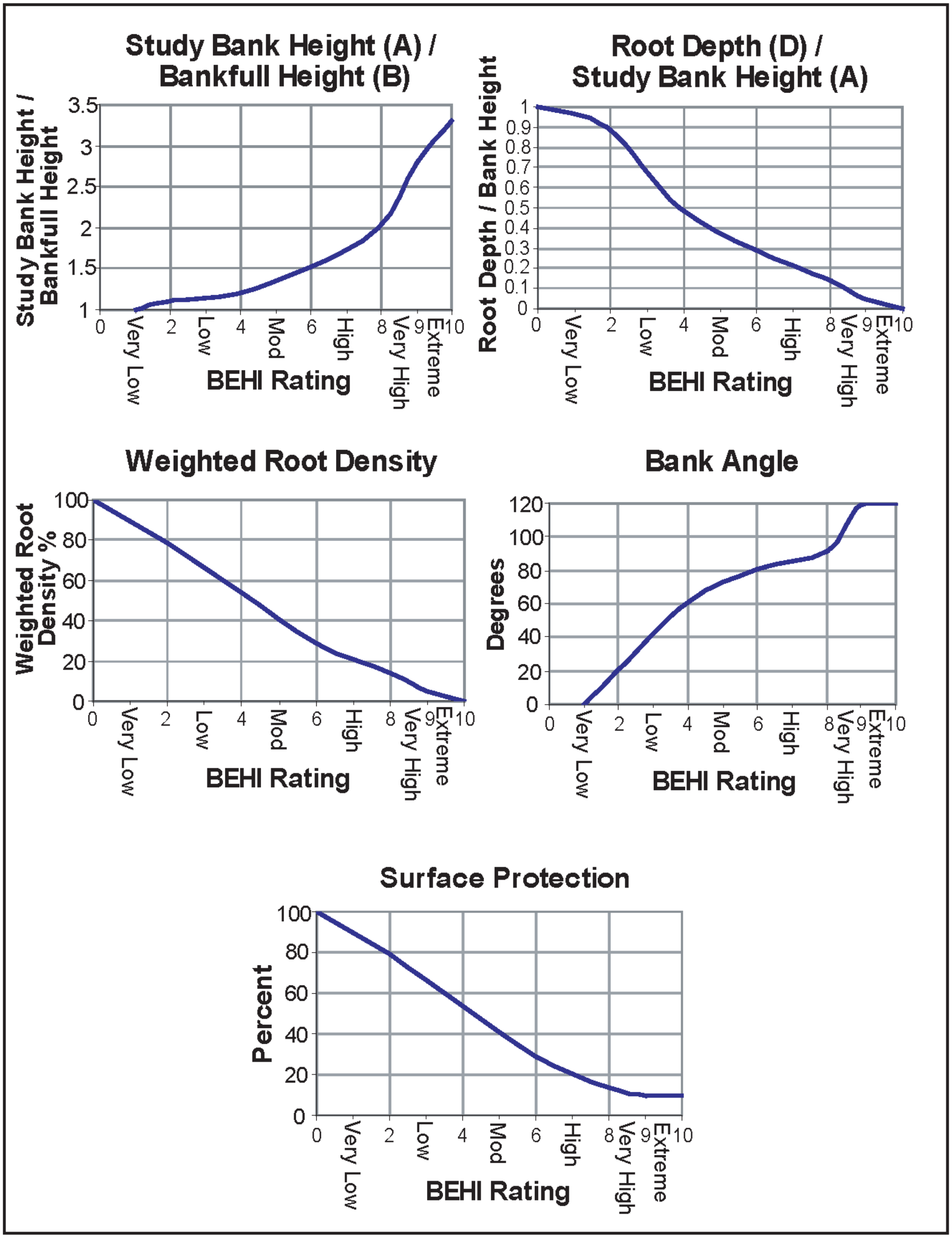


Figure 1.2. Bank Erosion Hazard Index (BEHI) Worksheet (2nd page) (Rosgen 2006)

Bank Height Ratio

Bank height ratio is a measurement used to determine the degree of incision, or the streams ability to access its floodplain (Rosgen 2006). The bank height ratio is found by the lowest bank height of the cross section divided by the maximum bankfull depth (Rosgen 2001). However, bank height ratio is not used for delineation criteria as it is similar to the entrenchment ratio. The bank height ratio is useful for determining the bank's stability as the ratios are categorized as stable (1.0), moderately unstable (1.1-1.3), unstable (1.3-1.5) and highly unstable (≥1.5).

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CHAPTER 2. PLANT COMMUNITY INFLUENCES ON INTERMITTENT STREAMBANK STABILITY

Abstract

The composition of the greenline plant community is linked to the stability of riparian ecosystems. Cool season exotic grasses are invading native plant communities across the northern Great Plains, potentially compromising streambank stability and increasing the risk of erosion within riparian ecosystems. To determine how the species composition of the greenline community impacts stream type and the risk of streambank erosion, thirty five reaches across five watersheds were sampled to determine the dominant greenline vegetation. At each reach sampled, a cross-section was conducted to determine stream type, greenline vegetation, and risk of streambank erosion. The stream types were delineated using Rosgen's classification of natural rivers. Canopy cover and composition was assessed using the line point intercept method along a 30.5 m transect in the greenline community. Plants recorded were grouped by their wetland indicator status for the central Great Plains. The Bank Erosion Hazard Index (BEHI) was used to assess the streams risk of erosion by calculating the difference between the bank height and bank full height, average plant rooting depth and density, bank angle degree, and the dominant texture of the bank material. Bank height ratio (BHR) was assessed as it is a measure of streambank stability and floodplain connectivity. A Nonmetric Multidimensional Scaling ordination was performed to analyze plant community influences. Analysis of the data determined that the most stable stream types (E and C channels), lower BEHI scores, and stable bank height ratios were associated with high amounts of litter and facultative wet species. In comparison, unstable F channels were associated with early successional species and bare ground. Sites with the higher BEHI scores were influenced by upland and facultative upland species and saline soils. Late

successional facultative wetland species therefore offer the most protection to intermittent streambanks.

Keywords: greenline, intermittent stream, riparian, plant species composition

Introduction

It is well documented that plants play a crucial role in the amount of soil erosion occurring on the landscape (Bilbro, 1991; Trimble, 1994; Unger and Vigil, 1998; Clary and Leininger, 2000; Butler *et al.*, 2006). Areas of reduced plant cover function differently than those with high amounts of cover; as plants influence nutrient cycling, infiltration, and soil retention (Rook and Tallowin, 2003; Printz *et al.*, 2014; Russell and Bisinger, 2015). For example, un-vegetated riparian areas have an increased risk of streambank failure due to absence of plant roots, which can lead to a large loss of soil (Marcuson, 1977; Meehan *et al.*, 1977; Beeson and Doyle, 1995). However, streambanks may also fail if the plant community occupying the banks are comprised of shallow rooted species, as their roots may not reach the boundary where water is eroding at the streambank (Petersen, 1986; Winward, 1994, 2000).

Within riparian areas plants that naturally occur in the greenline communities tend to have strong, deep roots that enhance bank stability (Winward, 2000). The greenline is the vegetation that occurs closest to the water's edge on a streambank. The deep rooting structure is important as streambanks naturally erode throughout the year at varying intensities based on local climate conditions (Hagerty *et al.*, 1981; Henderson, 1986; Medina, 1996). The greatest erosional force acting on streambanks occurs at their sides from flowing water in the stream channel where they have limited protection (Toledo and Kauffman, 2001). These characteristics of greenline vegetation maintain streambanks and buffer the erosive forces of flowing water (Winward, 2000).

Plants that naturally occur within greenline communities are hydrophytic, meaning they are usually found in areas of wet soil conditions. Two primary types of plants that occur within riparian areas are herbaceous and woody plants (Lyons *et al.*, 2000). Woody vegetation such as trees and shrubs are late successional plants in comparison to herbaceous vegetation that range from early to late successional species. Both woody and herbaceous vegetation have similar functions in riparian areas; however, the function of ones presence over the other can contrast (Lyons *et al.*, 2000). Historically in the Great Plains wooded riparian areas were uncommon as they are generally dominated by warm season grasses (Dodds *et al.*, 2004). While woody vegetation was documented to occur along some perennial streams in the Great Plains, it was rarely associated with headwater streams (Wiley *et al.*, 1990).

Herbaceous Vegetation

Herbaceous riparian vegetation enhances bank stability by portioning their roots throughout the soil profile. By portioning their roots these native herbaceous species form a sod near the surface while reaching deep into the soil profile supplying support to the stream bank up to a meter in depth (Wynn *et al*., 2004). In non-forested areas, herbaceous vegetation is able to thrive, as it is not shaded out by the forest canopy, reducing the amount of bare ground (White and Brynildson, 1967). When herbaceous vegetation is dominant, the low amount of bare ground reduces the risk of erosion on the top of the bank during floods (White and Brynildson, 1967). Herbaceous vegetation can be better at trapping sediments from overland flow than woody plants (Osborne and Kovacic, 1993; Castelle *et al.*, 1994; Parsons *et al.*, 1994), growing in dense communities that reduce the water’s energy allowing for the suspended sediment to settle out of the water and be deposited (Li and Shen, 1973; Hughes, 1997; Naiman and Decamps, 1997). It is recommended that managing for herbaceous vegetation on gentle sloping banks over woody vegetation, as herbaceous vegetation offers greater support for the bank surface (Davies-Colley, 1997; Trimble, 1997).

Plant Communities

Native greenline plant communities typically consist of obligate and facultative wetland species. Native greenline plant species most commonly found in the northern Great Plains include sedges (*Carex* spp.), rushes (*Juncus* spp.), spikerushes (*Eleocharis* spp.), bulrush (*Schonopelectus* spp.), and hydrophytic grasses such as prairie cordgrass (*Spartina pectinata* Bosc ex link) (Weaver, 1960; Micheli and Kirchner, 2002b; Ball *et al.*, 2003). These native plant species typically thrive in saturated to moist soils, preventing invasion from introduced species that are not adapted to anaerobic soil conditions (Blom and Voesenek, 1996). Maintenance of native greenline plant communities provides several ecological services such as nutrient filtration, sediment trapping, and flood damage reduction (Platts, 1979; Winward, 1994, 2000). Retaining native greenline plant communities dominated by hydric deep rooted plants helps ensure bank stability, avoiding mass wasting of soil (Platts, 1979; Winward, 1994, 2000).

The retention of native riparian species has been complicated as the northern Great Plains are currently undergoing an invasion as introduced cool season grasses are expanding at a high rate, reducing plant diversity (Sinkins and Otfinowski, 2012; DeKeyser *et al.*, 2013). With this transition, there is the potential to compromise streambank stability (Winward, 2000). The two primary species, Kentucky bluegrass (*Poa pratensis* L.) and smooth bromegrass (*Bromus inermis* L.), are wide spread across the northern Great Plains (Murphy and Grant, 2005; Travnicek *et al.*, 2005; Sinkins and Otfinowski, 2012; DeKeyser *et al.*, 2013; Toledo *et al.*, 2014). When these species are able to invade and replace native plants that occur within the greenline, many of the functions discussed previously are compromised as a result of differing rooting structures (Estes *et al.*, 2011).

These introduced species, particularly smooth bromegrass, are often used for seeding road ditches and other areas at risk of erosion (Huff and Bara, 1993). The introduction of introduced species puts native plant communities at risk of invasion, which could lead to streambank failure (Winward, 1994, 2000). The main ecological reason these competitive introduced grasses do not perform the same on streambanks as native greenline plant species is due to their shallow rooting structure (Winward, 1994). Both Kentucky bluegrass and smooth bromegrass grow the majority of their root mass in the top eight cm of the soil profile, becoming dense and sod forming (Uchytil, 1993; Howard, 1996). This shallow rooting depth compromises the toe slope, or the bottom, of the bank, leaving the soils unprotected and vulnerable to erosion (Wynn *et al.*, 2004). When the toe slope is unprotected, the force of the flowing water erodes away at the sides increasing the risk of bank failure and slumping (Kauffman and Krueger, 1984; Rosgen and Silvey, 1996; Wynn *et al.*, 2004).

It is recognized by many authors that hydrophytic plant species offer the most protection to perennial streambanks from water's erosive forces (Marcuson, 1977; Meehan *et al.*, 1977; Kleinfelder *et al.*, 1992; Hughes, 1997; Naiman and Decamps, 1997; Winward, 2000; Micheli and Kirchner, 2002b). However, little research has been conducted on intermittent streams within prairie systems (Matthews, 1988). Streams that exhibit intermittent stream flow typically have flow for only a portion of the year during the wet season. As the dry season progresses the water table lowers below the streambed and flow stops (Meinzer, 1923; Brooks *et al.*, 2013). The objective is this project was to determine what plant communities are best at supporting intermittent streambanks? We hypothesize that streams with greenline communities consisting deep-rooted obligate hydrophytic plants will be more stable and at a lower risk of bank erosion than streams with greenline communities consisting of shallow-rooted upland plants.

Materials and Methods

Watersheds and Soils

This study was conducted near the western boundary of the northern mixed grass prairie in southwest Bowman County, ND, USA (46° 3'45.08"N, 103°46'16.42"W). Five watersheds characterized by intermittent stream flow were assessed including: Spring, Skull, Horse, Sevenmile, and Fivemile Creeks (Figure 2.1). Each of these streams are found within Valley Type VIII, which are wide alluvial valleys that allow the streams space to meander (Rosgen and Silvey, 1996). These alluvial valleys formed from water erosion and deposition of soils derived from sandstone and limestone (Bluemle, 1980, 2000). Alfisols, Entisols, Inceptisols, and Mollisols (NRCS, 2006) are common soil orders in this region.

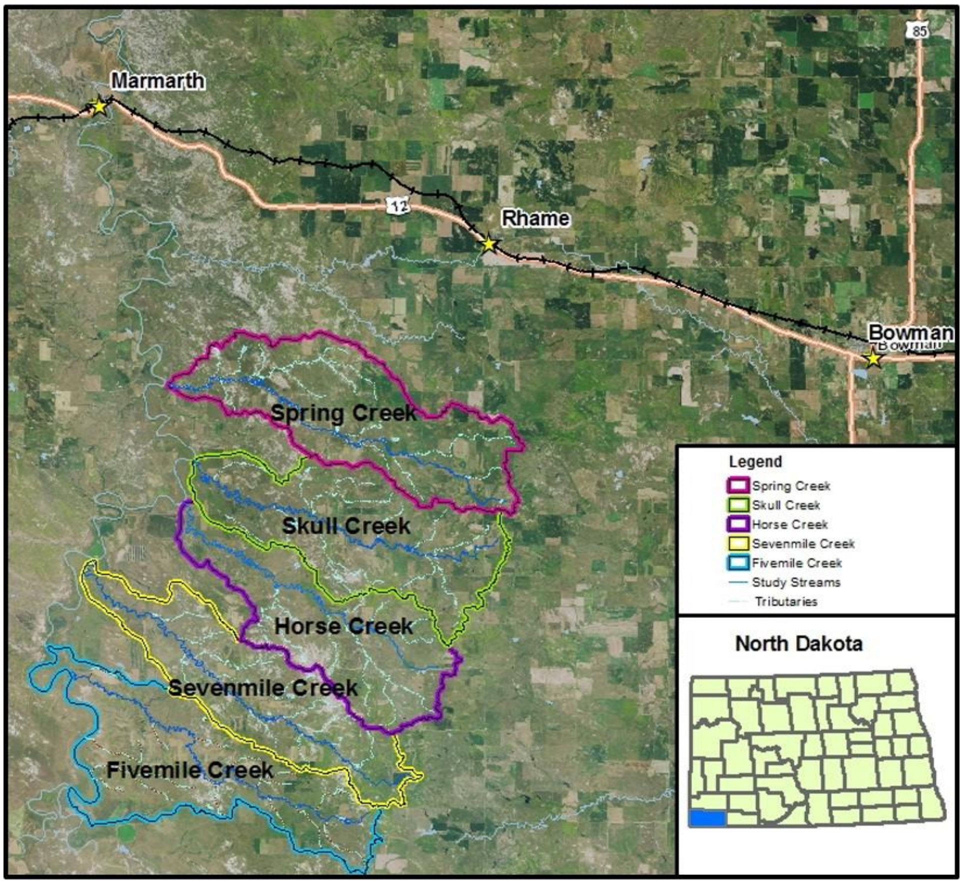

Figure 2.1. Study area and watershed locations in Bowman County, North Dakota.

The five watersheds contain 155 km of stream length with a cumulative drainage area of 390.5 hectares (USGS, 2014). Within the study area livestock production is the dominant land use, with perennial grasslands accounting for 65% of the cover (NRCS, 2006; USGS, 2010). Riparian areas within the study area comprise approximately 2.6 percent of the landscape (Table 2.1). Because the majority of the landscape has been retained in perennial cover, much of the native vegetation has been preserved. However, several introduced species such as Kentucky bluegrass, smooth bromegrass, and annual brome species (*Bromus arvensis* L. and *Bromus tectorum* L.) are common.

Table 2.1. Summary of land use of Bowman County, North Dakota within the study area derived from USGS Gap Analysis Program (USGS, 2010).

Watershed Land Use	**Total Acres**	**Percent**
Human Developed	567.55	0.59
Cropland	7623.98	7.92
Pasture/Hay	497.72	0.52
Open Water	250.01	0.26
Badlands/Barren	3949.34	4.10
Forest/Woodland	2132.98	2.22
Shrubland	14926.56	15.50
Grassland	63287.81	65.72
Disturbed-Introduced Vegetation	569.57	0.59
Disturbed, Other	10.50	0.01
Riparian/Wetland	2470.43	2.57
Total	**96296.45**	

Hydrologic Measurements

Prior to fieldwork, a watershed reconnaissance was conducted on each of the streams. The stream reconnaissance consisted of a complete foot survey to evaluate stream morphology, land use, dominant vegetation, and disturbances. These observations were recorded with a Trimble Geo 7X geographic positioning system (GPS). The gathered information was used to identify sampling locations across each watershed. A minimum of five sites were sampled per watershed using Rosgen's delineative criteria (Rosgen, 1985, 1994).

Rosgen's classification method was used to evaluate cross-section, longitudinal profile, and planform features at each sampling site (Rosgen, 1985, 1994). Streams were sampled at low flow in order to avoid false bankfull heights. Rosgen's classification system takes into account channel dimensions such as entrenchment ratio, width to depth ratio, sinuosity, slope, and channel material (Rosgen, 1985, 1994). Each site sampled consisted of a complete meander in order to determine the longitudinal profile and planform patterns. Longitudinal data such as water's slope was determined using a survey rod and laser level. Channel sinuosity was determined using ArcMap by dividing the stream length of the meander by the valley length. The cross-section profile data was obtained by using a laser level and survey rod for determining channel elevations. The data collected was input into Mecklenburg's (2006) version 4.3L of the Reference Reach Spreadsheet to determine channel type.

The bank erosion hazard index (BEHI) was used to determine the risk of bank erosion at each cross-section (Rosgen, 2006). This method was conducted on the streambank most susceptible to erosion. For example, the streambank on the outside of the curve would be sampled because it is exposed to faster flowing water. Eight variables were collected for the BEHI as described by Rosgen (2006). These variables are then used to evaluate five metrics that help explain erosional processes. The metrics are 1) ratio of bank height to bankfull height, 2) ratio of root depth to bank height, 3) root density percent, 4) bank angle degree, and 5) percent surface protection. The scores of the erosional processes are added up resulting in a BEHI score. The score ranges are very low (5-9.5), low (10-19.5), moderate (20-29.5), high (30-39.5) very high (40-45), or extreme (46-50) (Rosgen, 2006).

Bank height ratio (BHR) was assessed to determine the floodplain connectivity and stability of the channel. BHR was determined by assessing the degree of channel incision by dividing the lowest bank height by the maximum bankfull depth (Rosgen, 2001; Rosgen, 2006). BHR is considered an important value in regards to stream condition as it is used to determine if a stream is going to change from a stable state to an unstable state (Meehan *et al.*, 2016). BHR ratios of 1.0-1.05 are considered stable, 1.06-1.30 are moderately unstable, 1.31-1.50 are unstable, and ratios greater than 1.51 are highly unstable (Rosgen, 2001; Rosgen, 2006).

