University Nevada, Reno

Short-term Grazing Management Monitoring and Long-term Changes in Riparian Attributes of the Interior Columbia River Basin.

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Abstract

Rangeland managers often use herbaceous vegetation stubble height and woody shrub utilization or stream bank alteration to monitor annual effects of grazing on streams and riparian areas. Many riparian grazing management practices or strategies have been suggested yet little quantitative long-term or effectiveness data has been interpreted with regard to short-term or implementation monitoring and management practices over a diversity of watersheds. This study uses long-term broad scale ecological monitoring by the U.S. Forest Service (USFS) Pacfish/Infish Biological Opinions Effectiveness Monitoring Program (PIBO EMP) to analyze monitoring and management practices across the Interior Columbia River Basin U.S. Forest Service and Bureau of Land Management rangelands. Explorations of these quantitative relations can guide land managers in choosing appropriate grazing management practices and annual monitoring indicators for a site's particular geomorphic and vegetative characteristics.

Measures of five year change in seven physical and three vegetation variables measured by PIBO EMP were analyzed as responses to short term monitoring and allotment management practices. Multiple linear regression identified unique variables that were most strongly associated with responses which were then used in classification and regression tree (CART) analyses to facilitate interpretation of interactions and threshold effects. The hierarchical tree structure and splitting criteria aid GIS map algebra for management applications. Vegetation community type and/or geologic parent material were important predictors in all CART models for guiding management decisions. Suggestions for specific monitoring parameters and management practices are provided with caution. More years of use information, more specifics about timing and intensity of grazing activities and additional explanatory variables such as riparian fencing or water improvements would have improved this study. The biggest limitation with this study is sample size needed to account for the spatial and temporal variability inherent in the PIBO EM area.

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Introduction

This research describes relationships among public rangeland management practices, short-term "implementation" monitoring (IM) data and long term effects on fish habitat as reflected by the U.S. Forest Service Pacfish/Infish Effectiveness Monitoring Program (PIBO EMP). It's purpose is to help grazing land managers focus their approach for management and monitoring stream and riparian conditions on public grazing allotments. This research seeks to address knowledge gaps identified by the University of Idaho Stubble Height Review Team (2004)

> Linkages between stubble height and riparian functions have not been extensively researched nor documented through long-term monitoring. Research that identifies appropriate stubble height indicator values that should be associated with specific seasons of use, grazing strategies, etc. is also lacking. Caution should be used in setting stubble height indicator values until information is collected that relates the indicator value used to responses in riparian and aquatic variables (long-term trends) on the sites being monitored.

This study takes advantage of the first two years of a rigorously re-implemented long-term monitoring program. Quantitative changes in stream and riparian attributes (table 1) over a five year period (calculated as sample year two minus sample year one) were used as response variables in a series of multiple linear regression (MLR) and classification and regression tree (CART) analyses. Predictor variables were derived from rangeland management documents (annual operating instructions, allotment management plans, etc…) compiled and summarized with the help of rangeland managers, range technicians, fisheries biologists, field office secretaries and various other USFS and BLM employees. The legal and science context for a monitoring program across the Interior Columbia River Basin is described below. The “Science Background” serves as the introduction for a manuscript to be submitted to the journal Rangeland Ecology and Management.

Legal Background

The listing of steelhead, bull trout, and Chinook salmon populations as threatened or endangered throughout the Columbia and Snake River basins (status varies for populations of each species depending on location throughout the study area) in the early 1990’s required the U.S. Forest Service (USFS) and Bureau of Land Management (BLM) under Section 7 of the Endangered Species Act to consult with, National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS), to develop species recovery plans. These consultations resulted in a set of biological opinions referred to as the Pacfish/Infish Biological Opinions (PIBO). The PIBO provide management direction for recovery of anadromous fish-producing watersheds in Oregon, Washington, Idaho, and portions of California, Nevada and Western Montana. This management direction is referred to throughout this document simply as Pacfish/Infish.

Pacfish/Infish requires land managers in the Columbia River Basin to plan and implement management to improve or maintain stream and riparian conditions. Default riparian management objectives (RMOs) for stream pool frequency, water temperature, amount of large woody debris, bank angle, bank stability and width to depth ratio serve in lieu of site specific objectives that may be included in individual National Forest and BLM resource area management plans (U.S. Department of Commerce 1998).

To track progress toward attainment of RMOs and recovery of protected fish species the Biological Opinion calls for three levels of monitoring:

1. Short term (implementation) monitoring – documents compliance with management direction, allows land managers to evaluate [implementation] effects of management decisions and make changes as needed to promote desired conditions. US Dept. of Agriculture 2003[1])
2. Long term (effectiveness) monitoring – documents trends in either default or site specific RMOs.
3. Validation monitoring - In the context of PIBO examines whether the attainment of RMOs actually lead to recovery of threatened salmonid populations

The Interior Columbia Basin Ecosystem Management Project (ICBEMP), a coordinated effort between the USFS, BLM, USFWS, NMFS, and the Environmental Protection Agency (EPA) issued an environmental impact statement to replace Pacfish/Infish interim directions with more long-term plans for an ecosystem management framework (US Dept. of Agriculture 2000). A Framework for Incorporating the Aquatic and Riparian Habitat Component of the Interior Columbia Basin Strategy into BLM and Forest Service Plan Revisions published by ICBEMP (US Dept. of Agriculture 2004) provides management direction guidelines for integrating six components to incorporate into management plans:

- Riparian Conservation Areas (or appropriate direction accomplishing the same end)
- Protection of Population Strongholds for Listed or Proposed Species and Narrow Endemics
- Multi-scale Analysis
- Restoration Priorities and Guidance
- Management Direction (Desired conditions, objectives, management actions – names differ between Forest Service and BLM planning)
- Monitoring/Adaptive Management

The Framework recommends adaptive management to adjust practices as needed based on information gathered during all three levels of monitoring; (1) implementation, (2) effectiveness and (3) validation. Management objectives must also consider social, economic and biophysical functions of the ecosystem (US Dept. of Agriculture 2000).

Designated Monitoring Areas

Designated monitoring areas included in this study were selected using criteria from the 2003 "Implementation Manual" (US Dept. of Agriculture 2003[1]). Much work has since been done to improve DMA selection and monitoring methods. They are selected by a team of interdisciplinary professionals to represent overall pasture use, i.e. representative or critical areas should not be in places that receive little to no use or places that have extreme disturbance (e.g. next to a road or along a hardened water crossing for cattle). Rangeland managers use DMA sites to evaluate compliance or non-compliance with end of season use measures such as stubble height, woody browse and bank alteration. Land managers adjust site specific management plans as needed through documents such as Grazing Permits, Allotment Management Plans, Annual Operating Instructions, and letters to permitees to insure the desired end of season use goals are met.

Implementation Monitoring (IM)

In 1999 implementation monitoring pilot projects began for the stream reaches on USFS and BLM grazing allotments. Guidelines for implementation monitoring were issued in 2000 and in 2003 the USFS published an "Implementation Manual" outlining how monitoring sites should be selected and which indicators of stream and riparian health should be monitored (US Dept. of Agriculture 2003[1]). The Implementation Manual recommends DMA site selection be conducted by an interdisciplinary team to ensure that conditions reflect vegetative, hydrologic and geomorphic conditions throughout the allotment and considers effects on streams and riparian areas specifically.

Several indicators were recommended in the Implementation Manual and later in the Multiple Indicators Monitoring Manual (Burton et al. 2008) for use as "triggers" to move livestock and as end of grazing season target conditions (endpoint indicators). The decisions concerning which trigger(s) and endpoint indicator values to actually use are left to the range manger(s) responsible for the allotment. The selection of triggers and endpoint indicators should consider site specific conditions and management objectives. The most commonly used triggers are measures of vegetative resource use (i.e. percent of current season woody plant growth eaten, percent of available forage used and stubble height remaining) or disturbance (i.e. streambank alterations such as hoof shearing and trampling).

Residual stubble height is one of the most common livestock move triggers used by land mangers. Several papers about the use of stubble height publish conflicting and inconclusive results. Clary and Leininger (2000) recommend that increasing the validity of stubble height as a management tool will require the following research:

1. Determination of where a stubble height standard is efficient and effective, and where it is not appropriate.
2. Determination of proper stubble heights in high elevation or other sites where species composition and growing conditions result in relatively low-statured forage plants.
3. Evaluation of the relative preference of herbaceous vegetation and willows in different seasons under different combinations of herbaceous and woody species, and at different forage stubble heights.
4. Documentation of the direct impacts of livestock on streambanks of different stream types, parent materials, moisture conditions, and livestock occupancy levels as guided by stubble height.
5. Increased understanding of channel evolution and how recovery processes affect the local flood plain watertable and the green line (Winward 2000) vegetation in relation to different grazing intensities and residual stubble heights.

In 2003 a group of range managers, fisheries biologists and resource specialists assembled to begin addressing concerns over improper use of stubble height as an indicator of stream and riparian health. This group, known as the Stubble Height Review Team, published The University of Idaho Stubble Height Report in 2004. The UI Stubble Height Report identified two main problems concerning the use of stubble height as a trigger:

1) It is often the only indicator used
2) It is often viewed as a management objective rather than as a tool for achieving stream health objectives (i.e. streambank stability, bank angle).

The report suggests that more research is required to determine when, where and how specific stubble height targets should be set in relation to the vegetation type, soil, geology, and climate. This thesis tried to address some of these questions. The Report also suggests that appropriate complementary measures (such as bank alteration and woody plant utilization) should supplement stubble height as a guide to grazing allotment use and timing (University of Idaho Stubble Height Review Team 2004).

Cowley (2002) suggests:

> Research is needed to develop an understanding of the capacity of a stream to rebuild streambank under various conditions. It needs to consider climate, alteration timing, soil conditions, streambank material, vegetation composition of the streambank, and the amount of stable, vulnerable, and unstable banks.
> At least three questions need to be answered:
>
> - What is the threshold at which streambank damage cannot be repaired in the current year under various climatic regimes (length of the growing season), stream types, and riparian community types?
> - What is the threshold at which streambank damage retards recovery for various climatic conditions, stream types, and riparian community types?
> - What are streambank recovery rates for the various climatic conditions, stream types, and riparian community types?

A study conducted by Powell et al (2000) in Canadian areas of the Columbia River basin also makes recommendations for grazing use indicators and lists the following target levels for range use on streams in British Columbia:

- “Soil trampling/concentrated trampling - (> 20% of the surface affected by deep hoof prints) should not occur along high value fish habitat. . .”

- "Stream channel Shape -Livestock use should not destabilize stream banks or result in significant change in stream channel form (e.g., reduced bank height or loss of undercut bank)."
- "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."

Staff officers at each USFS and BLM field office (throughout this document I use the term "Field Units" to include USFS National Forests and Ranger Districts within them, and BLM Districts, Field Offices, and Resource Areas) are charged with the task of ensuring "implementation monitoring" data are collected annually. Data are collected under the direction of the Pacfish/Infish Biological Opinions and line officers at state and regional levels. The data are collected at DMA sites within each grazing allotment under jurisdiction of their field unit. Most of these data are stored in paper reports kept in files in the field unit offices. In 2000 an internet based electronic database was created to accumulate and store annual implementation monitoring data. Since 2000, there has been an increase in the amount of data entered and stored in the IM database. The present requirement for field units is to enter IM data on end of season stubble height, bank alteration and woody browse where applicable, the year before and the year EM sampling occurs.

Effectiveness Monitoring (EM)

The U.S. Forest Service Pacfish/Infish Biological Opinions Effectiveness Monitoring Program (PIBO EMP) began with a pilot study in 1998 on

Forest Service lands within the Salmon River Basin of central Idaho. In 2000, the Interagency Implementation Team (IIT), a cooperative USFS/BLM effort, expanded the pilot study to include all Federal lands within the Interior Columbia River Basin. This includes Forest Service lands within PACFISH and INFISH (20 National Forests) and BLM lands within PACFISH or with bull trout (10 Field Offices and Resource Areas). The PIBO EMP study design was finalized in the winter of 2000 (Kershner et al 2004), and the PIBO Effectiveness Monitoring Program first 5 year rotating panel began in 2001 (Henderson et. al 2005).

Science Background

Streams and riparian areas respond to management practices differently depending on hydrologic, geomorphic and vegetative settings (Naiman et al. 2004, Bendix and Hupp 2000, Belsky et al. 1999, Rosgen 1996, Stanley et al. 1991). The interactions between management, hydrology, geomorphology and vegetation form a many-to-many non-linear relationship in which changes in one or more of the four can lead to change in one or more of the other three. Riparian Proper Functioning Condition (PFC) Assessment (Prichard et al 1998) identifies many of the attributes and processes that interact and may indicate risk of deterioration of stream and riparian habitat. Factors such as the level of watershed, stream and riparian disturbance, soil organic matter content and degree of channel incision will affect the rate of change in stream and riparian condition (Sarr 2002). Any attempt to correlate management actions to long-term trends must take these factors into account and consider variations in potential and in specific relevant attributes and processes when interpreting results over a broad geographic scale.

The major factors that affect riparian areas and stream conditions are described below:

Hydrology

Discharge timing and water velocity have major impacts on the ecological structure of the riparian and aquatic communities associated with streams (Poff et al 1997). The availability of water to plants is one of the main factors distinguishing riparian zones from adjacent uplands. Regular inundation with water, presence of plant species adapted to prolonged inundation, and presence of soils characterized by features resulting from prolonged inundation (i.e. oxidized pore spaces, gleyed soil color) all indicate riparian wetland conditions (US Army Corps of Engineers 1987).

Bankfull discharge is the flow that has the greatest cumulative effect on shaping the channel and transporting sediments (Dunne and Leopold 1978). Changes in bankfull discharge can result from water diversions, reservoir regulation, timber operations, changes in vegetation, road building, and over grazing (Rosgen 1996).

The magnitude, duration and frequency of flood events will vary depending on the dominant water source supplying a stream. A stream fed by spring or snowmelt will be subject to much less severe fluctuations in discharge than streams that are subject to frequent rain-on-snow events (McDonald and Hoffman 1995). Alterations to the hydrologic processes described above can lead to reductions in riparian plant bio-mass and species diversity and encroachment of upland vegetation and stress tolerant invasive plants into streamside areas

(Stromberg 2001) as well as a change in the distribution and abundance of stream bank-stabilizing root biomass (Toledo and Kaufman 2001).

Geomorphology

Soil type, entrenchment ratio, gradient, sinuosity and width/depth ratio have been shown to effect the type and rate of stream and riparian zone response to management actions (Rosgen 1996, Montgomery and MacDonald 2002). Bank building processes of sediment transport, entrapment and retention will differ based on channel bank material particle size, channel form, riparian vegetation, and flood plain access. Channel banks with finer materials, with the exception of cohesive clays, erode more easily. Coarse materials, having larger pore spaces, allow for greater hyporheic exchange. These relations are confounded by complex interactions between vegetation and soil (Toledo and Kaufman 2001, Kleinfelder et al 1992).

Given the complexity of interactions among soils, vegetation, and hydrology, grazing management strategies affect stream and riparian habitats differently depending on the structure and texture of soil. A soils' susceptibility to grazing impacts such as compaction and hoof shearing on banks will be largely determined by soil type and root density (Kleinfelder et al 1992).

Vegetation

Vegetation affects the structure and function of riparian and stream systems depending largely on physical characteristics of the species present (Fitch and Adams 1998, Tabacchi et al. 2000). Characteristics such as; root length, root density and strength, stem length/stiffness and leaf characteristics affect bank stability, stream water temperature, stream channel roughness, sediment entrapment and retention, hydrologic function, nutrient cycling, inputs of woody debris, insect species richness and abundance (Kaufman and Kreuger 1984, Stanley et al 1991, Fitch and Adams 1998, Winward 2000, Belsky et al 1999)

Winward (2000) suggests monitoring stream reaches contained within a "riparian complex," a distinct unit defined by "overall geomorphology, substrate characteristics, stream gradient and associated water flow features, and general vegetation patterns." Within a riparian complex several community types may occur. The composition and successional status of vegetation indicate direct physical disturbances (management or natural causes) and indirect effects of soil and hydrologic changes over time. The concept of capability groups (Winward 2000) relates the vegetative successional status and soil types surrounding a stream reach to the capability of the stream to recover from disturbance.

Livestock Grazing Management

Livestock commonly graze rangelands during the growing season and often concentrate use along riparian areas (Kaufman and Krueger 1984) especially during the hottest times of the season (Wyman et. al. 2006). Number of growing season days in which vegetation could grow without pressures from domestic herd animals indicate opportunity for resilience to grazing (Clary and Webster 1989). The more time plants have to recover after grazing, the more energy may be harnessed and used for life support and growth (Wyman et al., 2006). Energy from the roots or leaves must be invested in above ground re-growth after a plant is grazed heavily, which is common along streams or close to water. Timing of grazing activities in relation to plant life cycle plays a crucial role in plant community recovery and maintenance. Reproductive success of plants may be diminished if grazing season coincides with critical plant life cycle processes such as flowering, pollination, seed dispersal or germination (Archer and Pyke 1991). Animals left on pasture from the beginning of the growing season until after the growing season may result in a condition in which plants have little or no time to recover after animals are removed, insufficient time to complete reproductive cycles, and little or no time to grow the structures that influence water velocity, erosion, deposition, and channel recovery.

Altering season of use or using a grazing system may help to improve rangeland riparian vegetation composition by allowing grazing to occur during the most vegetatively productive times of some years in exchange for using the same pasture in other years during less productive seasons, using the pasture in seasons when livestock are less likely to concentrate in riparian areas, or excluding grazing completely some years. This may benefit areas where one plant, plant part or plant community may be most vulnerable to disturbance in spring while another is most vulnerable during the summer (Platts 1991, Clary and Leininger 2000).

Management practices that can reduce grazing impacts to streams and riparian areas include placing water developments or salt supplements away from streams, reducing numbers of animals, herding animals to upland foraging areas or placing fences around to reduce or eliminate riparian access for all or portions of the grazing season (Wyman et al 2006, Sarr 2002, Tate et al. 2006).

