An Integrated Study of Ecosystem Processes

B-Bar Ranch, Montana

Capstone Class
Land Resources and Environmental Sciences
Montana State University
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1. Introduction

The legacy of western expansion in North America has left a patchwork of lands in various states of ecological well being. Management regimes have differed over the landscape, ranging from hands-off supervision to intensive resource extraction. These historic patterns can be seen throughout the western states, and many are present at the B-Bar Ranch. Immediately South of the ranch lies the large wilderness expanse of Yellowstone National Park, relatively unaltered by human contact. In contrast to such unspoilt land, the current holdings of the ranch contain large areas of past clear-cuts, visible in stumps and patches of young trees. In addition, ranching has persisted in Tom Miner Basin for many decades as a viable source of economic livelihood.

Regardless of the management regime, humans have undoubtedly altered the natural landscape surrounding the B-Bar. Understanding current environmental conditions, processes and the effects of management practices is critical to making wise decisions to safeguard these resources for future generations. This imperative is what draws many students to study environmental processes, and it was the impetus for an investigation of the B-Bar ranch by the 2006 Land Resources and Environmental Sciences Capstone class.

To explore these crucial fields of study, the capstone class created, designed and implemented research projects at the B-Bar, using knowledge gained in previous classes, internships and work experiences. Faculty at Montana State University assisted this process by contributing advice and guidance.

The B-Bar Ranch consists of many different ecosystem types that supported the various research projects including riparian, range, forest, and agricultural areas. The total acreage of the ranch is 9,000 acres, with an additional 11,000 acres leased from the Forest Service. The ranch is in the upper Tom Miner basin, at the southern end of Montana's Paradise Valley. The B-Bar shares its southernmost borders with Yellowstone National Park, which makes the ranch's holistic management practices critical to conservation efforts in Montana. The environmentally conscious practices of the ranch support a variety of wildlife including elk, deer, moose, black and grizzly bear, bighorn sheep, mountain lion, lynx, porcupine, badger, beaver, coyote, marmot, fish and bird species.

Besides conservation, the B-Bar Ranch is dedicated to numerous agricultural practices. Suffolk Punch draft horses and White Park cattle are raised on the ranch to preserve the species' genetic diversity. Both species are currently endangered, and the herds managed at the B-Bar are crucial to the survival and/or renewal of these historically significant animals. In addition, the ranch raises an Angus herd used mainly for maintaining grazing allotment standards. The ranch produces 200 – 270 tons of hay for winter feeding from a single cutting.

The 2006 capstone had a variety of research topics ranging from the hilltops to the valley bottom. The projects focused on pine beetle attack, nutrient cycling, weed management, irrigation, stream hydrology and the threat of whirling disease. Each of these topics is connected within the ecosystem. Pine beetle attacks affect the fuel load for fires, fires affect the sediment load to the stream, and changes in stream dynamics affect subsurface water flow. Irrigation practices affect the amount of water put into the system, which can alter the hydrology and characteristics of the stream. The presence of weeds in the system changes the amount and type of vegetative cover. Water may be more likely to runoff and carry sediment than to be absorbed into the soil horizons. The amount of sediment could change the hydrology of the stream and the likelihood of whirling disease being present in Tom Miner Creek. Each of these topics is designed to study different aspects of land resources and the classes taught within the Land Resources department. However different these topics may be, the underlining factor is understanding the environment and how actions in one part of the ecosystem may affect others parts of the connected web of our environment.

The LRES 2006 senior capstone course is designed to give soon-to-be graduates an opportunity apply the knowledge that has been acquired throughout the pervious years of study. Each student was given the opportunity to design their own experiment. From the first question to the final analysis, students created an individual lesson in which their own intelligence and abilities were tested. The capstone course provided a hands-on setting where all the students learned the frustration, dedication and satisfaction that comes from studies outside the traditional classroom setting. The knowledge acquired in this course will surely help students in future endeavors where ever they might be.

2. Pine Beetles on the B-Bar and the use of Remote Sensing for Predicting Distribution

Steven Jay, Kelly Sylvester, Matt Hall, Ryan Buerkle & Patrick Lawrence

Introduction

Pine beetles have naturally occurred in western ecosystems for thousands of years. They can have drastic effects upon the health of forests, periodically killing large swaths of trees and reducing the amount of forest cover. Potential effects are numerous: forage production may be increased, wildfire fuel loads may be built up, travel may become difficult for large ungulates, and wildlife food sources such as white bark pine seeds may be reduced in abundance.