Vegetative Measurements

Vegetation attributes of greenline plant communities was determined using the line point intercept method (LPI). LPI was used to determine species composition, vertical and basal cover by plant species, and quantify bare ground and litter amounts (Coulloudon *et al.*, 1999; Herrick *et al.*, 2005). LPI was collected along a 30.5 meter transect using the protocol described by Herrick *et al*. (2005) and placed parallel to the stream within the greenline plant community. A pin flag was dropped at one hundred evenly spaced locations along the transect and any plant that intercepted or made contact with the pin recorded. Hits on the soil surface were recorded as plant species, rock, litter, organic litter, moss, lichen, or soil to determine basal cover. Plant species were then grouped by their wetland indicator status, as defined by Reed (1988) and Lichvar (2012). Reed (1988) developed five categories: 1) obligate (OBL), 2) facultative wetland (FACW), 3) facultative (FAC), facultative upland (FACU), 5) upland (UPL) in attempt to use plants to recognize hydric soils. OBL species are found in hydric soils 99 percent of the time (Reed, 1988; Lichvar *et al.*, 2012). FACW species are found in wetlands approximately 67-99 percent of the time. FAC species are found in wetlands 34-66 percent of the time. FACU species are found in hydric soils 1-33 percent of the time, and UPL species are found in hydric soils less than one percent of the time (Reed, 1988; Lichvar *et al.*, 2012).

An additional grouping was created for plant species known to thrive in saline soils in attempt to interpret if salinity had an impact on streambank stability (Ungar, 1974). Worcester and Seelig (1976) found that use of known halophytes could be used to find saline seeps in North Dakota. Seelig (2000) stated that species such as inland saltgrass (*Distichlis spicata* (L.) Greene), alkali cordgrass (*Spartina gracilis* Trin.), and Nuttall’s alkali grass (*Puccinellia nuttalliana* (Schult.) Hitchc.) can be used as indicators of high saline soils.

Statistical Analysis

The PC-ORD ® (version 6.0) multivariate statistical software program was used to conduct a Nonmetric Multidimensional Scaling (NMS) ordination (McCune *et al.*, 2002; Peck, 2010) to interpret plant community effects on hydrologic measurements. The NMS was performed using the Sorenson (Bray-Curtis) distance measure. Final solutions met these conditions were sought: 1) stress less than 10 (based on Clark's rules of thumb), 2) a randomization test of $P \leq 0.05$, 3) dimensions that reduce stress more by at least 5, and 4) final instability (less than 0.0001) (Clarke, 1993; McCune *et al.*, 2002). Variable groups possessing a Pearson correlation coefficient (r) of 0.40 (absolute value) or greater with the selected dimensions were deemed interpretable (McCune *et al.*, 2002).

Permutation MANOVA (PERMANOVA) analysis was used to test for a difference between groups using the Sorenson (Bray-Curtis) distance measure ($P \leq 0.05$) (Anderson *et al.*, 2008). Groupings tested included channel type, BEHI, and BHR. PERMANOVA was chosen as it is a multivariate test and it does not need to meet linear assumptions (Anderson *et al.*, 2008). A pairwise comparison test was conducted in order to determine similar and dissimilar groups (Biondini *et al.*, 1988; Anderson *et al.*, 2008). No adjustments were made to the pairwise P values, such as the Bonferroni adjustment (McArdle and Anderson, 2001; Moran, 2003). The PERMANOVA analysis was done using PRIMER version 7 software with the PERMANOVA + add-on (Anderson *et al.*, 2008).

Pearson correlation coefficients were calculated between wetland indicator cover and these factors: entrenchment ratio (ER), BEHI, and BHR. The entrenchment ratio acts as a substitute continuous measurement for the Rosgen's stream classification where high values are associated with stability and low values are considered unstable (Rosgen, 1985, 1994).

Results

Hydrologic Measurements

Thirty-five stream reaches were sampled across the study area. These stream reaches were diverse ranging from near reference E channels to actively eroding F and G channels. Of the 35 cross-sections sampled, 14 E channels, seven C channels, nine B channels, three F channels, and two G channels were documented. The average entrenchment ratio was 5.93 for E channels, 5.26 for C channels, 1.73 for B channels, 1.23 for F channels, and 1.15 for G channels.

The bank assessments had similar results as the BEHI resulted in four very low, 11 low, 13 moderate, six high, and one very high rating. High streambank height and bank angle degrees supplemented with low surface protection and sandy bank material was responsible for the majority of the high risk BEHI scores. Bank height ratios of the cross sections resulted in eight stable, eight moderately unstable streambanks, six unstable, and 13 highly unstable streambanks. Sites with unstable stream channels and high/very high BEHI ratings also had highly unstable BHR. Four E channels and four B channels were also considered highly unstable.

Vegetation Measurements

Sixty-three different plant species were documented within the greenline communities associated with the 35 reaches (Appendix A). Hydrophytes, OBL and FACW species (Tiner, 1991) were the most abundant species within the greenline plant communities on all sites but one. Of the 63 species, the most common were woolly sedge (*Carex pellita* Muhl. ex Willd.), common spikerush (*Eleocharis palustris* (L.) Roem. & Schult. var. *palustris*), common threesquare (*Schoenoplectus pungens* (Vahl) Palla), alkali cordgrass, and prairie cordgrass (Table 2.2). The primary FACW species were prairie cordgrass and alkali cordgrass; whereas, common threesquare and common spikerush were the most common OBL species on the study.

Table 2.2 Important plant species and cover. The cover provided was determined from 35 sites where a line point intersect transect consisting of 100 points was conducted.

Common Name	Scientific Name	Native or Introduced	Average Cover (%)	Cover Range (%)
Litter	-	-	49	1-93
Bare Ground	-	-	4	0-22
Smooth Bromegrass	*Bromus inermis*	Introduced	4	0-36
Wooly Sedge	*Carex pellita*	Native	11	0-55
Inland saltgrass	*Distichlis spicata*	Native	1	0-19
Common Spike Rush	*Eleocharis palustris*	Native	19	0-75
Kentucky Bluegrass	*Poa pratensis*	Introduced	3	0-25
Common Threesquare	*Schoenoplectus pungens*	Native	35	0-99
Alkali Cordgrass	*Spartina gracilis*	Native	12	0-98
Prairie Cordgrass	*Spartina pectinata*	Native	41	0-100

Invasion from introduced species was minimal within the greenline as only 5 sites had 20% or more of exotic species present at the time of the study. FACW and OBL species were the most common on all stream channels as they accounted for 45% and 40% of canopy cover respectively. FACW species were the most abundant on E, B, and G channels. OBL wet species were the most common on C and F channels. G channels had the most FACU and UPL species. F and G channels had higher amounts of bare ground (4-6%) in comparison to the other stream channels (<3%). Saline tolerant vegetation was most abundant on F channels, accounting for 22% of the canopy cover. Common saline species were inland saltgrass, alkali cordgrass, and Nuttall's alkali grass.

Facultative upland species, saline soils, and bare ground had weak relationships with low ER; whereas, obligate species and high litter amounts had weak relationships with high ER (Table 2.3). Facultative wet species and litter were moderately and strongly correlated with low BEHI values; whereas, bare ground and upland species were moderately and weakly associated with high BEHI values, respectively. BHR had a weak negative relationship with facultative wet species and litter, and moderate relationship with bare ground.

Table 2.3. Pearson correlation coefficients between wetland indicator cover and Entrenchment Ratio (ER), Bank Erosion Hazard Index (BEHI), and Bank Height Ratio (BHR).

	Category		
Wetland Indicator	ER	BEHI	BHR
Facultative Wet	0.16	-0.50	-0.27
Obligate	0.27	-0.01	-0.09
Facultative	-0.15	0.04	0.15
Facultative Upland	-0.26	0.19	0.09
Upland	-0.13	0.27	0.07
Saline Soil	-0.20	0.13	-0.01
Bare Ground	-0.35	0.40	0.51
Litter	0.34	-0.62	-0.25

NMS analysis of the greenline produced a final solution with three dimensions and a final stress of 9.9, which indicates a good ordination with minimal risk of being falsely interpreted (Clarke, 1993). The final solution had a final instabilities of <0.0001. Together axis one and two accounted for 72% of the variation (axis one was 43% and axis two was 29%) within the dataset (Figures 2.2, 2.4, and 2.6). Axis three accounted for 19% of the variation (Figures 2.3, 2.5, and 2.7).

The indicator group that was positively correlated with axis one was FACW species and high amounts of litter (Figures 2.2, 2.4, and 2.6). The indicator group negatively correlated with axis one was OBL species and bare ground. Saline tolerant plant communities were positively related to axis two; whereas, the following parameters were negatively related to axis two: FACU species, UPL species, and litter. Axis three was positively correlated with bare ground and negatively associated with OBL species and litter (Figures 2.3, 2.5, and 2.7).

Channel Type

When interpreting the ordinations, Figure 2.2 shows that most of the E and C channel sites are associated with high amounts of litter and FACW species. F channels were characterized by a combination of saline tolerant species as well as OBL species, and increased amounts of bare ground. One of the two G channels was associated with FACU, UPL, and OBL species; whereas, the other G channel was located near the center of the graph as it was not associated with low or large values of the different factors. Low entrenchment ratios were positively associated with channels that had high amounts of bare ground (Table 2.3). High entrenchment ratios were characterized by a mixture of FACW species and OBL species (Table 2.3).

The PERMANOVA analysis showed that an overall test of stream channel types was at P = 0.09 level, but when comparing the pairwise tests it was determined that C and B channels differed (P = 0.04). These differences can be seen in the ordination figures (Figures 2.2 and 2.3) where C and B channels have minimal overlap.

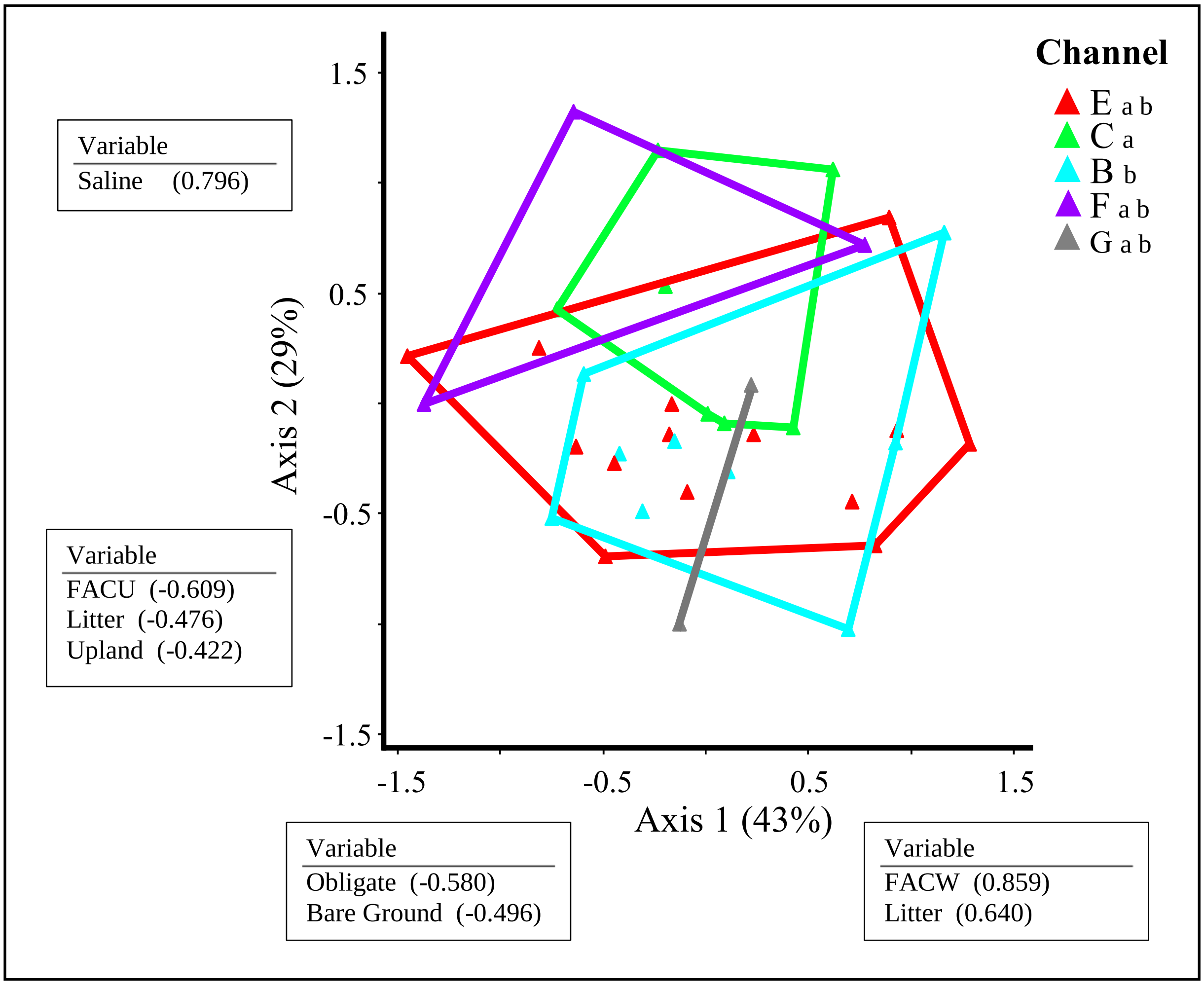

Figure 2.2. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline sites, litter, and bare ground's relationship with Rosgen's stream classification on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) stream classification system. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between channel types is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are consired significantly different from each other. The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 72% of the variation. This ordination has a low risk of false interpretation.

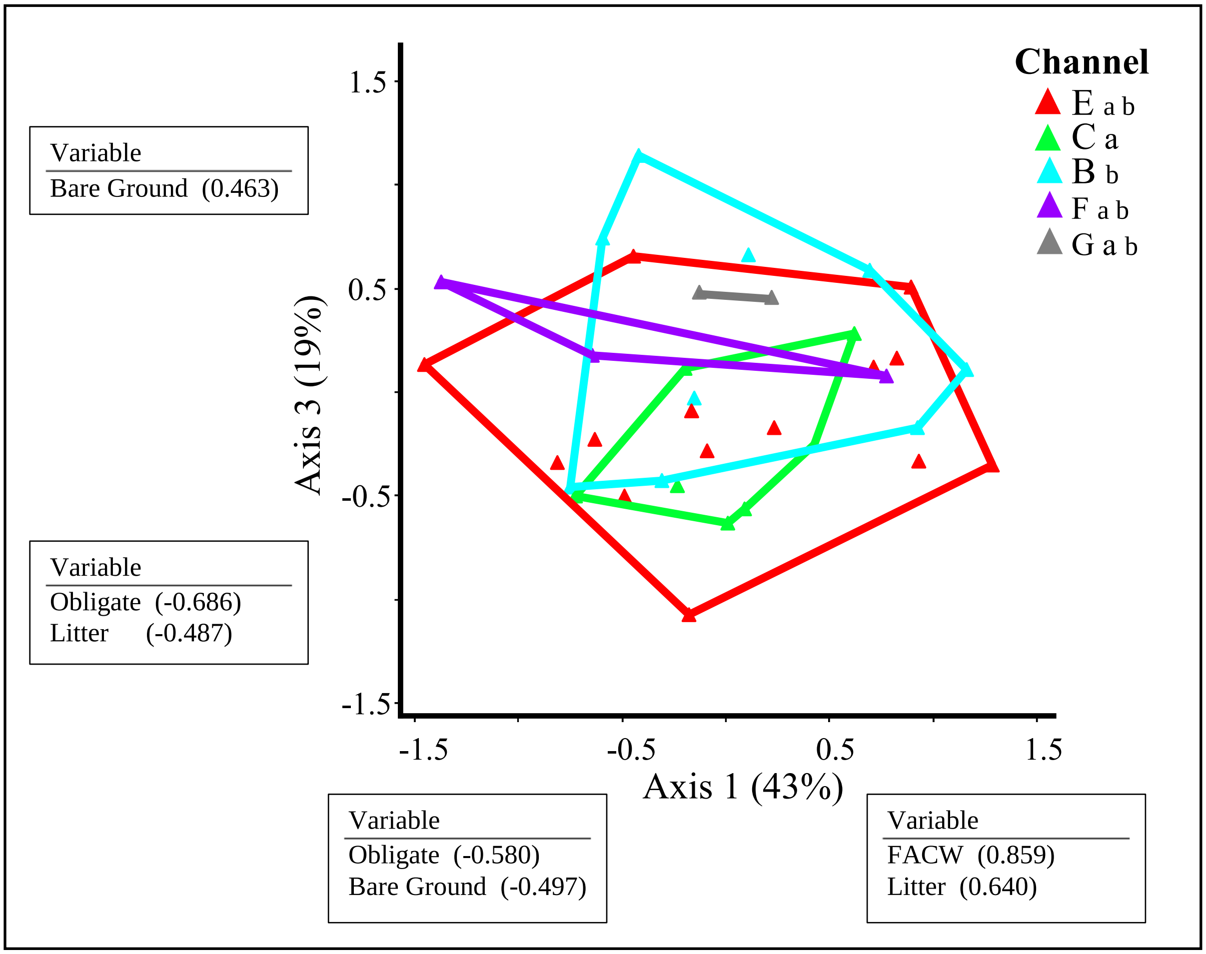

Figure 2.3. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline tolerant plants, litter, and bare ground's relationship with Rosgen's stream classification on axis 1 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) stream classification system. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between channel types is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other.The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 62% of the variation. This ordination has a low risk of false interpretation.

BEHI

Very low risk streambanks were associated with FACW species, high amounts of litter, and located in the middle of axis 2 (Figure 2.4), showing they did not have many saline or UPL plants. The low scoring streams had a similar relationship except for some influence by saline plant communities. Very low and low BEHI sites were negatively correlated with high amounts of FACW species and high litter amounts (Table 2.3). Stream banks with high and very high BEHI scores were associated with plant communities comprised of high amounts of FACU and UPL species as well as bare ground and saline plant communities (Table 2.3).

The PERMANOVA analysis showed that the BEHI groupings were not significantly different (P = 0.12). Results from a pairwise test determined that very low and high/very high risk streambanks differed (P = 0.006), as well as low risk streambanks and high/very high banks (P = 0.014). This can be seen in the figures 2.4 and 2.5 very low and low were associated with the positive end of axis 1 and had little overlap with the high/very high BEHI that were located at the negative end of the axis.

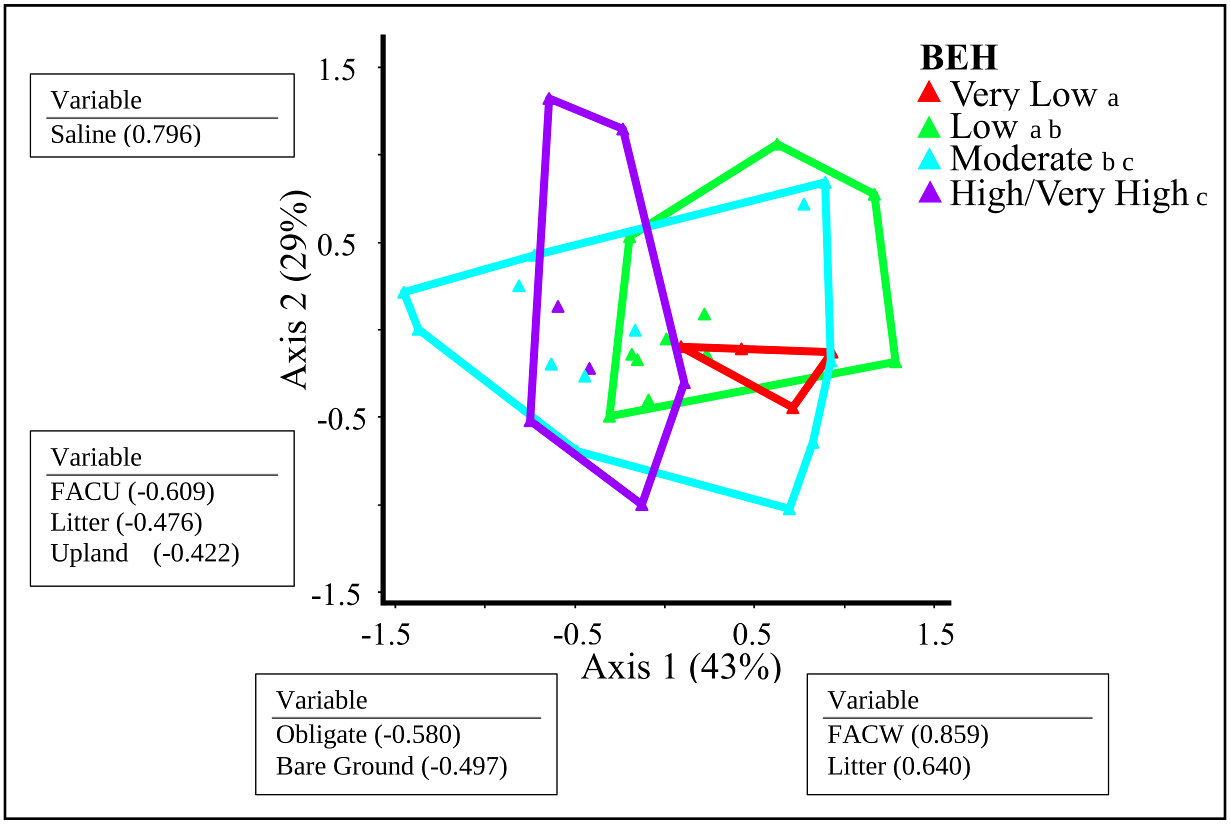

Figure 2.4. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline tolerant plants, litter, and bare ground's relationship with the bank erosion hazard index (BEHI) on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between BEHI categories is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 72% of the variation. This ordination has a low risk of false interpretation.