Objectives

This research seeks to address knowledge gaps identified by the University of Idaho Stubble Height Review Team (2004), Clary and Leininger (2000) and others. An attempt is made to discover quantitative relationships among the use of grazing management practices, implementation monitoring indicators and long term effects on streams and riparian areas. The analyses described in this study were performed with this general question in mind: within what environmental settings do certain management practices and monitoring indicators consistently correspond with improvements in certain PIBO EM parameters? Generally stated, the hypotheses being tested are:

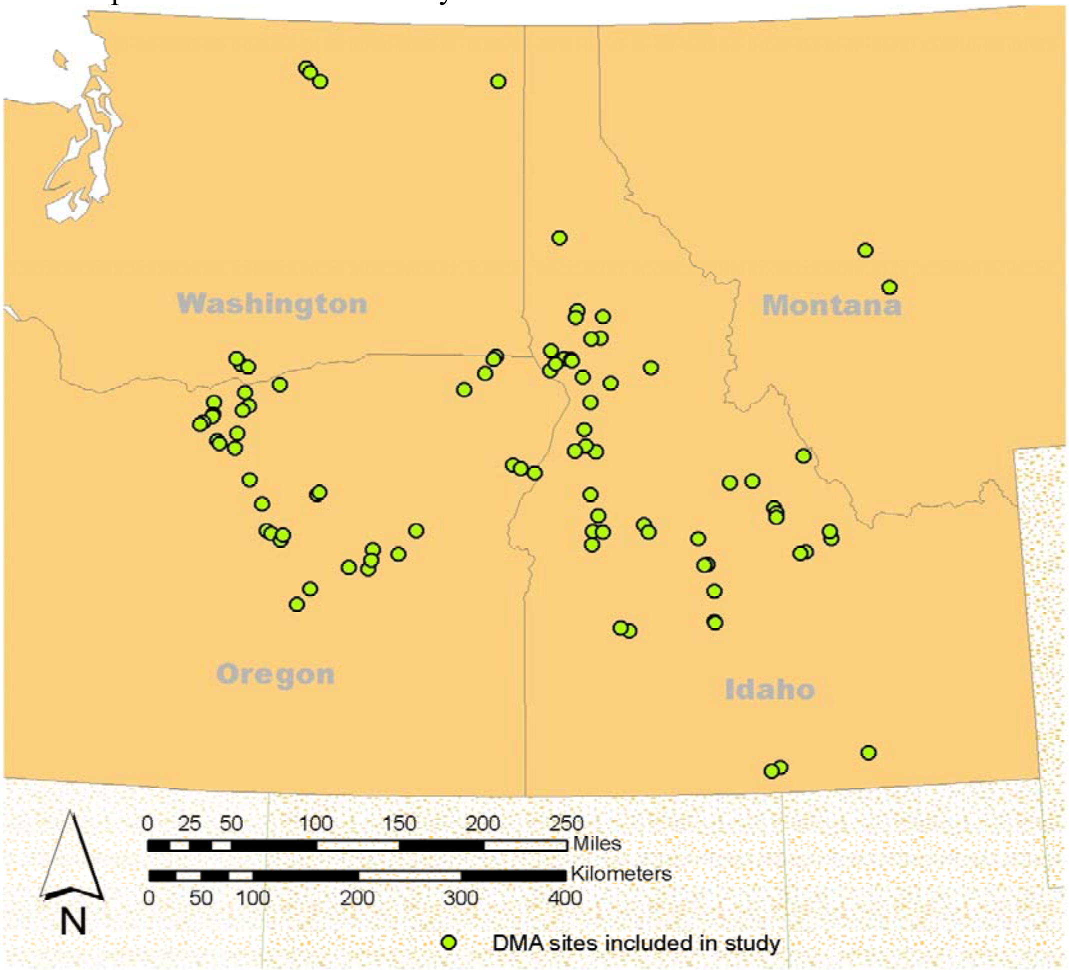
> h^0: Particular management practice(s) and monitoring indicator(s) do not consistently correspond with changes in PIBO EM parameters within particular geomorphic/vegetative settings.
>
> h^1: Particular management practice(s) and monitoring indicator(s) do consistently correspond with changes in PIBO EM parameters within particular geomorphic/vegetative settings.

Methods

Management and Implementation Monitoring Data Collection

Data collection efforts focused on 93 USFS and BLM DMA sites sampled by PIBO EMP in 2001 (n=43) and 2002 (n=50) and re-sampled five years later in 2006 and 2007 respectively. The DMA sites considered in this study are all assumed to be representative of the areas that are grazed in the watershed randomly chosen for study. However not all represent areas where livestock grazing causes riparian concerns. Ten of 79 assessed with photographs appeared to be on stream reaches where grazing is not likely to influence channel morphology. The potential for grazing influence appeared to be minimal on another 13. The sites are scattered throughout the Columbia River Basin between the Rocky Mountains of Montana and Idaho, westward to the Cascade Mountains in Oregon and Washington. Figure 1 provides a map of DMA sites included in this study.

Figure 1
Map of sites included in study



In 2006 and 2007 USFS and BLM agency staff were questioned about each DMA site. By the end of 2007, information pertaining to the management and monitoring of each of the 93 sites had been collected via email, electronic surveys, telephone interviews and visits to local field offices. The specific information collected included; locations of DMA sites, on/off dates for allotments and pastures, numbers of animals allowed to graze, years in which grazing practices such as fences, off-stream water developments and herding were used as well as measurement values for short-term indicators of stream and riparian condition such as bank alteration, herbaceous stubble height and woody plant use. Appendix 1 provides a sample of a completed questionnaire used to gather data from the field offices.

Each data set used the same PIBO Effectiveness Monitoring (EM) data for response variables. Data and notes were compiled in a Microsoft Access® database. Data pertaining to the period of the growing season un-grazed were included in a set named “GSUG”, while implementation monitoring data and other management practices (proportion of years each was used) were grouped in a set named “IMGT.” Data were split into two sets because the sample size for each was greater than was obtainable in a single data set. A year and a half of research effort documented season of use for 73 of the 93 DMA sites and documented other management practices and implementation monitoring on 46 sites. Twelve out of 73 sites were dropped from the GSUG data set and 7 of 46 from the IMGT data set because data were available for no more than 2 out of the 8 years. Additionally, 17 sites in the GSUG data and 7 in the IMGT data were missing Effectiveness Monitoring (response) data for stream bank parameters. For these reasons, the actual number of observations included in each analysis ranged from n=28 to n=51.

PIBO Effectiveness Monitoring Program Data Collection

Since 1999 the USFS PIBO Effectiveness Monitoring Program has sampled a suite of stream habitat parameters, and riparian vegetation on managed sites and reference sites (typically less impacted by human activities) throughout the Interior Columbia River Basin. The seasonal technicians are trained for a month (160 hours total) on stream geomorphology, hydrology and vegetation including plant taxonomy and how to follow protocols developed by PIBO EMP staff (Heitke et al 2007, Coles-Ritchie et al 2006). Tables 1 a-d provide definitions for all PIBO EM response variables used in this study.

Environmental Data Collection

Environmental data included in both the IMGT and GSUG data sets included geology type, vegetation type, precipitation, gradient and sinuosity. This was done because of evidence to suggest that stream responses to particular management practices will differ from one stream to another depending on environmental factors (Richards et al. 1996, Allan 2004). The intent was to discover management practices that would be most suited given specific environmental constraints.

Gradient and sinuosity were collected by PIBO EM sampling crews in 2006 and 2007. Geology type, vegetation type and precipitation were assigned from GIS data provided by Interior Columbia Basin Ecosystem Management Project (ICBEMP) (2001)

Vegetation type was based on a 2001 ICBEMP GIS polygon layer digitized from Küchler's map of Potential Natural Vegetation of the Conterminous United States (Küchler 1964). Kuchler's map delineated physiognomic regions based on a broad suite of criteria including precipitation, soil type, elevation, climate and existing vegetation. Vegetation types were generalized into three categories; forest, grassland and shrubland. Forests included cedar-hemlock pine forest, Douglas fir forest, grand fir-Douglas fir forest, western ponderosa forest and western spruce-fir forests. Grasslands included fescue-wheatgrass and wheatgrass-bluegrass. Shrublands included sagebrush steppe and juniper steppe woodland. Geologies were generalized into four basic types; sedimentary (alluvium, shale and mudstone), volcanic (felsic pyroclastic, mafic volcanic flow), granitic (granite and granitic gneiss) and metamorphic (interlayered meta-sedimentary). Precipitation values were estimated using PRISM GIS data. Variables Analyzed

Grazing Season vs. Growing Season (GSUG)

Animal on/off dates for allotments and pastures were used to derive scales and categories to describe use relative to growing season. Dates for last spring freeze (LSF) and first fall freeze (FFF) were estimated using station data from the National Climatic Data Center (http://cdo.ncdc.noaa.gov/).

Data from NCDC stations located within 25 miles of any PIBO sampling site were selected in ArcMap®. Sixty NCDC stations were found within 25 miles of any PIBO EMP site. Data from these sixty stations were used to calculate approximate last spring and first fall freeze dates. Dates were assigned to DMA sites by applying a regression equation to the elevation of each site. Using the NCDC station data for dates on which a 28°F threshold temperature has a 90% probability of occurring. All dates (on/off and first/last freeze) were converted to Julian days for analysis (i.e. January 1 = 1, December 31 = 365).

Multiple regression analyses were performed using PROC GLM in SAS®, implemented with the REGDIAG macro (Fernandez 2007) to determine the relationship among first fall and last spring freeze dates (response variables), elevation and latitude. Latitude showed a very weak correlation with freeze dates and thus was dropped. A simple linear regression was then performed in Excel using elevation (m) as the only predictor of first fall freeze dates ($r^2 = 0.548$; $p < 0.0001$) and last spring freeze dates ($r^2=0.657$; $p < 0.0001$). The regression equation for first fall freeze dates was: date = -0.010 * elevation (in meters) + 323.031. Last spring freeze dates were estimated using the same method resulting in: date = 0.0141 * elevation + 65.97. All dates resulting from regression analysis estimation were rounded to the nearest day.

Graphs like the ones in Figure 2a-d provided visualizations for each of the 93 sites in the study. These graphs were used to categorize sites based upon a set of decision rules about the number of days before or after last spring freeze and first fall freeze that animals are on pastures. Last spring and first fall freeze dates were used respectively to define the “beginning” and “end” of the growing season. On and off dates were then used to calculate the number of growing season days that each pasture was left ungrazed (zeros indicate grazing was all growing season long, and negative numbers mean grazing exceeded growing season). Table 2 provides definitions for all continuous variables used in the GSUG data set.

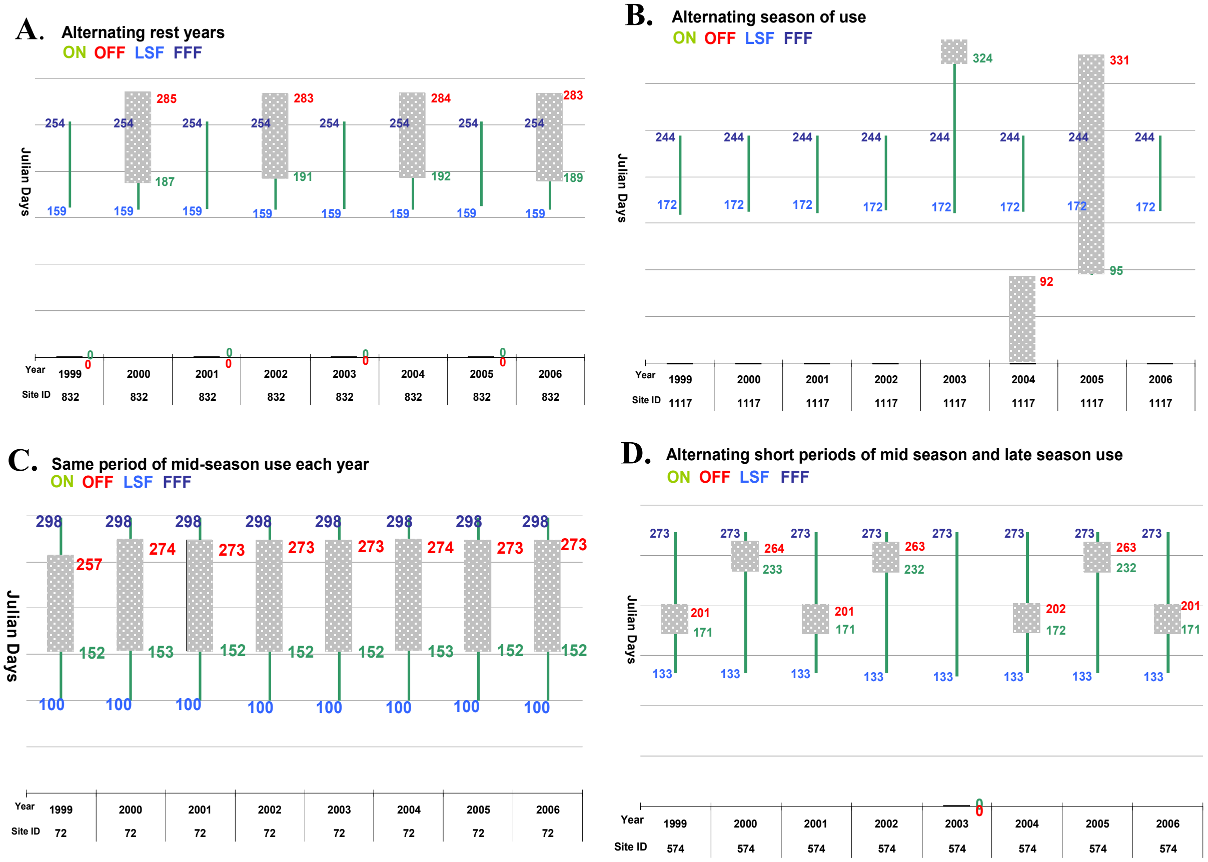


Figure 2a-d
Use dates relative to growing season on four different allotments. The grey bars indicate on and off dates while the green lines indicate the date of last spring and first fall freeze. Dates for each parameter are given in Julian days. **A** represents rotation of rest with 3 months of grazing from mid summer to fall. **B** represents missing data the first 4 years, then winter use followed by a complete growing season ungrazed, then 81/2 months grazing from before until after the growing season. **C** represents consistent yearly grazing from early May until late September. **D** represents rotation of use between early summer and fall use for four weeks each year with one rest year in 2003.

Sites were categorized according to variability among all years in the number of days after the last spring freeze that animals were allowed on (CAONLSF) and days before the first fall freeze animals were taken off (CAOFFF) pastures. Standard deviation in number of days was used as criteria for assigning categories. Sites with 7 or greater days difference in the on or off date among years respectively were categorized as varied (VA). Sites with fewer than 7 days difference in on or off date were categorized as not varied (NV). Sites were also categorized as having no grazing occurring any year (NG). Sites with fewer than three years of season of use data available were categorized as having no data available (no data). A third variability in season of use described variability in both on and off date. Sites with greater than one week variability in both on and off date were categorized as varied (VA). Sites with less than one week variability in both on and off date were categorized as not varied. Sites with no grazing or insufficient data were categorized using the same criteria as for the CAONLS and CAOFFF variables.

A category describing the average season of use (CAUSE) among all years was also created. Sites were categorized as early season grazing (early) if the average on date was before midpoint of growing season and the average off date was after 25% of growing season days had past and the average off date was before midpoint of growing season. Sites were categorized as mid season grazing (mid) if the average on date was two or more weeks after the last spring freeze and the average off date was two or more weeks before the first fall freeze. Sites were categorized as late season grazing (late) if the average on date was after the midpoint of growing season and the average off date was after 75% of the growing season had past. Sites were categorized as full season grazing (full) if the average on date was before the last spring freeze and average off date was after the first fall freeze. Sites were categorized as winter grazing (winter) if no grazing occurred during the middle of the growing season. Middle of the growing season was defined the time extending from a number of days equal to 25% of the total growing season after the last spring freeze up to a number of days equal to 25% of the growing season before the first fall freeze. Sites with fewer than three years of season of use data available were categorized as having no data available (no data).

Implementation Monitoring Data

Dedication to monitoring was evaluated as the proportion (0 - 1) of grazing years in which data were collected for trigger or endpoint indicators; stubble height (SH), bank alteration (BA) and woody utilization (WU).

Management Data

Variables were selected based on recommendations provided in BLM technical reference *Riparian area management: Grazing management processes and strategies for riparian-wetland areas* (Wyman et al. 2006). Tables 3a and 3b provide definitions for the management independent variables in the implementation monitoring and management (IMGT) data. The variables REST, GRZD, and TRSP are scaled as a simple tallies of years they occurred (0 – 8) within the eight year study period. All other variables are scaled from 0 to 1 according to the proportion of grazing years (total years – rest years) that the management practice was used on the site, since they would not be important in non-grazed years.

Model Development

Stepwise linear regression methods were used to select significant variables from each of the two data subsets – GSUG and IMGT. Analyses were performed using the REGDIAG macro for SAS (Fernandez 2003) which calculates regression models for every combination of predictors for a specified PIBO EM response. It lists the most parsimonious models based on AIC and SBC scores and provides parameter estimates for full models and the reduced "top models" list. Final models were selected iteratively by selecting explanatory parameters based on model AIC and SBC scores with manual selection based on examination of the parameter estimates, significance (F-test) of the full model and diagnostic plots for multicolinearity of variables and significant outliers. Among collinear variables (e.g. percent vs. number of growing season days ungrazed), only the most predictive (i.e. resulting in a final model with higher R^2 and lower p-value) was retained.

Once each final model was selected for a response using the REGDIAG macro its' IMGT or GSUG predictor variables were used in Classification and Regression Tree (CART) analysis using S-Plus®. The CART analyses served two primary purposes: 1) thresholds and their interactions are more intuitive to interpret than regression equations and thus better tools to convey relationships, and 2) they validated the MLR analyses. Preliminary trials of the CART methods using the full set of predictors were very similar to CART-based models using the REGDIAG MLR selected variables.

