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Analysis of Livestock Use of Riparian Areas:
Literature Review and Research Needs Assessment for British Columbia

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SUMMARY

Riparian areas are diverse, productive, and important to the overall ecological framework of British Columbia. There is heightened awareness of the potential effects of resource management activities in riparian areas. This concern is encapsulated in riparian regulations and guidelines of the *Forest Practices Code of British Columbia Act*. Information regarding livestock use of riparian areas was compiled and reviewed as a first step in developing research to address the information needs of riparian area management in British Columbia. Literature on the effects and interactions of livestock grazing in riparian areas throughout North America was reviewed. Six general conclusions were drawn from the synthesis and review of the literature:

1. Most of the available information on livestock–riparian interactions is primarily applicable to arid ecosystems (equivalent to, or drier than, the Bunchgrass biogeoclimatic zone),
2. Most of the available information on livestock–riparian interactions is applicable to lotic ecosystems (actively moving water),
3. Most of the research conducted has focused on contrasting extremes (e.g., comparing very heavy grazing to an ungrazed control),
4. Appropriate levels of livestock use that maintain good-quality riparian habitat are difficult to quantify,
5. Effects of livestock grazing in riparian areas on wildlife habitat are variable (grazing creates or enhances some wildlife habitat, while eliminating or degrading other wildlife habitat),
6. Riparian areas and the effects of livestock grazing have not been studied adequately at a landscape level.

Considering these general conclusions, nine recommendations were formulated to guide the development of research on livestock use of riparian areas. The recommendations are as follows:

1. Research on range riparian areas in British Columbia must focus on ecosystems outside those that the current body of literature represents; a system should be developed to prioritize which ecosystems need to be addressed first.
2. Research on range riparian areas in British Columbia must include wetlands, ponds, and lakeshores.
3. Research on range riparian areas in British Columbia should test the impact of livestock at stocking rates, levels of use, and timing that are normally or feasibly prescribed in British Columbia and recommend changes where the standard stocking rates are inappropriate.
4. Research addressing appropriate range use in riparian areas in British Columbia must include the physiological response of specific plants within specific habitats. Grazing prescriptions should not attempt to generate a level of use, or grazing system, that is universally appropriate for all riparian vegetation, in all ecosystem units.
5. A classification and description of all riparian types used for livestock grazing should be completed through an extension of the biogeoclimatic ecological classification and range reference areas system because

appropriate use depends on formulating range prescriptions on an ecosystem basis.

6. Research on the effects of range use (livestock grazing and hay cutting) on riparian wildlife species in British Columbia should focus initially on the effects and interactions with red- and blue-listed species.
7. Research on the effects of range use on riparian wildlife habitat in British Columbia needs to address the appropriate amount and connectivity of habitat necessary to sustain various wildlife populations.
8. Research on the effects of range use in riparian areas in British Columbia should address the issue at a landscape level in addition to measuring site-specific impacts to determine the cumulative and spatial consequences of individual site management.
9. Research on the effects of range use in riparian areas in British Columbia should address the management of the adjacent uplands to address the riparian issues at a landscape level.

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CONTENTS

1.1 The Importance and Function of Riparian Areas

Riparian areas are those vegetation zones supporting vegetation that is distinct from the adjacent uplands due to the presence or influence of water (streams, lakes, wetlands). The term "riparian" denotes a landscape position rather than a specific type of ecosystem; riparian areas are located next to a body of water or wetland.[1] Riparian areas are widely recognized as the most biologically diverse and productive of all temperate, terrestrial ecosystems (Kauffman and Krueger 1984). The structural and functional diversity of the many types of riparian areas makes generalizations about them difficult.

British Columbia's riparian areas are a source of plant diversity, and fish and wildlife habitat, and serve many other important ecological functions. These areas filter sediments from surface water, stabilize soil and stream banks, regulate water temperature, and provide many significant habitat attributes for terrestrial and aquatic wildlife (Stevens et al. 1995).

Riparian zones are important "focal points" for many natural resource products and resource uses because of the concentration of biological values found there (Buckhouse 1981). The riparian areas of the Interior of British Columbia are important for livestock production as a source of both forage and water (van Ryswyk et al. 1992; Wikeem et al. 1993). These areas are also important for individual and community water supplies, timber production, recreation, and many other consumptive and non-consumptive activities.

The distinct character of the riparian area is particularly evident in arid and semi-arid ecosystems. The contrast between the riparian zone and the adjacent upland creates abrupt demarcations between habitat types. Moreover, the local abundance of water relative to the upland attracts many species of wildlife. Most of the riparian issues in the current body of literature are focused in these arid and semi-arid areas. Rangelands in the Bunchgrass (BG), Ponderosa Pine (PP), and Interior Douglas-fir (IDF) biogeoclimatic zones of British Columbia contain riparian areas with these characteristics, but are not the only ecosystems in the province in which issues surrounding livestock use of riparian areas occur.

Riparian areas can embody many features important for wildlife habitat. However, the various riparian types have different types and degrees of habitat values, and their significance to wildlife is therefore variable. Wildlife activity is generally high in riparian areas because of the abundance of water and high biomass production. Where riparian plant communities containing shrubs or trees border grasslands, structural diversity of the landscape is higher due to the contrast with upland areas. The sinuous shape of the riparian areas of lotic ecosystems (associated with moving water such as creeks, rivers, and ephemeral streams) and some wetlands maximizes edge habitat. Moreover, multiple vegetative strata associated with some riparian types provide diverse nesting and feeding areas. Where tall shrubs and trees are present, the cooler, more humid microclimate is less harsh in summer than the upland areas. Lotic riparian corridors are important migration routes for some wildlife species and connect forest habitats (Thomas et al. 1979).

1 W. MacKenzie, Research Ecologist, B.C. Ministry of Forests, Research Branch, pers. comm., 1998.

Riparian areas are important corridors for bird movement and contain a higher avian diversity than adjacent uplands (Knopf and Samson 1988). For example, most (82%) breeding bird populations in shrub and dry forest communities of Colorado were in riparian vegetation, and 42–44% were exclusively within riparian habitats (Knopf 1985). Raptors also make disproportionately higher use of riparian habitat (Knight 1988). Similarly, small mammals make greater use of riparian habitats ($p < 0.05$) than the transitional and upland areas (Cross 1985). Riparian areas are particularly important to wildlife species at risk in British Columbia. In total, 84 terrestrial wildlife species at risk use riparian areas for all or part of their habitat needs (Stevens et al. 1995).

Lotic riparian areas, generally, have high biological diversity and productivity relative to the adjacent uplands; however, wetlands such as fens and bogs have relatively low diversity and restricted biomass production. Riparian areas are usually not fragile or static; they can be very resilient and dynamic. It is important, therefore, to separate changes due to resource use from those due to natural disturbance (Winward 1986). Riparian areas have evolved to withstand various natural disturbances. In lotic ecosystems, flooding is the most frequent disturbance of riparian zones, resulting in sediment deposition, bank cutting, and debris torrents (Agee 1988). Landslides, wind, and fires (Stevens et al. 1995) also naturally influence all riparian areas. Natural erosion and deposition rates can be high, and can be a driving force in riparian ecosystems, particularly in large fluvial systems (Winward 1986). Riparian areas are subject to modifications through grazing, browsing, bedding, burrowing, and damming by wildlife. For example, moose (*Alces alces*), mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) can modify the structure, abundance, and composition of riparian vegetation through grazing and browsing (Kay 1994).

Grazing or browsing by livestock can also modify riparian ecosystems. Stevens et al. (1995) outlined many of the potential impacts of livestock use:

1. reduction or elimination of vegetation through grazing, browsing, or trampling;
2. changes to vegetation structure;
3. selective destruction of vegetation through over-consumption, trampling, or lowering of the water table;
4. indirect erosion through reduction of plant root structure;
5. contamination of water with feces or sediments; and
6. degradation of wildlife populations through the degradation of their habitats.

Unlike wildlife species, however, the degree, timing, and frequency of livestock disturbance can be controlled.

1.2 The Forest Practices Code

Sustainable use of the range resources in riparian areas in British Columbia is legislated under the authority of the *Forest Practices Code of British Columbia Act* (FPC). The FPC designates riparian management areas in which most forest practices are greatly restricted (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). Range use is treated separately in the Riparian Management Area Guidebook (RMAG) because of the "unique effects and management constraints of range use." In fact, there are no setback requirements for grazing, as there are for other resource activities in some riparian types. Livestock grazing can therefore prominently influence riparian areas and must be appropriately prescribed to ensure the integrity of the ecosystems.

The RMAG suggests range use in riparian areas that is consistent with the following objectives:

> "minimize or prevent impacts of…range uses on stream channel dynamics, aquatic ecosystems, and water quality of all streams, lakes and wetlands," and

> "minimize or prevent impacts of…range use on the diversity, productivity, and sustainability of wildlife habitat and vegetation adjacent to streams, lakes and wetlands…"

The RMAG defines appropriate range use in terms of the maintenance of the "properly functioning condition" (PFC) of riparian areas. PFC is maintained when the effects of range use on the riparian habitats are, on average, small and within the range of natural variability. PFC is also maintained when the effects of range use are large and exceed the natural variability, but occur in no more than a small portion of a given habitat unit (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). The RMAG also suggests target conditions for range use of stream, wetland, and moist riparian habitats (Appendix 1) to ensure maintenance of PFC. The RMAG also recognizes that some localized over-use of riparian areas will occur and suggests that these areas be identified during range use planning. Most of the RMAG guidelines are not quantitative, and individual managers have the flexibility to determine levels of "significant" or "excessive" changes. Appropriate range use of riparian areas should be determined by the degree of disturbance caused by the range activity relative to the natural levels of disturbance. Often, however, the quantitative information on natural ecosystem conditions and variability needed for objective determinations is lacking.