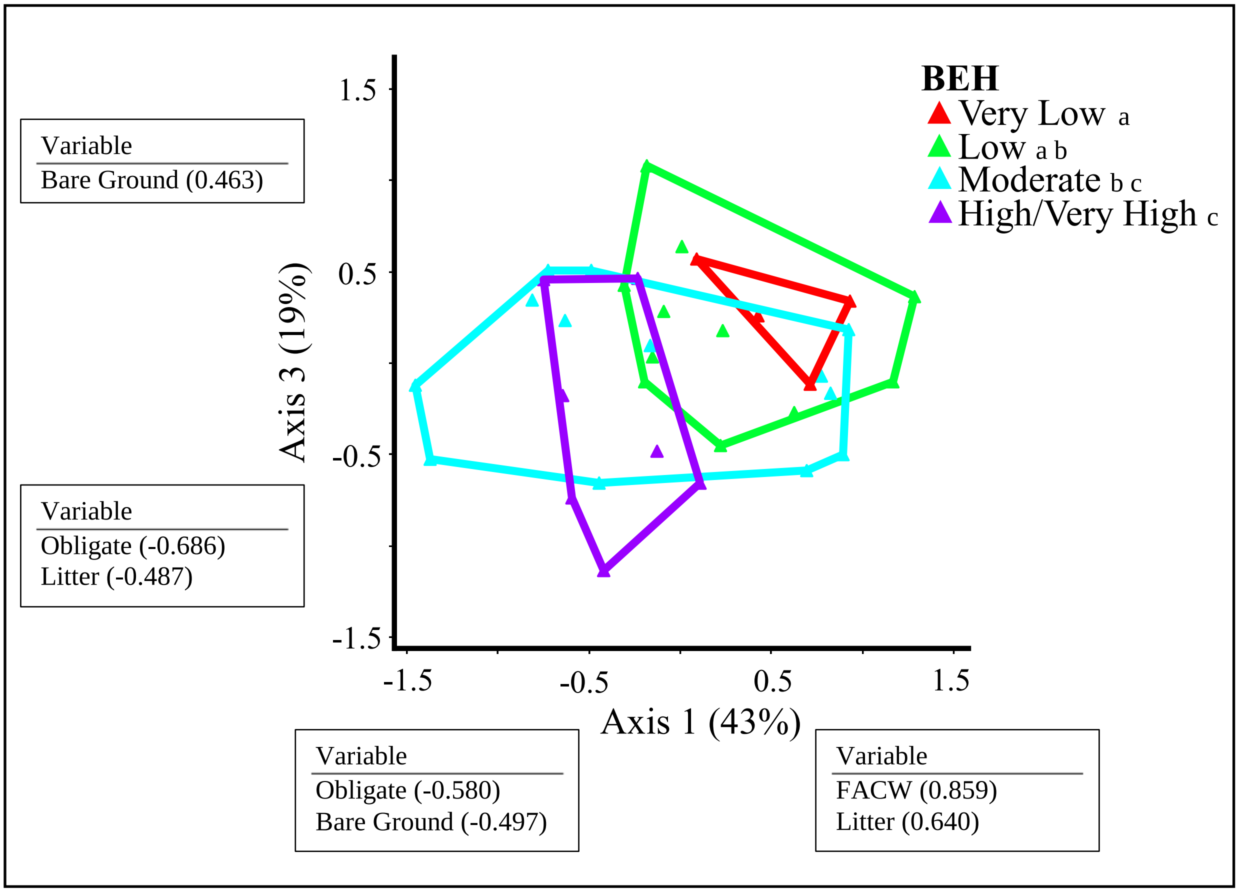

Figure 2.5. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline tolerant plants, litter, and bare ground's relationship with the bank erosion hazard index (BEHI) on axis 1 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between BEHI categories is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 62% of the variation. This ordination has a low risk of false interpretation.

BHR

When interpreting Figure 2.6, stable streambanks are weakly influenced by FACW species, litter, and OBL species. Unstable streambanks were influenced by OBL species and bare ground. The unstable and highly unstable streambanks trended towards greenlines with UPL and FACU species presence, and bare ground. Figure 2.7 shows a stronger relationship in regards to stable streambanks being influenced by OBL species. Unstable and highly unstable stream banks were positively correlated with high amounts of bare ground; whereas, low BHR were correlated with FACW and litter (Table 2.3).

PERMANOVA analysis indicated that BHR was not significantly influenced (P = 0.15) by wetland indicator categories. Results from a pairwise test determined that stable and highly unstable streambanks differed (P = 0.02).

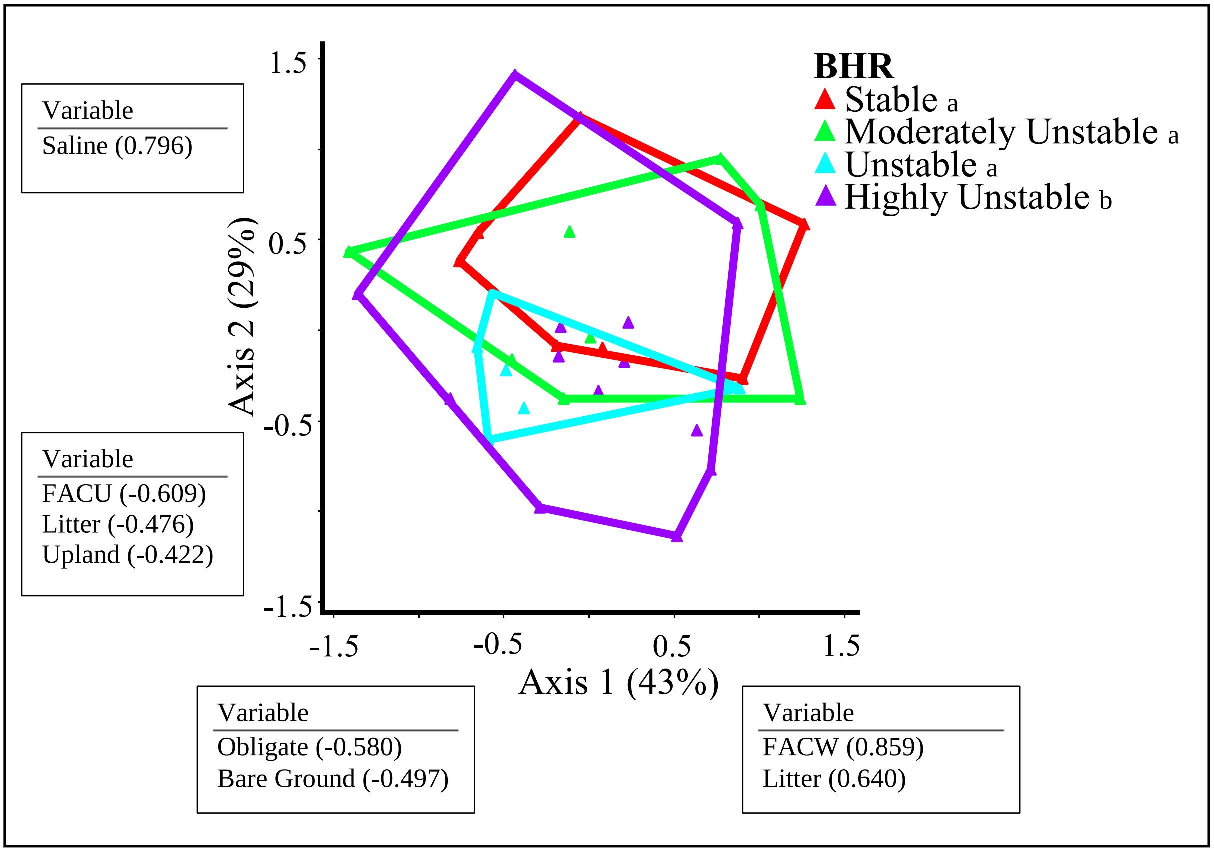

Figure 2.6. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline tolerant plants, litter, and bare ground's relationship with the bank height ratio (BHR) on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between BHR categories is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 72% of the variation. This ordination has a low risk of false interpretation.

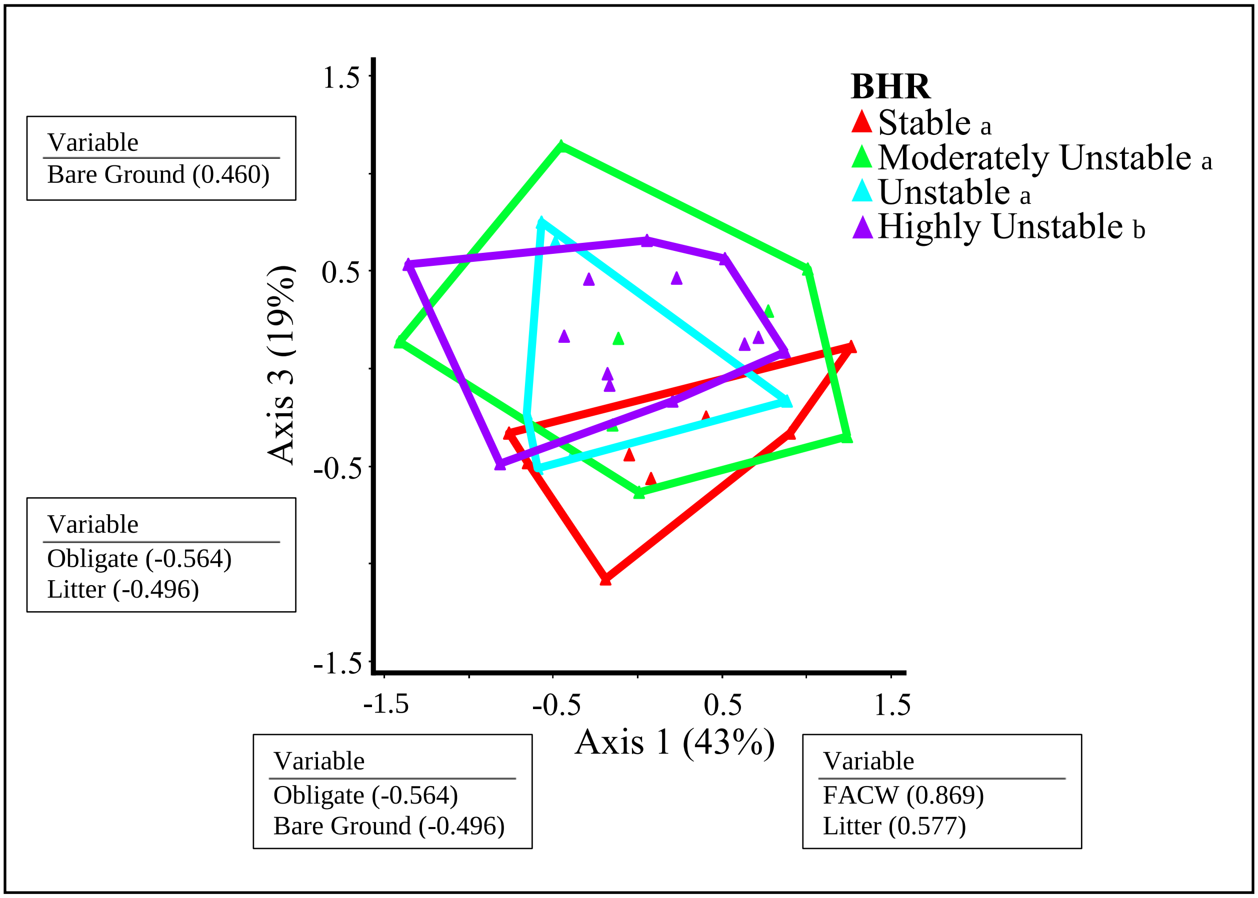

Figure 2.7. Non-metric multidimensional scaling ordination (NMS) displaying wetland indicator categories, saline tolerant plants, litter, and bare ground's relationship with the bank height ratio (BHR) on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The wetland indicator abbreviations are FACU (facultative upland) and FACW (facultative wetland). The correlation coefficient is stated behind the wetland indicator variable. Significant differences ($P < 0.05$) between BHR categories is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. The ordination had a final stress of 9.96 for a 3-dimensional solution and explained 62% of the variation. This ordination has a low risk of false interpretation.

Discussion

Our findings showed that FACW plant communities offer the greatest protection to intermittent streams. Sites with high amounts of FACW species generally had lower BEHI scores and lower BHR values. FACW plants can thrive when the soil is inundated and survive when flow has ceased (Lichvar *et al.*, 2012; Brooks *et al.*, 2013), common attributes of intermittent streams. Sites that were dominated by FACW species, in particular prairie cordgrass (56% of

FACW canopy cover), belonged to more stable stream reaches and were at a lower risk of erosion. Vande Kamp *et al.* (2013) conducted a study on a South Dakota stream where they also found prairie cordgrass was a common late successional species colonizing streambanks that were stabilizing. Prairie cordgrass is an efficient species for stabilizing intermittent streambanks as it is tolerant to a variety of different soil characteristics and moisture regimes (Weaver, 1960; Stubbendieck *et al.*, 1992).

We found OBL species to be associated with a mixture of stable and unstable stream channel types. F channel and high/very high BEHI reaches were associated with the abundance of common threesquare and higher bare ground. Deep rooted OBL plants are typically associated with increased streambank stability (Micheli and Kirchner, 2002a); however, OBL plants may stop growing or senesce during the dry season, leaving the soil susceptible to erosion during precipitation events (Capon, 2003; Stromberg *et al.*, 2005). Furthermore, during times of drought OBL species will have reduced vigor potentially decreasing their root strength until moisture patterns return to their favor (Chaves *et al.*, 2002; Vivian *et al.*, 2014). Bulrushes may not enhance streambanks in the same way true rushes (*Juncus* spp.), as they are not as well adapted to environments with flowing water (Larson, 1993; Micheli and Kirchner, 2002b).

We found communities with a combination of FACW species and OBL species were associated with stable stream channel types, very low and low BEHI, and stable BHRs. The mixture of OBL and FACW species were associated with stable stream reaches as these hydrophytic species rooting structures can promote streambank stability and the diversity allows for resilience to varying soil moistures (Capon, 2003). This combination of vegetation also supplies more protection to the toe slopes of streambanks as some *Schoenoplectus* spp. and *Eleocharis* spp. are emergent, allowing them to colonize parts of the bank that are otherwise unvegetated while the FACW species colonize the higher portions of streambanks (Larson, 1993; Abernethy and Rutherfurd, 2001). Dwire *et al.* (2006) found that areas which are flooded for short periods of time are often composed of a mixture of OBL and FACW species. Our findings reflect a similar species composition as FACW species were dominant while OBL species were common within the greenlines of the stable intermittent stream reaches sampled.

Stream reaches sampled that were incised (F and G channels) were correlated with FACU and UPL species. When a stream incises a lowering of the water table occurs (Daniels *et al.*, 1971; Winward, 1994; Rosgen, 1997). A change in water table depth results in hydraulic disconnectivity as the FACW and OBL species can no longer reach the water table resulting in a plant community shift (Schumm *et al.*, 1984; Winward, 2000; Chambers *et al.*, 2004; Rosgen, 2006; Stringham and Repp, 2010). While most plant communities on incised streams had an increase in abundance of FACU and UPL species, one of the G channels greenlines was dominated by FACU species.

Sites that had FACU and UPL species in their greenline were associated with G channels and channels with high/very high BEHI scores. This pattern was also consistent with the BHR as most of the highly unstable banks were composed of FACU and UPL species. These results are similar to Micheli and Kirchner's (2002a) findings that streambanks comprised of dry meadow species can be up to ten times more likely to fail than streambanks with hydric species. High BHR and a greenline comprised of shallow rooting species can lead to rapid erosion of streambanks as their roots are unlikely to reach depths enabling them to buffer flowing water's energy (Petersen, 1986; Medina, 1996).

Within the sites of high UPL and FACW species composition, nine sites had greenline plant communities, which were invaded by Kentucky bluegrass (≤ 25%; FACU) and smooth bromegrass (≤ 36%; UPL). This invasion aided in the high BEHI scores as a result of shallow rooting structure (Uchytil, 1993; Howard, 1996). Due to their roots being unable to reach the water boundary on the streambank, they offer minimal to no protection from streambank erosion (Petersen, 1986; Winward, 2000). Although both grasses were uncommon within the greenlines sampled, their presence could lead to future streambank instability as they are highly competitive with native plant species (Martin and Chambers, 2001; Toledo *et al.*, 2014). This poses a potential management conflict as leaving riparian areas idle has been shown to restore hydric vegetation (Kauffman *et al*., 1995); however, both smooth bromegrass and Kentucky bluegrass thrive in idle management (Grant *et al*., 2009).

Reaches of decreased canopy protection were associated with unstable F and G stream channels and high BEHI ratings (Beeson and Doyle, 1995). Our study showed areas with high amounts of bare ground were strongly correlated with G channels. This relationship of bare ground and associated “gully” channel may be the product of a lack of riparian vegetation and increased runoff (DeBano and Schmidt, 1989; Clary *et al.*, 1996). With low amounts of vegetation, rain events are able to facilitate splash erosion destroying soil aggregates on the surface (Pearce *et al.*, 1998). The dislodged soil particles are then subject to be eroded away by sheet flow, increasing the nutrient and sediment load of the stream (Butler *et al.*, 2006) and eventually forming water flow patterns such as rills and gullies (Gardiner and Miller, 2008). Micheli and Kirchner (2002b) found a linear relationship between root density and bank stability. As the amount of root mass decreases in the soil there is a reduction in shear strength of the bank as well as decreased organic matter inputs reducing the aggregate stability of the soil.

Our results showed a relationship with OBL species, bare ground, and saline plant communities being associated with F channels and high risk BEHI ratings. Part of this relationship may likely be the result of common threesquare; a single stemmed plant, early successional OBL species that provides low canopy cover (Jefferson, 1974). Nuttall's alkali grass roots typically reach a depth of 25 cm (NRCS, 2017); however, in entrenched stream channels much deeper rooting depths are required for bank stabilization. Alkali cordgrass and inland saltgrass, FACW species, typically have rooting lengths greater than 70 cm (Cooke *et al.*, 1993) enabling them to stabilize low banks. However, as a result of the saline conditions, the soil has reduced aggregate stability in these reaches putting them at higher risk of erosion (Mamedov *et al.*, 2002).

Due to a low number of F and G channels observed more data should be collected in the future to increase the strength of the statistical results. However, F and G channels are sensitive to management in the Great Plains and as a result they are more transient making it difficult to make observations on the conditions in which they exist resulting in a low sample size (Rosgen and Silvey 1996). We observed a wide spread of site plotting in the ordinations within groups. This spread indicates that certain groups can be influenced by opposite ends of the relationships of the parameters tested and still exist.

As predicted with the hypothesis, the streambanks consisting of shallow rooted upland vegetation were at a greater risk of eroding. Greenlines consisting of upland vegetation were also more likely to be associated with an unstable channel type (Winward, 2000; Micheli and Kirchner, 2002b). Plant species whose rooting systems are unable to reach deeper portions of the streambank provide minimal protection from the stress of flowing water in the streambank. As a result, large amounts of soil can be lost enabling stream morphology changes (Micheli and Kirchner, 2002a).

Conclusion

Our findings indicate that greenline composition based on wetland indicator status can aid in determining the stability of a stream reach. This is confirmed as the Rosgen stream classification and bank erosion hazard index had similar results in regards to plant composition and stability. FACW plant communities offered the greatest protection to intermittent streambanks as they can tolerate periods of low and high soil moisture. Conversely, greenlines composed of upland species and/or areas with patches of bare ground are at a higher risk of increased bank erosion and having an unstable stream channel.

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CHAPTER 3: WATERSHED ASSESSMENT: EVALUATING THE RELATIONSHIP BETWEEN RANGELAND HEALTH AND INTERMITTENT STREAM STABILITY

Abstract

It is widely recognized that riparian health is inherently linked to watershed condition and the health of the adjacent ecological sites. Land management has the potential to impact riparian stability as different uses may alter the ecological function(s) of ecological sites. To assess the relationship between the health of upland ecological sites and stream stability (stream type and risk of streambank erosion), thirty-five reaches across five watersheds were sampled in Bowman County, ND. The major land use in the study area is grassland as livestock production is the primary use. The stream types were classified using Rosgen's classification of natural rivers which separates stream channels based on their dimensions. The Bank Erosion Hazard Index (BEHI) was used to determine streambank's risk of erosion. Bank Height Ratio (BHR) was used to assess the risk of streambank failure. The 17 Indicators of Rangeland Health (IIRH) protocol was used to assess the ecological sites associated with each reach. IIRH evaluates the ecological functions of an ecological site by using 17 indicators to measure departure of soil and site stability, hydrologic function, and biotic integrity from the reference state. A Nonmetric Multidimensional Scaling ordination was performed to analyze the data. Analysis indicated that IIRH had the strongest relationship with BEHI and BHR. Streams with greater instability and high risk of erosion, F and G stream and those with a high BEHI ratings, were correlated with soils with increased compaction and decreased aggregate stability. Reaches with greater stability, E and C streams with low BEHI and BHR ratings, were associated with increased amounts of

litter and minimal IIRH departure. Based on these findings IIRH can be useful tool to determine if a stream reach is at risk of transiting to an unstable state.