Results

Descriptive Statistics

In the GSUG data set, categorical variables describing variability in the animal on date (CAONLSF) 15 sites were categorized as varied, 27 sites had no variation, nine sites were ungrazed and nine sites had insufficient (less than three years) data available. Categories describing variability in the off date (CAOFFF) included 19 sites with variation, 23 sites with no variation, nine sites with no grazing and nine sites with insufficient data. Categories describing variability in on and off date (VARIED) included 16 sites with variation, 26 sites with no variation, nine sites with no grazing and nine sites with insufficient data available. Categories of season of use (CAUSE) included eight sites with early season grazing, eight with mid season grazing 11 with late season grazing, three with winter season grazing, 12 with full season grazing, nine with no grazing and nine with insufficient data.

Two environmental categorical variables, vegetation type (VEGTYP) and geology type (GEOL) were included in both the GSUG and IMGT data sets. In the GSUG data 34 sites were categorized as forest 12 were grass and 14 were shrub. In the IMGT data set 25 sites were categorized as forest, five were grass and eight were shrub. In the GSUG data 15 sites were categorized as granitic, six were metamorphic, four were sedimentary and 35 were volcanic. In the IMGT data nine sites were categorized as granitic, five were metamorphic, two were sedimentary and 22 were volcanic.

Descriptive statistics for all of the continuous variables used in this study are listed in table 1 (response variables), table 2a-b (GSUG) and table 3a-b (IMGT). Descriptive statistics were calculated independently for each data set (GSUG and IMGT) because each included a different composition and number of observations. Numbers in these tables represent change in each parameter between time one (2001 or 2002) and time two (2006 or 2007).

Table 1a

Stream response variable definitions and descriptive statistics. Top numbers in descriptive statistics are from the GSUG data, bottom numbers are from IMGT data. Values are measures of change in each parameter over a five year period.

Abbreviation	Long name	Description	Units		Min	Avg	Max	st dev	n
stab2	% stable banks -	Percent stable banks using method of dividing 2 variables (number of covered stable and false bank measurements) by the total number of measurements. The category uncovered stable is considered unstable using this method.	%	GSUG IMGT	-63.7 -46.2	-1.3 0.82	57.1 57.1	23.82 23.11	43 31
stab3	% stable banks--	Percent stable banks using method of dividing 3 variables (number of covered stable, uncovered stable, and false bank measurements) by the total number of measurements.	%	GSUG IMGT	-31.5 -31.5	2.28 3.85	31 31	12.55 14.03	43 31
bnkangl	Bank angle	Average of all bank angle measurements	degrees	GSUG IMGT	-30 -26	-6.27 -4.9	13 13	10.22 9.98	43 31
uncutdp	Average undercut depth	Sum of all undercut depths (meters) / total number of measurements.	m	GSUG IMGT	-0.12 -0.12	0 0	0.08 0.08	0.03 0.03	43 31
uncutpc	% undercut banks	Number of locations with bank angles < 90 degrees and an undercut depth of > 5 cm / total number of bank measurements.	%	GSUG IMGT	-18.4 -18.4	2.45 1.36	30.9 30.9	9.71 9.98	43 31
anglt90	% of bank angles <90°	Number of locations with bank angles < 90 degrees / total number of bank measurements.	%	GSUG IMGT	-19.4 -19.4	0.56 -0.74	30.9 30.9	10.64 11.03	43 31

Table 1b

Riparian vegetation response variable *greenline wetland rating* definition and descriptive statistics. Top numbers in descriptive statistics are from the GSUG data, bottom numbers are from IMGT data. Values are measures of change in each parameter over a five year period.

Abbreviation	Long name	Description	Units		Min	Avg	Max	st dev	n
bf	Average bankfull width - from transects	Average of the bankfull widths (m) from the 20-25 channel transects.	m	GSUG IMGT	-5.9 -5.9	0.19 0.26	4.87 4.87	1.59 1.72	43 31
glwr	Greenline wetland rating	A measure of the abundance of obligate wetland species along the streambank. A wetland rating of 100 indicating all obligate wetland species and 1 being all upland species. The rating is calculated for each reach by summing the product of the relative cover of each species for which a wetland indicator status can be determined and a value corresponding to the species' wetland indicator status (1=upland, 25= facultative upland, 50=facultative, 75=facultative wet, 100=obligate wetland). Data from 2001 and 2002 was based on community type classifications. Community type wetland ratings were calculated using the average species cover values from the published community types and wetland rating values assigned to each species based on the wetland indicator status (Coles-Ritchie et al. 2007).	unitless	GSUG IMGT	-33.81 -19.4	1.56 0.6	27.31 15.38	10.74 8.37	59 37

Table 1c

Riparian vegetation response variable *cross-section wetland rating* definition and descriptive statistics. Top numbers in descriptive statistics are from the GSUG data, bottom numbers are from IMGT data. Values are measures of change in each parameter over a five year period.

Abbreviation	Long name	Description	Units		Min	Avg	Max	st dev	n
xswr	Cross-section wetland rating	A measure of the abundance of obligate wetland species in the riparian area. A wetland rating of 100 indicating all obligate wetland species and 1 being all upland species. The rating is calculated for each reach by summing the product of the relative cover of each species for which a wetland indicator status can be determined and a value corresponding to the species' wetland indicator status (1=upland, 25= facultative upland, 50=facultative, 75=facultative wet, 100=obligate wetland). Data from 2001 and 2002 were based on a variable riparian width, which included only what was considered riparian, up to a maximum of 27.5 m on each side of the stream. Beginning in 2003 the cross-section sample area was a fixed area, beginning 3 and ending 9.5 m from the greenline. Data from 2001 and 2002 was based on community type classifications. Community type wetland ratings were calculated using the average species cover values from the published community types and wetland rating values assigned to each species based on the wetland indicator status (Coles-Ritchie et al. 2007).	unitless	GSUG IMGT	-40.79 -24.83	-7.56 -6.74	13.32 12.29	10.47 8.46	59 37

Table 1d

Riparian vegetation response variable *effective ground cover* definition and descriptive statistics. Top numbers in descriptive statistics are from the GSUG data, bottom numbers are from IMGT data. Values are measures of change in each parameter over a five year period.

Abbreviation	Long name	Description	Units		Min	Avg	Max	st dev	n
egc	Effective ground cover	The percent of the riparian area (not including the greenline) with effective ground cover. In 2001 and 2002 the area considered to measure effective ground cover was a 2 cm circle located directly in front of the technician's toe. In 2001 effective ground cover was defined as live vegetation (within 1 m of the ground), litter, rocks greater than 2.5 cm, and stagnant water with less than 25% vegetative cover. In 2002 effective ground cover was defined the same way except stagnant water with less than 25% vegetation cover was considered bare ground. Data from 2001 and 2002 were based on a variable riparian width, which included only what was considered riparian, up to a maximum of 27.5 m on each side of the stream. In 2006 and 2007 the cross-section sample area was a fixed area, beginning 3 m and ending 9.5 m from the greenline. Effective ground cover data from 2006 and 2007 was collected at the ground surface in daubenmire quadrats placed at 3 meter intervals along the riparian cross section unless there was live vegetation within 1 m of the ground over the quadrat corners.	unitless	GSUG IMGT	-14.82 -12.12	-1.74 -0.57	21.7 21.7	7.34 7.29	59 37

Table 2a

Definitions and descriptive statistics for predictor variables used in the growing season ungrazed (GSUG) data set.

Short Name	Description	Units / Format	Minimum	Average	Maximum	Standard Deviation	n
GRW	Number of days from 90% probability of 28°F temperature last spring freeze until same probability temperature first fall freeze. Station data from all stations located within 25 miles of a PIBO EM site were used to compute from linear regression of dates and elevation.	Days	83.00	167.23	246.00	45.35	60
GRAZ	Number of days animals were on pasture	Days	0.00	67.86	230.00	67.46	53
GSUG	Average number of growing season days ungrazed that a pasture had no livestock on.	Days	0.00	107.91	245.00	63.06	53
PGSUG	Percent of the total growing season that a pasture had no livestock on.	Days	0.00	0.66	1.00	0.32	53
AVONLSF	Average number of days among years after the last spring freeze before livestock moved onto pasture.	Days	-35.00	62.18	245.00	63.55	51
AVOFFF	Average number of days among years before the first fall freeze after livestock are removed from pasture	Days	-55.00	67.55	245.00	81.12	51
SDONLSF	Standard deviation of the number of days among years after last spring freeze before livestock are moved on pasture. A measure of the degree to which season of use varies on a pasture. Sites that were not grazed 1999-2006 were assigned a 365 day standard deviation.	Days	0.45	72.73	365.00	137.70	51

Table 2b

Definitions and descriptive statistics for predictor variables used in the growing season ungrazed (GSUG) data set.

Short Name	Description	Units / Format	Minimum	Average	Maximum	Standard Deviation	n
SDOFFF	Standard deviation of the number of days among years before the first fall freeze after livestock are moved off a pasture. A measure of the degree to which season of use varies on a pasture. Sites that were not grazed 1999-2006 were assigned a 365 day standard deviation.	Days	0.00	72.03	365.00	137.37	51
REST	Number of years pasture was rested between 1999-2006	Years	0.00	1.82	8.00	3.11	51
PRECIP	Average precipitation for the sub-watershed as computed by the Interior Columbia Basin Ecosystem Management Project.	cm	226.98	653.07	1373.63	259.40	60
GRAD	Elevation change of the water surface from the bottom of the reach to the top of the reach divided by the reach length (measured along the thalweg), expressed as percent.	%	0.09	2.79	13.42	2.84	52
SIN	Reach length measured along the thalweg divided by the straight valley length from the bottom of the reach to the top of the reach.	ratio	1.00	1.26	2.27	0.25	55

Table 3a
Definitions and descriptive statistics for predictor variables used in the implementation monitoring and management (IMGT) data set.

Short Name	Description	Units / Format	Minimum	Average	Standard Deviation	n
REST	Number of years rested	years	0.00	0.55	1.33	38
GRZD	Number of years grazing	years	2.00	7.45	1.33	38
SALT	proportion of grazing years (expressed as a decimal) in which salt and/or dietary supplements were placed to lure animals away from riparian areas	decimal	0.00	0.64	0.44	38
RIDING	proportion of grazing years (expressed as a decimal) in which animals were moved away from riparian areas by riders	decimal	0.00	0.38	0.45	38
LTINT	proportion of grazing years (expressed as a decimal) in which numbers of animals were kept low to reduce impact	decimal	0.00	0.44	0.49	38
FNC	proportion of grazing years (expressed as a decimal) in which fences were in place to limit or eliminate riparian access	decimal	0.00	0.20	0.39	38
WTR	proportion of grazing years (expressed as a decimal) in which water developments were in place to lure animals away from riparian areas	decimal	0.00	0.18	0.39	38
TRSP	Number of years in which trespassing problems were reported	years	0.00	0.26	0.60	38

Table 3b
Definitions and descriptive statistics for predictor variables used in the implementation monitoring and management (IMGT) data set.

Short Name	Description	Units / Format	Minimum	Average	Standard Deviation	n
BAME	proportion of grazing years (expressed as a decimal) in which bank alteration was measured at the IM site	decimal	0.00	0.15	0.31	38
SHME	proportion of grazing years (expressed as a decimal) in which stubble height was measured at the IM site	decimal	0.00	0.46	0.31	38
WUME	proportion of grazing years (expressed as a decimal) in which woody utilization was measured at the IM site	decimal	0.00	0.05	0.14	38
PRECIP	Average precipitation for the sub-watershed as computed by the Interior Columbia Basin Ecosystem Management Project.	cm	384.85	697.66	236.92	38
GRAD	Elevation change of the water surface from the bottom of the reach to the top of the reach divided by the reach length (measured along the thalweg), expressed as percent.	%	0.21	2.84	2.85	35
SIN	Reach length measured along the thalweg divided by the straight valley length from the bottom of the reach to the top of the reach.	ratio	1.00	1.27	0.28	37

Regression Models

The regression models listed in table 4a-e and 5a-g were constructed with using dummy variables for categorical variables. Categorical levels with highest alpha-numeric sequence (i.e. “d” is higher than “a” in a-z sequence) were set to zero. This sequence was used because there is no evidence to support any significance to which variable should be the baseline. Setting one level of each categorical variable to zero allows for easy comparison of models. The equation for the numeric predictors remains the same with only the intercept changing depending on the combination of categorical levels. (See SAS online documentation: http://v8doc.sas.com/sashtml/stat/chap55/sect52.htm (last accessed November 9, 2008) for details on model construction.)

Table 4a

Multiple linear regression models for GSUG data. Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Bankfull	0.50	0.0031	36	Shrub	1.312	- 0.047 * GSUG + 0.041 * AVONLSF + 0.031 * AVOFFF - 0.017 * SDONLSF – 0.106 * GRAD
				Grass	2.405	
				Forest	2.258	
Bank Angle	0.46	0.0002	39	Granitic	6.649	– 0.046 * AVONLSF
				Metamorphic	0.004	
				Sedimentary	-13.166	
				Volcanic	-7.23	
Bank Stability 2	0.51	0.0427	36	Forest		- 0.354 * GRW + 0.495 * GSUG + 0.051 * PRECIP -4.159 * GRAD
				Early	-56.908	
				Late	19.142	
				Full	-18.489	
				Mid	-45.784	
				Winter	-55.686	
				No Grazing	-46.121	
				Grass		
				Early	-18.14	
				Late	57.909	
				Full	20.279	
				Mid	-7.016	
				Winter	-16.918	
				No Grazing	-7.354	
				Shrub		
				Early	-27.701	
				Late	48.348	
				Full	10.718	
				Mid	-16.577	
				Winter	-26.479	
				No Grazing	-16.915	

Table 4b

Multiple linear regression models for GSUG data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Bank Stability 3	0.55	0.0001	39	Forest		-0.023 * SDONLSF
				Granitic	9.668	
				Metamorphic	7.84	
				Sedimentary	9.374	
				Volcanic	-7.058	
				Grass		
				Granitic	18.432	
				Metamorphic	16.603	
				Sedimentary	18.137	
				Volcanic	1.705	
				Shrub		
				Granitic	18.54	
				Metamorphic	16.711	
				Sedimentary	18.245	
				Volcanic	1.814	
Undercut Depth	0.35	0.011	39	Granitic	0.007	- 0.00018 GRW - 0.000055 GSUG
				Metamorphic	0.024	
				Sedimentary	0.053	
				Volcanic	0.052	

Table 4c

Multiple linear regression models for GSUG data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Undercut Percent	0.59	0.019	36	Granitic		-2.03 * SDONLSF + 0.225 * SDOFFF – 0.538 * GRAD – 7.765 * SIN
				Early	-2.389	
				Full	-0.839	
				Late	4.137	
				Mid	9.756	
				No Grazing	-2.553	
				Winter	4.945	
				Metamorphic		
				Early	5.818	
				Full	7.367	
				Late	12.343	
				Mid	17.963	
				No Grazing	5.654	
				Winter	13.151	
				Sedimentary		
				Early	16.564	
				Full	18.113	
				Late	23.089	
				Mid	28.709	
				No Grazing	16.4	
				Winter	23.897	
				Volcanic		
				Early	13.617	
				Full	15.167	
				Late	20.142	
				Mid	25.762	
				No Grazing	13.453	
				Winter	20.951	

Table 4d

Multiple linear regression models for GSUG data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Angle Less Than 90	0.54	0.0065	39	Granitic		-0.305 * GSUG + 0.217 * AVONLSF
				Early	22.037	
				Full	-8.828	
				Late	1.334	
				Mid	12.896	
				No Grazing	9.64	
				Winter	34.994	
				Metamorphic		
				Early	28.715	
				Full	-2.15	
				Late	8.012	
				Mid	19.574	
				No Grazing	16.318	
				Winter	41.672	
				Sedimentary		
				Early	35.696	
				Full	4.831	
				Late	14.994	
				Mid	26.555	
				No Grazing	23.3	
				Winter	48.653	
				Volcanic		
				Early	39.834	
				Full	8.969	
				Late	19.131	
				Mid	30.693	
				No Grazing	27.437	
				Winter	52.791	

Table 4e

Multiple linear regression models for GSUG data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Greenline Wetland Rating	0.06	0.0995	46	NONE	-1.828	+ 0 .892 * GRAD
Riparian Cross-section Wetland Rating	0.19	0.0419	50	NONE	45.529	-0.261 * GRZ – 56.324 * PGSUG – 0.061 * SDOFFF + 2.647 * REST
Effective Ground Cover	0.34	0.011	50	Forest	-16.831	+0.044 * GRW + 17.559 * PGSUG + 0.034 * AVONLSF – 0.129 * AVOFFLSF – 0.009 * PRECIP
				Grass	-10.307	
				Shrub	-17.333	

Table 5a
Multiple linear regression models for IMGT data. Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Bankfull	0.51	0.05	28	Forest Grass Shrub	2.897 1.107 2.078	-0.860 * TRSP -1.172 * FNC -1.508 * SHME + 3.376 * WUME – 0.088 * GRAD – 0.535 * SIN
Bank Angle	0.44	0.009	31	Granitic Metamorphic Sedimentary Volcanic	9.35 1.652 -13.066 -4.282	+ 5.420 * SHME – 0.009 * PRECIP
Bank Stability 2	0.43	0.045	28	Forest Grass Shrub	1.881 18.634 26.65	+ 24.731 * RIDE + 21.912 * FNC – 34.076 * SHME – 2.362 * GRAD

Table 5b

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Bank Stability 3	0.7	<0.0001	31	**Forest**		-16.859 * SHME
				Granitic	19.369	
				Metamorphic	15.324	
				Sedimentary	26.832	
				Volcanic	-2.738	
				Grass		
				Granitic	26.653	
				Metamorphic	22.608	
				Sedimentary	34.116	
				Volcanic	4.546	
				Shrub		
				Granitic	30.887	
				Metamorphic	26.842	
				Sedimentary	38.35	
				Volcanic	8.78	

Table 5c

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Undercut Depth	0.68	0.001	31	**Forest**		+0.0479 * SALT – 0.0621 * RIDE – 0.207 * LTINT -0.081 * WUME
				Granitic	-0.007	
				Metamorphic	-0.015	
				Sedimentary	0.036	
				Volcanic	0.02	
				Grass		
				Granitic	-0.046	
				Metamorphic	-0.053	
				Sedimentary	-0.003	
				Volcanic	-0.018	
				Shrub		
				Granitic	0.009	
				Metamorphic	0.002	
				Sedimentary	0.052	
				Volcanic	0.037	