1.3 Objectives

New information, specific to the conditions prevalent in British Columbia, is needed to develop objective guidelines that will assist in prescribing range use in riparian areas. Some of this information can be adapted or synthesized from existing sources, but original research and monitoring to establish a sound ecological rationale are also required. This information will refine our understanding of the structure and function of riparian areas, and the level and frequency of natural disturbances; and will provide objective assessments of the impacts of range activities. An ecologically centred database, incorporating all important values, would assist range use planning that follows the regulations set forth in the RMAG and adheres to the intent of the FPC.

Before specific research projects on the effects of livestock grazing in riparian areas are begun, though, there is a need to compile existing information, review field situations, and analyze research priorities. The general objective of this analysis is to develop a logical basis for research and extension on livestock management in riparian areas of British Columbia.

The information needs for the planning and management requirements under the FPC are emphasized. The specific objectives are:

1. to review and compile existing scientific information on livestock influences on, and interactions with, riparian areas relevant to British Columbia; and
2. to develop recommendations to guide range practices research for riparian areas in the Interior of British Columbia.

2 SCOPE

The current knowledge of livestock–riparian interactions was assessed by reviewing published literature. The review focused on information relevant to British Columbia, though not necessarily limited to its geographic boundaries. The literature on riparian ecology, and interactions with various resource management activities, is extensive. One bibliography alone listed 3252 references related to riparian research and management (van Deventer 1992). Moreover, several existing literature reviews and synthesis papers from other jurisdictions exist on the subject (Gifford and Hawkins 1978; Thomas et al. 1979; Blackburn 1983; Kauffman and Krueger 1984; Skovlin 1984; Winward 1986; Fleischner 1994; Belsky et al. 1999). The literature review in this analysis, while broad, is not meant to include all riparian-related literature. This literature review is intended to characterize the issues in British Columbia and place them in the context of the current state of knowledge.

The effect of livestock use on the transmission of waterborne diseases is addressed in a separate analysis (Newman et al. 2000) because of the specific nature of that literature. The effects of livestock use on water quality are, therefore, not detailed in this review.

This study also did not review information specific to the Coast Mountains and Islands physiographic region of British Columbia (Valentine et al. 1978), including the Mountain Hemlock, Coastal Western Hemlock, and Coastal Douglas-fir biogeoclimatic zones (Figure 1). Range use of Crown lands in these ecosystems is less than 0.5% of the provincial resource and is not generally considered part of the range resource (Wikeem et al. 1993).

Any body of information on a given discipline is a mixture of scientific experiments, unreplicated monitoring, empirical observations, synthesis and reviews, opinion, and theories. This is true of the literature reviewed for this analysis. Kauffman and Krueger (1984) reviewed riparian literature and observed that many studies had not followed the scientific method. However, non-scientific studies have value in this type of synthesis, and therefore some have been included. Literature cited in this analysis is prefaced or qualified with explicit references about the type of information reviewed (experiment, observations, literature review). Probabilities, as reported by the authors, are included from studies or experiments where a statistical analysis was conducted. Statements of fact included in this document that are not followed by measures of confidence did not have probabilities reported in the original document.

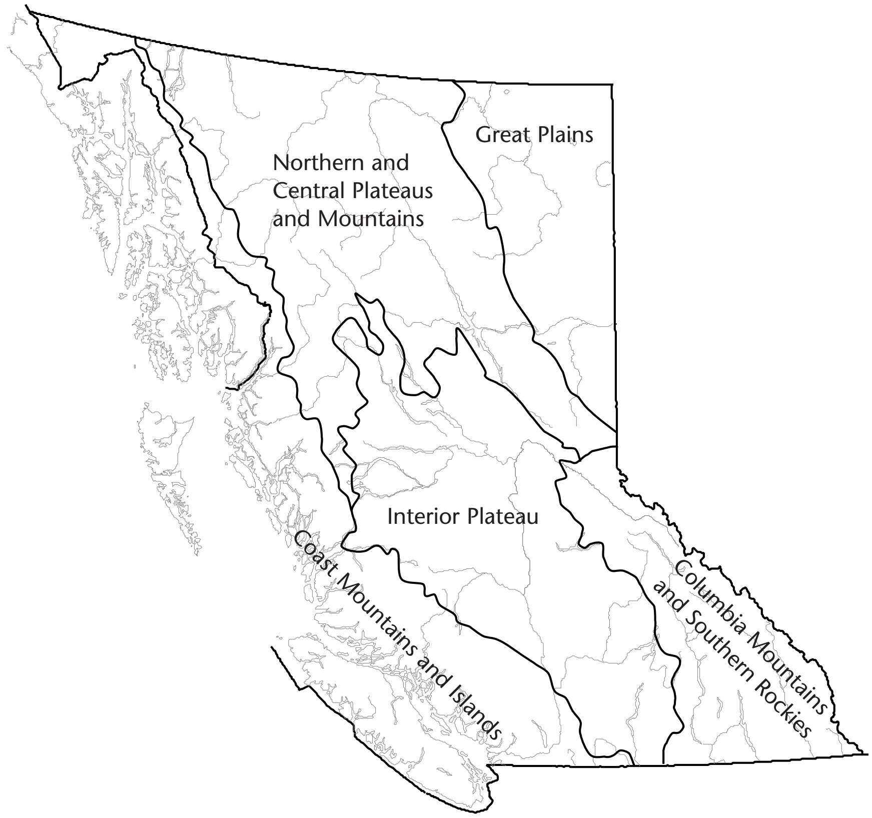

FIGURE 1 *Physiographic regions of British Columbia.*

3 LITERATURE REVIEW

3.1 Overview of Riparian Areas in British Columbia's Rangelands

Extent The riparian areas of British Columbia, comprising wetlands, stream edge, and lakeshore riparian zones, are extensive. In the central Interior and northern British Columbia alone, approximately 880 000 ha of wetland meadows in the Sub-Boreal Spruce (SBS) and the Sub-Boreal Pine–Spruce (SBPS) biogeoclimatic zones can be used for hay production and grazing (Wikeem et al. 1993). The Ministry of Forests recognizes a "wetland" range type in British Columbia for inventory and management, although no readily available estimate exists for the extent of this range type (B.C. Ministry of Forests 1994). Previous attempts to estimate the wetland range type are rudimentary and subjective, because of a lack of inventory and research to provide objective information (B.C. Ministry of Forests 1980). Organic meadows, which incorporate primarily wetland riparian types, comprised 8000 ha of the Bulkley–Northwest Region's (now part of the Prince Rupert Forest Region) range resource, although only 3000 ha were used for grazing or hay cutting at that time (B.C. Ministry of Forests 1980). Meadows made up 20 000 ha and 278 000 ha of the range resources in the Kamloops and Cariboo forest regions, respectively, in that same period. Area of wetland range for other regions was not estimated. Individual range unit reports indicate that meadow types comprised up to 10% of the area of individual range units in the Peace River area, and up to 15% of the area of range units in the Prince George area (B.C. Ministry of Forests 1980).

Forage Production and Use Riparian zones are important and productive sources of forage on Crown rangeland. In fact, the most common agricultural use of wetlands in British Columbia's Interior is grazing (van Ryswyk et al. 1992). Sedge (*Carex* spp.) production on interior meadows ranges from 560 to 6000 kg/ha and can be increased with fertilization (Wikeem et al. 1993). Forage production from wetland range types averages 1500–5000 kg/ha (B.C. Ministry of Forests 1994). The level of use is unknown for most wetland types. At higher elevations of the Interior Plateau and in the Chilcotin River valley, about 65% of the total wetlands are suitable for hay production and pasture for domestic livestock (van Ryswyk et al. 1992).

3.2 Livestock Behaviour and Diet in Riparian Areas

Behaviour and Habitat Selection In arid and semi-arid landscapes livestock concentrate around sources of water: "the distribution of water may influence the distribution of cattle (*Bos* spp.) and the utilization of forage more than any other single factor" (Jardine 1919). In general, cattle make disproportionate use of riparian areas relative to the uplands because riparian areas contain more palatable forage, are closer to water, and have favourable microclimatic conditions (Skovlin 1984).

In an arid range in New Mexico, livestock use of vegetation decreased nearly linearly with distance from available water (Valentine 1947). Similarly, livestock grazing in sagebrush (*Artemisia* spp.)–bunchgrass communities in Idaho and Nevada was observed to decrease with distance from water and shade (Phillips 1965). In their assessment of livestock distribution in a ponderosa pine (*Pinus ponderosa*)–Douglas-fir (*Pseudotsuga menziesii*) ecosystem in Oregon, Gillen et al. (1984) found that, although wet meadows accounted for only 3–5% of the range unit they studied, that habitat accounted for 24–47% of the livestock observations. Liggins (1999) studied cattle habitat use and behaviour in seven habitat types in the SBPS biogeoclimatic zone near Williams Lake, B.C. Riparian habitat types received high levels of use, especially compared to forest types and during early morning foraging. Platts and Nelson (1985) visually estimated livestock use of arid rangelands in Idaho, Nevada, and Utah and concluded that streamside vegetation was used twice as heavily as the adjacent uplands. Bryant (1982) found that livestock selected the riparian zone over the uplands throughout most of the summer grazing season in a dry forest ecosystem regardless of aspect. Furthermore, Pinchak et al. (1991) observed that 77% of livestock use was within 366 m of water in arid Wyoming habitats, and wetlands were one of the habitats most preferred by cattle.