Drought conditions throughout the western United States and the legacy of fire suppression may have caused an increase in pine beetle activity. Lack of moisture can stress trees to a point where they are less capable of fending off pine beetle attacks. Successful trees use their resources to produce pitch, forcing the beetles out of the tree in a process called "pitch-out". Pine beetles preferentially attack large, mature trees that are less able to resist invasion, and fire suppression has increased this opportunity.

Pine beetles attack a tree by burrowing through the tree bark into the phloem, the layer which transports water and nutrients throughout the tree. They release a pheromone which attracts other beetles to the attacked tree, and an anti-attractant when the maximum capacity has been reached (Amman 1989). The incoming beetles then search for a new host tree, and choose the next victim based upon proximity. In this way, their short-term flying abilities often lead to mass tree mortality in a concentrated area. Therefore, we would expect greater beetle survival and reproduction in areas with dense stands of trees. Another method by which pine beetles kill trees is through the blue stain fungus. Beetles often carry this parasite into the tree, which blocks the conductive vessels in the inner bark and sapwood. This often kills a tree in one generation of activity.

Our group was interested in determining the extent of pine beetle attack on the B –Bar ranch and assessing whether environmental conditions such as elevation, slope, aspect or tree density correlated to higher success rates of pine beetle attack.

The first objective of this project was to adequately map the pine beetle distribution on the B – Bar ranch.

Hypothesis 1 - It is possible to create a map of pine beetle distribution by the use of remote sensing to within 85% accuracy.

Through the use of the pine beetle distribution map, three factors that could affect tree moisture content and their correlation to pine beetle activity will be tested.

Hypothesis 2 – The slope of the landscape is directly proportional to pine beetle presence (increase in slope leads to increase in pine beetle distribution).

Hypothesis 3 – The elevation is directly proportional to pine beetle presence (decrease in elevation leads to increase in pine beetle distribution).

Hypothesis 4 – Pine beetle presence will be highest on south facing aspects.

Hypothesis 5 – Basal area is proportional to pine beetle infestation (Increase in density increases pine beetle presence). The final hypothesis was intended to compare tree stand density and pine beetle activity. This hypothesis could determine whether there exists a relationship between stand density and pine beetle distribution, as a wide variety of randomly selected sites with different densities will be included in the testing of the hypothesis. The hypothesis was tested using field sampling.

Methods

Two tree stands were selected for sampling, based on ease of access and possibility of pine beetle infestation. A representative point was chosen within a forest stand and a hiking pole used to mark this point. Three basal area factor prisms, 10, 20, and 30, were tested to determine which one would be used to generate a large number of samples as well as sample plots, to create variability within the sampling. Each of the three prisms of basal area factor were used to assess the trees within a variable plot. The basal area factor of each prism affects how many trees are inside the plot. The 30 basal area factor prism averaged 8 to 10 trees per plot and was chosen to be used for the entire sampling procedure.

A distance of 50 meters between sampling points was chosen because of the low number of pine beetle red and gray attacked trees. A red attacked tree has been killed by pine beetles within the past year and still has most of its needles, which are red. A grey attack tree has been dead for over one year and the needles have turned gray. The pixels containing grey and red attack trees might have a different reflectance value than pixels with only green trees.

The first sample point was 25 meters from the stand edge, to reduce edge effects. The variable plot method was used for sampling at each point. Variable-plot sampling does not have a fixed plot radius like other methods (Bell-Dillworth1989). The number of trees that are counted in a plot is dependent on the prism basal area factor, distance to the center of the plot, and the diameter of the tree. This method requires only approximate diameters of trees and saves significant time otherwise spent on field calculation without losing accuracy.

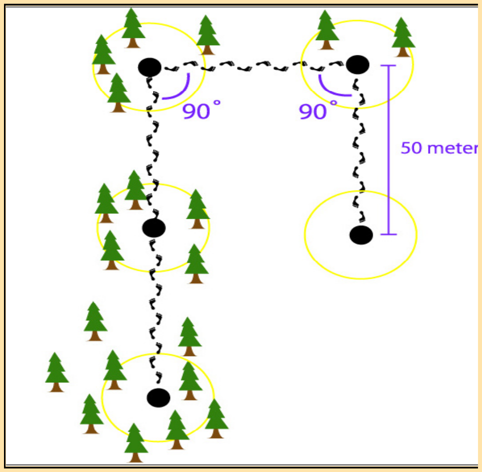

Fig 1. Depiction of Grid Sampling Method

Trees in the plot were examined for pine beetle attack by looking for small holes in the bark and pitch tubes on the bark. The presence or absence of pine beetle attack and the tree species was recorded for each tree. The slope and aspect were measured at each sample point using a clinometer and compass. The northing, easting, and elevation were found with a GeoXT GPS receiver.