Table 5d

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Undercut Percent	0.53	0.008	31	**Forest**		+6.508 * FNC – 10.110 * WTR
				Granitic	-7.718	
				Metamorphic	-11.999	
				Sedimentary	8.879	
				Volcanic	7.326	
				Grass		
				Granitic	-12.865	
				Metamorphic	-17.145	
				Sedimentary	3.733	
				Volcanic	2.18	
				Shrub		
				Granitic	0.17	
				Metamorphic	-4.111	
				Sedimentary	16.767	
				Volcanic	15.214	

Table 5e

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Angle Less Than 90°	0.56	0.044	28	**Forest**		-7.067 * LTINT + 7.333 * FNC - 17.840 * SHME – 0.534 * GRAD
				Granitic	4.606	
				Metamorphic	5.406	
				Sedimentary	15.114	
				Volcanic	14.573	
				Grass		
				Granitic	-4.417	
				Metamorphic	-3.617	
				Sedimentary	6.092	
				Volcanic	5.55	
				Shrub		
				Granitic	9.69	
				Metamorphic	10.49	
				Sedimentary	20.199	
				Volcanic	19.657	

Table 5f

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Greenline Wetland Rating	0.46	0.003	34	Forest Grass Shrub	-2.655 -0.409 4.585	- 4.920 * FNC – 12.225 * WUME +1.172 * GRAD
Riparian Cross-section Wetland Rating	0.11	0.284	37	Forest Grass Shrub	-6.12 -6.368 -13.12	+ 5.013 * WTR

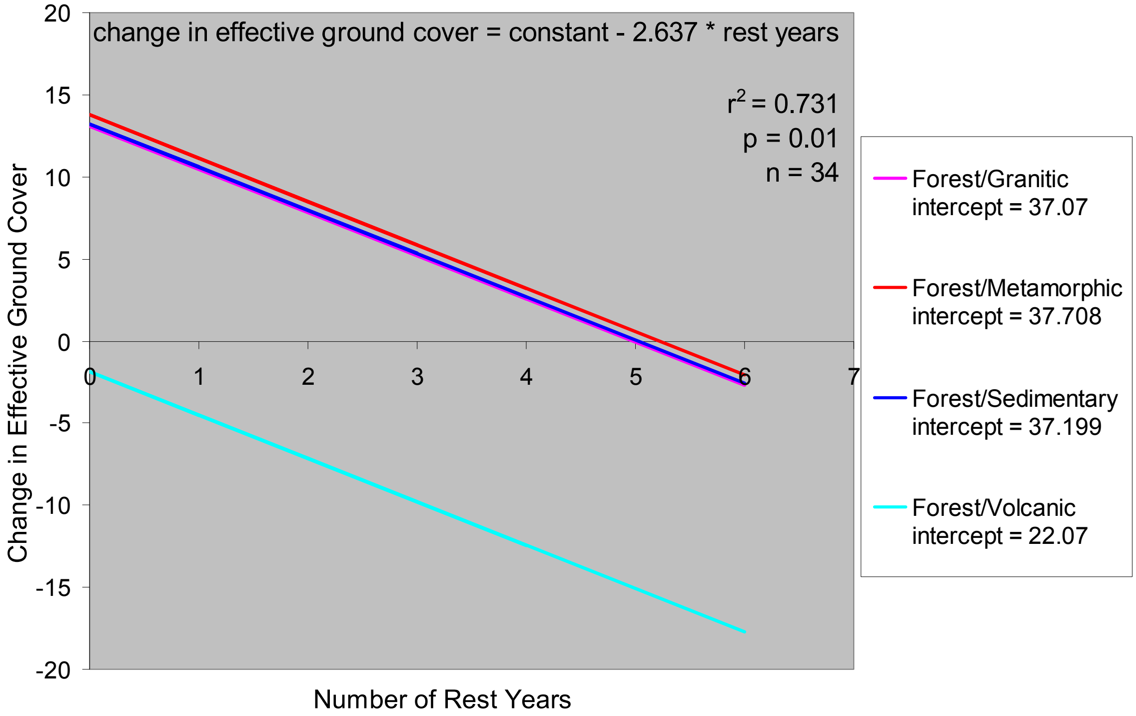
Table 5g

Multiple linear regression models for IMGT data (continued). Numeric independent variable parameter estimates (listed in the "Model" column) remain the same for each dependent variable. Only the intercept changes given each combination of categorical independent variables.

Response	R^2	Pr>F	n	Category	Intercept	Model
Effective Ground Cover	0.73	0.01	34	**Forest**		-2.637 * REST + 4.034 * SALT – 8.236 * RIDE – 5.732 * LTINT -10.932 * FNC -5.551 * BAME – 5.679 * SHME – 10.764 * WUME – 0.024 * PRECIP + 0.708 * GRAD
				Granitic	37.07	
				Metamorphic	37.708	
				Sedimentary	37.199	
				Volcanic	22.07	
				Grass		
				Granitic	28.605	
				Metamorphic	29.243	
				Sedimentary	28.734	
				Volcanic	13.605	
				Shrub		
				Granitic	27.757	
				Metamorphic	28.395	
				Sedimentary	27.886	
				Volcanic	12.757	

The graph in figure 3 illustrates how the MLR models in this study may be used by managers to visualize the predicted response of change in a management variable of interest.

Figure 3
Comparison of predicted effect of increased rest years on effective ground cover in three different geology types in forest range allotments. All model parameters except the intercept and *rest* were held constant at their mean values. Only the intercept of volcanic geology type was significantly different ($p < 0.0001$)



Regression Tree Analyses

Predictor variables for the CART models were selected using MLR methods because CART is not able to detect collinearities in the data and thus may provide results that are over fit and thus not very informative. The models below were generated using

S-Plus. Trees were created using node size criteria of less than ten observations to stop the splitting with minimum node size of five. Splitting was also set to stop if the deviance of the response values within a node reached ten percent of the overall response deviance. Trees were pruned if nodes could be eliminated with less than ten percent drop in the response deviance explained. The vertical length of the tree branches indicate the amount of response deviance explained by that particular node. For example when considering season of use (GSUG data set) change in bankfull width (Figure 5a) was explained mostly by the average number of days after the last spring freeze that animals were allowed on a pasture (AVONLSF) and by the number of growing season days ungrazed (GSUG). The other variables (vegetation type and stream gradient) were not as effective in explaining the deviance in bankfull width response.

Figure 4a
Change in **bankfull width** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

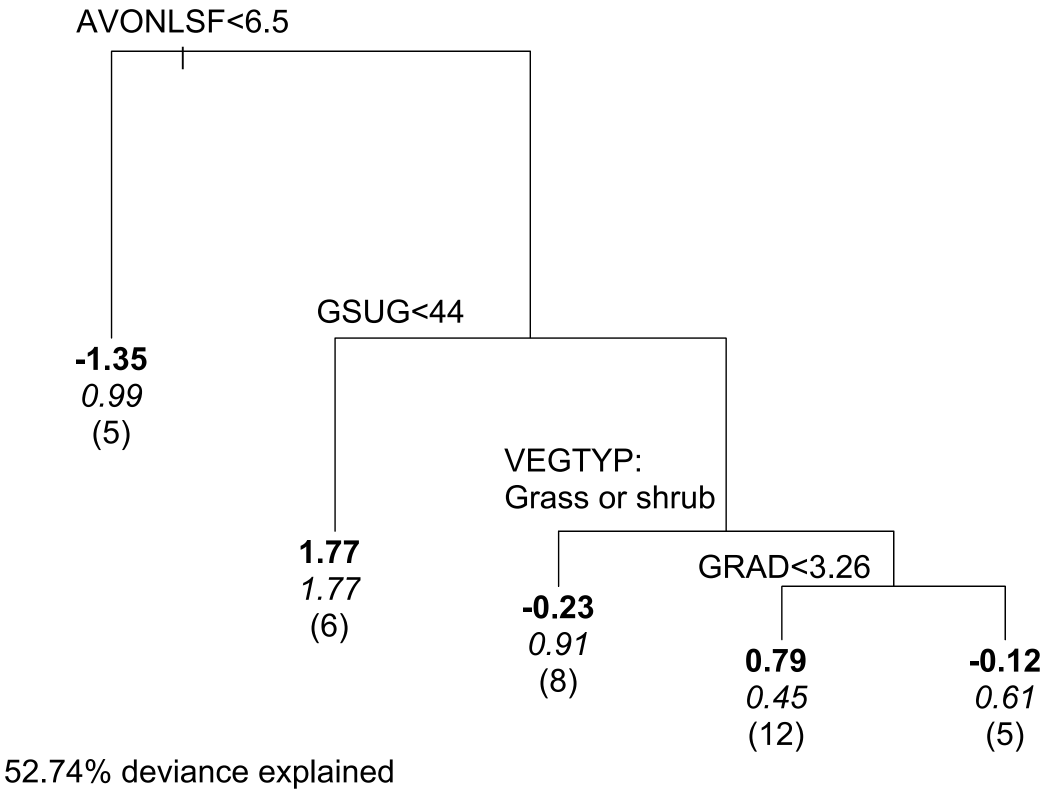
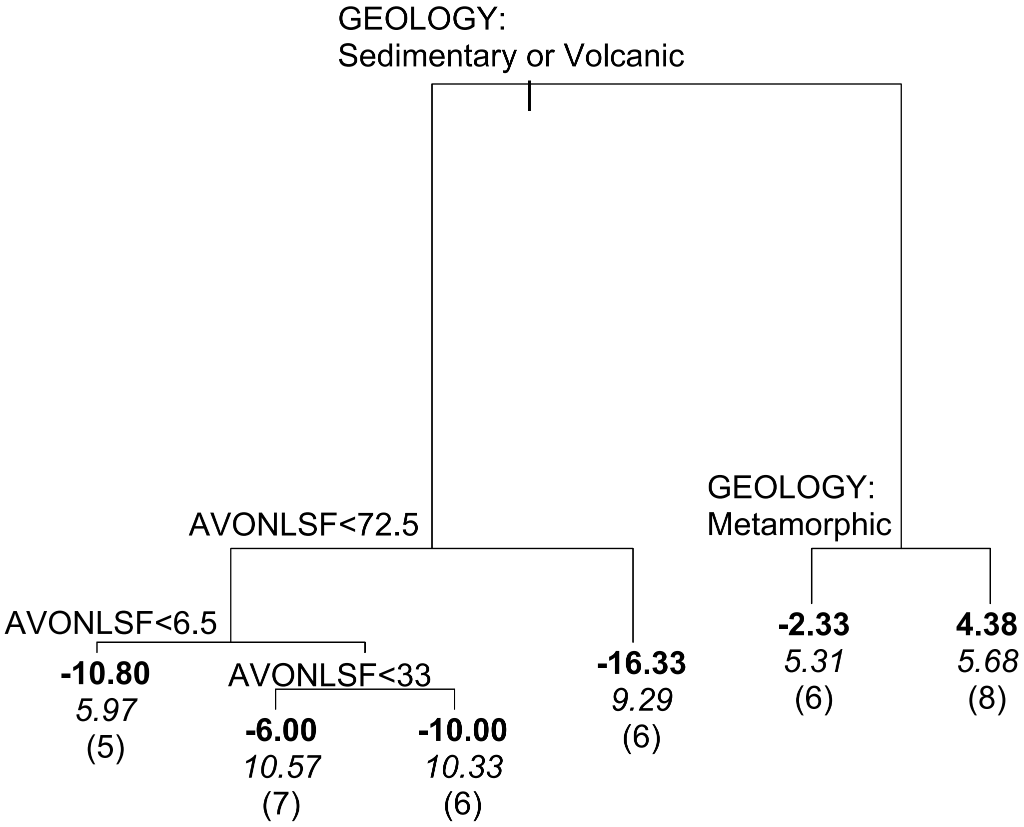


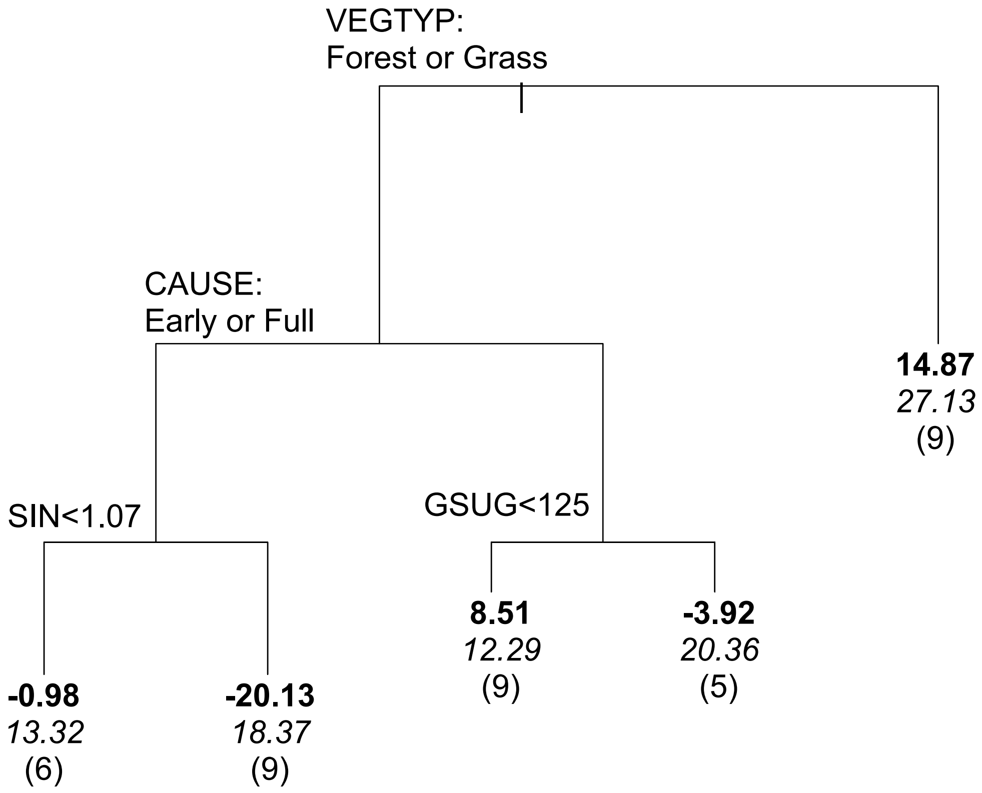
Figure 4b
Change in average **bank angle** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



44.54% deviance explained

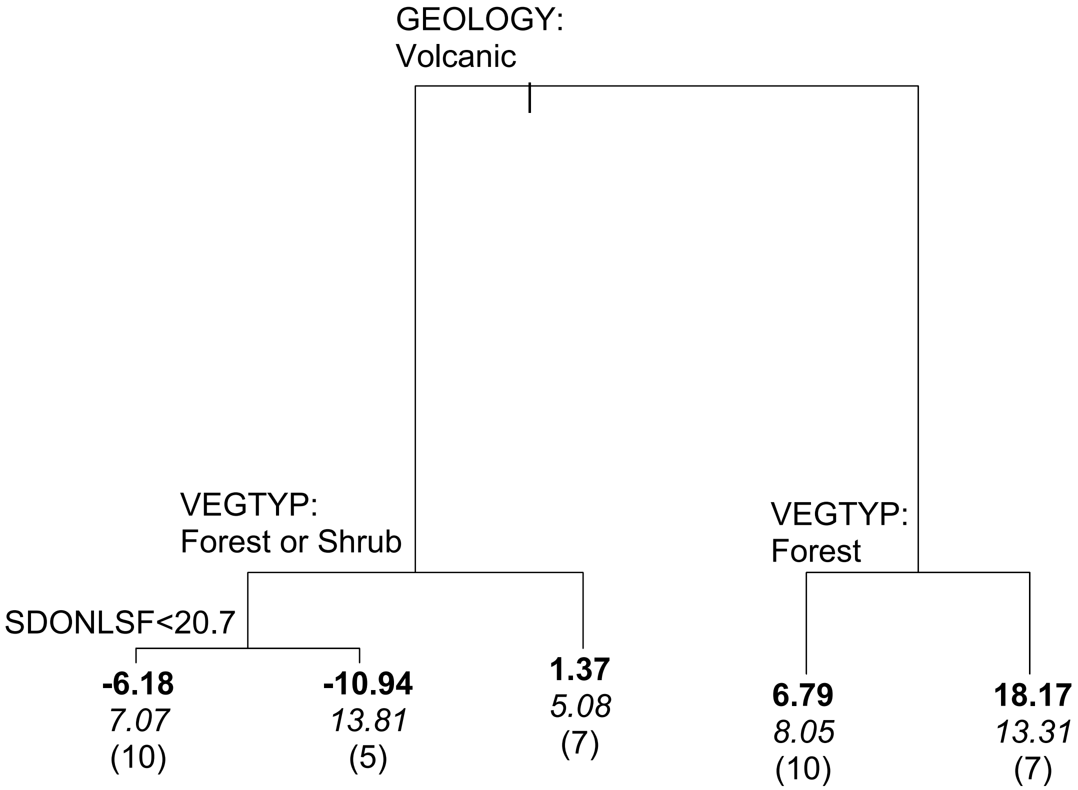
Figure 4c

Change in percent stable banks **(bank stability 2)** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



34.05% deviance explained

Figure 4d
Change in percent stable banks **(bank stability 3)** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold**), standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



54.18% deviance explained

Figure 4e
Change in average bank **undercut depth** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value **(bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