The season of use may influence the amount of time livestock spend in the riparian zone. Smith et al. (1992) examined habitat selection by cattle in a greasewood (*Sarcobatus* spp.) steppe at different seasons. Cattle use of the river channel and floodplain was proportionally greater than predicted by the area of these habitat types in spring and summer. However, cattle use of the floodplain was not out of proportion relative to area available in the autumn months. Livestock use of the upland was always proportionally less than expected by the available area. In another study, cow–calf pairs and yearlings spent 66% of their time in riparian zones during the summer period (July to early September) in northeast Oregon, but only 12% of their time in this zone later in the season (Bryant 1982). In contrast, Liggins (1999) found that cattle use of riparian habitat types remained high, or increased, throughout the grazing season.

The condition and management of the adjacent upland also contribute to livestock behaviour and habitat selection. This can be attributed to both accessibility and quality of forage in the upland. Logged ponderosa pine–Douglas-fir forest communities in Oregon were preferred by cattle second only to wet meadows (Gillen et al. 1984). In another study, cattle showed a preference for riparian habitats over clearcuts, second-growth forests, and burned areas of a mixed conifer–oak (*Quercus* spp.) habitat in the Sierra Nevadas of California (Kie and Boroski 1996). The average distance from streams to cattle locations was less ($p < 0.01$) than the average distance from streams to random points within the cattle range (with a total home range of 163–279 ha). The authors concluded that the "…relative lack of herbaceous forage on upland sites likely contributes to cattle preferences for riparian habitats…" (Kie and Boroski 1996). This factor can be particularly significant in British Columbia where logging activity and road construction have provided access to upland areas not previously available for grazing. Conversely, forest ingrowth and encroachment from fire suppression in British Columbia have decreased the available upland forage (Daigle 1996) and may be concentrating livestock use in the riparian belt.

Livestock preference for riparian zones may also be due to favourable topography because livestock tend to avoid steep slopes or rugged terrain. Riparian zones generally occur in valley bottoms or on areas of gentle slope. Roath and Krueger (1982) concluded that cattle use of riparian vegetation was increased partly by the limitations on livestock movement imposed by the surrounding steep slopes. Bryant (1982) found that slopes less than 35% received 85% of cattle use, which may have contributed to greater use in the riparian zone. Pinchak et al. (1991) found that cattle preferred slopes less than 7% in the arid foothills of Wyoming.

The type of grazing system may also influence livestock habitat selection. Cattle occupied the riparian zone of a Douglas-fir–ponderosa pine habitat 2.4 times more under a continuous grazing system than under deferred rotation in early season, but approximately the same amount of time in both habitats in the fall (Gillen et al. 1985). This study also found that cattle occupation of riparian areas did not respond to small differences in temperature or humidity. In a study using low cattle stocking rates in a pine–fir forest in Nevada, cattle were observed in the riparian zone only during a period of drought (Huber et al. 1995).

Little is known about cattle behaviour and habitat selection in more mesic (wetter, cooler) ecosystems where the upland microclimate is more favourable, and water sources and palatable forage are more evenly distributed. Bryant (1982) observed that when mean ambient temperature dropped and mean relative humidity increased, livestock moved out of the riparian zones into the upland. No studies could be located that directly investigated cattle behaviour and habitat selection in more mesic habitats.

Livestock Diet Not surprisingly, a wide variety of riparian plant species is represented in livestock diets because of the high diversity of riparian ecotypes used for livestock production. Selection of forage and browse species depends mainly on the palatability of the available vegetation, which varies with the season of use, current weather patterns, and the phenology of the plants. Generalizations about diet and preference for individual plant species are difficult to make because palatability varies widely. Both cattle and sheep

(*Ovis aries*) prefer leaf material over stem and woody tissue, and green (or young) plants to dry (or old) plant material (Arnold 1981). Cattle are primarily grazers, although they will readily browse when green grass is not available (Holechek et al. 1998).

The studies of cattle diets in riparian vegetation types reinforce the theory that cattle are primarily grazers. Grasses, predominantly Kentucky bluegrass (*Poa pratensis*), formed 80% of cattle diet on montane riparian meadows in northeast Oregon (Holechek et al. 1982), even though grasses made up only 67% of the cover in the plant community. Hayes (1978) observed that water sedge (*Carex aquatalis*) was highly palatable to cattle. In a replicated study of cattle diets in riparian vegetation, Huber et al. (1995) tested three levels of grazing use: light grazing (1500 kg/ha forage remaining), moderate grazing (1000 kg/ha forage remaining), and an ungrazed control. They concluded that diets were not influenced by stocking ($p > 0.10$), but did shift in composition to more grasses and grass-like plants as the grazing season progressed. Overall, sedges and rushes (*Juncus* spp.) comprised 30% of cattle diets in the pine–fir forest in Nevada (Huber et al. 1995). Cattle diets in a mixed conifer–oak habitat of California were primarily forbs in the riparian areas (Kie and Boroski 1996). In fact, cattle diets in the riparian vegetation types included very few woody species such as willows (*Salix* spp.) or grasses. Cattle diets in the Blue Mountains of Oregon included primarily grasses early in the grazing season. However, diet composition shifted to increased use of shrubs (of which willows comprised approximately 30%) as the grasses became drier, more mature, and presumably less palatable (Roath and Krueger 1982).

Riparian forage can be of high quality. Crude protein of riparian forage in southwest New Mexico was 4.1% higher ($p < 0.01$) than that of the adjacent upland forage (Neel et al. 1986). As with other forage variables, quality can vary with soils, microclimate, season, and previous use; therefore, these data must be used cautiously.

Little information on cattle weight gains on riparian forage is available. Daily gains from wetlands in British Columbia are within the general range of values for grazing on native forest vegetation. Average daily gains on sedge meadows range from 0.22 to 0.24 kg in the IDF to 0.64 kg in the Montane Spruce (MS) biogeoclimatic zones (Wikeem et al. 1993). Cattle gained an average of 0.41 kg/day on a riparian diet dominated by Kentucky bluegrass in northeastern Oregon (Holechek et al. 1982). Comparisons of diets from different areas are difficult, however, without information on specific breeds, class and age of livestock, and the type of management system.

3.3 Effect of Livestock on Bank Shape and Stability

Livestock use of the riparian zone may influence bank shape and stability in two ways: by direct sloughing or shearing of the bank, or by changing or reducing vegetation cover, thereby altering the stability of bank materials.

Direct Sloughing and Shearing Livestock can physically damage stream banks due to pressure from their hooves. The static load of a cattle hoof is reported to range from 2.8 to 10.9 kg/cm^2. These loads can increase by 2–4 times when the animal travels (Abdel-Magid et al. 1987). Excessive livestock trampling can break down stream banks, resulting in lowered (flattened) bank angles and a reduction in bank undercutting (Platts 1981; Kauffman et al. 1983; Hubert et al. 1985; Platts and Nelson 1989) as well as accelerated bank erosion (Kauffman and Krueger 1984).

Platts and Nelson (1989) compared stream characteristics in a sagebrush–bunchgrass community with season-long grazing (May to September) at 90% use to an ungrazed area. They observed that the ungrazed area generally had steeper bank angles, and larger bank undercuts. The flattened bank angles observed in the grazed areas can result in increased stream channel width and decreased water depth, which may be detrimental to fish populations. A reduction in bank undercutting is also considered detrimental to fish populations (Platts 1981). Marlow and Pogacnik (1985) found that soil moisture content affected ($r^2 = 0.85$) stream bank susceptibility to trampling and that postponing grazing until after stream banks had dried to less than 10% soil moisture content would protect riparian soils from damage.

Reduced Vegetation Cover Vegetation strongly influences the stability and shape of the stream bank through its influence on erosion rates (Hickin 1984; Ikeda and Izumi 1990; Millar and Quick 1993; Beeson and Doyle 1995) and deposition rates (Clary et al. 1996). Livestock can detrimentally influence the erosion–deposition cycle. They can both accelerate soil erosion (bank degradation) and decrease deposition on stream banks (bank building) during flood events, largely due to excessive removal of vegetative cover (Platts 1981; Kauffman et al. 1983; Myers and Swanson 1992). The consequence of both increased erosion and decreased deposition along the stream bank can be reduced water quality through increased suspended sediments, and increased in-channel deposition. Both results can greatly degrade aquatic habitats. Moreover, transport of soils and fine organic materials from the site decreases the fertility of the soils and can reduce capacity to support vegetation of any type (Brady 1984).

Soil with 16–18% root volume had 20 000 times the resistance to any level of erosion as did soil without roots (Smith 1976). A study of stream bank stability in British Columbia evaluated erosion before and after a flood event at 748 bends on the Salmon River, Deadman River, Bonaparte River, and Chase Creek (Beeson and Doyle 1995). The authors found that bends without vegetation were nearly 5 times more likely to erode ($p < 0.001$) than vegetated sections of these rivers during flood events. Major erosion events (bank retreat exceeding 45 m) were 30 times more common on unvegetated bends.