Keywords: Rangeland Health, Intermittent Stream, Land Use, Riparian, Watershed Management

Introduction

The ecological function of the upland plant community has an impact on riparian stability. Past research; however, has found varying results within stream reaches of the same watershed under similar upland management indicating differences in plant communities (Shandas and Alberti 2009). Currently there is no method available to assess the relationship an upland plant community, and its associated management, has on the riparian community (Shandas and Alberti 2009). Rivers and streams are influenced and controlled by their catchment and valley; specifically, the valley regulates channel migration, slope, and provides the longitudinal profile for the stream (Dunne and Leopold 1978; Montgomery and MacDonald 2002; Rosgen 1994). However, research connecting the ecological status of the upland to stream condition at the catchment scale has been difficult to quantify. Recently, intensive agricultural watersheds have been investigated to determine the effects on water chemistry and biology of the streams (Jarvie et al. 2002; Meynendonckx et al. 2006; Roberts et al. 2007; Tong and Chen 2002). The majority of this research has focused solely on management within riparian areas (Batchelor et al. 2015; Gregory et al. 1991; Haan et al. 2010; Magner et al. 2008; Miner et al. 1992; Stillings et al. 2003; Vande Kamp et al. 2013). There has been little work conducted at a landscape scale on how upland management influences stream morphology (Allan 2004; Clary et al. 2000; Covino 2017; Sheppard et al. 2017; Wiens 2002).

Fluvial landscapes are complex as they are influenced by climate, geology, vegetation patterns, watershed area, and land use (Hagerty et al. 1981; Hooke 1980; Kovalchik and

Chitwood 1990; Rosgen and Silvey 1996). These landscapes have formed over geologic time from wind and water erosion constructing drainage patterns (Kovalchik and Chitwood 1990). Within the drainage pattern of a stream different features such as flood plains and terraces may be observed (Gregory et al. 1991). Geomorphology plays a critical role in upland function as it dictates soil characteristics and vegetation found within both riparian and upland ecological sites (Rosgen and Silvey 1996; Stringham and Repp 2010).

Riparian ecological sites are a function of hydrology compared to upland ecological sites which are a function of soil and geomorphology (Stringham and Repp 2010). State and transition models (STM) for riparian ecological sites are influenced by hydrological connectivity and fluvial surfaces. Plant species occur in different plant community bands based on water requirements (Stringham and Repp 2010; Winward 2000). A riparian ecological site may be altered by hydrological events, such as floods, that create bank failure or incision (Rosgen 2006). As a stream changes its morphology the water table adjusts, forcing the plant community components to change position within the riparian complex (Stringham and Repp 2010). Similar to upland ecological sites, riparian sites are influenced by land management practices, influencing plant composition and hydrology (Stringham and Repp 2010).

Uplands can, and often do, contain a complex of ecological sites, each with their own physical characteristics, creating a mosaic pattern across the landscape (Wiens 2002). The functions of each ecological site are based on the soil and plant community conditions, which in return influences local hydrology (Stringham et al. 2003). Upland ecological sites functioning near reference condition should have minimal soil erosion and high water infiltration rates during precipitation events in relation to the same ecological site in a degraded state (NRCS 2017). Therefore, the state of an upland ecological has potential to influence the state of riparian ecological sites found within the landscape. Upland sites in a degraded or altered state can be subject to increased overland flow and soil loss (Stringham et al. 2003).

Upland ecological sites that are not functioning properly can have negative impacts on the functions of adjacent ecological sites. Improperly functioning uplands suffer from altered hydrology and soil loss erosion (Pellant et al. 2005). In situations where overland flow is common due to low infiltration rates, soil can be lost through the formation of rills and gullies (DeBano and Schmidt 1989). As time progresses under a degraded state, soil stability will decrease as the A horizon is depleted leading to increased erosion rates (Brady and Weil 2002; Follett and Reed 2010). Portions of the landscape that are actively eroding are subject to splash erosion as they are unprotected by vegetation allowing sediment to be moved towards the stream by overland flow. Overland flow is one of the main contributors to stream sediment loads on landscapes suffering from rill and raindrop splash erosion (Leopold 1994). Increased flow resulting from runoff adds stress and increases erosion of streambanks (Magner and Steffen 2000; Rosgen and Silvey 1996). The high sediment load as a result of upland erosion and streambank failure can alter the morphology of a stream as the sediment transport capacity is overwhelmed allowing for channel widening and point bar formation (Howard and Knutson 1984; Poff 2002; Simon and Hupp 1986).

Water has several fates when it reaches the soil surface during precipitation or snowmelt events. Water will either move as runoff or infiltrate the soil surface. Overland flow and rill erosion can occur depending on the intensity of the precipitation event and surface slope (Gardiner and Miller 2008). Rill erosion may cause gully formation over time, resulting in mass soil loss (DeBano and Schmidt 1989). When water infiltrates the soil there is a lower risk of erosion during high magnitude stormflow events (Clary et al. 2000). The infiltration rate of soil is influenced by slope, vegetation, soil moisture content, water holding capacity, soil texture, shrink-swell clays, connectivity and size of soil pores, and soil organic matter (Bagarello et al. 2004; Brooks et al. 2013; Chowdary et al. 2006; Schaetzl and Anderson 2005). During precipitation events, areas with large amounts of bare ground tend to have low infiltration rates as splash erosion plugs soil pores with dislodged soil particles (Ela et al. 1992).

Vegetation plays a large role in watershed catchments in both upland and riparian areas. Vegetation protects and stabilizing soils (Clary and Leininger 2000). Vegetative structure and litter provide canopy cover and protect the soil surface from splash erosion (Pearce et al. 1998). Plant roots stabilize soil by binding to soil particles, preventing wind and water erosion. Perennial herbaceous vegetation is particularly effective at preventing soil erosion due to the high density of fine and very fine roots (Tufekcioglu et al. 1998). Exudates from plant roots add organic matter to the soil increasing the aggregate stability, infiltration rates, and water-holding capacity of the soil (Tufekcioglu et al. 1998). When soil organic matter is increased more energy is required to disperse soil particles (Wischmeier and Mannering 1969).

We cannot alter the geomorphology of a watershed (valley type), but land management decisions can impact stream morphology. Retention of diverse plant communities helps ensure hydrologic regulation (Gerla 2007; McLaughlin and Walsh 1998), water filtration (Duchemin and Hogue 2009), and decreased runoff and erosion (Power 2010). When plant communities are invaded by exotic species ecosystem services and functions can be lost or diminished, such as hydrologic regulation resulting in more runoff (Estes et al. 2011). Areas of the landscape that are altered from perennial to annual vegetation, such as row crop or small grain production, suffer from high amounts of soil erosion and overland flow (Johnston 2013; Zaimes et al. 2004). By changing the landscape from perennial vegetation to one dominated by annual vegetation the hydrology can be altered, increasing peak flows of streams (Villarini et al. 2011). Flood control is reduced (Group 1998; Knox 2001) and sediment loads of streams increased (Brooks et al. 2013; David et al. 2009) with this type of extreme vegetation change. If the sediment load is too high the stream can lose its equilibrium, resulting in a change of stream channel type (Schumm 1977).

Quantifying the effects uplands can have on the catchment conditions at the watershed scale is complex. There are many variables to consider when assessing the upland ecological site from soil conditions, slope, vegetation, and different land use practices. The task of addressing all of these variables becomes problematic when collecting data, as access to all areas within a watershed may be difficult. Additionally, researchers rarely have knowledge of watershed function before humans modified the hydrology of the landscape. These situations make it difficult to assess the effects upland degradation has on riparian systems and stream morphology (Clary et al. 2000). The use of ecological sites STMs gives researchers an idea of the reference state condition of uplands and riparian ecological sites (Stringham et al. 2003; Stringham and Repp 2010; Westoby et al. 1989).

Pellant et al. (2005) developed a protocol (Interpreting Indicators of Rangeland Health) to standardize comparisons of current ecological states to the reference condition. The Interpreting Indicators of Rangeland Health Protocol (IIRH) gives researches and land managers a tool to determine how far an ecological site's functions has departed from its potential (Carter et al. 2017; Toledo et al. 2016). Upland degradation has the potential to influence a stream's morphology (Clary et al. 2000). Healthy soils and plant communities in the uplands increase infiltration and decrease overland flow (Pyke et al. 2002). High overland flow results in more water traveling through the stream channel at higher velocities, leading to channel entrenchment and widening (Poff 2002; Rosgen and Silvey 1996).

Ecologists recognize watershed land use influences riparian areas, but anthropogenic effects at the landscape scale are poorly understood (Allan et al. 1997). However, Allan et al. (1997) concluded best plan management at a local scale may provide benefits. For this reason we conducted a study assessing the relationships between stream state and condition of upland ecological sites. There were two primary objectives: 1) evaluate the relationship between the current state of the stream and the condition of the adjacent upland ecological site(s), and 2) determine if the IIRH Protocol can be used to assess riparian and watershed health (Pellant et al. 2005). We hypothesized that stable streams will be positively correlated to sites that have low departures of the 17 indicators of rangeland health from their reference state.

Methods

Site Description

This study was conducted near the transitional zone of the shortgrass and mixed grass prairie in southwest Bowman County, ND, USA (46° 3'45.08"N, 103°46'16.42"W). Five watersheds characterized by intermittent stream flow were assessed including: Spring, Skull, Horse, Sevenmile, and Fivemile Creeks (Figure 3.1). Within each watershed there are multiple drainage patterns that connect to the central stream valley. The stream valleys of southwestern North Dakota are well developed and formed by wind and water erosion of surface bedrock (Bluemle 2000). These well-developed valleys are characteristic of Rosgen’s Valley Type VIII which tend to contain “E”, “C”, “F”, and “G” Channels (Rosgen and Silvey 1996). Valley Type VIII is characterized as leaving adequate space for streams to meander within their alluvial valley. The valleys in this region formed in alluvium from the processes of water eroding sand and limestone (Bluemle 1980, 2000).

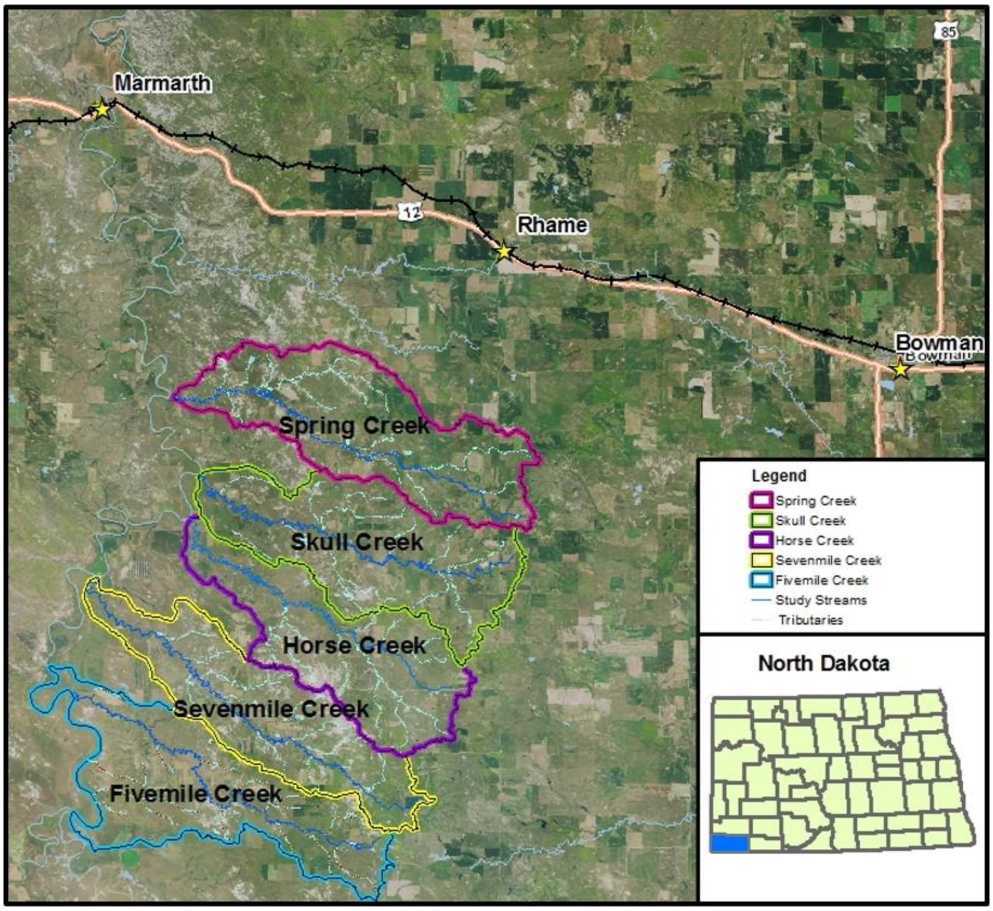

Figure 3.1. Study area and watershed locations in Bowman County, North Dakota. This study area lies adjacent to the Montana and South Dakota borders.

This study area lies within three Major Land Resource Areas (MLRA) including MLRA54, MLRA 58C, and MLRA 58D (NRCS 2006). The vegetation is characteristic of mixed grass prairie species within all three MLRAs. MLRA 54, the rolling soft shale plain, receives 355 to 455 mm of precipitation per year. The topography within MLRA 54 varies from rolling hills and buttes to badlands. Soils typically are loamy or clayey and found within the Mollisols and Entisols soil orders. MLRA 58C makes up the smallest component within the study area. MLRA 58C, northern rolling high plains, receives 355-430 ml of precipitation and characterized by badland topography. Loamy soils belonging to Entisols, Inceptisols, and Mollisols soil orders are common. MLRA 58D, northern rolling high plains, makes up the largest portion of the study area. MLRA 58D receives 355 to 430 ml of precipitation per year. MLRA 58D is generally flat with rolling hills and occasional buttes. The mixed minerology of MLRA 58D typically consists of loamy or clayey textures belonging to Alfisols, Entisols, Inceptisols, and Mollisol orders (NRCS 2006).

The watersheds in the region account for 155 km of stream length and a total drainage area of 390.5 hectares (USGS 2014). Agriculture, particularly livestock production, is the dominant land use with 65% of the area in perennial grasslands (NRCS 2006; USGS 2010). Riparian areas within the study area account for approximately 2.6% of the landscape (Table 3.1). Rangeland is the dominate land type, with native vegetation common. Nevertheless, several introduced species including crested wheatgrass (*Agropyron cristatum* L.), (Kentucky bluegrass (*Poa pratensis Leyss.*), smooth bromegrass (*Bromus inermis Leyss.*), annual brome grasses (*Bromus arvensis* L. and *Bromus tectorum* L.), Canada thistle (*Cirsium arvense* L.), and leafy spurge (*Euphorbia esula* L.) are common.

Table 3.1. Summary of land use within the study area located in Bowman County, North Dakota. Derived from USGS Gap Analysis Program (USGS 2010).

Watershed Land Use	**Total Acres**	**Percent**
Human Developed	567.55	0.59
Cropland	7623.98	7.92
Pasture/Hay	497.72	0.52
Open Water	250.01	0.26
Badlands/Barren	3949.34	4.10
Forest/Woodland	2132.98	2.22
Shrubland	14926.56	15.50
Grassland	63287.81	65.72
Disturbed-Introduced Vegetation	569.57	0.59
Disturbed, Other	10.50	0.01
Riparian/Wetland	2470.43	2.57
Total	**96296.45**	

Hydrologic Measurements

A watershed reconnaissance was conducted on each stream using a complete foot survey before sampling. Recorded during the reconnaissance period was stream morphology, land use, upland vegetation, and disturbances on the landscape. Observations were recorded with a Trimble Geo 7X geographic positioning system (GPS). The reconnaissance information was used to select sampling sites that represented different management units within each watershed. A minimum of five sites were sampled within each watershed using Rosgen's delineative criteria (Rosgen 1985, 1994).

Rosgen's classification of natural streams required the evaluation of a cross-section, longitudinal profile, and planform features (Rosgen 1985, 1994). Stream sampling was conducted during low flow as a preventive measure of recording false bankfull heights. Stream features recorded include entrenchment ratio, width to depth ratio, sinuosity, slope, bank height ratio (BHR) and channel materials (Rosgen 1985, 1994). Each site sampled consisted of a complete meander in order to describe the longitudinal profile and planform patterns.

Longitudinal data included water’s slope, which was determined using a laser level and survey rod. Channel sinuosity was determined using ArcMap and dividing the stream length of a full meander by the valley length. Cross-section data was obtained using a laser level and survey rod to determine channel elevations. Data was entered into version 4.3L of the Reference Reach Spreadsheet to determine stream channel types (Mecklenburg 2006).

The bank erosion hazard index (BEHI) was used to determine the risk of bank erosion at each cross section (Rosgen 2006). Streams banks that were at greatest risk of failure or rapid erosion, such as the outside of the curve, were evaluated. The BEHI uses eight quantitative and qualitative variables described by Rosgen (2006). The variables were used to evaluate five metrics that influence the susceptibility of the bank to erosion. The metrics are 1) ratio of bank height to bankfull height, 2) ratio of root depth to bank height, 3) root density %, 4) bank angle degree, and 5) % surface protection. The scores of the erosional processes were totaled to create a BEHI score. The score ranges are very low (5-9.5), low (10-19.5), moderate (20-29.5), high (30-39.5) very high (40-45), or extreme (46-50; Rosgen 2006).

The BHR was calculated for each site to determine floodplain connectivity and stability of the stream channel. BHR is calculated by dividing the low bank height by the bankfull discharge height (Rosgen 2006). A BHR of 1-1.05 indicates a stable channel with good connectivity to its floodplain, 1.06-1.30 is considered moderately unstable as the stream is somewhat incised, 1.31-1.50 is unstable as the river is incised, and > 1.51 is highly unstable as the stream channel is incised and the stream has lost access to its floodplain (Rosgen 2001b).

Rangeland Health Assessment

Uplands were assessed using the Interpreting Indicators of Rangeland Health (IIRH) protocol (Pellant et al. 2005). Rangeland health assessments were conducted on the dominant ecological site(s) adjacent to the stream sampling points. The IIRH protocol uses qualitative assessments to evaluate soil/site stability, hydrologic function, and biotic integrity. The IIRH protocol uses 17 different indicators to evaluate the soil and vegetation conditions to determine if the ecological site has departed from its reference state. Ecological site reference sheets were obtained from the NRCS Field Office Technical Guide for each MLRA (NRCS 2017). As recommended in the IIRH protocol, a team was assembled consisting of a soil scientist and range ecologists to ensure consistency (Pellant et al. 2005).

Statistical Analysis

The PC-ORD ® (version 6.0) multivariate statistical software program was used to conduct a Nonmetric Multidimensional Scaling (NMS) ordination (McCune et al. 2002; Peck 2010) to interpret plant community effects on hydrologic measurements. The NMS was performed using the Relative Euclidean distance measure. The Relative Euclidean distance measure was chosen as it eliminates differences in total abundance and standardizes the data (McCune et al. 2002). Indicators pertaining to each attribute were analyzed independently. Final solutions meeting these conditions were sought: 1) stress less than 10 (based on Clark's rules of thumb), 2) a randomization test of $P \leq 0.05$, 3) dimensions that reduce stress more by at least 5, and 4) final instability (less than 0.0001) (Clarke 1993; McCune et al. 2002). Indicators and attributes possessing a Pearson correlation coefficient (r) of 0.40 (absolute value) or greater were selected for discussion (McCune et al. 2002).

Permutation MANOVA (PERMANOVA) analysis was used to test for a difference between groups in ordination space using Relative Euclidean distance measure ($P \leq 0.05$) (Anderson et al. 2008). PERMANOVA allows for assessment of ecological processes and multivariate data that does not always meet linear assumptions (Anderson et al. 2008). Each attribute and its associated indicators were analyzed with stream channel type, BEHI rating, and BHR rating. A pairwise test was conducted to determine which groups were similar and dissimilar (Biondini et al. 1988; Anderson et al. 2008). No adjustments were made to the pairwise P values, such as the Bonferroni adjustment (McArdle and Anderson 2001; Moran 2003). The PERMANOVA analysis was done using PRIMER version 7 software with the PERMANOVA + add-on (Anderson et al. 2008).