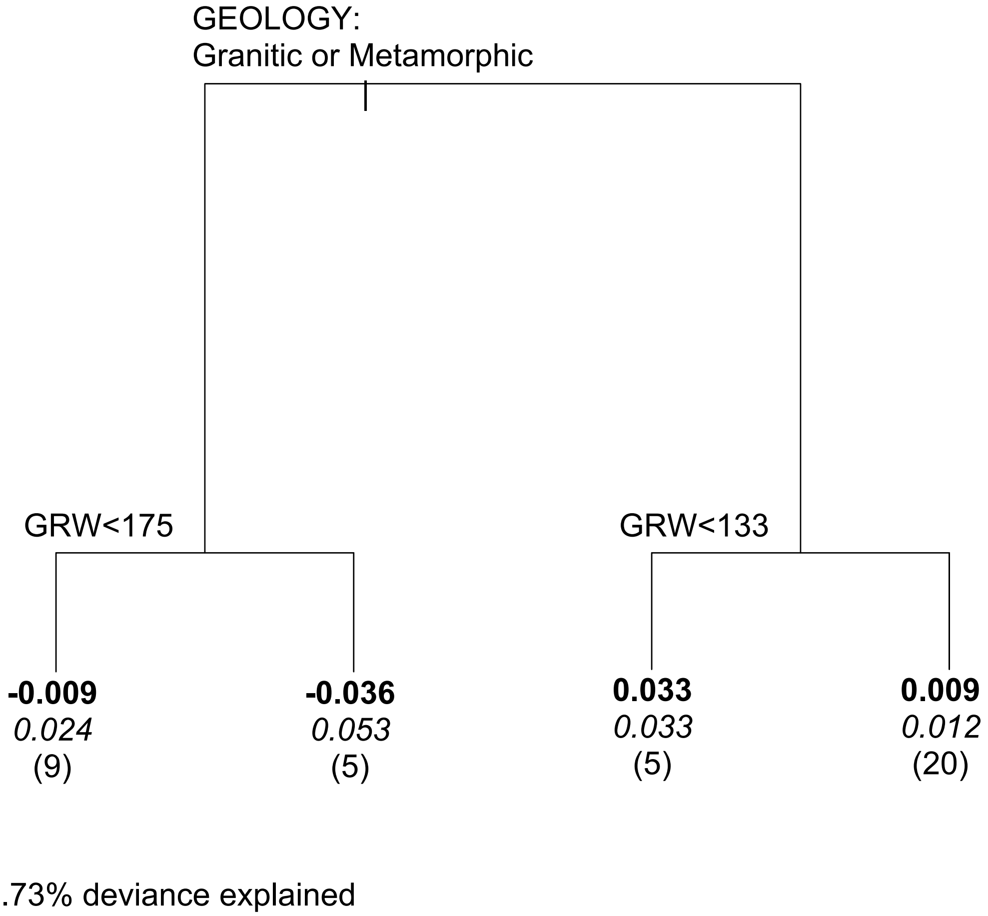


Figure 4f
Change in percent of bank **undercut percent** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

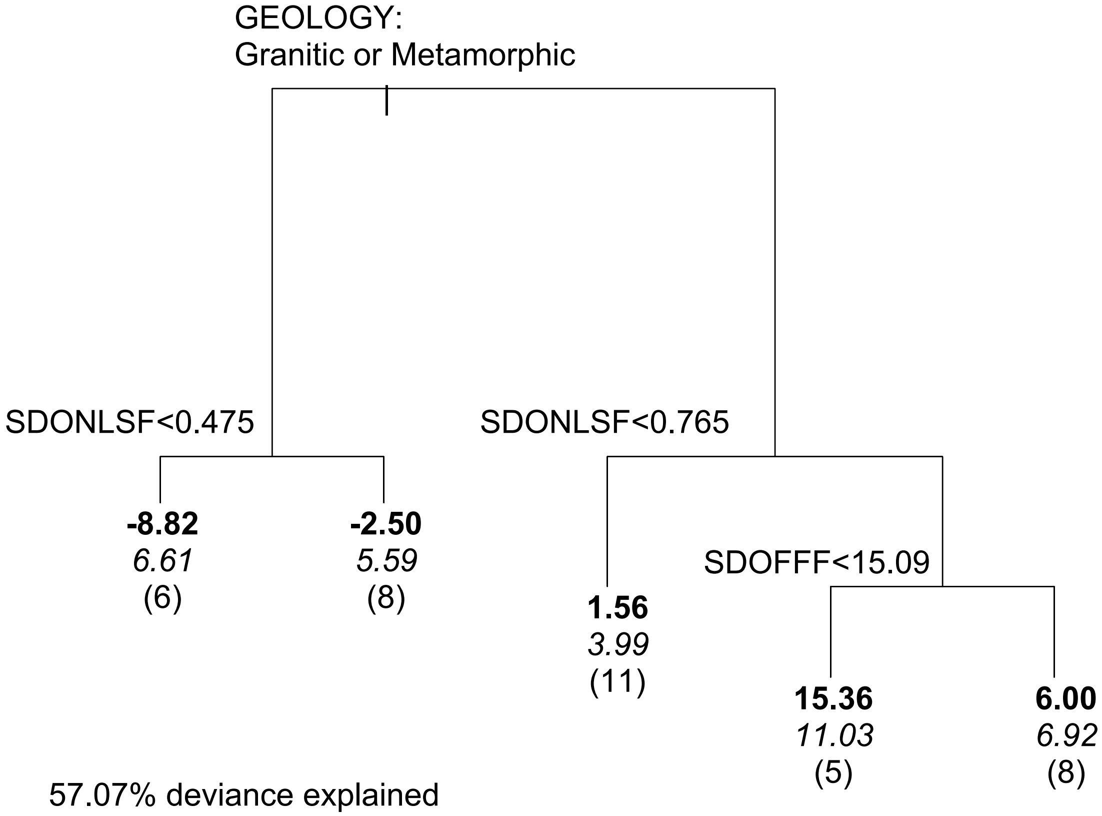
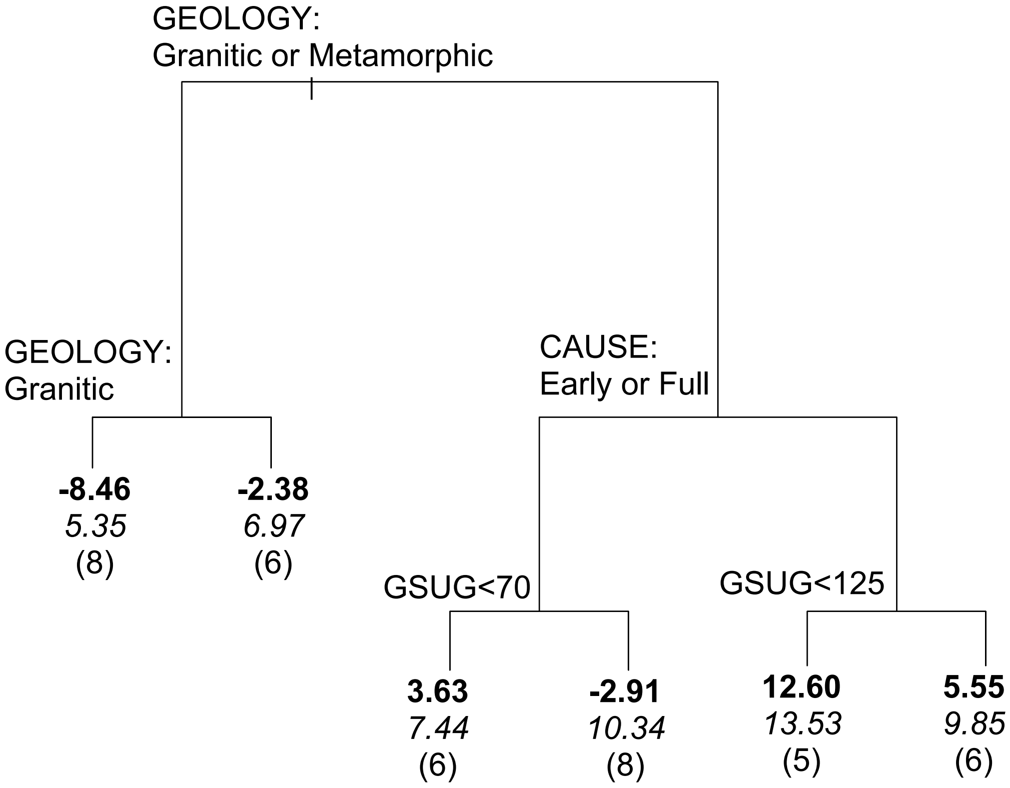


Figure 4g
Change in percent of banks with **angle less than 90 degrees** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



39.15% deviance explained

Figure 4h
Change in **greenline wetland rating** CART model using GSUG predictor variables. Tree was pruned from nine to four terminal nodes with an eight percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

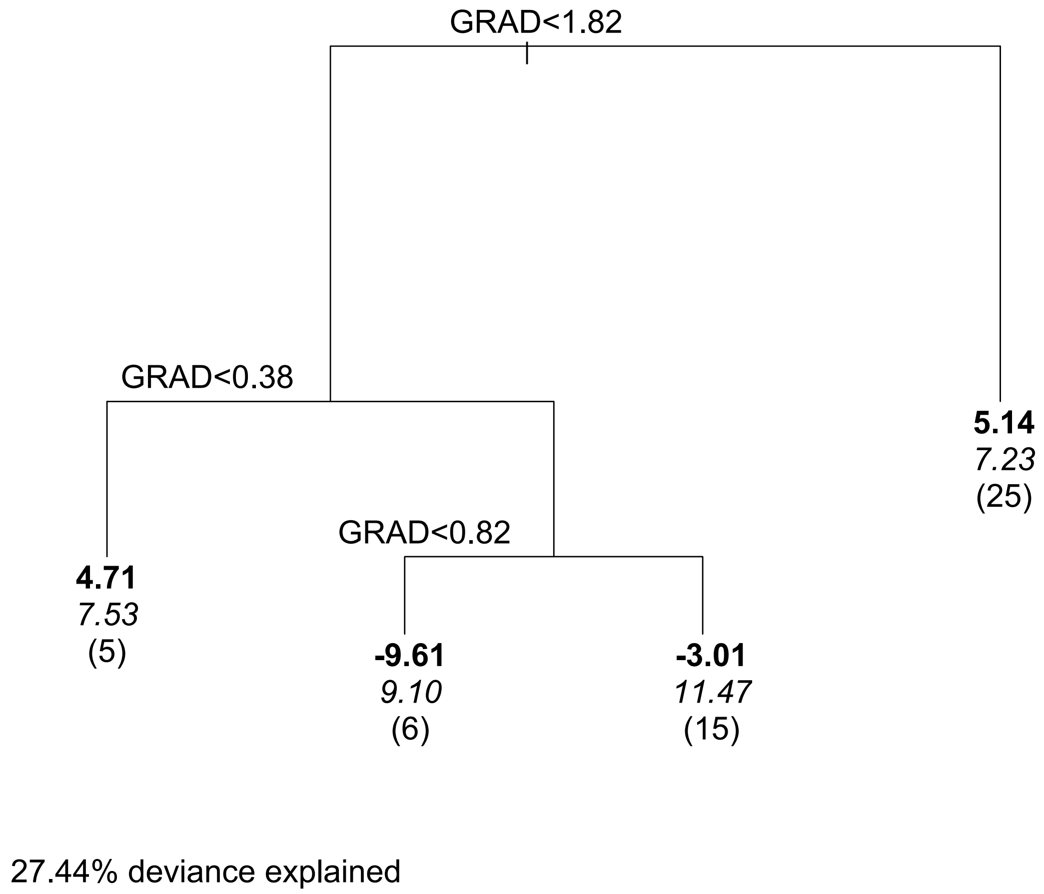
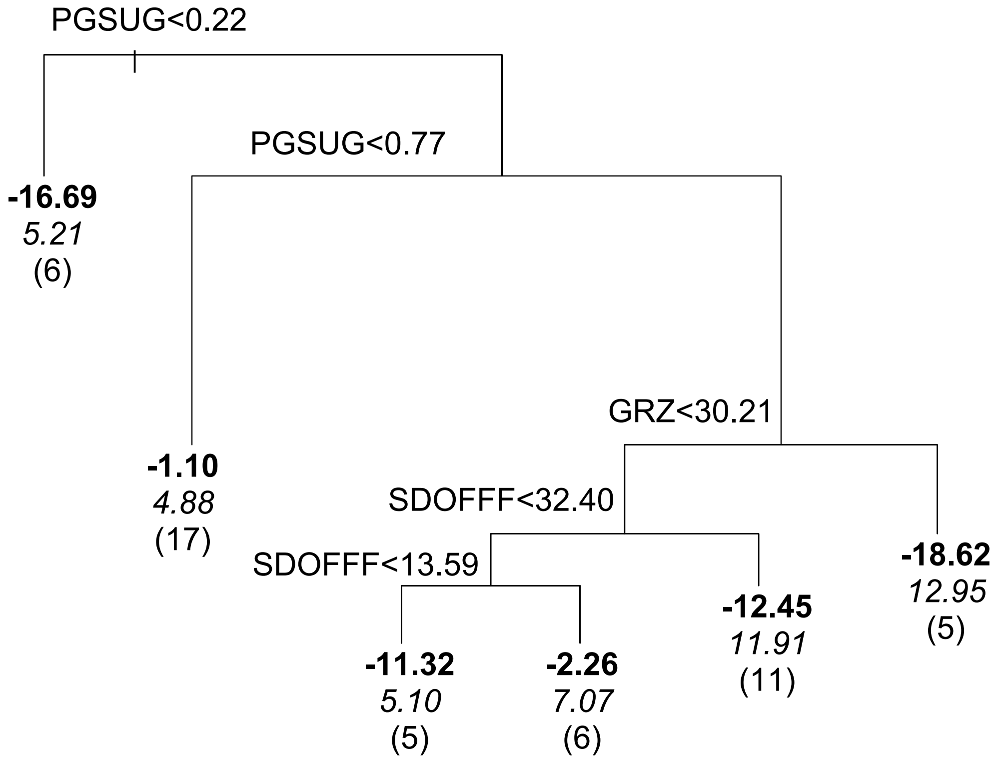


Figure 4i
Change in **riparian cross-section wetland rating** CART model using GSUG predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



43.60% deviance explained

Figure 4j

Change in **effective ground cover** CART model using GSUG predictor variables. Tree was pruned to 6 terminal nodes with a two percent drop in deviance explained versus the full model with seven terminal nodes. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

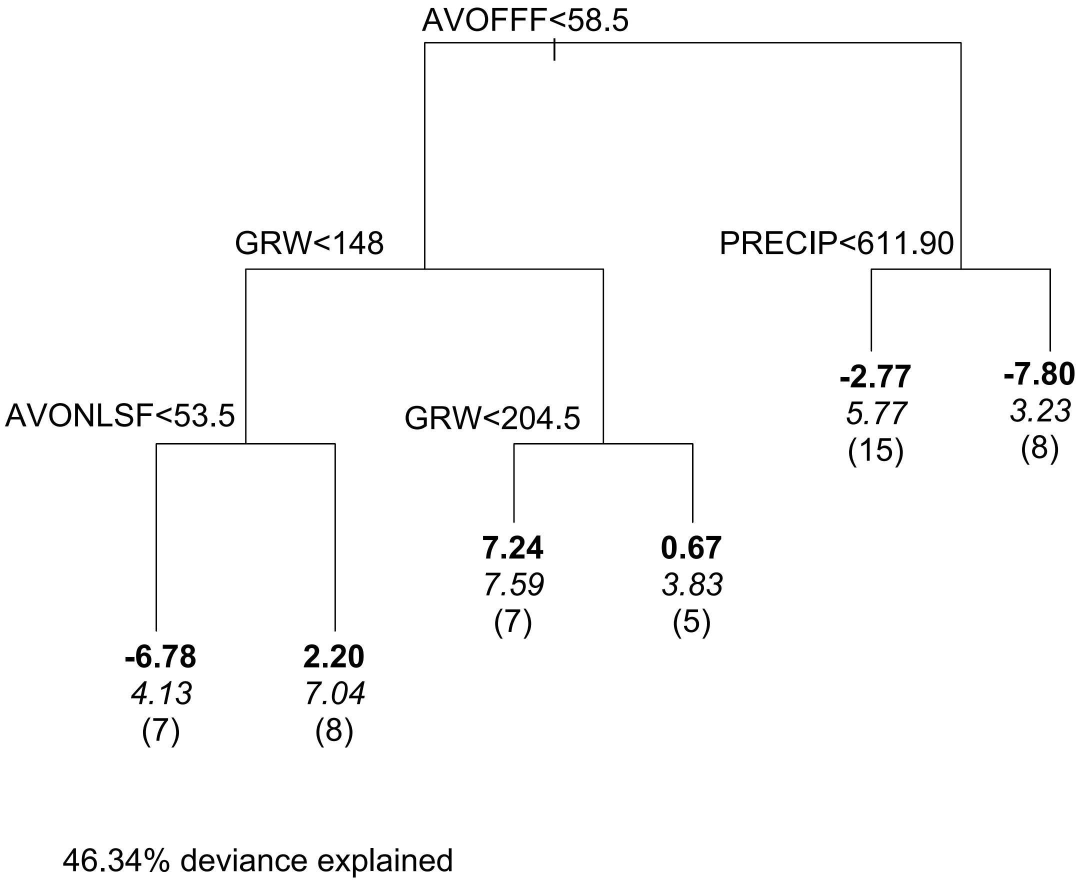


Figure 5a
Change in **bankfull width** CART model using IMGT predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