In a simulated stream channel, vegetation types with different morphological characteristics were tested for their ability to both entrap and retain sediment (Clary et al. 1996). The presence of vegetation increased sediment entrapment by 700% over unvegetated surfaces. Sediment entrapment increased with decreasing vegetation length (down to approximately 1.5 cm) because longer vegetation tended to deflect water flow away. Conversely, and for apparently the same reason, sediment retention was greatest with longer vegetation. The combined effects of deposition and retention were maximized with flexible vegetation ranging in length from 1.5 to 15 cm.

Stream Channel Characteristics The breakdown of stream banks by livestock trampling and the loss of stabilizing vegetation by excessive grazing can lead to secondary impacts on certain stream channel characteristics. For example, channel width and depth, bank water depth, and channel bed material are often reported to be affected by livestock grazing in riparian areas (e.g., Platts 1981; Kauffman et al. 1983; Hubert et al. 1985; Platts and Nelson 1989). Hubert et al. (1985) found increased channel width and decreased channel depth ($p < 0.05$) on heavily grazed reaches of two Wyoming streams. The authors also reported that channel width was negatively correlated ($r = -0.527$, $p = 0.032$) with brook trout abundance and that channel depth was positively correlated ($r = 0.671$, $p = 0.006$) with brook trout abundance. However, other studies conclude that livestock do not significantly influence these characteristics (Hayes 1978; Siekert et al. 1985). For example, stream channel morphology was not influenced by grazing over a 9-year period in an oak–ponderosa pine community in New Mexico (Medina and Martin 1988). The authors concluded that large-scale hydrologic and geomorphic processes were responsible for the stream changes observed. Similarly, intense, short-term grazing in the spring had no adverse affects on stream channel morphology in a semi-arid region of Wyoming (Siekert et al. 1985).

Other stream channel characteristics, such as sinuosity, riffle-to-pool ratio, and degree of stream bend, are highly dynamic and dependent largely on the watershed basin geology and channel materials (Skinner 1994). Even so, a few studies report detrimental changes to these characteristics resulting from livestock grazing in riparian areas (e.g., Marcuson 1977; Hubert et al. 1985).

Livestock Management It is reasonable to expect that livestock impacts on bank shape and stability will increase with increasing livestock use. For example, Hayes (1978) observed that bank degradation increased with increased cattle concentration and increased forage and browse use along stream banks in a mixed lodgepole pine (*Pinus contorta*)–Douglas-fir–spruce (*Picea* spp.) forest in Idaho, particularly in late summer and early fall. Similarly, stream bank loss from an area grazed in late summer at moderate stocking (0.5 animal unit month [AUM]/ha) and use (50–60%) was 3.3 times greater ($p < 0.05$) than the ungrazed area in a ponderosa pine community in eastern Oregon (Kauffman 1982).

Some studies report no statistically significant effects on bank shape and stability due to level of grazing[2] (e.g., Buckhouse et al. 1981; Marlow and Pogacnik 1985; Bohn and Buckhouse 1986; Marlow et al. 1989). For example, a 3-year study in southwest Montana found little direct relationship ($r^2 = 0.06$) between stream bank damage and level of cattle use (Marlow and Pogacnik 1985). In a 3-year study of a montane area in Oregon, various grazing treatments applied at a moderate stocking rate (0.3 AUM/ha) resulted in no difference on the erosion rate of stream banks compared with the control area (Buckhouse et al. 1981). The authors observed that most erosion occurred in the winter due to flooding and ice scouring, independent of the grazing treatment.

The inconsistencies among studies examining livestock management impacts on bank shape and stability are partially due to the large diversity of stream channel types and associated riparian zones that occur. Many factors,

2 Belsky et al. (1999) caution that studies reporting a lack of statistical significance may have stochastic or design problems such as high variability among treatment plots or insufficient recovery periods after protection from grazing. The authors cite Peterman (1990) who argues that studies with few treatment replications or high spatial variability will have low power (i.e., poor ability) to detect environmental change.

other than livestock use, determine bank shape and stability. Church (1992) suggests that the most important of these include:

1. the flood regime characteristics of the stream;
2. the amount, timing, and nature of sediment and debris delivered to the stream;
3. the nature of the materials through which the stream flows;
4. the local geological history of the area;
5. the local climate;
6. the nature of riparian vegetation;
7. human modifications of the channel (direct effects); and
8. land-use practices (indirect effects), including livestock management.

A universally appropriate level of use, or grazing system, is unlikely to exist for riparian areas. Livestock management strategies in riparian areas should be conditioned by the watershed characteristics of the area (Myers and Swanson 1992). For example, in the IDF and MS zones of British Columbia, the topography is characteristically flat-lying Interior Plateau physiography. The hydrology is snowmelt-driven and the valley bottoms are commonly composed of glacial outwash materials. These watersheds typically have channels with relatively common morphologies and associated riparian zones and will likely have similar susceptibilities to disturbance by livestock.[3] However, watersheds outside of these areas may have substantially different responses to disturbance by livestock.

3.4 Effect of Livestock on Riparian Plant Community Structure and Function

Livestock use can alter the structure and function of riparian plant communities in several ways. Grazing, browsing, and trampling can change the quantity and composition of plant species, as well as the quantity and depth of plant roots. Livestock can also change the vertical structure and distribution of vegetation. Moreover, selective removal, and/or trampling damage, can alter the age structure of plant communities (Skinner 1994).

Depth and Stability of Root Zone Despite the important influence that plant roots exert in stabilizing riparian terrain, little information is available on the amount and type of plant root systems necessary to maintain stability under different riparian conditions. Direct relationships between the amount of herbage removal and root structure is largely unknown for riparian plants; however, the general relationship is well understood for upland forage species. For example, Weaver (1950) found a progressive decline in the root mass of little bluestem (*Andropogon scoparius*) with increasing grazing intensity.

In ecosystems where they naturally occur, a layer of deeply rooted sedges or grasses along a stream edge has been termed a "universal feature of excellent ecological condition" in the riparian zone (Winward 1986). When replaced by Kentucky bluegrass, Winward (1986) concluded that the changed plant community resulted in very unstable soils. The amount of grazing and browsing that can be sustained on riparian areas without detrimental root loss and destabilization of riparian soils is unknown.

3 D. Hogan, Research Scientist geomorphology, B.C. Ministry of Forests, Research Branch, pers. comm., 1999.

Grazing Effects on Herbaceous Vegetation Selective grazing by livestock can influence the composition of herbaceous vegetation in the riparian zone. A comparison of a 30-year exclosure to an area continuously grazed at 65% use in northern Colorado showed that total vascular plants and grass canopy cover were greater ($p < 0.05$) in the exclosure (Schulz and Leininger 1990). Twice as much plant litter was recorded in the exclosure and 4 times more bare ground occurred in the grazed area. Moreover, grazing shifted the composition of grasses away from fowl bluegrass (*Poa palustris*) to Kentucky bluegrass. Conversely, canopy cover of other riparian species such as tufted hairgrass (*Deschampsia caespitosa*), Nebraska sedge (*Carex nebraskensis*), and beaked sedge (*Carex rostrata*) were similar ($p > 0.05$) in an area grazed at 65% use and in a 30-year exclosure. Weaver and Darland (1948) also observed a shift to Kentucky bluegrass along a creek with increasing grazing intensity on the mid-grass prairie in Nebraska. They concluded that the shift from native forages to Kentucky bluegrass was an early sign of habitat degradation. Kauffman (1982), however, found no overall significant differences ($p > 0.05$) in species diversity, species richness, or species equitability in riparian plant communities grazed at 50–60% use in late summer compared with an ungrazed control.

Martin (1993) compared the effects of spring–fall grazing on the shoreline vegetation of two pothole wetlands to three fenced potholes excluded from grazing for 20 years on Becher's prairie in British Columbia. The plant community in both grazed and ungrazed riparian areas shifted to Kentucky bluegrass and needle-and-thread (*Stipa comata*) over that time. The living plant cover in the grazed areas increased from 44.1 to 62.4%, while cover in ungrazed areas remained relatively stable, increasing from 60.3 to 62.3%. Season-long grazing along the banks of water reservoirs of the Missouri River resulted in both a 42% decline of cover and a 75% decline of the standing crop biomass compared with an ungrazed control (Hoffman and Stanley 1978). Grazing did not influence the average number of plant species (14.9). The authors noted that the mosaic of shifting plant populations resulting from regular flooding kept the shore vegetation at an early seral stage and made an assessment of the level of use by livestock difficult.

Other range practices such as hay cutting may affect the plant species composition of wetlands. Plant species richness increased ($p < 0.001$) in a saline marsh in California after burning (De Szalay and Resh 1997). The increase was attributed to colonizing plant species. The same habitat did not increase in species richness following mowing of the vegetation.

Livestock can also affect plant biomass directly by removal and indirectly by the subsequent effect on production. Grazing can stimulate or diminish plant production depending on the timing, intensity, and frequency of defoliation. Two years of cattle grazing on beaked sedge stands increased shoot production by 27.4% ($p < 0.05$), although the grazing effects may have been confounded by disproportionately higher rodent use in the ungrazed exclosures (Allen and Marlow 1992). A single-year study in California on a Nebraska sedge meadow showed that grazing decreased residual herbage and shoot heights of spring regrowth, although it did not change the rooted shoot frequency or density of sedge (Ratliff and Westfall 1987). Seasonal grazing of riparian areas in a big sagebrush ecosystem of northern Nevada was shown to decrease graminoid biomass by 50% ($p < 0.01$), and resulted in lower plant height ($p < 0.01$) than vegetation in an 11-year exclosure (Clary and Medin

1990). Schulz and Leininger (1990) recorded approximately twice the standing crop production in a 30-year exclosure (2410 kg/ha) than in an area continuously grazed at 65% use (1217 kg/ha). Bryant (1985) tested the effects of various grazing systems for their effect on riparian plant communities in the Blue Mountains of northeast Oregon. While the plant community composition did not change, annual herbage production increased 2–3 times with rest–rotation, deferred rotation, and short-duration–high-intensity grazing systems compared with season-long grazing at 70% use. Complete exclusion of grazing increased herbage production by 5 times. Smith (1973), however, found no difference in production of grazed and ungrazed whitetop (*Scolochloa festucacea*) in prairie wetlands.