Results

Hydrologic Measurements

Thirty-five stream reaches were evaluated during the duration of the study. The sampled stream reaches' states varied as near reference E and C channels, degraded F and G channels, transitional B channels and confined E channels were all present. There was a total of 14 E channels, seven C channels, nine B channels, three F channels, and two G channels documented. The average entrenchment ratio was 5.93 for E channels, 5.2 for C channels, 1.73 for B channels, 1.23 for F channels, and 1.15 for G channels.

Rosgen's classification of natural streams resulted in a low number of F (three channels) and G (two channels) channels, reducing the statistical strength of our analysis. Due to the low sample size the ordinations may show exaggerated relationships. However, as a result of multiple ecological sites per unstable stream channel there were five F and five G channels tested. Based on the results we observed a lot of spread between groups indicating that stable and unstable stream characteristics can have similar IIRH scores. For this reason, caution is recommended when interpreting "outliers," or sites located away from the majority of the groupings in ordinal space.

The BEHI resulted in four very low, 11 low, 13 moderate, six high, and one very high rating. Due to low a low sample size the high and very high sites were grouped together as high/very high for analysis. Bank height ratios of the cross sections resulted in eight stable, eight moderately unstable, six unstable and 13 highly unstable streambanks. Of the 13 sites that had high and very high BEHI ratings, ten had unstable to highly unstable BHRs.

Rangeland Health

Seventeen ecological sites were assessed, the most common being sandy terrace (15), loamy (9), loamy terrace (7), and Sandy (7). A total of sixty individual ecological sites were evaluated that ranged from extremely departed to near reference condition. IIRH ratings for soil and site stability resulted in 41 none to slight, 9 slight to moderate, 6 moderate, 4 moderate to extreme and 0 extreme to total ratings. IIRH ratings for hydrologic function resulted in 13 none to slight, 14 slight to moderate, 25 moderate, 8 moderate to extreme and 0 extreme to total. IIRH ratings for biotic integrity resulted in 4 none to slight, 11 slight to moderate, 19 moderate, 20 moderate to extreme and 6 extreme to total.

Soil and Site Stability

Majority of the sites had minimal soil and site stability departures in regards to the relevant indicators (Table 3.2). No ecological sites sampled had an extreme to total departure for the soil and site stability indicator. A departure in gullies and wind erosion was only recorded on one site each. Bare ground, soil loss, compaction layer, and the soil and site stability attribute accounted for majority of the departures. Flow patterns and compaction layer were the only indicators to have sites with extreme to total departures.

Table 3.2. Summary of ecological sites sampled and their associated Soil and Site Stability Attribute ratings. The number of sites associated with none to slight (N-S), slight to moderate (S-M), moderate (M), moderate to extereme (M-E), and extreme to total (E-T) can be observed.

		Soil & Site Stability				
Ecological Site	n	N-S	S-M	M	M-E	E-T
Clayey	1	1	-	-	-	-
Claypan	2	-	-	1	1	-
Loamy	9	6	2	-	1	-
Loamy Overflow	2	2	-	-	-	-
Loamy Terrace	7	4	2	1	-	-
Saline Lowland	5	2	3	-	-	-
Sands	3	3	-	-	-	-
Sandy	7	4	1	2	-	-
Sandy Terrace	15	11	1	1	2	-
Shallow Loamy	1	1	-	-	-	-
Sub Irrigated	3	3	-	-	-	-
Thin Claypan	2	2	-	-	-	-
Wet Meadow	2	1	-	1	-	-
Wetland	1	1	-	-	-	-

NMS analysis of soil and site stability and its related indicators, channel type, BEHI, and BHR produced final solutions with two dimensions and a final stress of 8.7, which indicates the ordination produced a picture with low risk of false conclusions (Figures 3.2-3.4) (Clarke 1993). These solutions were stable with final instabilities of 0. Axis one accounted for the most variation explaining 72%, whereas axes 2 accounted for a smaller amounts of variation explaining 21% (Figures 3.2-3.4).

Channel Type

Soil compaction, soil loss, and soil attribute were positively correlated with axis one. Flow patterns was negatively correlated with axis one. Axis two was positively influenced by bare ground and negatively correlated with the presence of rills. PERMANOVA analysis indicated that stream type was not influenced (P = 0.16) by soil and site stability indicators. A pairwise comparison found differences may exist between E and G Channels (P = 0.04), C and G Channels (P = 0.03). Figure 3.2 displayed that bare ground and water erosion features were associated with G channels (Figure 3.2). F channels were influenced by soil compaction, soil loss, bare ground, and the overall site and stability attribute. C channels tended to have uplands with the least amount of departure.

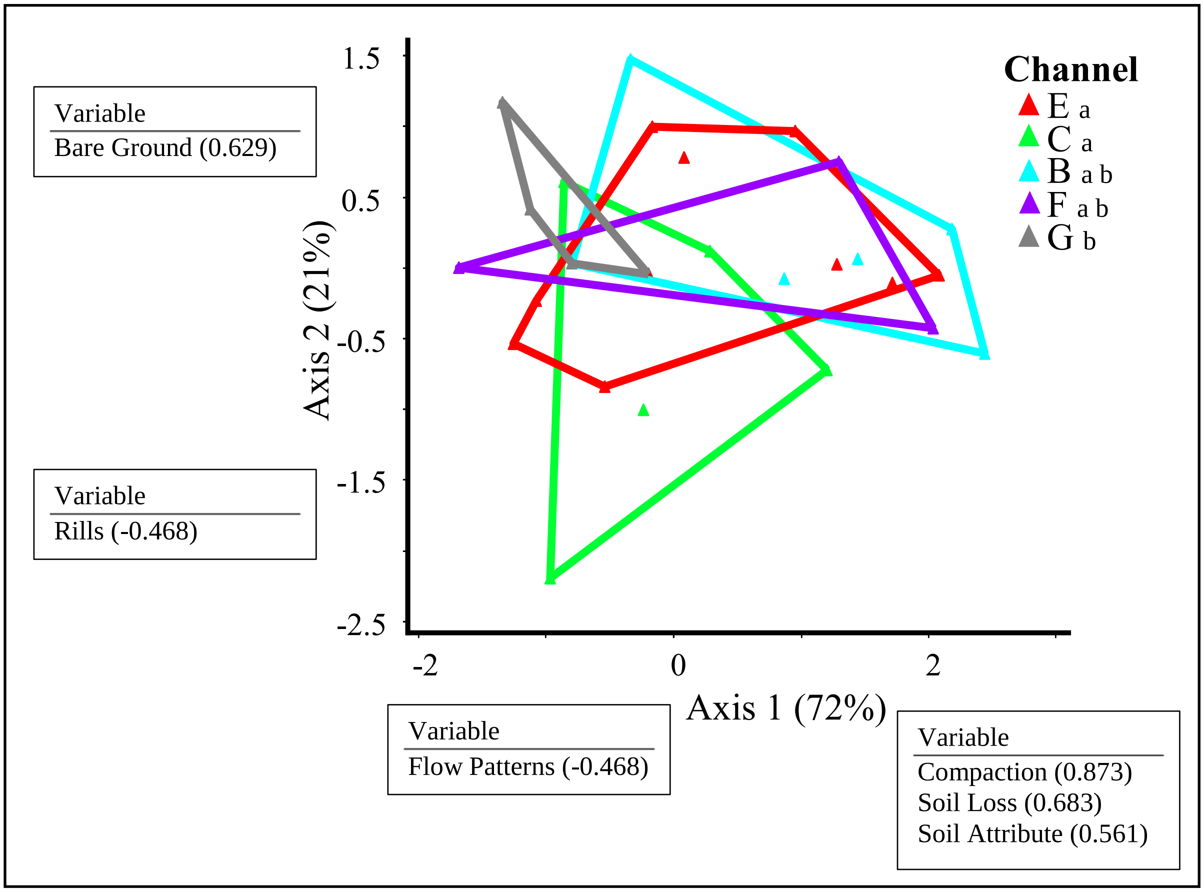

Figure 3.2. Non-metric multidimensional scaling ordination (NMS) displaying the soil attribute and related indicators' relationship with Rosgen's stream classification on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) classification of natural streams. The variables and their correlation value are displayed on their associated side of the axis. Significant differences (P < 0.05) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 2-dimensional solution had a final stress of 8.7 and explained 93% of the variation. This ordination has a low risk of false interpretation.

Bank Erosion Hazard Index

PERMANOVA analysis showed that BEHI was not influenced (P = 0.16) by soil and site stability indicators. When interpreting the relationship between soil and site stability and its corresponding indicators relationship with BEHI (Figure 3.3), streambanks with moderate to very high risk of erosion tended to have poor soil and site stability indicator scores. Sites rated moderate or higher were positively correlate with axes one and two. Whereas, streambanks at low risk of erosion were typically negatively correlated with axes 1 and 2, suggesting they had minimal departures in soil and site stability recorded during the IIRH assessment.

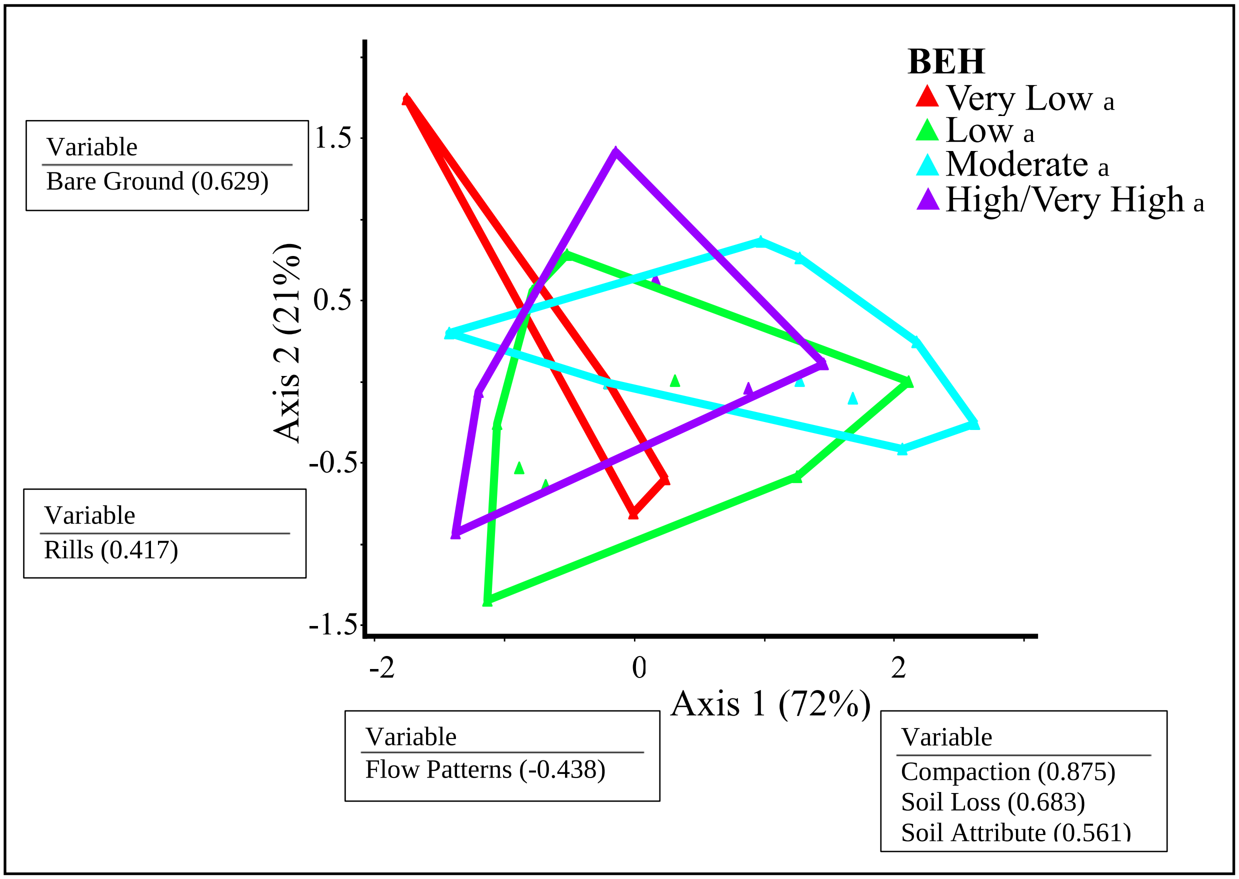

Figure 3.3. Non-metric multidimensional scaling ordination (NMS) displaying the soil attribute and related indicators' relationship with the bank erosion hazard index (BEHI) on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BEHI groupings is denoted by the lowercase letters following the BEHI group. Categories that do not share a lower case letter are considered significantly different from each other. This 2-dimensional solution had a final stress of 8.7 and explained 93% of the variation. This ordination has a usable picture.

Bank Height Ratio

PERMANOVA analysis showed BHR was not significantly influenced ($P > 0.05$) by soil and site stability. A pairwise test showed a stable BHR differed from highly unstable streambanks ($P \leq 0.04$). When interpreting the relationship between soil and site stability and its corresponding indicators relationship with BHR (Figure 3.4), unstable and highly unstable streambanks were found to be associated with high departures in bare ground, soil loss, compaction, and the overall soil and site stability rating.

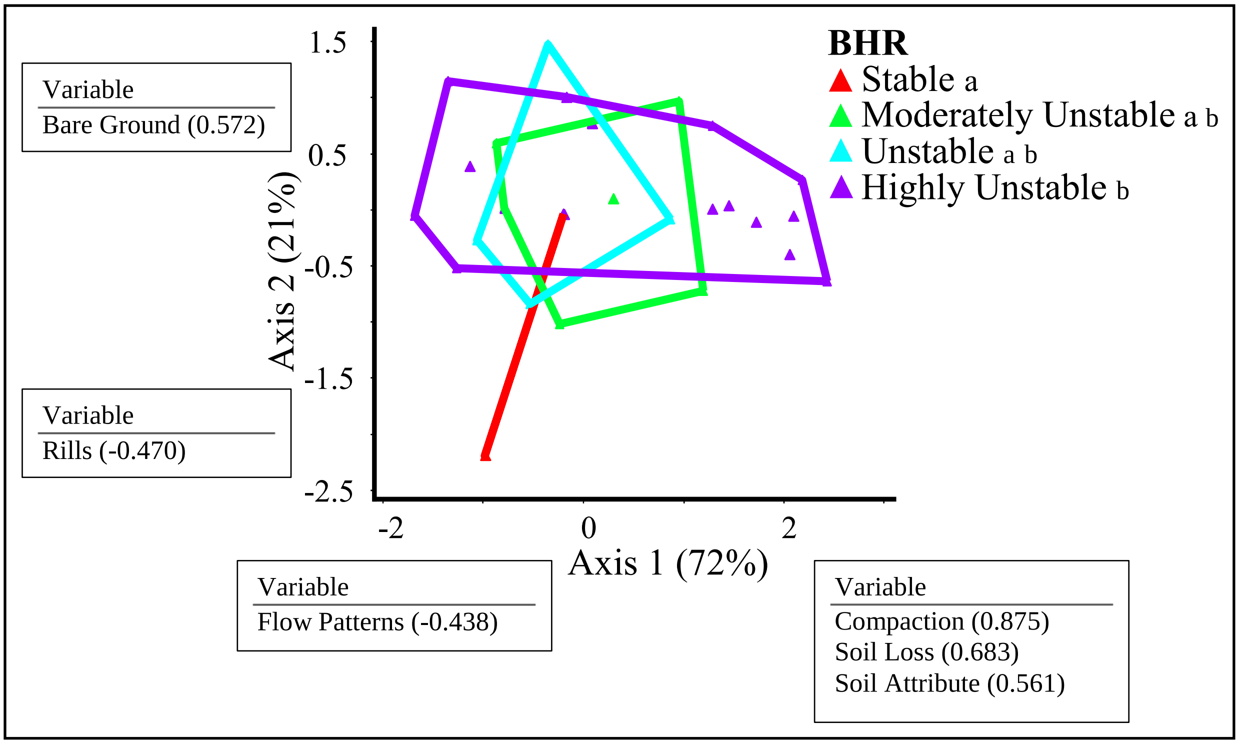

Figure 3.4. Non-metric multidimensional scaling ordination (NMS) displaying the soil attribute and related indicators' relationship with bank height ratio (BHR) on axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BHR groupings is denoted by the lowercase letters following the BHR type. Categories that do not share a lower case letter are considered significantly different from each other. This 2-dimensional solution had a final stress of 8.7 and explained 93% of the variation. This ordination has a low risk of false interpretation.

Hydrologic Function

The hydrologic function of the sites assessed varied in departure from none to slight to moderate to extreme; however, most sites were rated moderate (Table 3.3). Hydrologic indicators that had departures were flow patterns, bare ground, litter, compaction, infiltration and soil loss. Flow patterns, infiltration, compaction, and litter were the only indicators that had extreme to total departures.

Table 3.3. Summary of ecological sites sampled and their associated Hydrologic Function Attribute ratings. The number of sites associated with none to slight (N-S), slight to moderate (S-M), moderate (M), moderate to extereme (M-E), and extreme to total (E-T) can be observed.

		Hydrologic Function				
Ecological Site	n	N-S	S-M	M	M-E	E-T
Clayey	1	1	-	-	-	-
Claypan	2	-	-	-	2	-
Loamy	9	3	2	2	2	-
Loamy Overflow	2	-	-	2	-	-
Loamy Terrace	7	0	2	4	1	-
Saline Lowland	5	1	2	2	0	-
Sands	3	1	1	1	-	-
Sandy	7	1	1	5	0	-
Sandy Terrace	15	2	5	5	3	-
Shallow Loamy	1	1	-	-	-	-
Sub Irrigated	3	1	-	2	-	-
Thin Claypan	2	1	1	-	-	-
Wet Meadow	2	1	-	1	-	-
Wetland	1	1	-	-	-	-

NMS analysis of hydrologic function and its related indicators, channel type, BEHI, and BHR produced final solutions with three dimensions and a final stress of 8.5, which indicates the ordination produced a picture with low risk of false conclusions (Clarke 1993). These solutions were stable with final instabilities of 0. Axis one and two accounted for most of variation explaining at 84% (axis 1 was 39% and axis two 45%); whereas, axes three accounted for 10% of the variation (Figures 3.5-3.10).

Indicators positively correlated with axis one include soil compaction, soil loss, infiltration, and the hydrologic function attribute. Litter was negatively correlated with axis one. Axis two is positively correlated with bare ground and flow patterns, and negatively influenced by infiltration, litter, and the hydrologic function attribute. Axis three is negatively correlated with soil compaction.

Channel Type

PERMANOVA analysis showed stream type was not influenced ($P > 0.05$) by hydrologic function. However, a pairwise test showed E channels differed from G channels ($P = 0.03$); as well as, C channels differed from G channels ($P = 0.04$). When interpreting the relationship between the hydrologic function and its corresponding indicators relationship with channel type (Figures 3.5 and 3.6), stable E and C channels were found to be associated with higher than average litter amounts. F channels were characterized by soil compaction and decreased infiltration rates. G channels were associated with increased bare ground and flow patterns.