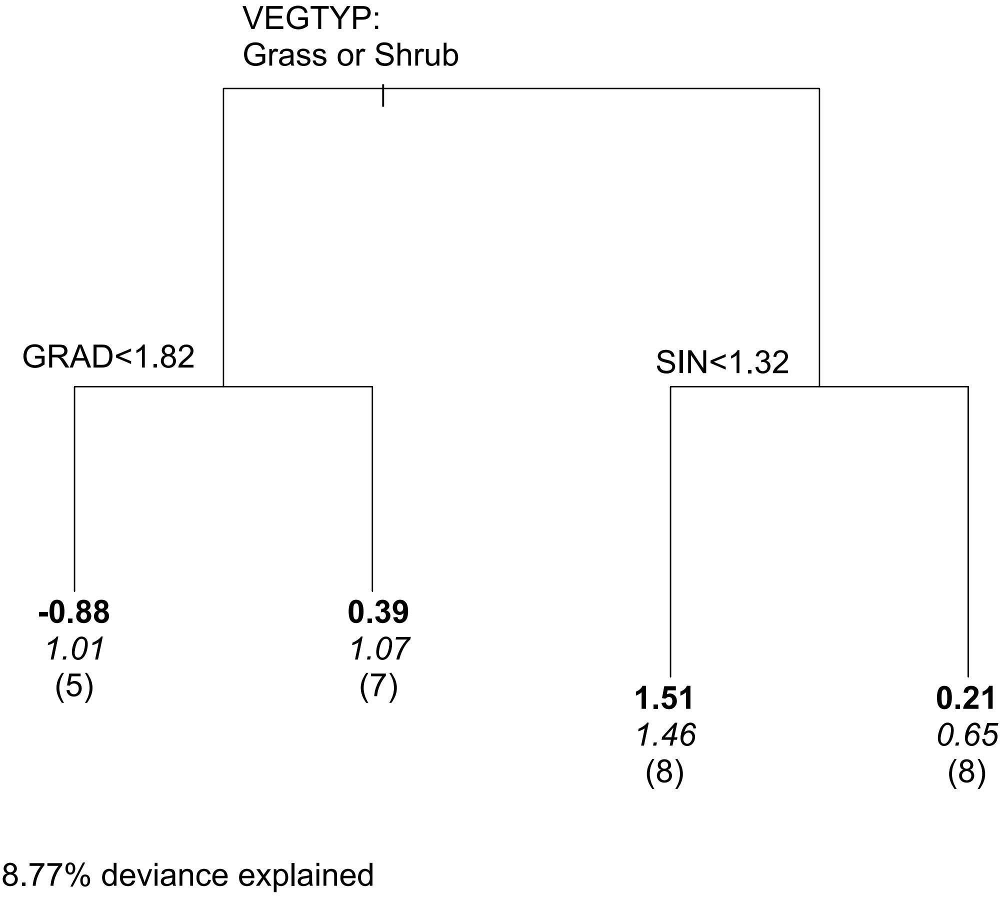


Figure 5b

Change in **bank angle** CART model using IMGT predictor variables. Tree was pruned from five to four terminal nodes with a one percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

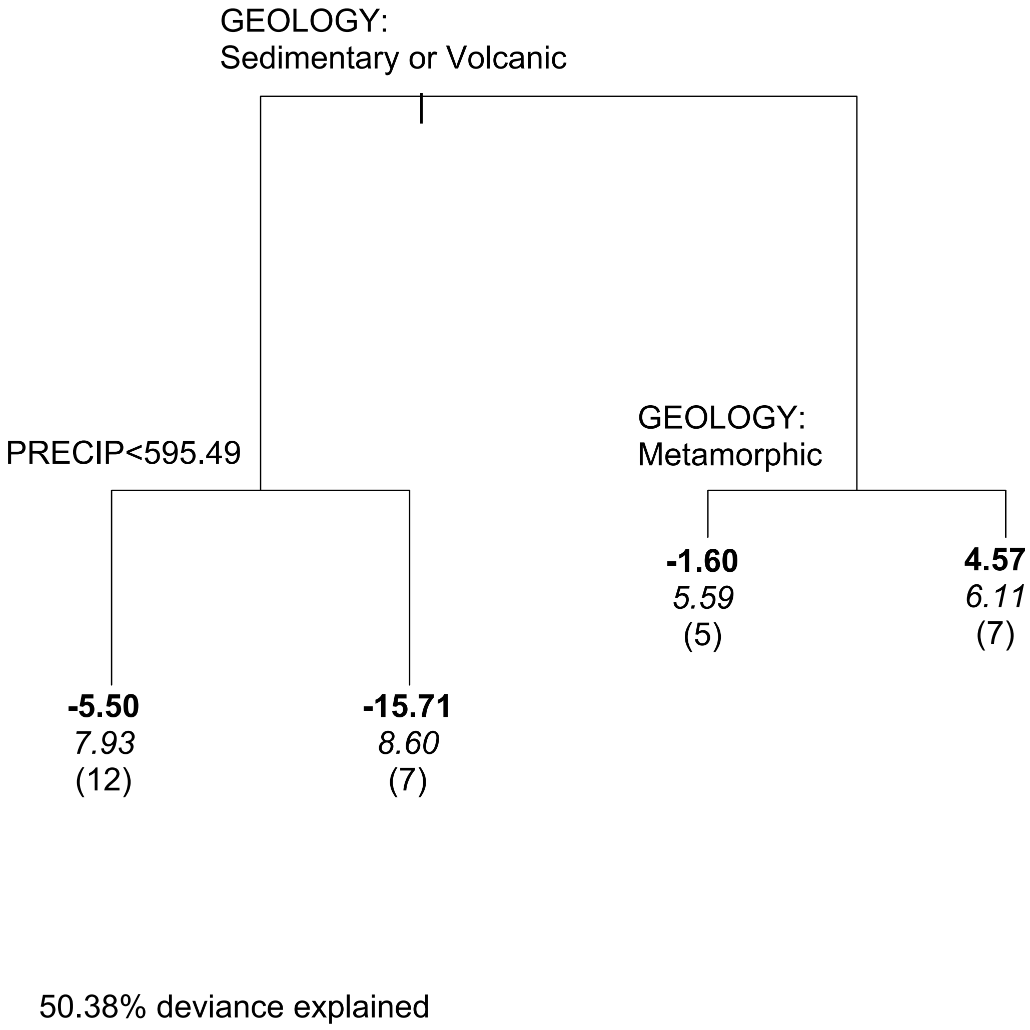
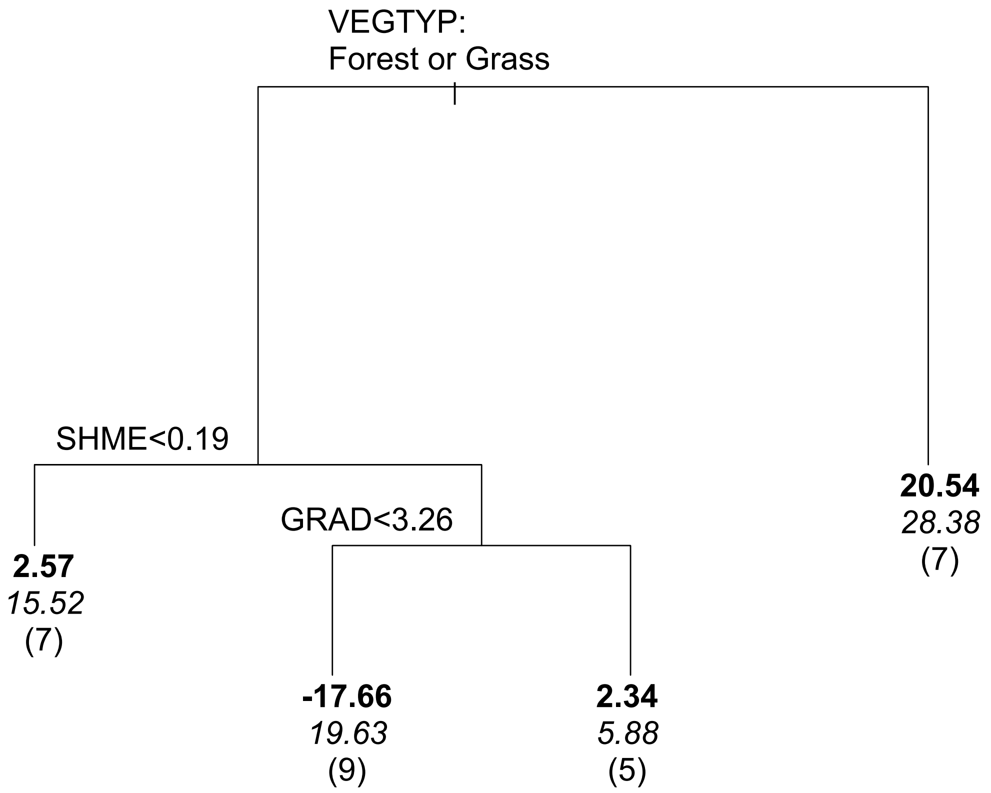
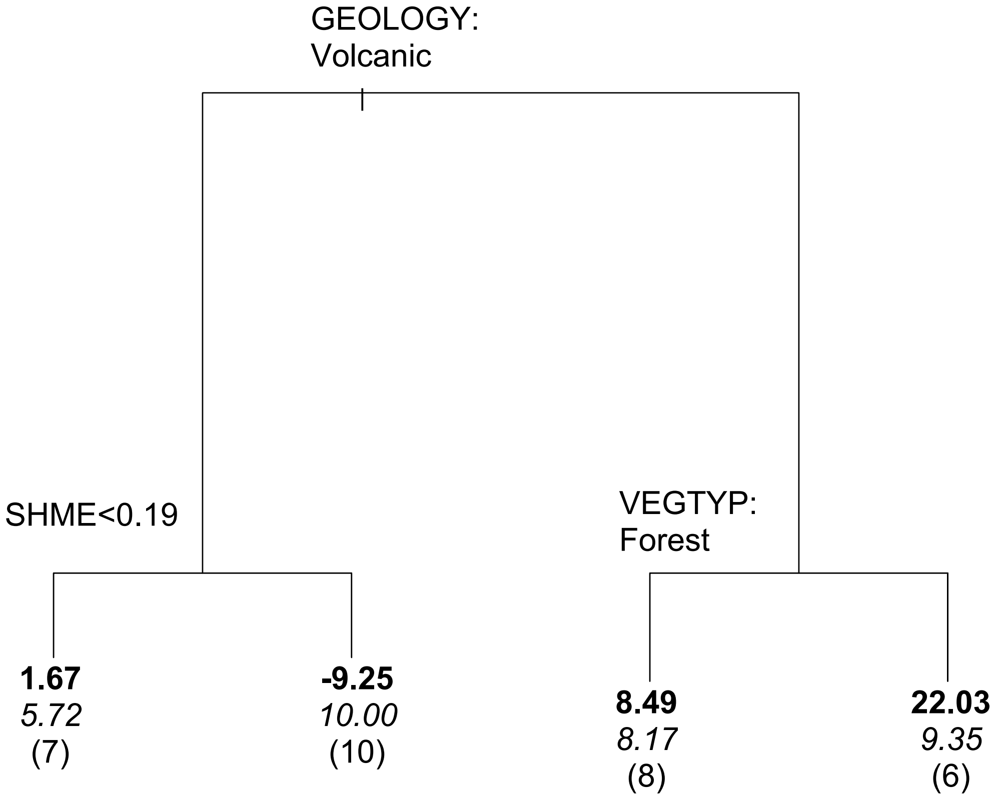


Figure 5c
Change in percent stable banks **(bank stability 2)** CART model using IMGT predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



38.01% deviance explained

Figure 5d
Change in percent stable banks **(bank stability 3)** CART model using IMGT predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



66.11% deviance explained

Figure 5e
Change in average bank **undercut depth** (meters) CART model using IMGT predictor variables. Tree was pruned from five to two terminal nodes with a four percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

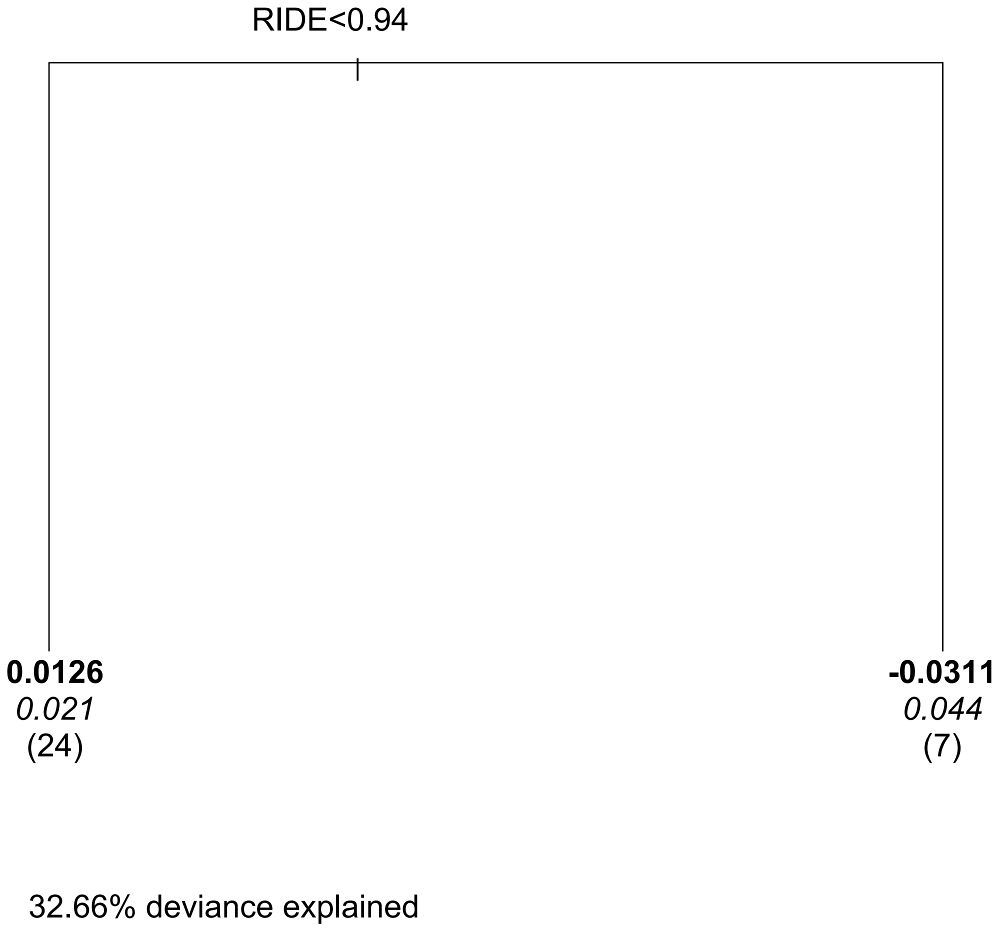


Figure 5f
Change in bank **undercut percent** CART model using IMGT predictor variables. Tree was pruned from four to three terminal nodes with a two percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.

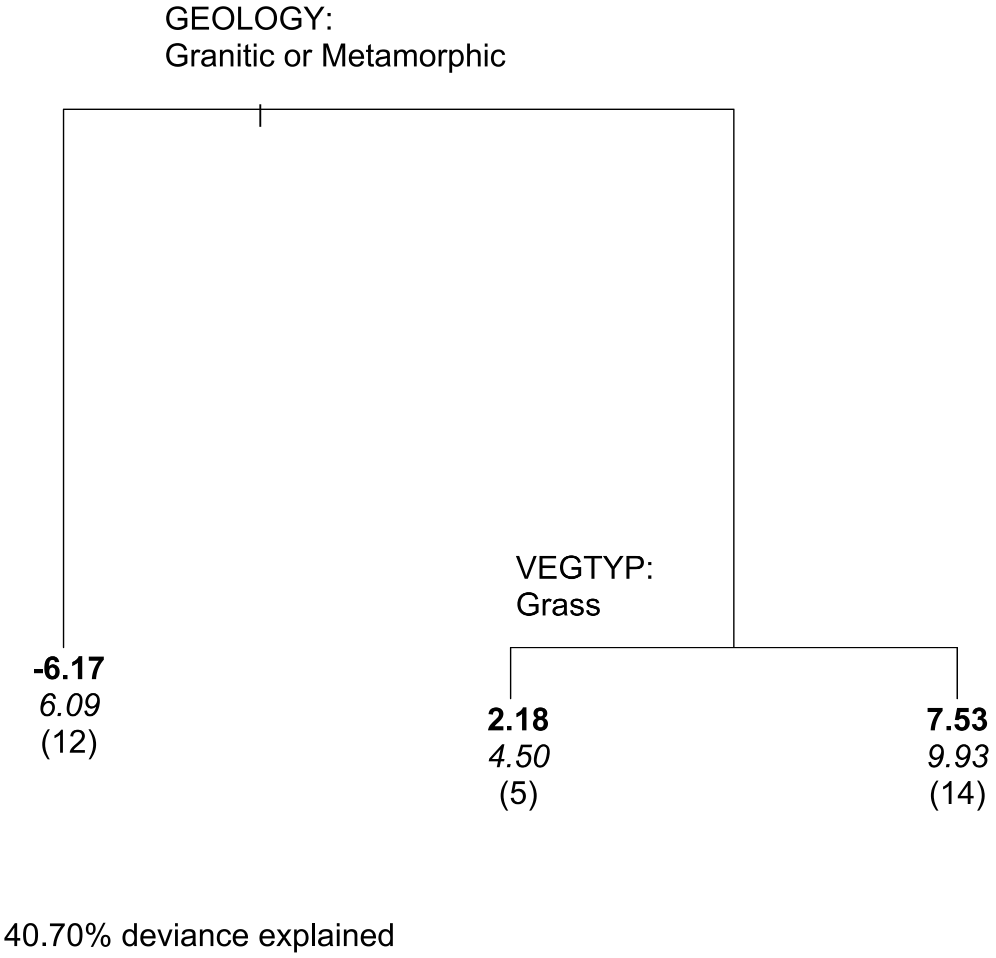
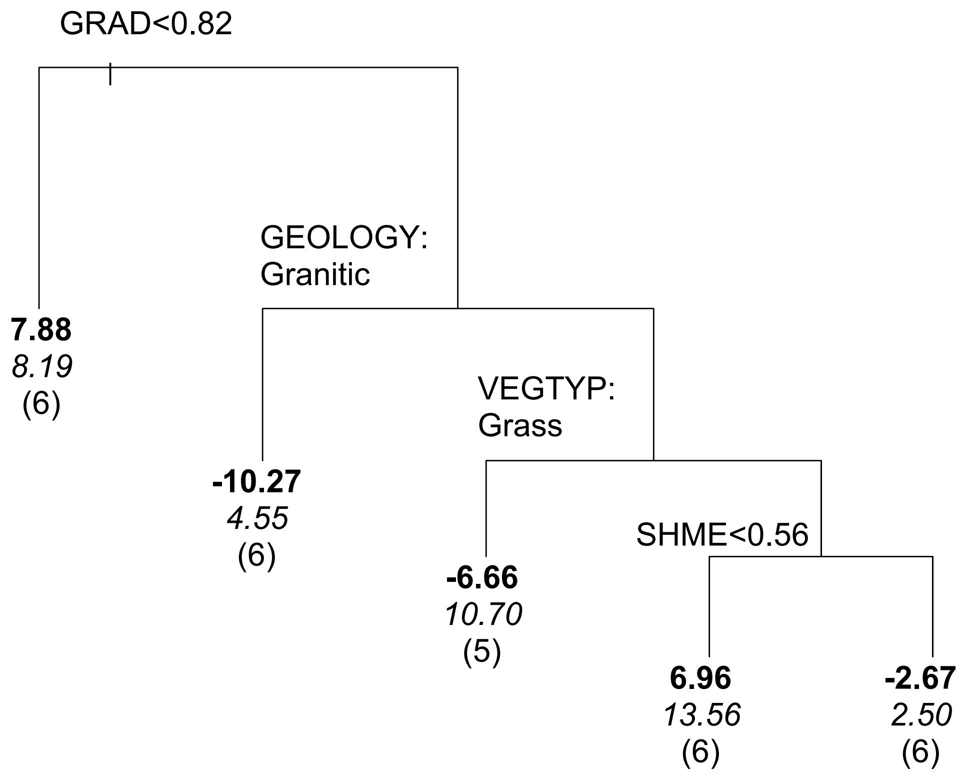
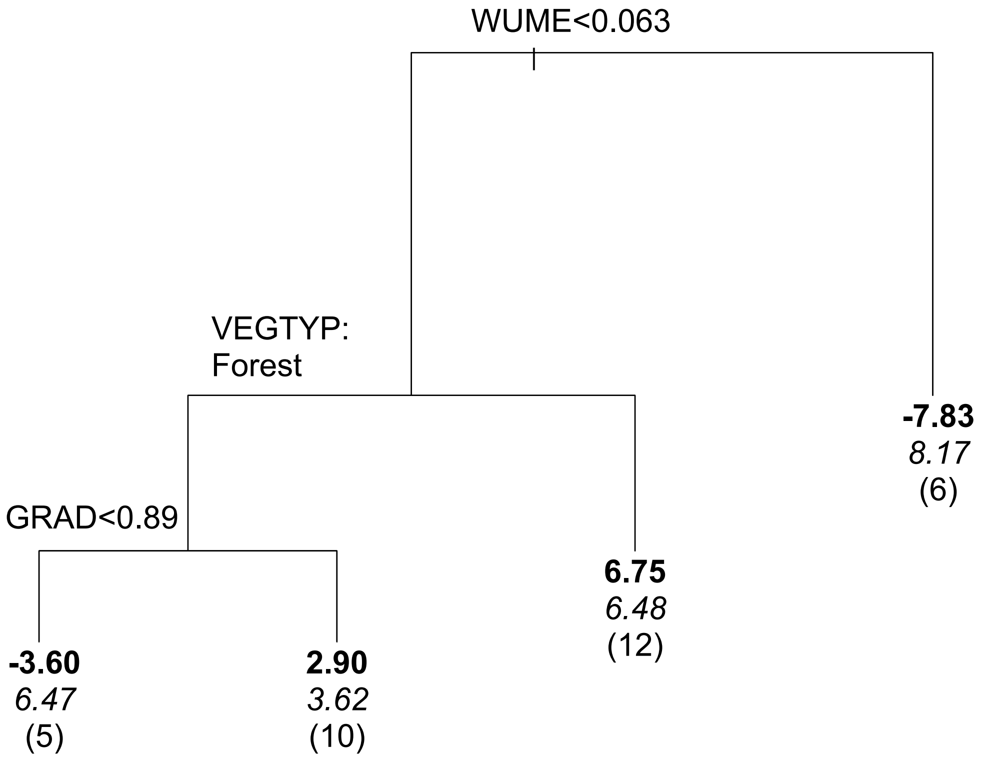