The timing, amount, and frequency of grazing that can be sustained in riparian areas without detrimental effects on the plant community is poorly understood. Different plant species respond differently to grazing, and individual species response may vary depending on the phenological and physiological stage of the plants.

Browsing Effects on Shrub and Woody Vegetation Excessive browsing is detrimental to shrub communities and is often associated with overuse of the entire range resource. Cattle will often browse more heavily on overgrazed range. In fact, dead and dying willows were used as one of the first "good indicators" of overgrazing (Jardine 1919). More recently, Kauffman and Krueger (1984) concluded from a literature review that excessive use of woody vegetation along streams could generally be termed negative. Note that the absence of shrubs and trees from a riparian area is not necessarily an indication of habitat degradation. Not all riparian plant communities have a shrub or tree component. For example, 10 of 16 wetland plant communities in the dry, cool IDF biogeoclimatic subzone in British Columbia do not have a tall-shrub or tree layer (Steen and Roberts 1988).

Most of the studies investigating livestock influence on riparian shrubs relate to the effects on willows. In riparian ecosystems, willows represent an important shrub genus. In arid grassland and steppe vegetation, the willow community may be the only tall shrub represented in either the riparian or adjacent upland systems. The response of willows to livestock browsing appears to be highly variable. Willow biomass declined ($p < 0.01$) at a site stocked at 2.2 AUM/ha on the Great Plains in northeast Colorado (Sedgwick and Knopf 1991). However, the investigators noted that the biomass removal by livestock was generally a minor component of total biomass removal compared with that removed by flooding. A season-long grazing system in a sagebrush–bunchgrass zone was shown to decrease the density of sandbar willow (*Salix exigua*), but did not influence the density of Pacific willow (*Salix lasiandra*) (Shaw 1992). Grazing at light to moderate stocking in either the fall or the spring did not influence the density of either willow. Billig (1992) reported increases in willow density ($p < 0.05$) in areas of Colorado from which cattle had been recently excluded. A grazed riparian area (level of grazing not quantified) in Nevada had less willow ($p = 0.03$) and overstory vegetation abundance ($p < 0.01$) than a 30-year exclosure (Ammon and Stacey 1997). Peach-leaf willow (*Salix amygdaloides*) recovered 10 years after livestock exclusion from a streamside riparian area in the sagebrush steppe of southern Washington State (Rickard and Cushing 1982).

Browsing may also reduce willow populations by restricting plant reproduction. Heavy browsing by native ungulates in Yellowstone Park eliminated willow seed production from an original 109 000–583 000 seeds/m^2 of female canopy cover (Kay and Chadde 1992). The authors concluded that light browsing may stimulate willow growth but the elimination of seed production has a long-term effect on the community resulting from decreased recruitment of new individuals. Long-term browsing may, therefore, reduce willow populations by affecting reproductive success.

A combination of trampling and browsing can also alter the structure of willow populations. Krueger and Anderson (1985) showed that 41% of willow stands in a riparian habitat within a ponderosa pine community were tunnelled (the lower branches were removed, forming paths through the normally intermeshed vegetation) by cattle. On average, the tunnels were 0.75 to 0.95 m high and theoretically could increase the visibility and access to wildlife in the willow thickets, thus increasing the risk of predation. Schulz and Leininger (1990) reported that willows were both older and larger in a 30-year exclosure compared with a grazed area, indicating that cattle browsing had affected both the age structure and size of the plants.

Browsing effects on willows are not all negative. Some riparian species, such as Drummond willow (*Salix drummondiana*) and Booth willow (*S. boothii*), depend on newly developed gravel bars, freshly broken banks, or seasonal deposition of sediment for establishment (Winward 1986). Soil disturbance by livestock could help the establishment of these species.

Browsing can also affect riparian trees, primarily by reducing or eliminating regenerating trees, mainly aspen (*Populus tremuloides*) and cottonwood (*Populus trichocarpa*). Jardine (1919) remarked that cattle reduced aspen regeneration and stripped leaves as high as they could reach on overgrazed range. In fact, heavy cattle browsing has been suggested as a technique to control aspen regeneration in the prairie parkland ecosystems, which include areas of the Peace River region of British Columbia (Fitzgerald and Bailey 1984). Kay (1994), using repeat photo comparisons, exclosure data, and a literature review, concluded that excessive native ungulate browsing in Yellowstone Park had reduced tall willow, aspen, and cottonwood communities by 95% since the late 1800s. In his comprehensive literature review, Skovlin (1984) concluded that the negative impacts of heavy or uncontrolled cattle grazing on shrubs and trees was primarily from damage to the regenerative stage of woody plants. Although Kauffman (1982) found no overall significant change ($p > 0.05$) in plant species composition when grazed at 50–60% use in late summer, he did conclude that cattle browsing was affecting the succession of willow and cottonwood communities on instream gravel bars. In this study, alder (*Alnus* spp.) was being replaced by cottonwood in the ungrazed exclosures. Indeed, grazed areas had an average of 13.1 stems/ha of cottonwood, compared with 23.7 stems/ha in the ungrazed controls. In another study, seasonal grazing of riparian areas in a big sagebrush upland in northern Nevada resulted in a 20-fold increase in non-willow, large-shrub biomass ($p < 0.04$) compared with the ungrazed controls (Clary and Medin 1990). The authors concluded that recent browsing by cattle had not greatly affected aspen regeneration because aspen stands were similar between grazed and non-grazed areas.

3.5 Effect of Livestock on Riparian Wildlife and Wildlife Habitat

Livestock influence wildlife populations primarily through modification of wildlife habitats. Some researchers have concluded that the change induced by livestock is "deleterious" to wildlife (Fleischner 1994). With the exception of repeated, heavy grazing, however, these modifications are not necessarily detrimental. Grazing, as with any disturbance, can create new habitats and niches as others are modified or eliminated. In general, the most appropriate measure of the effects of livestock use is not in their impact on a single habitat or site, but how the grazing disturbance is distributed across the landscape in both time and space. The total and relative amounts of habitat at different seral stages and the connectivity between different patches of habitat are important considerations in assessing the impact of livestock on wildlife habitat. The Biodiversity Guidebook for the FPC (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995) provides targets for seral stage distributions, temporal and spatial distributions, old seral stage retention, landscape connectivity, stand structure, and species composition for landscape units. In general, though, these targets represent a "best guess" or negotiated value, and research is required to quantify these parameters.

Sometimes modifications to the habitat of one species can have a detrimental effect on an entire riparian system. For example, the beaver (*Castor canadensis*) is sometimes regarded as a "keystone" wetland species, in that it can completely change the size and character of a riparian area (Kay 1994). Beaver create and maintain riparian areas through their activities. In fact, beaver have been transplanted in some jurisdictions to reclaim degraded riparian areas. Beaver dams hold water and trap sediments, thereby raising the water table and extending the riparian area into adjacent uplands. By reducing peak flow events and augmenting lower water levels in summer, beaver dams regulate the hydrology of the system. Kay (1994) deduced that destruction of willow and aspen plant communities, through excessive browsing by elk and moose, had eliminated much of the beaver habitat and main food source in Yellowstone Park. He added that overgrazing by wildlife on adjacent uplands also contributed to the demise of the beaver by increasing soil erosion, and thereby filling beaver ponds, and decreasing the quality and visibility in the water in the beaver ponds. Presumably, excessive grazing or browsing by livestock would have the same effect on beaver habitats.

Effect on Small Mammals Livestock use influences small mammals primarily by influencing the amount and kind of herbaceous cover. As different small mammals require different types and levels of vegetation for escape hiding cover and food sources, the presence of livestock benefits some species and hinders others.

Martin (1993) compared rodent populations in grazed and ungrazed riparian areas of ponds in the Chilcotin of British Columbia. The rodents were more numerous ($p < 0.01$) in the ungrazed ($n = 58$) than the grazed ($n = 48$) area. Moreover, the proportions of the species differed among the treatments. Voles (*Microtus* spp.) were more numerous in the grazed area ($n = 26$) compared with the ungrazed area ($n = 12$). Conversely, deer mice (*Peromyscus maniculatus*) were more abundant in the ungrazed ($n = 69$) than in the grazed area ($n = 30$). Western jumping mouse (*Zapus princeps*) was trapped exclusively within the ungrazed area ($n = 5$). In riparian areas in a ponderosa pine–sagebrush upland in Colorado, the species richness of small mammals was the same in grazed areas as in three ungrazed exclosures (Schulz and

Leininger 1991). However, there was only a 19% overlap in species between the two treatments. Small mammals were more abundant in the exclosures ($n = 41$) than in the grazed areas ($n = 28$). Much of the difference in abundance was due to western jumping mouse populations ($n = 22$ in exclosures, $n = 1$ in grazed area). Conversely, deer mice responded positively to grazing ($n = 1$ in exclosures, $n = 15$ in grazed area). Kauffman (1982) recorded an average 80% decrease ($p < 0.05$) in populations of deer mice and voles after moderately stocked, late summer grazing in a riparian zone within a ponderosa pine community in eastern Oregon compared with an ungrazed control. However, by the following August, the area had been recolonized to the same species composition and density as occurred pre-grazing. In a montane riparian area of Colorado, 61% grazing use in a willow–bluegrass–sedge community was shown to change the composition of small mammal species, but not the level of complexity and diversity (Tucker 1987). Deer mice dominated in the grazed areas, while western jumping mice were found almost exclusively ($p < 0.05$) in the exclosures. The total number of small mammals trapped in a Nevada riparian habitat within a sagebrush upland was 30% greater in an 11-year exclosure compared with areas grazed season-long (Medin and Clary 1989). Johnson (1982) concluded that grazing might have increased the abundance of small mammal species requiring low vegetation cover and decreased the abundance of small mammals that required the converse. For example, he found that 85% of the mountain voles (*Microtus montanus*) were in the grazed areas. The density and diversity of small mammals in riparian areas were greater in a spring-grazed area in a sagebrush–bunchgrass community in Idaho compared with a fall-grazed site (Clary and Medin 1993).