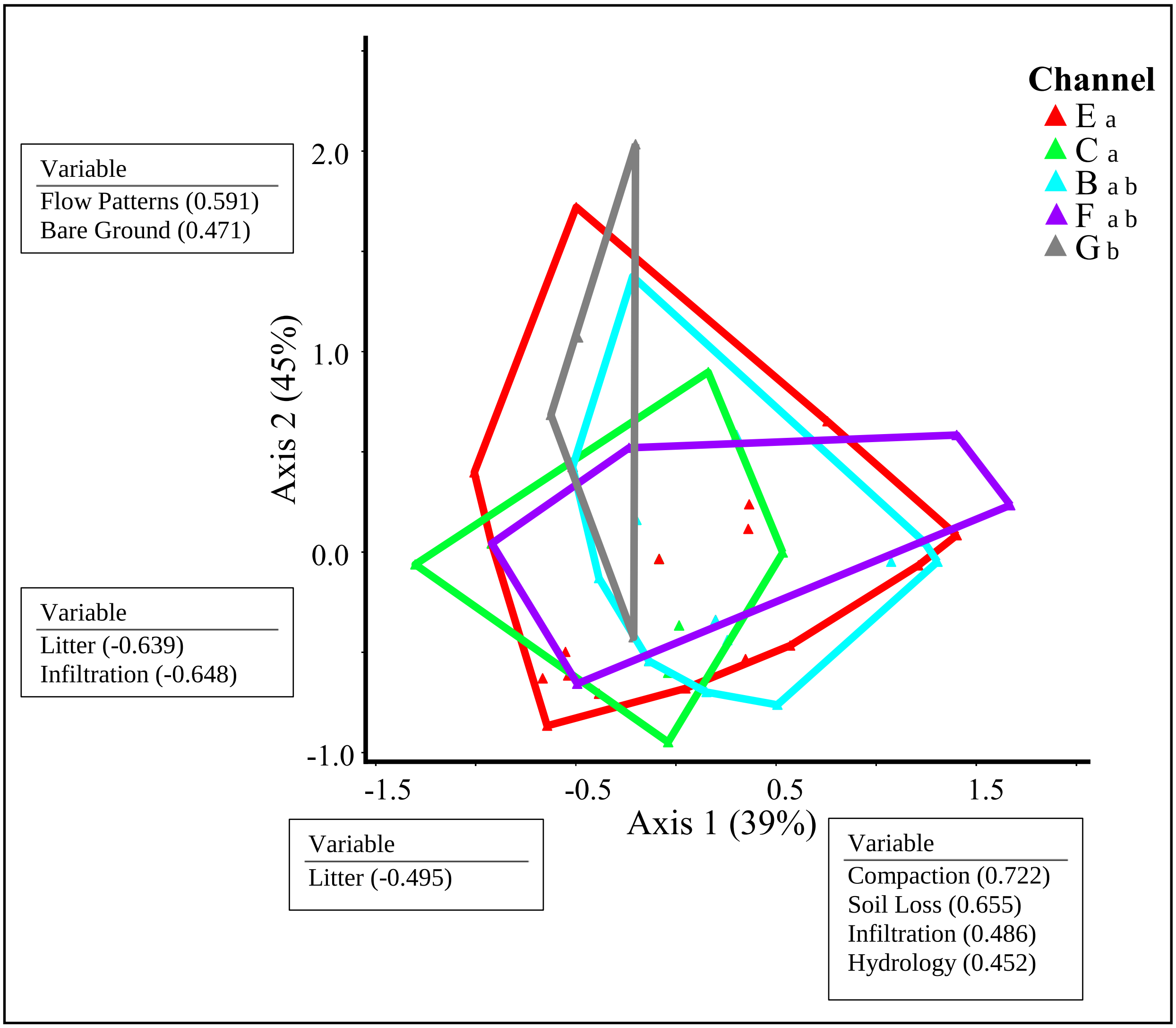

Figure 3.5. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with Rosgen's stream classification depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) classification of natural streams. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 84% of the variation. This ordination has a low risk of false interpretation.

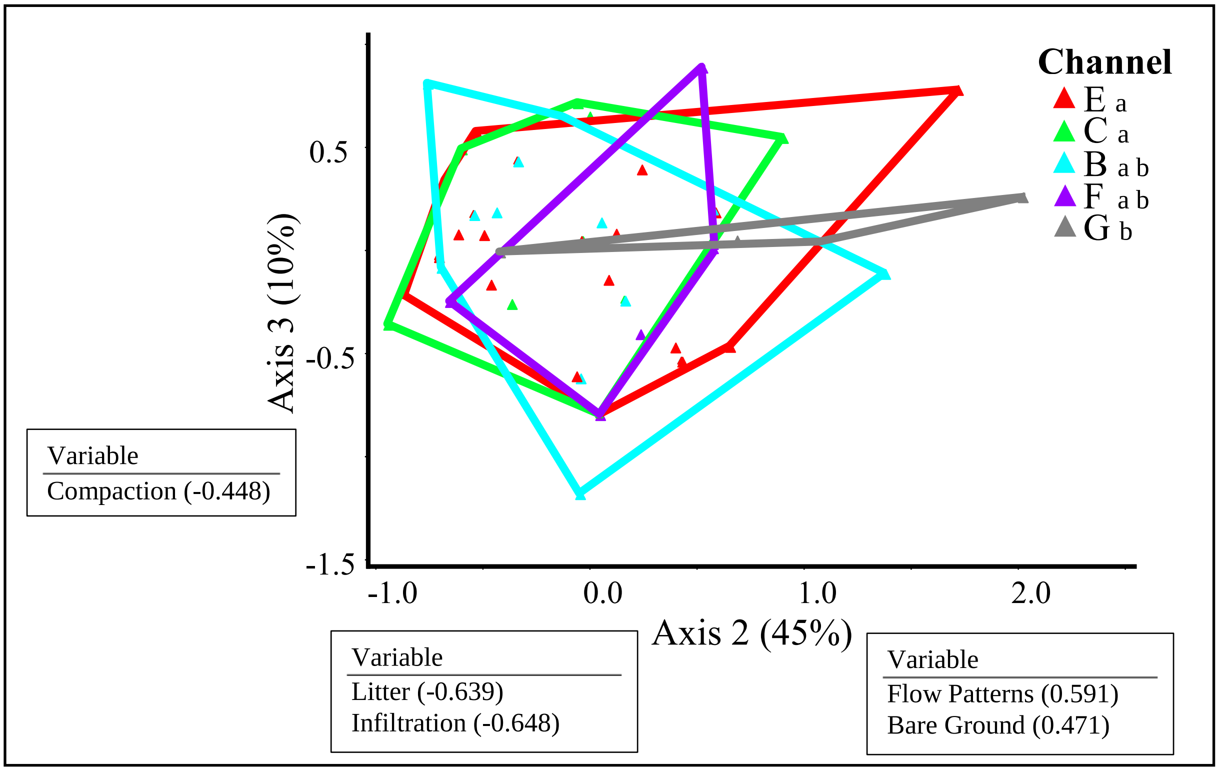

Figure 3.6. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with Rosgen's stream classification depicting axis 2 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) classification of natural streams. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 55% of the variation. This ordination has a low risk of false interpretation.

Bank Erosion Hazard Index

The PERMANOVA analysis showed BEHI groupings were influenced ($P = 0.015$) by the hydrologic function and its associated indicators. A pairwise comparison showed very low risk streambanks differed from moderate risk streambanks ($P = 0.003$). The pairwise test also showed that low BEHI streambanks differed from moderate BEHI streambanks ($P = 0.034$). When interpreting the relationship between upland hydrology and BEHI, banks at low risk of erosion were associated with uplands with higher than average amounts of litter (Figure 3.7). High and very high risk streambanks were associated with ecological sites with departures in hydrologic function, compaction, soil loss, and decreased infiltration. Figure 3.8 shows the relationship between high risk and moderate risk streambanks with flow patterns and bare ground.

The difference between very low and moderate can best be seen in Figure 3.7, as there is minimal overlap between the two categories. Very low risk streambanks appeared to be largely influenced by the litter indicator. Similar to very low risk, low risk streambanks were influenced by litter; whereas, moderate risk streambanks were influenced by soil compaction.

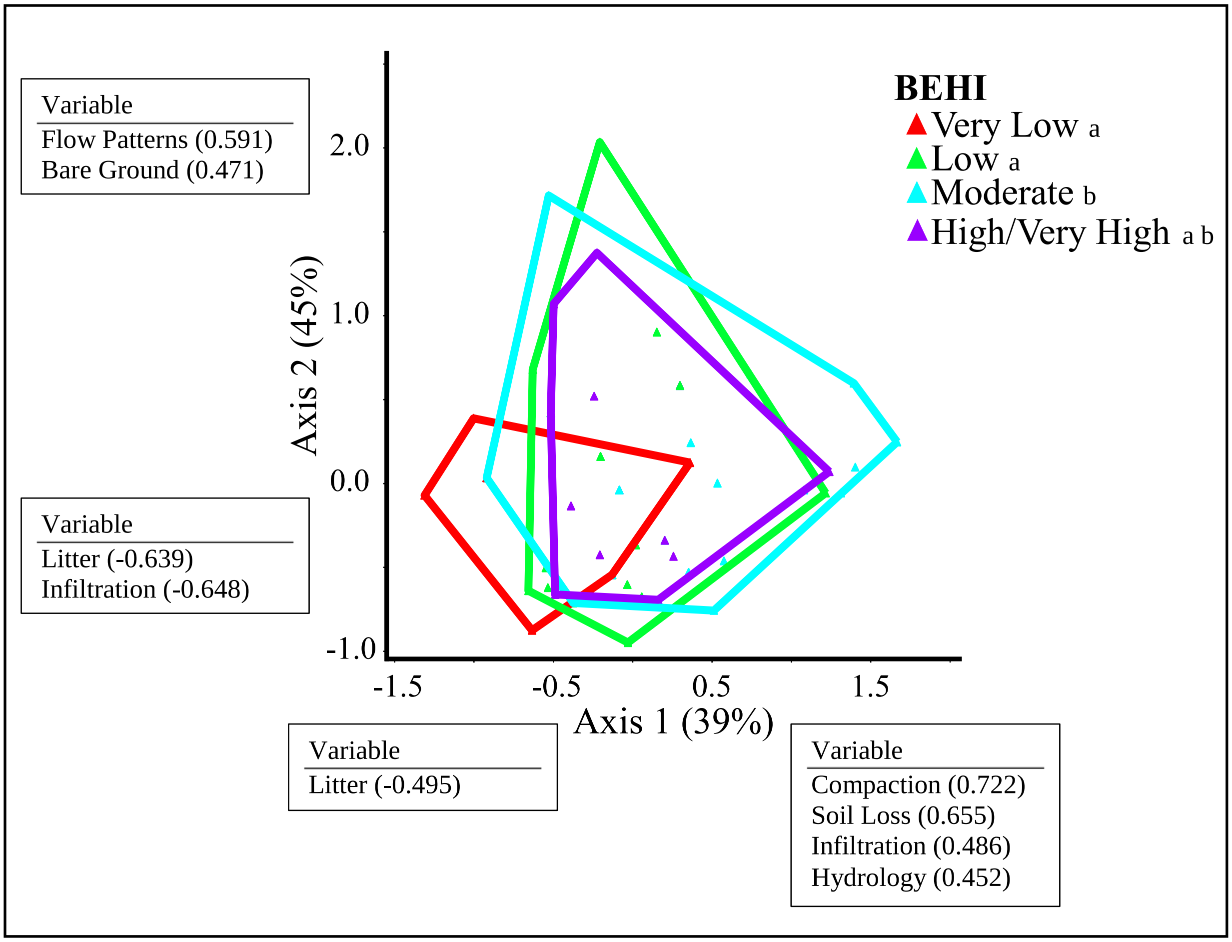

Figure 3.7. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with the bank erosion hazard index (BEHI) depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BEHI groupings is denoted by the lowercase letters following the BEHI group. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 84% of the variation. This ordination has a low risk of false interpretation.

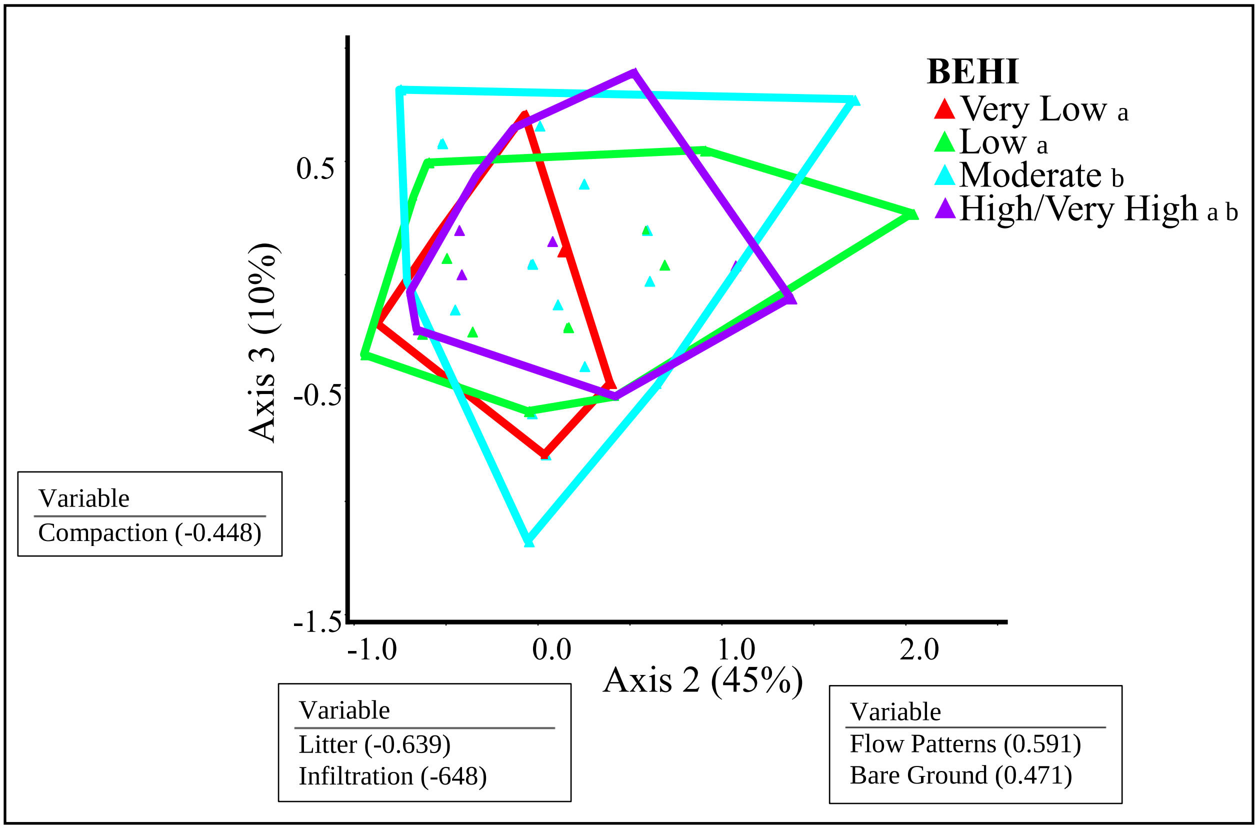

Figure 3.8. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with the bank erosion hazard index (BEHI) depicting axis 2 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BEHI groupings is denoted by the lowercase letters following the BEHI group. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 55% of the variation. This ordination has a low risk of false interpretation.

Bank Height Ratio

PERMANOVA showed BHR was not influenced ($P = 0.17$) by hydrologic function indicators. However, a pairwise test determined that streams with stable BHRs and highly unstable BHRs differed ($P = 0.029$). This can be seen in the ordinations (Figures 3.9 and 3.10) as the stable sites and highly unstable sites have minimal overlap. Stable streambanks were positively influenced by higher than expected amounts of litter (Figure 3.9). Highly unstable streambanks were associated with departures in soil compaction, soil loss, and the infiltration indicators as well as the hydrologic function attribute. Figure 3.10 shows that flow patterns and bare ground also influenced highly unstable streambanks.

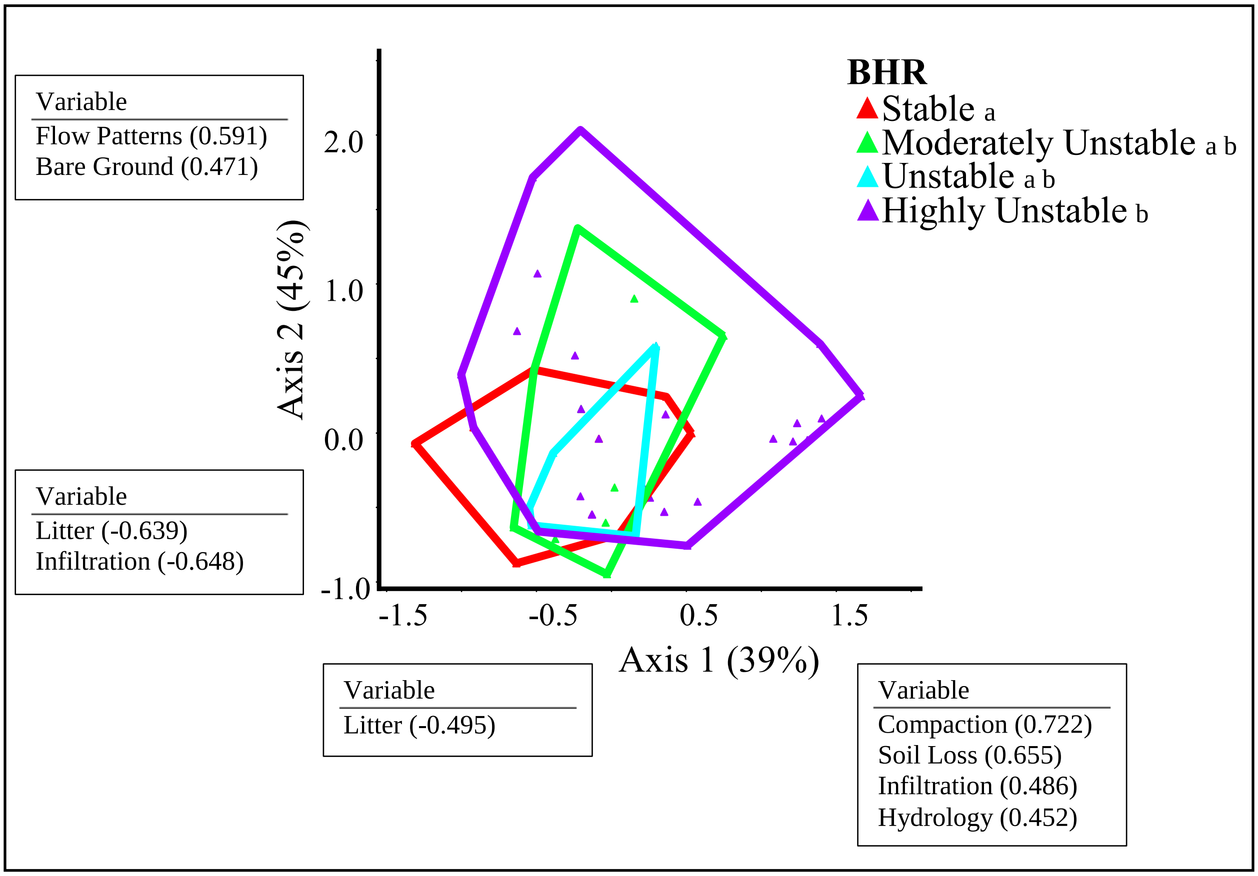

Figure 3.9. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with bank height ratio (BHR) depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BHR groupings is denoted by the lowercase letters following the BHR type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 84% of the variation. This ordination has a low risk of false interpretation.

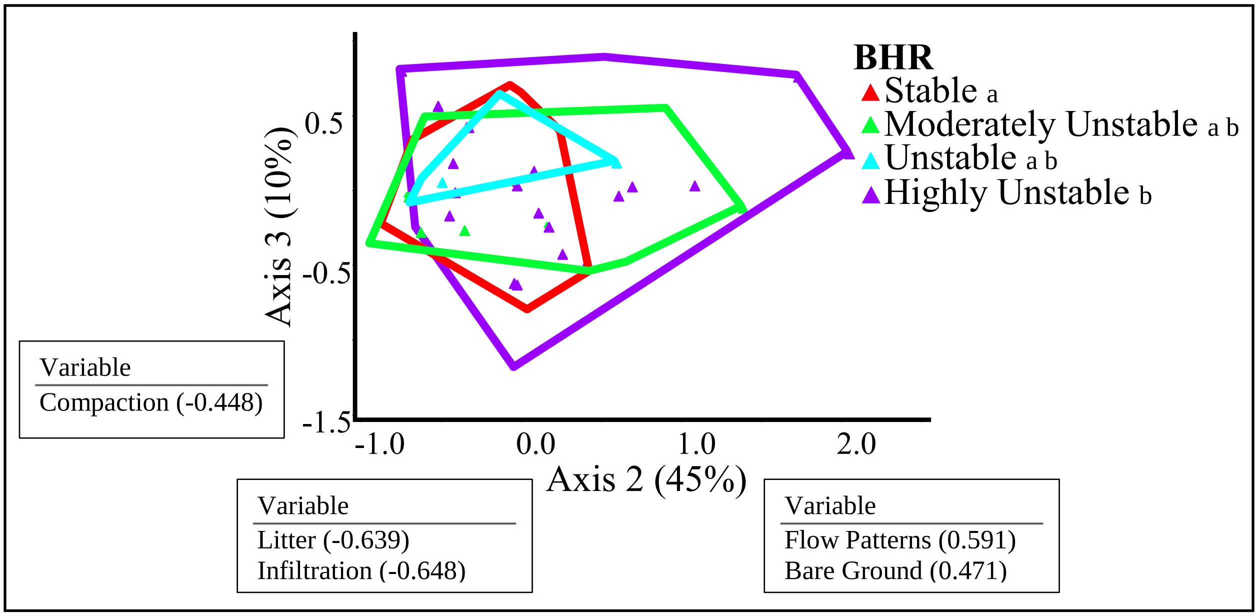

Figure 3.10. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with bank height ratio (BHR) depicting axis 2 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the (BHR) categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between BHR groupings is denoted by the lowercase letters following the BHR type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 8.5 and explained 55% of the variation. This ordination has a low risk of false interpretation.