Figure 5g
Change in percent of banks with **angle less than 90 degrees** CART model using IMGT predictor variables. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



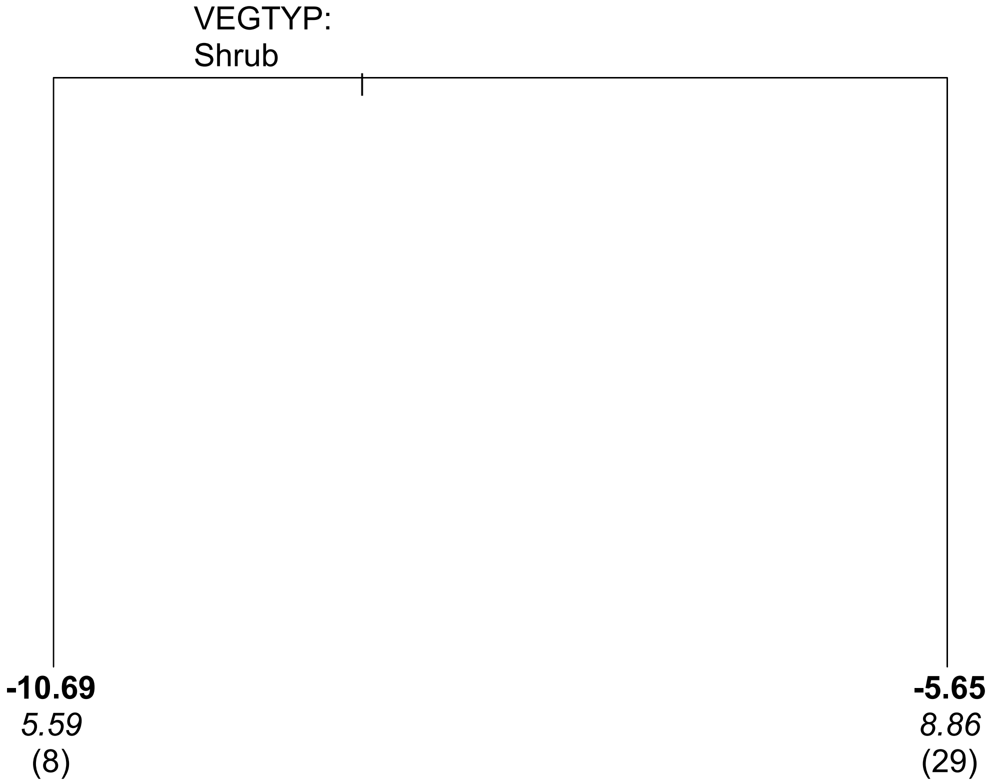
47.10% deviance explained

Figure 5h
Change in **greenline wetland rating** CART model using IMGT predictor variables. Tree was pruned from five to four terminal nodes with a one percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



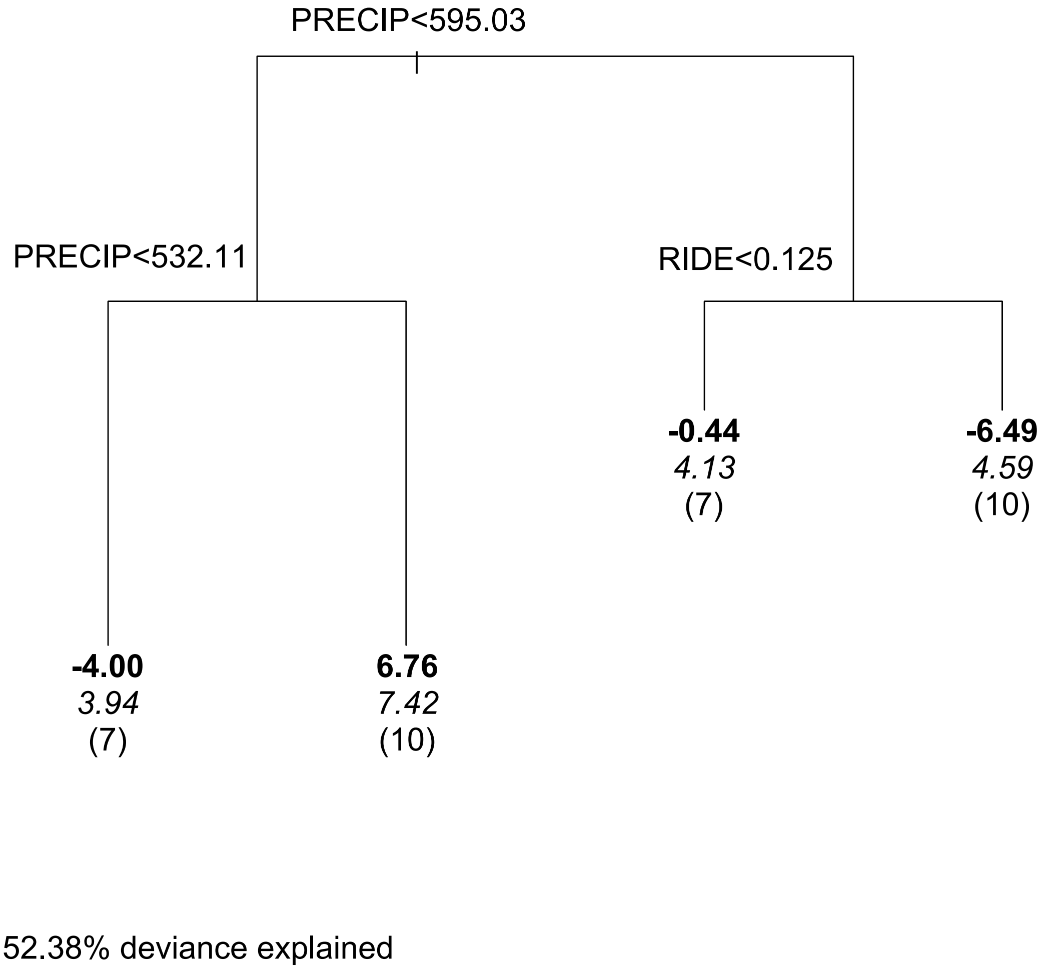
47.74% deviance explained

Figure 5i
Change in **riparian cross-section wetland rating** CART model using IMGT predictor variables. Tree was pruned from three to two terminal nodes with less than one percent drop in deviance explained. Split is labeled with response variable and value that determines split to the left. Mean response value (**bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



6.17% deviance explained

Figure 5j
Change in **effective ground cover** CART model using IMGT predictor variables. Tree was pruned from six to four terminal nodes with a ten percent drop in deviance explained. Non-terminal nodes are labeled with response variable and value that determines split to the left. Mean response value **(bold)**, standard deviation (*italic*) and number of observations (parenthesis) are labeled on each terminal node.



Interpretation of GSUG Results

Length of growing season

Longer growing season lead to increased plant biomass productivity when all other parameters are equal. Warren et al (1986) found soil physical characteristics were different, infiltration rates were higher and sediment production was lower during growing season compared to dormant periods on sites with silty clay soils. McKeon et al (2008) found length of growing season to be one of two primary factors accounting for spatial variability in livestock carrying capacity.

The regression models in this study suggest decreases in **bank stability 2** (table 4a) and average **undercut depth** (table 4b), associated with longer growing seasons (GRW). **Effective ground cover** increased with longer growing season (table 5c). The GRW variable had some influence on **undercut depth** (figure 4e) and positive relationship with **effective ground cover** (figure 4j) on sites where the average off date (AVOFFF) is fewer than 58 days before the first fall freeze (i.e. grazing extends to later in the growing season).

Length of grazing season

Grazing the entire length of the growing season is generally considered incompatible with sustaining healthy riparian and stream conditions (Fitch and Adams 1998, Platts 1991). When cattle are allowed to graze the entire growing season they tend to concentrate in riparian areas. Length of grazing season (GRZ) measured in number of days was found in MLR to correlate with diminished **riparian cross-section wetland**

rating (table 4e). This relationship was supported in the CART analyses for sites that were grazed for more than 77% of the growing season (figure 4i).

Growing season un-grazed

A greater number of growing season days in which no grazing occurs on a pasture will increase the time that vegetation has to recover from grazing pressures. In this study one predictor variable measures the number of growing season days ungrazed (GSUG) while another measures the percent of the total growing season ungrazed (PGSUG). The GSUG had a narrowing effect on **bankfull widths**, and a positive (increasing) effect on **bank stability 2** (table 4a).

Percent of growing season ungrazed showed a negative effect on **riparian cross-section wetland rating** supported in the MLR model (table 4e). The CART model (figure 4i) for **riparian cross-section wetland rating** suggests a threshold with sites ungrazed less than 22% (i.e. grazed for 78% of the growing season) and sites ungrazed more than 77% of the growing season (i.e. grazed less than 23% of the growing season) showing the most negative responses.

A positive relation between PGSUG and **effective ground cover** was shown in the MLR model (table 4e) but the deviance explained by PGSUG was not great enough to be retained in the CART model.

Grazing strategy

Some literature suggests certain grazing systems are better than others (Platts 1991, Wyman et al 2006) while others suggest that any system of grazing that is well implemented, including continuous season long grazing, will lead to improved conditions (Clary and Webster 1989). Because explicit data on specific grazing strategies used were not consistently available, season of use and variability in season of use were used to describe grazing strategies using four categorical variables CAONLSF, CAOFFF, CAUSE and VARIED, and five continuous variables AVONLSF, AVOFFF, SDONLSF, SDOFFF and REST (see table 2 and methods section for descriptions).

CAUSE

Among the grazing strategy categorical variables, only CAUSE (season of use basd on average onand off dates) was found to have weak relations to **bank stability 2**, bank **undercut percent** and bank **angle less than 90**. Of these three response variables, only **bank stability 2** retained CAUSE as an important predictor variable in the CART model. The models suggest:

- *Early*, *mid*, *winter* and *no grazing* showed negative influence on **bank stability 2** while *late* and *full* season grazing showed a positive influence (table 4a). The CART model (figure 4c) suggests that *early* and *full* season grazing have negative impact on **bank stability 2** when streams have sinuosity greater than 1.07 and are located in forest or grass vegetation types.

- *Early* season grazing, *full* season grazing and *no grazing* correlate with diminished improvements in **percent undercut** banks compared to *late*, *mid* and *winter* grazing (table 4c).

- *Full* season grazing exhibited a negative relation with percentage of banks with **angle less than 90** in sites with *granitic* and *metamorphic* geology types (table 4d).

AVONLSF

Increase in the average number of days after the last spring freeze that animals are allowed on a pasture (AVONLSF) showed positive relationships with **bankfull width** (table 4e and figure 4a), and increase in **effective ground cover** (table 4e and figure 4j) in both the MLR and CART models with the greatest proportion of deviance explained by AVONLSF in the CART model for change in bankfull width (figure 4a). Percentage of banks with **angle less than 90** also showed a positive relationship with AVONLSF but the deviance explained was not great enough to be retained in the CART model.

AVOFFF

Increasing the average number of days before the first fall freeze that animals must be removed from pastures (AVOFFF) showed a negative relation to **effective ground cover** in both MLR and CART models (table 4e and figure 4j). Increasing AVOFFF showed a widening effect on **bankfull width** in the MLR model (table 4a) but did not explain enough response deviance to be included in the CART model.

SDONLSF

Standard deviation of the on date measured in days after the last spring freeze is intended in this study as an indicator of a deferred or stuttered deferred rotational grazing system. In deferred rotation systems pastures are used during different portions of the growing season each year. This allows vegetation opportunity to store energy and complete critical life cycle portions every other year (deferred rotation) or two years in four (stuttered deferred rotation) (Platts 1991).

Multiple linear regression analyses indicated a negative relationship between SDONLSF and **bankfull width** (table 4a), **bank stability 3** (table 4b) and bank **undercut percent** (table 4c). Deviance explained was not sufficient to retain SDONLSF as a predictor in the CART model for **bankfull width**. The CART model for **bank stability 3** supported the negative relationship of greater SDONLSF on bank stability in forest and shrub vegetation types with volcanic geology type (figure 4d). The CART model for **undercut percent** contradicts the MLR model, showing a positive effect of SDONLSF (figure 4f). Given threshold values for SDONLSF of less than a day, the nodes are in effect separating sites that practically have no on date variation from sites that do.

SDOFFF

Standard deviation of the off date was used with basically the same intention as SDONLSF of indicating rotational grazing. Multiple linear regression models indicated a negative relation between SDOFFF and **riparian cross-section wetland rating** (table 4e). The corresponding CART model for **riparian cross-section wetland rating** (figure 4i) suggests a threshold effect with sites having less than 13.5 days and more than 32.40 days of variability in the off date showing the most negative responses.

The MLR model for bank **undercut percent** indicates a positive relationship with SDOFFF (table 4c). The corresponding CART model (figure 4f) shows a more positive response with fewer than 15 days variability in off date with SDOFFF only being important in sedimentary or volcanic sites with variability in the on date.

REST

Allowing pastures to rest for an entire growing season allows riparian communities to recover from disturbances and move closer to their natural potential (Platts 1991).

Number of years that pastures were rested correlated with increased **riparian cross-section wetland rating** in the MLR model (table 4e) but did not explain sufficient response deviance to be retained in the corresponding CART model (figure 4i).

Interpretation of IMGT Results

REST

Increasing number of rest years showed a negative response in **effective ground cover** in the MLR model (table 5g) but did not explain deviance sufficient to be included in the CART model (figure 5j).

GRZD

The number of years pastures were grazed did not show significant relationship to any of the response variables in this study.

TRSP

Number of years in which animal trespassing was reported as a problem on pasture showed a negative relationship with **bankfull width** (table 5a) but did not explain sufficient deviance to be included in the corresponding CART model(figure 5a).

SALT

Salt and other dietary supplements can be used to reduce use of riparian areas by dispersing animals more evenly throughout a pasture. To be effective, Wyman et al (2006) recommend placing such supplements ¼ to ½ mile from streams. During visits to several of the sites in this study salt supplements were found directly adjacent to a few of the streams. Because of the uncertainty in exactly how salt and other supplements were used during the period of study the effectiveness SALT (placed to lure animals away from the stream) as a predictor of stream and riparian response is questionable. A positive relationship was detected however in the MLR model for bank **undercut depth** (table 5c). The deviance explained by SALT was not sufficient to be retained in the corresponding CART model (figure 5e).