Effect on Birds Similar to their influence on small mammals, livestock use influences bird populations primarily by influencing the kind, amount, and structure of vegetation. Passerine birds are particularly sensitive to changes in the shrub and tree component. Livestock influences are highly variable, however, and many avian species benefit from livestock grazing. In general, livestock activity promotes birds that favour open, disturbed habitat, and has a negative effect on those that prefer closed, undisturbed areas.

In riparian areas in a ponderosa pine–sagebrush upland in Colorado, the total number of bird species was greater in grazed areas ($n = 21$) than in three exclosures ($n = 14$). Notably, there was only a 15% species overlap between the two treatments (Schulz and Leininger 1991). The total number of bird sightings, however, was the same in both areas. Passerine bird abundance in a shrub–steppe habitat in Oregon was 5–7 times greater in a 40-year exclosure compared with two grazed areas (Taylor 1986), although the level of grazing that created this disparity was not quantified. The author related the differences in the abundance of perching birds to the volume ($r = 0.86$, $p < 0.001$) and height ($r = 0.56$–0.86, $p < 0.01$) of shrubs (predominantly willows). Kauffman (1982) found very few short-term impacts on riparian avian populations subject to late-summer grazing (August 25 to October 1) at moderate stocking (0.5 AUM/ha) and moderate use (50–60%) in a ponderosa pine community. In a montane riparian area of Colorado, 61% grazing use in a willow–bluegrass–sedge community increased the diversity of birds by increasing the complexity of the vegetation structure (Tucker 1987). Wilson's warbler (*Wilsonia pusilla*) was found exclusively in the exclosure and the Lincoln's sparrow (*Melospiza lincolnii*) was twice as abundant ($p < 0.05$)

in the exclosure. Conversely, the American robin (*Turdus migratorius*) was twice as abundant ($p < 0.05$) in the grazed area. Bull and Skovlin (1982) detected no difference ($p > 0.10$) in the number of avian species between three cover classes of deciduous vegetation in a riparian zone in a Douglas-fir–dominated community. When the birds were separated into different guilds based on their habitat preferences, deciduous tree–dwelling birds, not surprisingly, were found to be more abundant ($p < 0.10$) under moderate (15–30%) and high (>40%) deciduous canopy cover. Neither the number of breeding bird species nor total bird density differed between a seasonally grazed riparian area and an 11-year exclosure in a shrub–steppe community in Nevada (Medin and Clary 1991). There were differences, though, in species composition between the grazed and ungrazed area. For example, Vesper's sparrow (*Pooecetes gramineus*) occurred only in the grazed areas, whereas MacGillivray's warbler (*Oporornis tolmiei*) and the American kestrel (*Falco sparverius*) were exclusive to the ungrazed exclosure. In Idaho, Clary and Medin (1993) did not detect any difference in breeding bird species composition, densities, or diversity between spring- and fall-grazed areas in a sagebrush–bunchgrass community.

Stocking rates also influence the effects of livestock grazing on bird habitats. Season-long grazing at a heavy stocking rate (15 AUM/ha) was compared with a light stocking rate (1.5 AUM/ha) for the effect on riparian bird populations in a ponderosa pine community in western Montana (Mosconi and Hutto 1982). Overall, total bird density for each site was similar; however, species composition differed between the sites. Flycatchers, and ground-foraging and foliage-gleaning insectivores were most affected by grazing, while bark-foraging birds were relatively unaffected by grazing. The heavily grazed site had significantly less vegetative ground cover, shrub cover, mid-canopy cover, and shrub volume, yet supported eight species of birds exclusive to that area compared with 12 species that were exclusive to the lightly grazed area.

The timing of grazing can also influence riparian bird populations. Different grazing periods can result in different structures in the plant community or can have impacts on the birds during their crucial nesting or migrating periods. Knopf et al. (1988) examined the effects of winter versus summer cattle grazing on three different guilds of passerine birds in riparian communities in a sagebrush–bunchgrass community in Colorado. The bird guilds were based on their degree of specialization in habitat choice. The authors concluded that habitat generalists, including yellow warblers (*Dendroica petechia*), savannah sparrows (*Passerculus sandwichensis*), and song sparrows (*Melospiza melodia*), did not differentiate between winter- or summer-grazed areas. Conversely, habitat specialists, including willow flycatchers (*Empidonax traillii*), Lincoln's sparrow, and white-crowned sparrows (*Zonotrichia leucophrys*), did not occur or were "accidental" within the summer-grazed area. The difference in habitats was characterized by the presence of decadent willow in the summer-grazed area, indicating that poorly timed grazing had a negative effect on avian habitat.

Grazing may also influence bird populations by reducing the quality of the nesting sites or by exposing them to increased predation through reduced hiding cover. In a riparian habitat within a pine–sagebrush upland of Nevada, Ammon and Stacey (1997) found greater predation of nests ($p < 0.05$) in a grazed area (86%, $n = 6$) compared with a 30-year exclosure (36%, $n = 14$). The authors concluded that the difference was due to less vegetation cover in the grazed area.

Effect on Waterfowl Grazing may affect waterfowl through changes to nesting and brood-rearing habitat or through trampling of nests. Spring duck pair populations in a bunchgrass–shrub community in Montana were observed to increase in rest-rotation pastures excluded from cattle grazing or grazed only during the spring or early summer the previous year. Conversely, duck pairs decreased in pastures grazed in the summer or fall of the previous year (Gjersing 1975). The author concluded that pair populations and duck broods seemed to respond positively to the increased residual plant cover found in pastures that were rested or grazed only in the spring or early summer. Moreover, of the eight nests found during the study, three had been trampled by cattle. The author suggested delaying spring turnout until waterfowl nesting had been completed. Kirsh (1969) found more duck pairs along an ungrazed shoreline and recorded twice the nesting success on ungrazed areas as on grazed shoreline. Whyte and Cain (1981) found that different vegetation communities around three small, artificial ponds in South Texas responded differently to grazing at 2.8–4.2 ha/AUM. They concluded that cattle generally produced a severe effect on shoreline vegetation, and that the effects increased with increasing animal pressure (AUM per length of shoreline). They could find few positive values of grazing for waterfowl or nesting marsh bird habitat. The authors concluded that fencing off shorelines and carefully planned management that allows for rest from grazing at key times would control the impact of cattle grazing on waterfowl habitat.

Grazing dense stands of emergent vegetation may benefit some classes of waterfowl. In a review, Kantrud (1990) found that nearly all studies indicated that reductions in the height and density of tall emergent water plants by either fire or grazing were generally beneficial to dabbling and diving ducks. These waterfowl and their broods prefer wetlands with openings in the marsh canopy. The openings caused by grazing increased the interspersion of cover, which decreased visibility between conspecific pairs and, therefore, allowed for more nesting pairs. Openings in the marsh vegetation were also theorized to improve the invertebrate food resource resulting from the increased habitat heterogeneity. The author also concluded that removal of most or all of the emergent or shoreline vegetation had universally negative effects on waterfowl.

Effect on Fish and Aquatic Habitats Livestock may influence aquatic habitats in three interconnected ways. First, livestock can alter the shape or stability of riparian terrain such as bank shape and slope. Second, livestock can influence the kind and amount of overhanging vegetation that provides shade, hiding cover, and organic matter input for the aquatic system. For example, rainbow trout (*Salmo gairdnerii*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*) habitat is negatively affected by the removal of canopy cover overhanging streams (Boussu 1954). Removal of canopy cover over small streams can result in detrimental increases in water temperature and reduction in organic matter contribution to the aquatic ecosystem (Everest and Harr 1982). Last, livestock can affect water quality parameters such as temperature, suspended solids (from both feces deposition and soil particles from increased erosion), and turbidity.