Biotic Integrity

Biotic Integrity had the most departures from the reference state of the three attributes as only four sites were rated none to slight (Table 3.4). The indicators with the most departure were functional/structural groups, litter amount, and invasive plants with 11, 2 and 9 sites reporting extreme to total departure, respectively. Invasive plants documented during the study included Kentucky bluegrass, cheatgrass, field brome, smooth bromegrass, and Canada thistle. Indicators with the least departure were soil resistance to erosion, annual production, and reproductive capability of perennial plants.

Table 3.4. Summary of ecological sites sampled and their associated Biotic Integriy Attribute ratings. The number of sites associated with none to slight (N-S), slight to moderate (S-M), moderate (M), moderate to extereme (M-E), and extreme to total (E-T) can be observed.

		Biotic Integrity				
Ecological Site	n	N-S	S-M	M	M-E	E-T
Clayey	1	-	-	-	1	-
Claypan	2	-	-	-	2	-
Loamy	9	1	3	2	2	1
Loamy Overflow	2	-	-	-	1	1
Loamy Terrace	7	-	-	4	3	-
Saline Lowland	5	-	1	4	-	-
Sands	3	-	2	1	-	-
Sandy	7	1	-	1	5	-
Sandy Terrace	15	-	1	6	5	3
Shallow Loamy	1	-	-	1	-	-
Sub Irrigated	3	-	1	-	1	1
Thin Claypan	2	-	2	-	-	-
Wet Meadow	2	1	1	-	-	-
Wetland	1	1	-	-	-	-

NMS analysis of biotic integrity and its associated indicators, channel type, BEHI, and BHR produced final solutions with three dimensions and a final stress of 9.1, which indicates the ordination produced a picture with low risk of false conclusions (Clarke 1993). These solutions were stable with final instabilities of 0. Axis one and two accounted for most of variation explaining at 68% (axis 1 was 36% and axis two was 32%); whereas, axis three accounted for 24% of the variation (Figures 3.11-3.16).

The invasive plants indicator was positively correlated with axis one. There were no indicators negatively associated with axis one. Axis two was positively correlated with the litter amount indicator. Indicators negatively correlated with axis two are soil surface resistance to erosion, soil surface loss or degradation, and compaction layer. Axis three was positively correlated with the functional structural group indicator and the biotic integrity attribute.

Channel Type

PERMANOVA analysis showed stream channel type was not influenced ($P > 0.05$) by biotic integrity indicators (Figures 3.11 and 3.12). Sites influenced by high amounts of litter and invasive species tended to be associated with unstable F and G channels. These unstable channels were also correlated with soil compaction, reduced resistance to erosion, and soil loss. When interpreting axes one and three (Figure 3.12), a relationship of altered functional/structure groups and invasive species was associated with F and G channels.

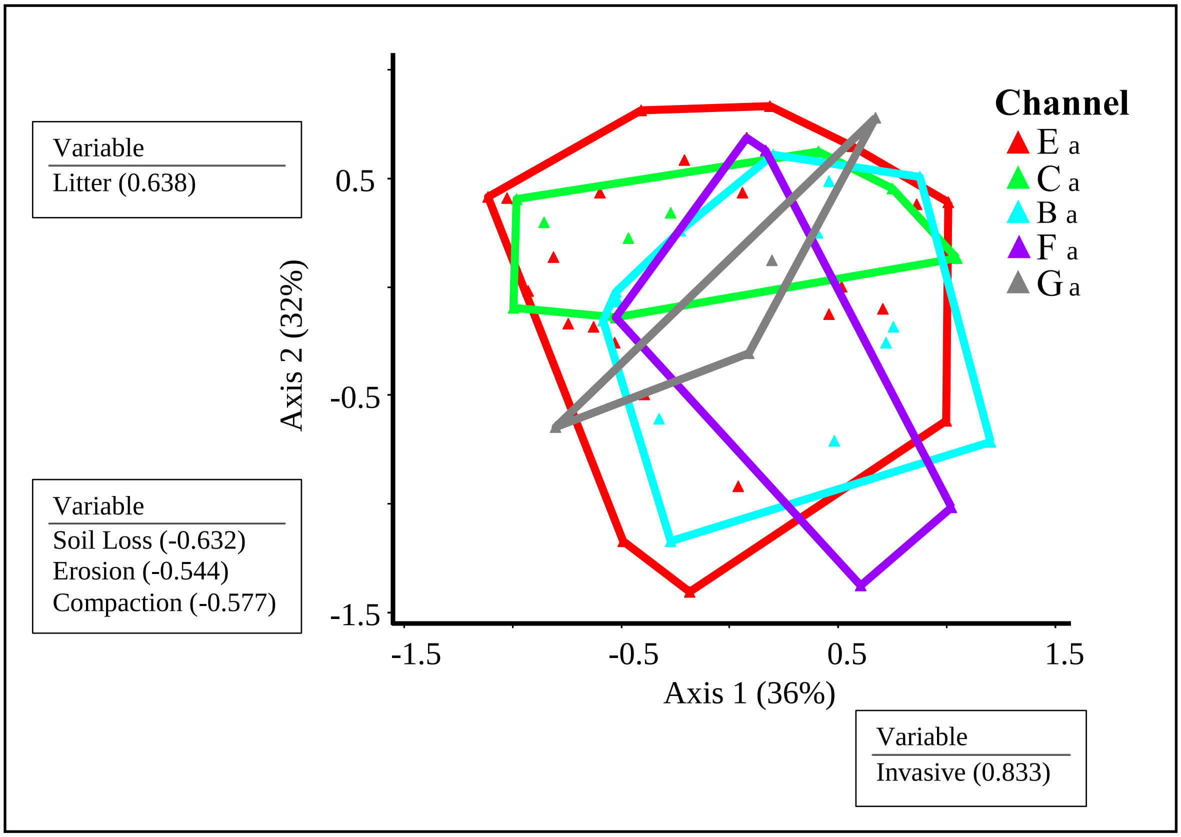

Figure 3.11. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with Rosgen's stream classification depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) classification of natural streams. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.1 and explained 68% of the variation. This ordination has a low risk of false interpretation.

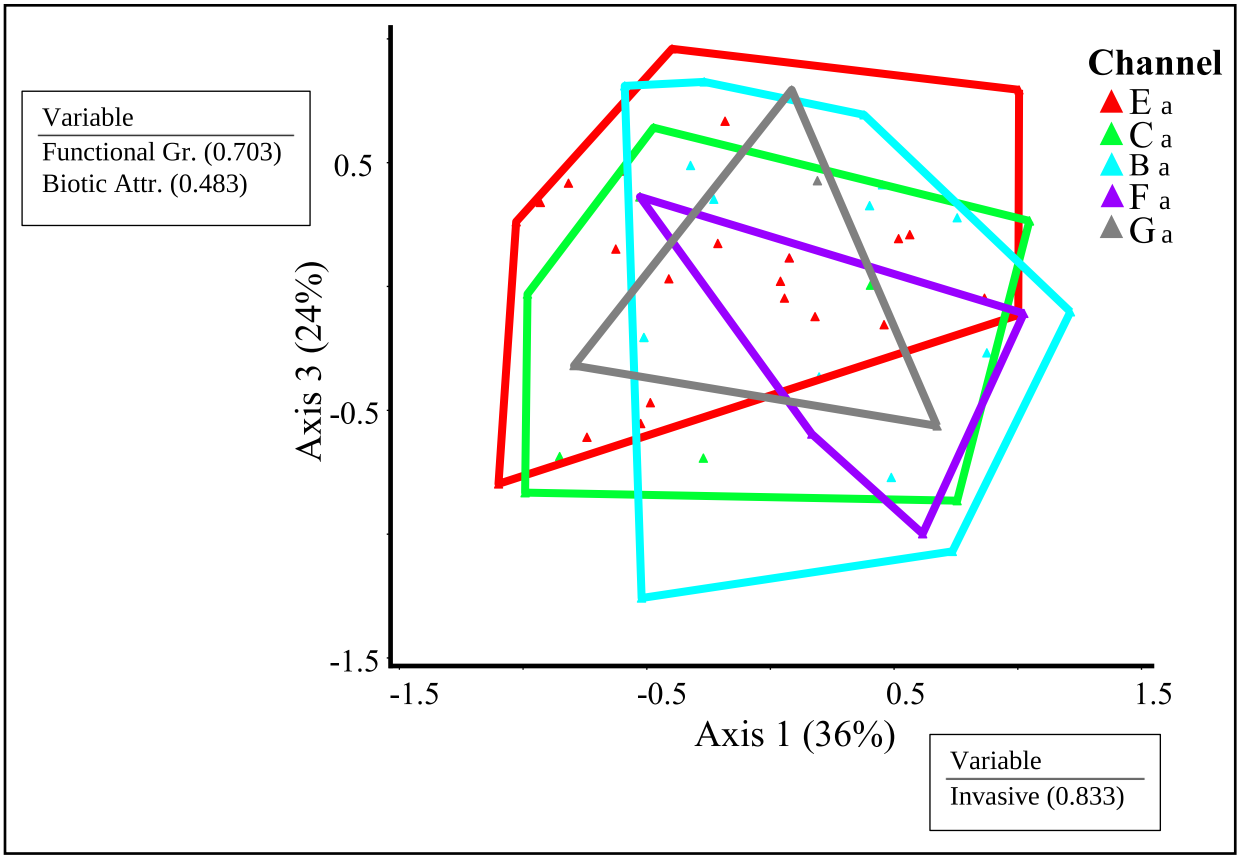

Figure 3.12. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with Rosgen's stream classification depicting axis 1 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent individual stream channels based on Rosgen's (1994) classification of natural streams. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.1 and explained 60% of the variation. This ordination has a low risk of false interpretation.

Bank Erosion Hazard Index

PERMANOVA analysis showed BEHI category was not influenced ($P = 0.09$) by biotic integrity indicators. However, the pairwise test showed streams with very low BEHI and moderate BEHI differed (P = 0.015). The pairwise test indicated that low BEHI and moderate BEHI may be different (P = 0.055).

Streambanks with very low and low BEHI ratings were associated with higher than expected amounts of litter (Figure 3.13). Departures in soil surface loss or degradation, soil compaction, and soil surface resistance to erosion were associated with streambanks having high/very high BEHI. Sites with both high amounts of litter and invasive species tended to have moderate to high/very high BEHI. Figure 3.13 displays that moderate and high/very high BEHI streambanks are associated with invasive species, altered function/structural groups, and departed biotic integrity.

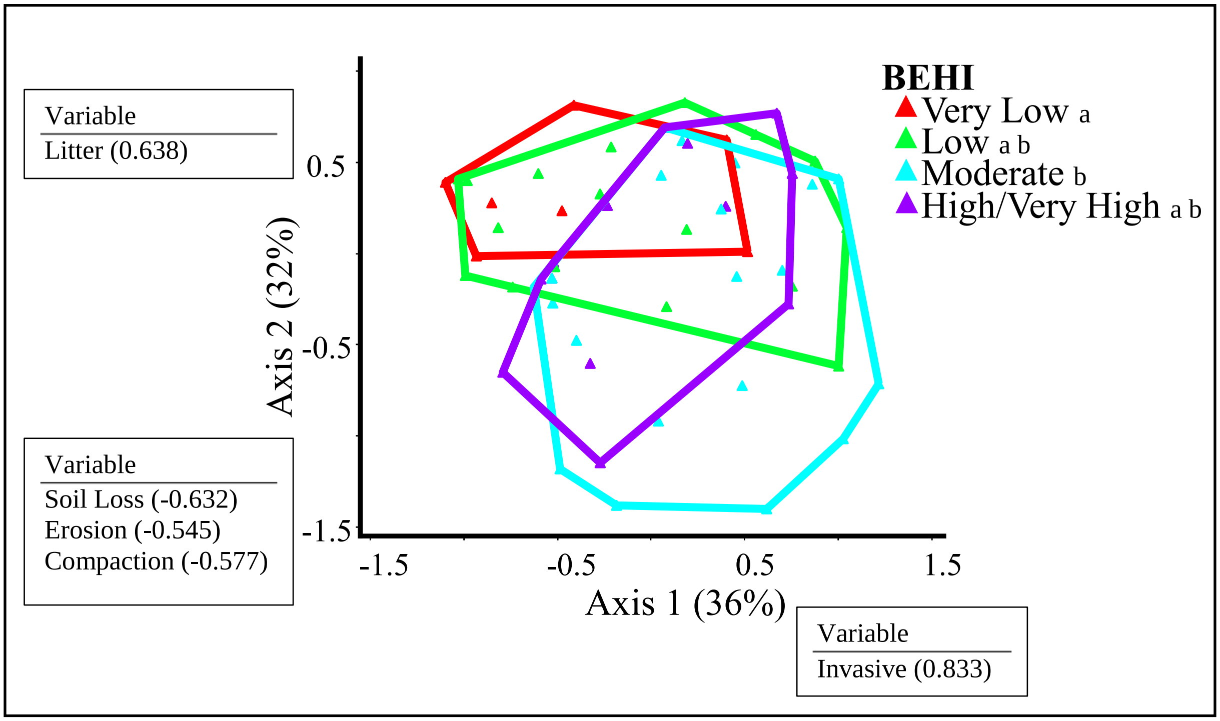

Figure 3.13. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with the bank erosion hazard index (BEHI) depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.1 and explained 68% of the variation. This ordination has a low risk of false interpretation.

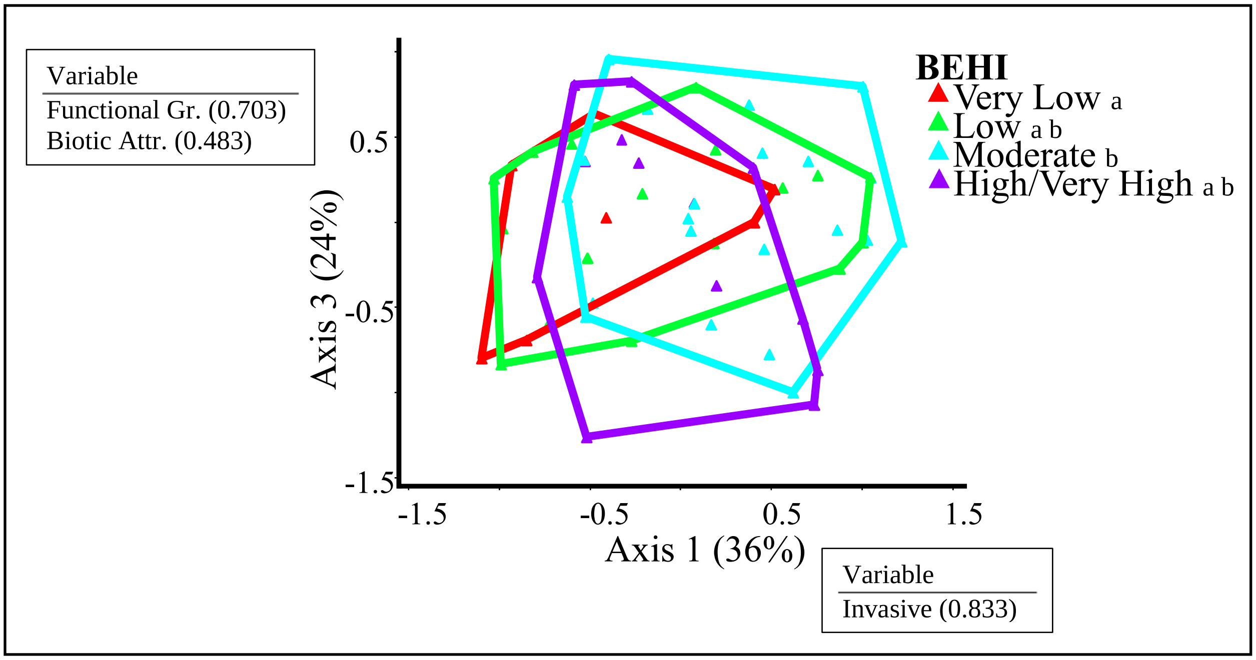

Figure 3.14. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with the bank erosion hazard index (BEHI) depicting axis 1 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BEHI categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.1 and explained 60% of the variation. This ordination has a low risk of false interpretation.

Bank Height Ratio

PERMANOVA results showed the groupings were trending ($P = 0.075$) to have a difference between the BHR groupings. A pairwise test showed stable and highly unstable BHRs differed ($P = 0.04$). Stable sites were associated with departures in litter (Figure 3.15). Highly unstable sites were associated with invasive species and high litter amounts. Unstable, and some highly unstable sites were associated with invasive species, soil surface loss or degradation, and soil compaction. Figure 3.16 shows the relationship between highly unstable and unstable streambanks with alteration of functional/structural groups, presence of invasive species, and departed biotic integrity.

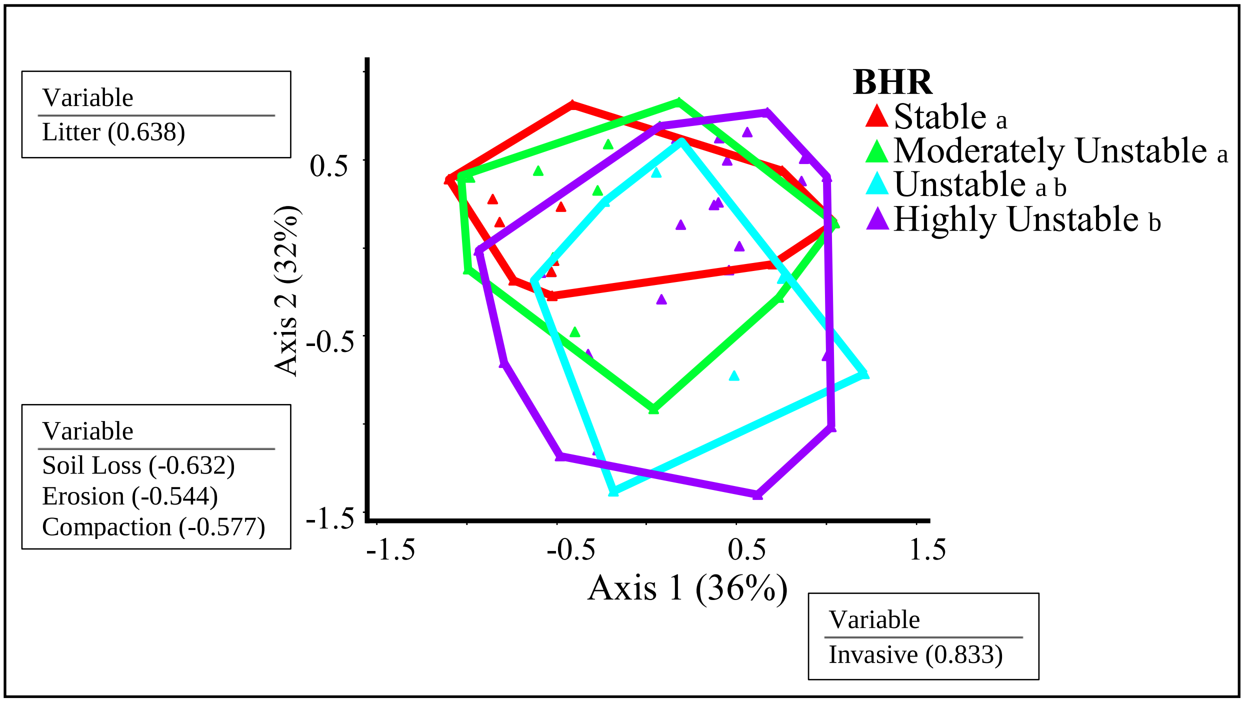

Figure 3.15. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with bank height ratio (BHR) depicting axis 1 and 2 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The variables and their correlation value are displayed on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.96 and explained 68% of the variation. This ordination has a low risk of false interpretation.