RIDE

Herding animals to disperse use throughout pastures can help to reduce time animals spend in riparian areas and thus minimize impacts to streams and riparian areas (Wyman et al 2006). Multiple linear regression analysis suggested a positive relationship between RIDE and **bank stability 2** (table 5a).

The deviance explained was not sufficient to be retained in the corresponding CART model (figure 5c). Bank **undercut depth** (table 5c and figure 5e) and **effective ground cover** (table 5e and figure 5j) both showed negative response in MLR and CART associated with increased proportion of grazing years that herding was used to manage grazing. These negative responses are not what one would expect from what is generally considered a good practice. These relationships may merely reflect a practice that simply has not had time to initiate a positive response or a greater need for riding in situations where other management is effective. This idea is more thoroughly explored in the discussion section below.

LTINT

This variable was defined as the proportion of years that grazing was allowed in which numbers of animals were lower than in preceding years. This measure of implementing lower stocking rates showed negative response in MLR analyses for **undercut depth**, percentage of banks with **angle less than 90**, and **effective ground cover (table 5c, 5e and 5g)**. These responses are counterintuitive and were not supported by retention of the LTINT variable in CART analyses (figures 5f, 5g, and 5j).

FNC

This variable was defined as the proportion of years that grazing was allowed that any type of fence was erected to exclude or limit access to riparian areas. Multiple linear regression analyses suggested a negative relation between fencing and **bankfull width (stream channel narrowing)**, and **effective ground cover** (Tables 5a and 5g) **Bank stability 2**, **undercut percent**, were positively correlated to fencing (Tables 5a and 5d). The variable FNC did not explain deviance sufficient to be retained in any of the CART models **(figures 5a, 5j, 5c, and 5f)**.

WTR

Placing water developments away from streams helps to reduce concentration of cattle in riparian areas by providing an alternative water source (Wyman et al 2006). The predictor variable WTR was measured as the proportion of years that grazing was allowed on a pasture in which water developments of any kind were used to help reduce time cattle spend in streams and riparian areas.

Multiple linear regression analyses indicated a negative response in bank **undercut percent** (table 5d), and a positive response in **riparian cross-section wetland rating** (table 5d). Neither of these relationships showed up in the corresponding CART models figures 5f and 5i).

SHME

Stubble height measurements are used by rangeland managers as an indicator of level of resource use. Used as a trigger stubble height is measured during the grazing season to help land managers decide the appropriate action needed to ensure excessive use does not occur. As an end-point indicator stubble height measurements can guide managers toward meeting long-term objectives (Clary and Leninger 2000, University of Idaho Stubble Height Review Team 2004). If for example a pasture is consistently grazed to achieve an end of the season stubble height of six inches but long term objectives such as bank stability, and bank angle are not being met, land managers may decide to set a target stubble height of ten inches and/or try other management practices, possibly in conjunction with the six inch target height.

The variable SHME is a measure of dedication to monitoring (as are BAME and WUME). That is, the proportion of years that grazing was allowed in which stubble height was actually measured and recorded for use as a guide to management. In multiple linear regression analyses dedication to stubble height monitoring was negatively correlated to **bankfull widths**, **bank stability (2 and 3)** and percentage of banks with **angle less than 90** (table 5a,b and e). Dedication to stubble height monitoring positively correlated to increased average **bank angle (**table 5a). Negative relations were supported in CART analyses for **bank stability 2** in forest and grass vegetation types (figure 5c), **bank stability 3** (figure 5d) in volcanic geology types, and **angle less than 90** (figure 5g) in streams with gradient greater than 0.82 with sedimentary, volcanic or metamorphic geology type and forest or shrub vegetation types.

All responses to SHME indicated in this study are (with the probable exception of bankfull width) generally undesirable. Although it is beyond the scope of this thesis to explore why this counterintuitive response is shown, some speculation is provided in the discussion below.

BAME

Bank alteration is typically measured using transects along the greenline. Evidence of hoof shearing or trampling intersecting the transect are measured and tallied to derive a percent value of banks that have been altered as a result of grazing animals (Burton et al 2008, Bengeyfield and Svoboda 1998). Measurement of bank alterations is used for similar reasons as stubble height, as a trigger to move livestock or as an endpoint indicator.

Mulitple linear regression analysis suggested a negative relationship between increased dedication to monitoring and **effective ground cover** (table 5g). This relationship is counterintuitive and was not supported by the corresponding CART model (figure 5i).

WUME

Woody plant utilization is an indicator of range utilization typically measured using classifications such as light, moderate, heavy etc… based on ocular estimates of percent of total biomass or current season growth used (Winward 2000, Burton et al 2008). Increased dedication to monitoring woody plant utilization correlated with widening of **bankfull width** (table 5a) and decreases in average bank **undercut depth** (table 5c), **greenline wetland rating** (table 5f) and **effective ground cover** (table 5g). Of these relationships only decrease in **greenline wetland rating** was supported in CART analysis (figure 5h).

Discussion

This study represents what may be the most extensive attempt to date at providing quantitative data on the effects of rangeland management practices on streams and riparian areas. While many studies have pointed out effects on streams and riparian areas associated generally with grazing (e.g. Armor et al. 1994, Belsky et al. 1999, Kaufman and Kreuger 1984, Sarr 2002) and case studies have provided results associated with strategies used within pastures within very narrow geographic ranges (e.g. Leege et al 1981, Gillen et al. 1985, Schulz and Leininger 1990, Myers and Swanson 1995, Holland et al 2005) none have attempted to make use of such a geographically extensive data set to provide a set of interpretations for managers charged with the ominous task of managing areas that span hundreds of square miles. The models developed in this study provide a good starting point and framework for further exploration of cause effect relations for management practices on streams and riparian areas. In future years as more PIBO EM sites are repeated more robust analysis of trend will be possible with greater ability to tie observed trends back to on the ground management activities. Utilization of these improved and more extensive data could help improve the validity of the models developed in this study and allow for development of more robust models using more sophisticated statistical procedures.

The models developed in this study serve as general interpretations for land managers with streams and riparian areas identified on allotments under their management. For example if a stream is experiencing reduction in undercut banks, a land manager may consult the regression trees provided for the PIBO EMP parameter angle less than 90 (Figures 4g and 5g) and find that streams with granitic and metamorphic soil parent materials witnessed, on average, reductions in bank angles less than 90˚ while sites with sedimentary and volcanic soil parent materials generally showed improvement. Based on this information land managers may choose to be more cautious when dealing with allotments that have granitic or metamorphic parent materials because stream banks may be slower to recover and be more susceptible to deterioration than stream banks with volcanic or sedimentary parent materials. If this attribute were deemed important given this slow response, objectives should reflect this difference with either a greater time to meet the desired condition or lesser amount of improvement to expect. If the stream happens to have volcanic or sedimentary materials the land manager could then move downward through the tree to notice that sites with these geologic types tend to show better improvement when late, mid or winter season grazing strategies are employed. Use of strategies recommended by these models will by no means guarantee success but simply provide a reasonable starting point, supported by quantitative data, for considering objectives and revisions for terms of grazing permits and allotment management plans.

Some models in this study provide results that seem at first glance counterintuitive. For example, models for bank angle, bank stability 2, bank stability 3 and angle less than 90˚ in the IMGT data set (figures 5 b, c, d and g respectively) indicate a negative response associated with greater dedication to monitoring stubble height (SHME). Declines in these attribute are not likely the result of stubble height measurements being a bad thing, but more likely result from an alternate explanation. One possible explanation could be increased monitoring occurring on sites that have been identified as at risk or having witnessed high levels of disturbance in the past.

Negative responses associated with management practices that presumably would improve conditions given sufficient time such as more frequent herding of animals to uplands (RIDE figure 5e and j) or more frequent woody utilization monitoring (WUME figure 5h) should be carefully examined for alternate explanations when using models provided in this study. Alternate explanations may include insufficient time for change to occur or different rates of response for different stream types (Magilligan and McDowell 1997).

The criteria for selecting DMA sites in combination with the assumption for the analyses that streams had potential to respond to changes in livestock management may have much to do with counterintuitive responses found in this study. . The DMA sites for this study were chosen to be representative of grazing use in the randomly chosen pastures within the randomly chosen sub watersheds. Interpretations of available photos suggest that 24 out of 79 sites have little or no grazing impacts apparent or likely. Thirty four of these 79 sites were assessed to be of channel morphology types that were irrelevant to bank trampling. Analyses of grazing management influences could reach different conclusions if focused on only streams and reaches with a potential to respond quickly to management. Streams provide a different learning opportunity if their morphology is controlled by bedrock or boulders or they are in steep canyons where livestock rarely go. The focus of this study is on the response of streams and reaches broadly representative of the grazed pastures across the Interior Columbia Basin. It is not on those places where a time limited management staff might focus their management efforts to have the greatest impact, as would be reflected by the DMA selection criteria of Burton et.al.,(2008)

Many of the response variables are likely correlated and have interactions. An example could be that an increase in wetland vegetation (higher wetland rating) is associated with increases in bank stability, decreases in bank angle, and increases in bank undercuts. Therefore land managers should consider all response attributes to determine if a positive response in one (e.g. greenline wetland rating or effective ground cover) may ultimately lead to improvements in another (e.g. bank stability or undercut banks).

Heavy grazing and poor management often result in stream downcutting or incision (Belsky et al 1999). Incision can be caused by other management and natural processes such as capture of a road or trail, flooding after fire, tectonic uplift, etc., In incised stream channels energy cannot be dissipated as well as for channels with more accessible floodplains. Therefore incised channels are associated with increased bank erosion during high flows, less frequent inundation and less sediment deposition on the floodplain. In this study there was no direct evaluation of the relationship between livestock and channel incision, but greater periods without grazing (GSUG and PGSUG) were correlated to decreases in bankfull width and increases in bank stability. Those results support the concept that effective management of livestock decreases or prevents some of the processes that lead to incision and it allows system recovery. Revegetation and succession along bare banks followed by sediment deposition and its stabilization can occur in reaches that are ready to recover. Readiness is indicated by the incision having gained sufficient width for a two-stage channel, an active channel with adjacent floodable area next to the active channel. This is also consistent with the conclusions of Wyman et al. (2006) discussing riparian grazing management and Magilligan and McDowell (1997) who state that channel narrowing often occurs after livestock exclusion.

Examination of the regression trees suggest certain parameters predict long term response more often and some more consistently explain a greater amount of response deviance. Table 6 provides a summary of predictors used in the CART models for each of the response variables. Predictors are assigned one to three stars with more stars indicating greater deviance explained by that predictor. Predictors that were considered in this study but not used in any of the CART models (REST, CAONLSF, CAOFFF, VARIED, BAME, WTR, FNC, LTINT, REST, GRZD and TRSP) were excluded from the table.

Table 6a

Summary of relationships among predictor and response variables from CART models. + = positive relationship, - = negative relationship, “T” indicates threshold effect present and “I” indicates interaction effect present. Cells with both positive and negative indicate conflicting results between GSUG and IMGT model or a threshold or interaction effect. Greater number of like symbols indicates greater strength of the relationship.

GSUG data										
	BF	BKANG	STAB2	STAB3	ANGLT90	UNCUTDP	UNCUTPC	GLWR	XSWR	EGC
GRW						-				+ T
GRZ									-	
GSUG	-		-		-					
PGSUG									- T	
AVONLSF	+	T								+
AVOFFF										-
SDONLSF				I			+			
SDOFFF							- I		- + T	
CAUSE										
Early			-		-					
Mid			+		+					
Late			+		+					
Full			-		-					
Winter			+		+					
No Grazing			+		+					
IMGT data										
	BF	BKANG	STAB2	STAB3	ANGLT90	UNCUTDP	UNCUTPC	GLWR	XSWR	EGC
SHME		-	-	-	-					
WUME								-		
RIDE						-				-

Table 6b

Environmental variables										
	BF	BKANG	STAB2	STAB3	ANGLT90	UNCUTDP	UNCUTPC	GLWR	XSWR	EGC
VEGTYP										
Forest	++		--	+ I	+		++	-	-	
Grass	--		--	+	-		+	+	-	
Shrub	--		++	+ I	+		++	+	--	
GEOL										
Granitic		++		++	--	-	-			
Metamorphic		- +		++	-	-	-			
Sedimentary		--		++	+	+	+			
Volcanic		--		--	+	+	+			
PRECIP		-								- T
GRAD	- + I		+		-			- + I		
SIN	-		-							

Not surprisingly the environmental variables GEOL and VEGTYP were the most commonly selected variables included in the regression trees and tended to explain the most deviance in responses. One or both of these variables were included in at least one model (GSUG or IMGT) for each of the predictor variables. This supports recommendations in existing literature to consider geomorphology and vegetation communities when determining desired future condition for streams and riparian areas on managed grazing lands (Bengeyfield and Svoboda 1998, Wyman et al. 2006, Milchunas and Lauenroth 1993).

Actual measurement values for short term monitoring data (stubble height, woody utilization & bank alterations) were seldom available for every year on the DMA sites in this study. Implementation monitoring on DMA sites in the Pacfish/Infish area is currently only required to be conducted 2 out of every five years (USDA FS 2003[1]).

More frequent data collection would have helped improve the statistical power of the analyses in this study would aid future research efforts.

The strength of each individual model presented serves to either support or dispute the hypothesis stated in the introduction. That is, certain management practices and monitoring indicators consistently correspond to improvements of certain PIBO EMP parameters. The models presented are intended as guides for exploring potential cause/effect relationships between grazing management and stream and riparian conditions.

The number of DMA sites for analysis in this study was low. At the time of this study, only 20% of the PIBO sites had two years of EM data. As the number of remeasured PIBO EM sites increases the ability to evaluate change and relate that change to grazing practices will increase. Given the large amount of spatial and temporal variability encompassed within the PIBO study area a large sample size will be required to overcome random sources of variability. Out of a total of 93 DMA sites sampled by PIBO EMP in 2001 and 2002 only 39 were included in the IMGT analyses and 61 for the GSUG analyses. The actual number of observations used in each analysis varied from 36-51 for the GSUG analyses and 26-37 for the IMGT analyses. Because of these low sample sizes validation of the data was limited. The models developed in this study represent the best that could be done given the limited sample size. More information on allotment use including size of pastures, number of pastures within allotments, dates of use for pastures and locations of allotment improvement structures such as riparian fences and water developments could possibly have been useful in this study and could aid in future research.

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Appendix 1

Sample questionnaire used for implementation monitoring and management data from field units

District/Field Office	###############					Name	**name of person completing form**
Stream Name	**Fictitious Creek**	PIBO reach code	**###-##-##-##-#**			Date	**10-Aug**
UTM Zone	**11**	Easting	**########**	Northing	**##########**		
		Latitude		Longitude			

Section A

Are annual monitoring data available for this DMA site?
☑ Yes (complete section B and C)
☐ No (go to section C)

How far from coordinates listed above is the annual monitoring site? (estimate to nearest meter or foot)				List coordinates of annual monitoring site if available						
				UTM	Zone	Easting	Northing	or	Latitude	Longitude
Meters:		Feet:								

Notes:	annual monitoring site is the same as PIBO EMP site

Section B (annual monitoring data)

Please check boxes for type of data collected and list values for each year:

Fill in box below

		☑ Stubble Height			☑ Woody Species Utilization			☑ Bank Alteration			Other	
		Target	Actual		Target	Actual		Target	Actual		Target	Actual
1999	Trigger	3		Trigger	use		Trigger	10%		Trigger		
	Endpoint	4	6	Endpoint			Endpoint			Endpoint		
2000	Trigger	3	4	Trigger	use		Trigger	10%		Trigger		
	Endpoint	4	6	Endpoint			Endpoint			Endpoint		
2001	Trigger	3	4	Trigger	use		Trigger	10%		Trigger		
	Endpoint	4		Endpoint			Endpoint			Endpoint		
2002	Trigger	3	3	Trigger	use	Yes	Trigger	10%	Yes	Trigger		
	Endpoint	4	3	Endpoint			Endpoint			Endpoint		
2003	Trigger	3	5	Trigger	use	No	Trigger	10%	No	Trigger		
	Endpoint	4	5	Endpoint			Endpoint			Endpoint		
2004	Trigger	3	5	Trigger	use	No	Trigger	10%	No	Trigger		
	Endpoint	4	5	Endpoint			Endpoint			Endpoint		
2005	Trigger	3		Trigger	use		Trigger	10%		Trigger		
	Endpoint	4	5	Endpoint			Endpoint			Endpoint		
2006	Trigger	3		Trigger			Trigger			Trigger		
	Endpoint	4		Endpoint			Endpoint			Endpoint		

Will annual monitoring data be collected in 2006? ☑ Yes ☐ No
Will annual monitoring data be collected in 2007? ☑ Yes ☐ No

Section C

What animals use pasture?

How many animals have grazed each year?
(fill in boxes for each animal / year)

	☑ Cattle	☐ Sheep	☐ Horses	Other	Fill in box below
1999	200				
2000	180				
2001	40				
2002	80				
2003	100				
2004	88				
2005	84				
2006	84				

How are animal units defined for this pasture?		Cow calf pair							
		1999	2000	2001	2002	2003	2004	2005	2006
Dates of use	on	9/2	9/2	7/13	8/26	7/8	7/2	8/5	6/15
	off	9/6	9/6	8/5	9/6	8/7	8/10	8/29	7/11
Check years in which trespassing has been a problem (Describe extent of trespass activity)		☐	☐	☐	☐	☐	☑	☑	☐
		2005- 9 cows entered another pasture, but were removed after notification 2004: 40-60 head trespasses on another pasture							

Check Boxes for years that any of the following practices have been used on this pasture

		1999	2000	2001	2002	2003	2004	2005	2006
Salting / dietary supplements		☑	☑	☑	☑	☑	☑	☑	☐
Riding upland		☑	☑	☑	☑	☑	☑	☑	☐
Light intensity use		☐	☐	☐	☐	☐	☐	☐	☐
Fencing riparian areas		☑	☑	☑	☑	☑	☑	☑	☐
Off-stream		☐	☐	☐	☐	☐	☐	☐	☐
other		☐	☐	☐	☐	☐	☐	☐	☐
other		☐	☐	☐	☐	☐	☐	☐	☐