Most studies of livestock effects on aquatic habitats have focused on small streams in arid ecosystems. These studies generally suggest dramatic impacts from heavy grazing and marginal to no impact from light grazing. In a comparison of exclosures to areas subject to season-long grazing in the Blue

Mountain region of Oregon, Claire and Storch (1983) recorded that 24% of the fish population in grazed areas were game fish, while 77% of the fish population in ungrazed stream reaches were game fish. They noted that the grazed section was devoid of shrub cover and daily water temperatures were 12°F higher than water temperatures inside the exclosures. Moreover, daily fluctuations in water temperature averaged 27°F in the grazed area compared with 13°F inside the exclosure. In a montane riparian area of Colorado, areas excluded from grazing had twice the overhanging vegetation and undercut stream banks ($p < 0.05$) and a narrower and deeper stream channel than areas grazed to 61% use in a willow–bluegrass–sedge community (Tucker 1987). Based on these habitat differences the author concluded that the exclosure produced superior fish habitat. Hubert et al. (1985) studied the effects of grazing on two streams in Wyoming running through a sagebrush-dominated upland. Eight times greater mass of brook trout per kilometre was found on the lightly grazed portion of the creek than on the heavily grazed portion. The authors attributed the difference to increased stream depth, overhanging bank cover, overhanging vegetation, and shaded cover on the lightly grazed stream. No difference in brook trout productivity was found between a lightly grazed stream reach and an area with no grazing. Marginal increases in stream water temperature, turbidity, and fecal coliform resulting from livestock grazing did not influence brook trout densities in a prairie ecosystem in North Dakota (Modde et al. 1986). The study concluded that vegetation cover had the greatest impact on brook trout numbers. Chapman and Knudsen (1980) determined that livestock access (level of use was not quantified) was responsible for decreasing the wetted area by 19% ($p < 0.10$) and overhead cover by 81% ($p < 0.01$) in riparian areas of a red alder (*Alnus rubra*) community in coastal Washington State. Biomass of coho salmon (*Oncorhynchus kisutch*), however, was not affected by livestock access.

No studies directly examining the effect of livestock use on lake or pond aquatic habitats, or on fish populations, were found.

Effect on Other Wildlife Information of the effects of range use on other wildlife species or habitats is very limited. For example, information regarding grazing impacts on herpetofauna (reptiles and amphibians) is minimal (van Woudenberg 1993). Livestock have been implicated in trampling the eggs of western painted turtle (*Chrysemys picta belli*), and compacting the soil, thus impeding nest digging (Martin 1993). However, the author did not collect data on the livestock impacts or use around the western painted turtle habitat, or have a control area for comparisons. Szaro et al. (1985) found that wandering garter snakes (*Thamnophis elegans vagrans*) in New Mexico were 5 times more abundant in an ungrazed streamside riparian area than in a heavily grazed area.

Likewise, information on the impacts of grazing or range use on insects and other invertebrates is scant. The single published research relates to a coastal riparian habitat. In that study, prescribed burning increased the density of invertebrates in a saline marsh dominated by saltgrass (*Distichlis spicata*) in California (De Szalay and Resh 1997). Mowing, however, did not influence the invertebrate populations. Using simulation models, Neckles and Wetzel (1989) emphasized a positive relationship between residual plant cover and invertebrate populations. They concluded that periodic undisturbed seasons must be included in wetland harvest schedules to permit litter accumulations for the aquatic invertebrates.

3.6 Range Management Techniques for Riparian Areas

Managing riparian areas can be difficult because any one section of a stream, lakeshore, or wetland is usually a mosaic of wetland vegetation types. This is true of British Columbia's riparian areas (Runka and Lewis 1981; Steen and Roberts 1988). Grazing systems and other range practices must be developed that are appropriate for the riparian habitats that are most sensitive to grazing impacts. Livestock controls (fencing, salt location, herding) will never be refined enough to differentiate use between small bands of intermixed vegetation. Range management in riparian areas is further complicated because little is known about what constitutes appropriate use for maintaining any given vegetation type or terrain form at any one desired condition (Skinner 1994). On a landscape basis, a mosaic of disturbed, recovering, and protected areas generally maximizes habitat, and consequently species diversity (Skinner 1994). However, the appropriate proportions of these seral stages are unknown. Local disturbance can be detrimental, however, particularly to rare or threatened species. In such instances, unmanaged grazing could lead to serious habitat degradation and to extirpation or extinction of species with restricted distributions.

The options in a riparian area for the range manager are essentially the same for managing the upland portions of a range unit. Livestock can be managed by any of the following, singly or in combination:

1. controlling animal distribution (to prevent animals from concentrating in the riparian zone);
2. controlling the timing of access (to prevent grazing and browsing when riparian soils, plants, or wildlife are most vulnerable to damage);
3. adding adequate rest from grazing to allow for recovery of the riparian vegetation before it is grazed or browsed again; and
4. controlling the intensity of grazing (set the stocking rate of livestock so that there is adequate carryover of vegetation to sustain the plants and soil).

Distribution Techniques The strong attraction of cattle to the riparian habitat in arid and semi-arid landscapes for shade, water, and lush vegetation makes controlling their distribution without exclusion fencing problematic. Skovlin (1984) observed that conventional grazing systems designed for extensive uplands do not necessarily achieve acceptable livestock distribution in the riparian zone because livestock prefer riparian areas. Miner et al. (1992) concluded that the amount of time spent drinking or loafing in a stream area could be reduced by 90% with the use of an off-site water tank. The use of salt blocks on upland sites, and off-site watering, however, were unsuccessful in changing livestock distribution in a dry-forest ecosystem in Oregon (Bryant 1982). Gentle slopes, cool microclimate, available water, and abundant forage were too much of an attraction for livestock. Kauffman and Krueger (1984) concluded that the inability to control livestock distribution was the limiting factor for range use of riparian systems. Furthermore, they surmised that rest-rotation and/or special grazing systems, where the riparian zones are treated as special use pastures, had been the most successful in maintaining functioning condition in the riparian zone. May and Davis (1982) recommended several range management options for maintaining riparian health based on their observations and experience. They suggested herding livestock away from riparian areas, providing off-site diet supplements and water, culling problem animals, and locating trails away from streams to mitigate problems.

Kovalchik and Elmore (1992) proposed that corridor exclusion fencing, riparian pastures, spring grazing, and winter grazing were highly compatible with maintaining willow-dominated riparian plant associations. Conversely, spring–fall pasture rotations, deferred grazing, late-season grazing, and season-long grazing were incompatible with these plant communities and led to overbrowsing of the willows.

Appropriate Timing of Grazing There is no universally appropriate timing of grazing that will mitigate negative impacts in the riparian zone. Individual plant species respond differently to different timing of grazing based on the physiological stage when it occurs. The development, and consequently the response of an individual plant species to grazing or browsing, can vary with geographic location, annually, and seasonally with local weather patterns. Likewise, palatability and regrowth potential can vary widely in an individual species throughout the growing season. Platts (1982) suggested that late-season grazing was best suited for riparian areas because of the following:

1. soils are drier and less susceptible to compaction;
2. plants have set seed and built up carbohydrate reserves; and
3. grazing may be beneficial because the trampling effect would aid some seed establishment.

Others (e.g., Hayes 1978; Kovalchik and Elmore 1992) have found riparian areas most sensitive to damage with fall grazing.

Appropriate Level of Use and Length of Rest Required for Recovery With the wide variety of riparian habitat types and potential effects of livestock use, there is little agreement on what constitutes an appropriate level of use. Some generalizations, however, have been developed through both reviews of the literature and practical experience. Platts (1982) theorized that cattle use greater than 65% altered the riparian zone in arid ecosystems, while use less than 25% had insignificant impacts in those habitats. In a review of literature on grazing effects on riparian areas, Skovlin (1984) concluded that moderate and light grazing (not defined quantitatively) have few irreversible effects. Kauffman and Krueger (1984) concluded that changes to the riparian habitats were insignificant with livestock use under 25%. None of the authors established quantitative thresholds at which level of use started to become detrimental, nor did they address the amount of recovery time necessary after various levels of use.

Little information is available on the length of rest required for recovery of riparian vegetation. Like other variables of interest, this will be highly site-specific, and can be influenced by the level of use, soil types, annual and seasonal weather patterns, and other site attributes. Typically, shrubs require longer periods of recovery than herbaceous vegetation. Special provisions for extended periods of rest may be required to allow for the establishment and growth of new shrubs and trees to a size and/or phenology where they are no longer palatable to livestock, or can reproduce before being browsed.

Other Management Influences Other management variables, such as the kind and class of livestock used, may influence the potential impacts on riparian areas. May and Davis (1982) surmised that sheep have less of a negative influence on riparian areas than do cattle. Platts (1982) also observed that sheep have little effect on streams and the riparian environment; he suggested that it was because they had to be herded daily. Practical considerations may make changing the kind of livestock infeasible and, therefore, of little use as a range management tool in British Columbia.

Little attention has been given to the difference in use and impact on riparian areas by different livestock classes. Similarly, the influence of animal behaviour and the use of selective breeding and culling of problem animals have not been explored.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Most Available Information Is Applicable Only to Arid Ecosystems

Most of the research and literature on range riparian issues has been produced in the western continental United States; as such it relates to the ecosystems and management constraints that predominate there. Little information, beyond general principles, is relevant to most of British Columbia's rangelands. Of the applicable information, most pertains to the BG zone, with some studies in areas comparable with the very dry subzones in the IDF and PP. Very little information exists that is directly relevant to wetter, cooler ecosystems in British Columbia, including important livestock producing areas in the Boreal White and Black Spruce (BWBS), Engelmann Spruce–Subalpine Fir (ESSF), Interior Cedar–Hemlock (ICH), most of the IDF, MS, SBS, and SBPS biogeoclimatic zones. Specific information on livestock behaviour, habitat selection, forage and browse preferences, and impacts on riparian terrain, soils, water, vegetation, and wildlife for riparian areas in British Columbia outside of the BG, PP, and IDF is lacking.

Recommendation #1: Research on range riparian areas in British Columbia must focus on ecosystems outside those that the current body of literature represents. A system should be developed to prioritize which ecosystems need to be addressed.