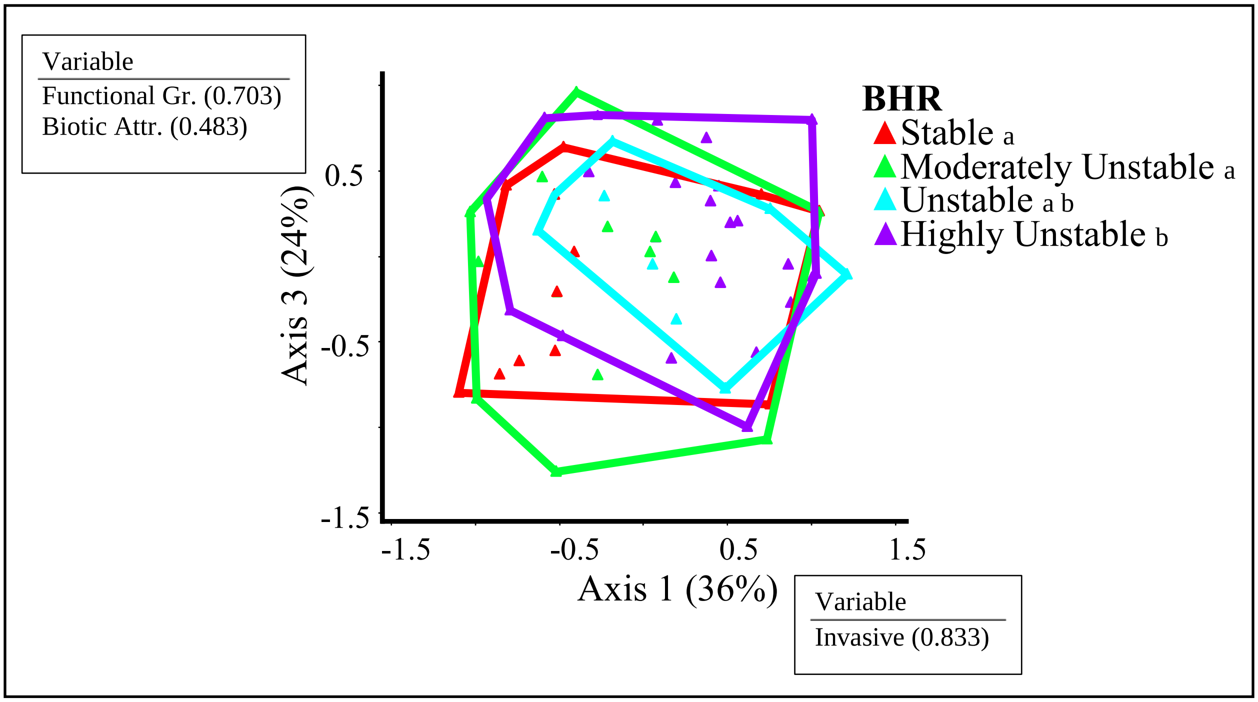

Figure 3.16. Non-metric multidimensional scaling ordination (NMS) displays the hydrologic function attribute and related indicators' relationship with bank height ratio (BHR) depicting axis 1 and 3 across thirty-five cross-sections in Bowman County, North Dakota. The different colored polygons represent the BHR categories of each cross-section. The variables and their correlation value are displayed_on their associated side of the axis. Significant differences ($P < 0.05$) between channel type is denoted by the lowercase letters following the channel type. Categories that do not share a lower case letter are considered significantly different from each other. This 3-dimensional solution had a final stress of 9.1 and explained 60% of the variation. This ordination has a low risk of false interpretation.

Discussion

Soil and Site Stability

The soil and site stability indicators of IIRH showed departures from reference condition in soil characteristics of the adjacent uplands increased the chance of the associated riparian ecological site being in an unstable or at-risk state. We observed uplands with higher than expected bare ground amounts to be associated with highly unstable BHRs, and development of F and G channels. F and G channels showed a relationship with ecological sites with departures in soil compaction, resistance to erosion, soil surface loss or degradation, functional/structural groups, and invasive plants. The poor upland soil properties of F and G channels indicates the soil structure and aggregate stability has been altered, facilitating excess runoff and sediment loss (Kasper et al. 2009; Kodešová et al. 2009; Printz et al. 2014). Other common relationships observed included soil compaction, soil surface loss or degradation, and an overall departed soil and site stability attribute being associated with unstable stream channels and high BEHI streambanks.

Uplands with higher than expected amounts of bare ground often facilitate soil erosion from wind and precipitation events, creating sediment movement that may reach stream channels (Schwarte et al. 2011). Large areas of bare ground in combination with a compaction layer will increase the amount of runoff, adding more force to stream flow during precipitation events (Brooks et al. 2013; Rosgen and Silvey 1996; Unger and Kaspar 1994). The departure of soil surface loss or degradation was mostly a result of a decreased depth of the A horizon. The surface of the A horizon has the highest amount of organic matter which aids in infiltration and increases aggregate stability (Brady and Weil 2002; Follett and Reed 2010). When sites have one, or a combination of departures in soil compaction, soil surface loss, degradation, and bare ground the site and stability is often threatened as these indicators have the potential to increase runoff and erosion further (Pellant et al. 2005; Rosgen and Silvey 1996; Unger and Kaspar 1994).

We did not find a significant relationship between IIRH and BEHI rating. However, the BEHI has been shown to be an accurate predictor of increased sediment loads from bank erosion (Rosgen 2001a). Although sediment load was not measured during this study high amounts of soil erosion in the uplands can overwhelm riparian vegetation's trapping capacity introducing increased sediment amounts into the stream channel (Clary et al. 1996). The increased sediment load from upland and streambank erosion has effects on chemical, physical and biotic components of the stream influencing turbidity, dissolved oxygen, nutrient levels, and sediment transport (Allan et al. 1997; Brooks et al. 2013; Byers et al. 2005; Fitch and Adams 1998; Rosgen 2006; Rosgen and Silvey 1996; Wood and Armitage 1997). High sediment levels may overcome the sediment transport capabilities of a stream leading to changes in stream morphology as they are thrown out of equilibrium (Magner and Steffen 2000; Simon and Rinaldi 2000). Streams with excessive sediment loads often times form point bars; which deflect flow into streambanks further facilitating erosion and channel widening (Howard and Knutson 1984; Simon and Rinaldi 2006). In extreme circumstances stream channels may become braided as the stream does not have enough power to move sediment through its channel (Leopold and Wolman 1957; Simon and Rinaldi 2006). As a stream aggrades from high sediment loads the risk of flooding increases as the stream bed rises and water storage capacity decreases (Leopold 1994).

Upland sites near reference condition for soil and site stability typically were associated with E and C channels, very low and low BEHI scores, and a stable BHR. When considering how each soil and site stability indicator is related to erosional features it helps explain the relationship of “healthy” streams and near reference uplands. When the soil site and stability of the upland ecological sites are functioning properly the amount of water infiltrating the soil is greater than that of degraded sites, lowering the amount of erosion and runoff (Pellant et al. 2005), and ultimately lowering the amount of stormflow (Clary and Leininger 2000). Streams are more likely to be capable of buffering the additional energy obtained from precipitation events when reducing the amount of stormflow (Galay 1983).

Hydrologic Function

Thy hydrologic function attribute and BEHI had the strongest relationship. Unstable streambanks and streambanks at high risk of erosion were influenced by a combination of soil compaction, soil surface loss or degradation, infiltration and presence of flow patterns. The hydrologic attribute was associated with the high BEHI streambanks and unstable streambanks indicating the hydrology of the area has been altered. Based on these results, lowered infiltration rates and increased runoff amounts are likely influencing the stream channels (Allan et al. 1997; Poff and Allan 1995). The hydrologic function results also showed high amounts of bare ground and flow patterns were associated with unstable G channels. The presence of flow patterns indicates water is often moving as overland flow at these sites and entering the streams as runoff. Debano and Schmidt (1989) found flow patterns on the uplands were responsible for increased surface runoff and peak flows. F channels were loosely correlated with the presence of a compaction layer and reduced infiltration due to altered plant community rooting depths. This combination of departure would increase lateral flow, facilitating runoff (Printz et al. 2014).

The indicators associated with hydrologic function showed stable stream reaches, particularly C channels, were associated with higher than expected amounts of litter in the uplands than those with none to slight departures. This was true for channel type, BEHI, and BHR. Although high amounts of litter is a departure, the litter is adding canopy protection to the soil from splash erosion (Brooks et al. 2013; Clary and Leininger 2000). Furthermore, the litter is acting as a buffer during heavy precipitation and snowmelt events as it adds roughness to overland flow. By slowing the movement of overland flow the increased litter can increase the amount of precipitation that infiltrates the soil, thus reducing stormflow and sediment loads of the streams (Brooks et al. 2013; Naeth et al. 1991).

Biotic Integrity

Indicators associated with biotic integrity showed unstable stream channels and bank features were primarily associated with invasive plants, altered functional/structure groups, and biotic integrity. The high BEHI streambanks and unstable streambanks were associated with uplands whose plant communities were altered from the reference state and invaded. Sites that had high amounts of invasive species had high departures in functional/structural groups as the invaders greatly reduce, and sometimes eliminate some of the expected groups. Depending on the scale of invasion, the invasive plants indicator has a ripple effect, as the invaders often times influence several other indicators (Pellant et al. 2005; Printz et al. 2014). As a result, sites with departed biotic integrity were associated with streambanks having high/very high BEHI and unstable/highly unstable BHRs.

Common invasive and/or introduced species on the ecological sites assessed were Kentucky bluegrass, smooth bromegrass, annual bromegrasses, and crested wheatgrass. Kentucky bluegrass and smooth bromegrass are shallow rooting perennial rhizomatous grasses that form dense thatches on the soil surface, negatively influencing infiltration and runoff (Pierson et al. 2002; Taylor and Blake 1982). Despite annual bromegrasses being shallow rooted, infiltration rates have had mixed results with decreased (Boxell and Drohan 2009) and increased infiltration rates being documented (Gasch et al. 2013). Crested wheatgrass was not listed as invasive on the reference sheets; however, we found crested wheatgrass to be associated with altered structural functional groups as it often times was a dominant species when present. Henderson and Naeth (2005) also found crested wheatgrass to be competitive with native species in the northern Great Plains. These invasive and introduced species are highly competitive with native species resulting in lowered diversity, and sometimes forming monocultures in invaded areas (Harris 1967; Henderson and Naeth 2005; Morrow and Stahlman 1984; Murphy and Grant 2005; Toledo et al. 2014). These species reduce erosion where they are present (Hull and Pechanec 1947; Orr 1970), but they may result in decreased infiltration and overland flow

(Boxell and Drohan 2009; Pierson et al. 2002; Taylor and Blake 1982), increased litter amounts (DeKeyser et al. 2009; Ogle et al. 2003), altered soil structure (Printz et al. 2014), and mortality of neighboring plants (Dillemuth et al. 2009; Melgoza et al. 1990), resulting in altered functioning of ecological sites (Pellant et al. 2005; Toledo et al. 2014).

Conversely, stable stream types, low BEHI values, and stable BHRs were associated with increased amounts of litter, similar to hydrologic function. Contrary to hydrologic function, the NMS analysis showed increased amounts of litter can have a negative influence on stream morphology when the upland ecological sites are invaded. This occurred when ecological sites with plant invasion rated greater than or equal to moderate departure and/or litter amounts rated greater than or equal to moderate departure. The high litter and plant invasion relationship was observed when looking at BEHI. Although there is higher amounts of litter present, a shift in plant rooting structure from invasion may be altering the hydrology of the site (Pierson et al. 2002; Taylor and Blake 1982). Pierson (2002) found that high amounts of litter may not facilitate increased infiltration in the presence of short and sod-forming grasses.

Summary

Stable streams, E, C, and B types with low BEHIs and BHRs tended to be associated with upland ecological sites with low IIRH departures and above average amounts of litter (< moderate departure). Unstable F and G channels tended to be associated with high amounts of bare ground (≥ slight to moderate departure); whereas, E, C, and B channels typically were near reference condition (≤ slight to moderate). The F channel sites that had compaction layers also had surface soil loss or degradation departures (≥ moderate). F channels also were associated with altered infiltration and runoff rates due to departures in biotic integrity caused by altered plant community structure. Ecological sites associated with F and G channels were altered the most when comparing the three attributes, indicating stream morphology was influenced by upland state. Ecological sites with plant invasion (≥ moderate departure) and/or high litter amounts (≥ moderate departure) were associated with an increased risk of stream channel instability.

When comparing all departures, the F and G channels, moderate and high/very high risk BEHI, and unstable and highly unstable BHRs had the highest average departures. Unstable channel types, unstable BHRs, and high BEHI had higher departures of the soil and site stability attribute and the biotic integrity attribute. The hydrologic function attribute had the greatest departure of the unstable and highly unstable BHR, indicating altered hydrology in the uplands puts stream channels at risk of transitioning states; however, hydrologic function did not have the greatest departure between channel type and BEHI group.

Based on these findings indicators that provided the most insight were related to the hydrologic function attribute. This is appropriate given the hydrologic function attribute provide insight into how water moves across the landscape (Pellant et al. 2005). Sites associated with bare ground and soil compaction had unstable stream reaches, high BEHI values, and high BHR. This correlation between stream morphology and degradation in the uplands is likely contributing to increased storm flow capable of moving a stable reach out of equilibrium. Conversely, sites with no compaction and higher than expected amounts of litter (> slight to moderate departure) were associated with stable stream types, low BEHI, and low BHRs. By investigating the soil conditions managers can gain insight into previous disturbances of the soil which may have a legacy effect influencing reaches of a stream (Riley et al. 2003; Townsend et al. 2004).

Although the analysis did not find a significant relationship between stream stability and the soil and site stability attribute, this attribute and its related indicators are important as many of them are shared with hydrologic function (Pellant et al. 2005). Soil compaction and can lead to increased erosion rates and the development of rills, water flow patterns, and gullies (Pellant et al. 2005). Within our study, we found the soil and surface loss or degradation to be an important indicator from the NMS analysis. As an ecological site loses its A horizon depth it also loses its chance to return to its reference state. As the soil and site stability of a site becomes degraded the biotic integrity may be influenced as the nutrients and soil structure are altered (Pimentel et al. 1995).

This does not mean the biotic indicators are unimportant in regards to watershed management. Having diverse vegetation in the uplands retains ecological services, which in return have a positive feedback to the other two attributes. This was observed on sites with plant invasion and high litter amounts as the increased litter amounts lost its benefit to the assessed stream parameter observed in soil and site stability and hydrologic function attribute analysis. Invasive species have the potential to alter hydrology by changing soil structure, plant community composition and distribution relative to infiltration, add excess litter to the surface, lead to soil surface loss or degradation departures, and potentially create rill erosion (Angers and Caron 1998; Jordan et al. 2008; Pellant et al. 2005; Pierson et al. 2002; Printz et al. 2014; Taylor and Blake 1982). When a species dominates a site the structural functional groups are altered, which was not significant in this study; however, an alteration of the structural functional groups directly influences the infiltration rate relative to the plant community. This is important as sites with infiltration rate departures were associated with high/very high BEHI categories, unstable BHRs, and highly unstable BHRs.

Our research showed IIRH is positively correlated with stream stability. Ecological sites near reference condition were associated with stable stream types and low risk of bank erosion, with the exception of litter amount. IIRH showed promise as a predictor of watershed health; however, additional research is needed to verify these findings. Particularly, more information should be collected following the same protocol in different regions and in watersheds with perennial streams to determine its accuracy to predict stream stability.

Implications

The BEHI and BHR should be focused on during watershed assessments. Rosgen's (1994) classification of natural streams is useful for communication and STMs; however, PERMANOVA analysis found no relationship with channel type and rangeland health. The IIRH, BEHI, and BHR can be used to monitor long-term trends within a watershed. Managers who chose to partake in implementing a similar monitoring program should choose locations that are accessible and can be sampled periodically for an extended period of time. Implementation of this monitoring program allows managers to track the indicators linked to stream stability: bare ground, soil compaction, litter amounts, and plant community composition. Land managers should take caution if they chose to manage for high litter amounts as increased litter can harm native warm season grasses and increase chances of exotic invaders (Facelli and Pickett 1991; Printz et al. 2014; Suding and Goldberg 1999). Land managers should use adaptive management to make adjustments based on monitoring results of the upland ecological sites and stream morphology.

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APPENDIX. LIST OF PLANT SPECIES AND THEIR ASSOCIATED WETLAND INDICATOR STATUS DOCUMENTED DURING LINE POINT INTERCEPT SAMPLING

Common Name	Scientific Name	Indicator Status[1]
Common Yarrow	*Achillea millefolium* L.	**FACU**
Crested Wheatgrass	*Agropyron cristatum* (L.) Gaertn.	**UPL**
Western Ragweed	*Ambrosia psilostachya* DC.	**FACU**
Silver Sagebrush	*Artemisia cana* Pursh	**FACU**
Cudweed Sagewort	*Artemisia ludoviciana* Nutt.	**UPL**
Field Brome	*Bromus arvensis* L.	**FACU**
Smooth Bromegrass	*Bromus inermis* Leyss.	**UPL**
Northern Reedgrass	*Calamagrostis stricta* (Timm) Koeler	**FACW**
Wooly Sedge	*Carex pellita* Muhl. ex Willd.	**OBL**
Clustered Field Sedge	*Carex praegracilis* W. Boott	**FACW**
Pitseed Lambsquarter	*Chenopodium berlandieri* Moq.	**UPL**
Floodman's Thistle	*Cirsium flodmanii* (Rydb.) Arthur	**FAC**
Wavy Leaf Thistle	*Cirsium undulatum* (Nutt.) Spreng.	**FACU**
Canadian Horseweed	*Conyza canadensis* (L.) Cronquist	**FACUPL**
Giant Sumpweed	Cyclachaena xanthifolia	**FAC**
Inland Saltgrass	*Distichlis spicata* (L.) Greene	**FACW**
Barnyardgrass	Echinochloa crus-galli (L.)	**FAC**
Spikerush	*Eleocharis palustris* (L.) Roem. & Schult. var palustris	**OBL**
Canada Wildrye	*Elymus canadensis* L.	**FACU**
Quackgrass	*Elymus repens* (L.) Gould	**FACU**
Slender Wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners	**FACU**
Scouring Rush	*Equisetum laevigatum* A. Braun	**FAC**
American Licorice	*Glycyrrhiza lepidota* Pursh	**FACU**
Curlycup Gumweed	*Grindelia squarrosa* (Pursh) Dunal	**UPL**
Annual Sunflower	*Helianthus annuus* L.	**FACU**
Maxamillian Sunflower	*Helianthus maximiliani* Schrad.	**FACU**

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[1] The common name, scientific name, and the species associated wetland indicator status is provided. Wetland Indicator status can be obligate (OBL), facultative wetland (FACW), facultative (FAC), facultative upland (FACU), or upland (UPL) Reed, P.B., 1988. National list of plant species that occur in wetlands: Central Plains (Region 5). Washington, DC: U.S. Fish and Wildlife Service Biological Report.

Common Name	**Scientific Name**	**Indicator Status[1]**
Nuttall's Sunflower	*Helianthus nuttallii* Torr.	**FACW**
Foxtail Barley	*Hordeum jubatum* L.	**FACW**
Baltic Rush	*Juncus arcticus* Willd.	**FACW**
A. Water Horehound	*Lycopus americanus* Muhl.	**OBL**
Rough Bugleweed	*Lycopus asper* Greene	**OBL**
Black Medic	*Medicago lupulina* L.	**FACU**
Alfalfa	*Medicago sativa* L.	**UPL**
White Sweetclover	*Melilotus officinalis* (L.) Lam.	**FACU**
Field Mint	*Mentha arvensis* L.	**FACW**
Scratchgrass	*Muhlenbergia asperifolia* (Nees ex Trin.)	**FACW**
Stiff Goldenrod	*Oligoneuron rigidum* (L.)	**FACU**
Switchgrass	*Panicum virgatum* L.	**FAC**
Western Wheatgrass	*Pascopyrum smithii* (Rydb.) Á. Löve	**FACU**
Fowl Bluegrass	*Poa palustris* L.	**FACW**
Kentucky Bluegrass	*Poa pratensis* L.	**FACU**
Water Smartweed	Polygonum amphibium	**OBL**
Erect Knotweed	*Polygonum erectum* L.	**FAC**
Norwegian Cinquefoil	*Potentilla norvegica L.*	**FAC**
Nuttall's Alkaligrass	*Puccinellia nuttalliana* (Schult.) Hitchc.	**OBL**
Short Buttercup	*Ranunculus cymbalaria* Pursh	**OBL**
Prairie Rose	*Rosa arkansana* (Porter)	**FACU**
Curly Dock	*Rumex crispus* L.	**FAC**
Sandbar Willow	*Salix interior* Rowlee	**FACW**
Common Threesquare	*Schoenoplectus pungens* (Vahl) Palla	**OBL**
Buffaloberry	Shepherdia canadensis (L).	**FACU**
Canada Goldenrod	*Solidago canadensis* L.	**FACU**
Missouri Goldenrod	*Solidago missouriensis* Nutt.	**UPL**
Small Bur Reed	*Sparganium natans* L.	**OBL**
Alkali Cordgrass	*Spartina gracilis* Trin	**FACW**
Prairie Cordgrass	*Spartina pectinata* Bosc ex Link	**FACW**
Western Snowberry	*Symphoricarpos occidentalis* Hook.	**UPL**
Heath Aster	*Symphyotrichum ericoides* (L.)	**FACU**
White Panicle Aster	*Symphyotrichum lanceolatum* (Willd.)	**FACW**
Common Dandelion	*Taraxacum officinale* F.H. Wigg	**FACU**
Hybrid Cattail	*Typha ×glauca* Godr. (pro sp.) [*angustifolia*]	**OBL**
Canada Violet	*Viola canadensis* L.	**FACU**
Rough Cocklebur	*Xanthium strumarium* L.	**FAC**