4.2 Most Available Information Is Applicable to Lotic Ecosystems

Lotic ecosystems include riparian areas associated with moving water such as creeks, rivers, and ephemeral streams. These areas represent an important and sizable component of the riparian resource in the arid western United States (Kauffman and Krueger 1984). The intermountain area of the continental United States alone contains over 19 480 km of streams (Skovlin 1984). Added concern over fish and other aquatic resources in streams in the arid portions of the United States has contributed to much literature on livestock impacts on streamside vegetation, wildlife, and geomorphology.

Lentic riparian areas, or those areas associated with lakes, marshes, and other wetlands are much less studied. Expansive areas of wetlands and wet meadows in central and northern British Columbia (Wikeem et al. 1993) comprise most of the riparian areas used for rangeland. Basic information, such as the preference for different forage and browse species in these systems, and the response of these species to different frequency, intensity, and timing of defoliation, is lacking. Without such information, meaningful range prescriptions cannot be formulated for these riparian types.

Recommendation #2: Research on range riparian areas in British Columbia must include lentic ecosystems, including wetlands and lakeshores.

4.3 Research Has Focused on Contrasting Extremes

Much of the literature is devoted to comparing heavily grazed areas with ungrazed or very lightly grazed areas. Ungrazed controls or reference areas can be useful for establishing baseline information on the structure and function of riparian areas, and for measuring the natural level of disturbance without grazing. However, research contrasting heavy grazing to no grazing has very limited applicability in developing management prescriptions because heavy, uncontrolled grazing is not prescribed on Crown rangeland in British Columbia. Heavy grazing and browsing are well known to be detrimental; further resources need not be expended to confirm this.

Contrasting extremes may be useful in a limited set of circumstances to raise awareness, or to highlight concerns for demonstration. However, it will not build upon the knowledge base necessary to make meaningful management prescriptions for British Columbia's riparian areas.

Recommendation #3: Research on range riparian areas in British Columbia should test the impact of livestock at stocking rates, levels of use, and timing that are normally or feasibly prescribed in British Columbia.

4.4 Appropriate Level of Use Is Difficult to Quantify

A central debate surrounding livestock use of riparian areas is defining what constitutes an appropriate level of use by livestock. It is generally accepted that severe overgrazing and overbrowsing have resulted in many negative changes to riparian areas in North America. There is less information on what constitutes overgrazing in any given system and what ameliorating effects grazing systems, season of grazing, and livestock behaviour modification may have (Buckhouse 1981).

It is also generally accepted (Platts 1982; Kauffman and Krueger 1984; Skovlin 1984) that light grazing (25% use or less) is inconsequential. The actual level at which grazing changes from being benign to detrimental is an important question. Timing and length of recovery for the system, seral stage of the community, and plant community goals (as dictated by land-use planning) all need to be factored into determining the type and degree of use that is acceptable.

An appropriate level of grazing for the system will be determined by the level of grazing or browsing use that is safe for the most sensitive species in that system. "The physiological reaction of plants to grazing should form the basis for development of sound grazing management practices" (Hedrick 1958). Furthermore, individual species may respond differently to grazing or browsing in different habitats (because there will be different resource availability and environmental stresses to aid or hinder the plant's recovery from the grazing disturbance). However, that type of detailed ecophysiological information is lacking for most riparian species. As with other variables, the response of individual plant species to grazing will not be the sole determinant of appropriate range use; the desired plant community goals established during range use planning must also be considered.

Recommendation #4: Research addressing appropriate use in riparian areas in British Columbia must include the physiological response of specific plants within specific habitats, and not attempt to generate a level of use, or grazing system, that is universally appropriate for all riparian vegetation, or riparian types.

Recommendation #5: Appropriate use depends on formulating range prescriptions by ecosystem. Therefore, classification and representative area descriptions of all riparian types used for livestock grazing should be completed. An extension of the biogeoclimatic ecological classification and range reference areas system may be the best means to accomplish this.

4.5 Effects on Wildlife Species Are Variable

Livestock impacts on riparian wildlife species are variable. Certain changes to a riparian area may benefit some species while adversely affecting others because of the variety of habitat requirements of different wildlife species (Skovlin 1984). For example, several studies have concluded that grazing causes a shift in bird and small mammal species while maintaining the same level of diversity (Mosconi and Hutto 1982; Tucker 1987; Schulz and Leininger 1991). A comprehensive assessment of livestock effects on red- and blue-listed species in British Columbia, however, has not been conducted. Therefore, no conclusions relative to individual species at risk can be determined.

Recommendation #6: Research on the effects of range use (livestock grazing and hay cutting) on riparian wildlife species in British Columbia should initially concentrate on the effects and interactions with red- and blue-listed species.

A mixture of disturbance, recovery, and protected areas has been suggested as the best approach to maximize habitat diversity and consequently species diversity across the landscape (Skinner 1994). The appropriate amount and connectivity among these different habitat types required to sustain a diversity of wildlife is not known. British Columbia–specific information on the influence of livestock grazing on habitat structure is also generally lacking.

Recommendation #7: Research on the effects of range use on riparian wildlife habitat needs to address the appropriate amount and connectivity of habitat necessary to sustain various British Columbia wildlife populations.

Contrasting extreme grazing situations to ungrazed areas for their impacts on wildlife will have limited applicability for characterizing the true nature of livestock impacts on wildlife in riparian areas. An understanding of the impacts of moderate and light grazing is necessary to develop meaningful prescriptions for range use that are compatible with wildlife habitat requirements.

4.6 Systems Have Not Been Studied at a Landscape Level

Many questions remain as to the effects of livestock use in riparian areas in regard to the cumulative effects over time and space. For example, how does the disturbance created by livestock at a single site contribute to disturbance across the entire watershed? Can repeated small-scale grazing or browsing disturbance make a system more susceptible to erosion from large-scale, less frequent events such as fire and flooding? How much separation in time and space across the landscape is needed between grazing events to maintain various wildlife populations? In general, little information regarding the effects of grazing at a landscape level is available, nor is there good information on how disturbances in the watershed created by livestock (timing, scale, and distribution) compare with natural disturbance regimes.

Recommendation #8: Research on the effects of range use in riparian areas in British Columbia should address the issue at a landscape level in addition to measuring site-specific impacts to determine the cumulative and spatial consequences of individual site management.

Upland condition and management can have an equal or dominant role in use and effects on the riparian system by either encouraging or discouraging livestock use of the riparian area. Specific attributes of the upland such as the type and amount of forage, the quality and distribution of water sources, and the accessibility and ease of movement through the upland can dictate the amount of use there, and consequently the use in the riparian zone. Therefore, the riparian system must not be looked at in isolation from the surrounding uplands.

Recommendation #9: Research on the effects of range use in riparian areas in British Columbia should address the management of the adjacent uplands.

TABLE A1.1 *Target conditions for range use of stream riparian areas (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995)*

Attribute	Target condition
Stream channel shape	Livestock use should not destabilize stream banks or result in a significant change in stream channel form (e.g., reduced bank height or loss of undercut bank).
Soil trampling	Concentrated trampling (> 20% of the surface affected by deep hoof prints) should not occur along known high-value fish habitat (e.g., spawning and overwintering area) unless identified and approved in a range use plan.
Known fish spawning areas	Livestock watering should not occur in or affect known fish spawning areas.
Stream bank vegetation	The amount and height of shrub cover on and overhanging the bank should be at least 85% of the amount and height of stream bank vegetation in the absence of grazing.
Nutrient levels of stream water	Range use should not result in excessive nutrient enrichment as indicated by accelerated algae production and water quality detrimental to fish.
Wildlife	Provisions should be made for residual cover and other attributes to meet requirements of dependent wildlife species.

TABLE A1.2 *Target conditions for range use of wetland and lake areas (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995)*

Attribute	Target condition
Edge vegetation	Vegetation structure and composition should be at least 75% similar to the Desired Plant Community (DPC) for the habitat unit or, if less, should be managed in an upward trend towards the DPC. In the latter case, the rate of recovery should be at least 75% of the rate of recovery under total cattle exclusion.
Nutrient levels	Range use should not result in excessive nutrient enrichment as indicated by accelerated algae production.
Soil trampling	Concentrated trampling (> 20% of the surface affected by deep hoof prints) should not exceed more than 5% of the perimeter of the wetland or lake unless identified and approved in a range use plan.
Wildlife	Provisions should be made in the range use plan for residual cover and other attributes to meet requirements of dependent wildlife species.

TABLE A1.3 *Target conditions for range use of moist riparian habitats (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995)*

Attribute	Target condition
Vegetation	Vegetation structure and composition should, on average, be at least 75% similar to the desired plant community structure and composition for the range habitat unit Desired Plant Community (DPC). Areas with vegetation significantly impacted by range use (vegetation less than 50% similar to the DPC) should occupy no more than 10% of the range habitat unit. Where these criteria are not currently met, the vegetation should be managed in an upward trend towards the desired plant community, and the rate of improvement should be at least 75% of that which would occur with total cattle exclusion.
Mineral soil exposure	The percentage of mineral soil exposed should, on average, be no more than 10% greater than that of the DPC. Areas where exposed mineral soil is the predominant surface condition as a result of livestock use should occupy no more than 5% of the range habitat unit.
Soil compaction	Areas of surface compaction or puddling caused by cattle use should not occupy more than 5% of the area of the range habitat unit.
Wildlife	Provisions should be made for residual cover and other attributes to meet requirements of dependent wildlife species.

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