A bearing was determined that would approximate the contour of the forest stand, for ease and speed of travel. A point was collected, then a tape line used to measure 50 meters on the chosen bearing to the next point. The process was continued through the stand forming a grid of sample points (Figure 1).

Analysis

To test for possible correlations between pine beetle attack and the environmental variables, a logistic regression was used. To analyze the slope, aspect, elevation and density data, we looked for correlations to areas of forest that were "attacked" or "not attacked". Such designations are binary in nature rather than continuous, preventing any attempts to use standard regression models, since a line does not adequately describe the results. Thus, it was necessary to use a logistic regression model to give probabilities for our set of explanatory variables.

The logistic regression model takes the form:

$$\text{Logit}(\pi) = B_0 + B_1x_1 + B_2x_2 + B_3x_3 + B_4x_4$$

With the link between the binary and continuous data as:

$$\pi = \frac{e^{\eta}}{1 + e^{\eta}}$$

Values B_1 through B_4 are the coefficients associated with the x variables, which are slope, aspect, elevation and density. B0 is a constant. π is the link and η is equivalent to the statement $B_0 + B_1x_1 + B_2x_2 + B_3x_3 + B_4x_4$. Rather than using this full equation, we evaluated each of the x variables separately when considering slope, aspect, density and elevation, with equations as follows:

$$\text{Logit}(\pi) = B_0 + B_1x_1$$

To find the values for B0 and B1, the statistical software package S+ was be used. Results from Table 1 were entered into a chi-squared test, from which it was determined that density was the only significant predictor of pine beetle attack. Its p-value was 0.001, well below the 0.05 significance threshold. Other variables were above the 0.05 threshold, thus they were discarded.

Table 1. Statistical results from the logistic regression run in S+

Variable	**Degrees of Freedom**	**Deviance**
Density	1	11.513
Slope	1	0.155
Elevation	1	0.325
Aspect	2	1.374

Knowing that density and pine beetle attack were correlated, we next attempted to determine whether tree stand density could be detected using remote sensing techniques. We obtained a image from the satellite Landsat ETM+ taken on August 11, 2006, which contained full information from the satellite's 7 bands (Blue, Green, Red, NIR, MIR, TIR and MIR), though the blue band had very little brightness.

Coordinates associated with sample plots were matched up to the downloaded image using the Convert Pixel to ASCII function in Erdas Imagine 9.0. This process resulted in a table of spectral data associated with each plot. This table was then inserted into S-Plus, with tree density as the independent variable and the band brightness values as the response. A stepwise linear regression was performed to find the bands with the highest correlations. This process runs through the variables forwards and backwards, sequentially dropping bands that do not register as predictors. Bands 3 and 7 were found to be predictors and subsequently run through a simple multiple linear regression to verify the results.

Results

Bands 3 and 7 (red and middle infrared) were the best predictors of tree density for our given image and study area. It was expected that bands 3 and 4 would be the best predictors (red and near-infrared), but results contradicted our expectations. The Middle Infrared band measures moisture content, so it logical that this output would be correlated to tree density since a higher quantity of vegetation results in higher moisture values. However, we would expect NIR vs. Red to provide a stronger prediction, which was not the case.

The p-value for bands 3 and 7 was computed as 0.06836 with S +, indicating that the predictors were significant. The multiple R2 value, however, was 0.059, indicating that these bands explained very little of the variance. Therefore, for this study area and image data, predicting tree density and consequently pine beetle attack probability is not possible. To do so, we would need predictor bands that were both significant and explained a larger proportion of the variance.

This result is not surprising, as several anomalies were discovered in our data. Blue band values were found to be mostly 0, where we would expect higher values in a forested area. Such low values indicate that the radiometric correction techniques used to modify the image may have detrimentally altered the band data. Blue is not a good predictor for vegetation, so it is unimportant to our study aside from its suggestion that other bands may also contain errors. This may have altered the entire analysis process by corrupting the original image.

The largest anomaly, however, was that we would expect the predictors of density to be the red and near infrared bands, but they were found to be insignificant when analyzed in concert.

Conclusion

Pine beetles are a good indicator of overall forest health and the possibility of fire risk. To map the presence and severity of pine beetles in a forest ecosystem, it is important to have an infestation distribution large enough to establish patterns and trends. The beetle infection rate on the B-Bar was not large enough to establish these trends. Because of the lack of trees affected by beetles and findings of no significance from our image analysis process, a map using remote sensing could not be made. The other hypothesis that could not be accurately studied or successfully disproved was the correlation between pine beetle and slope, elevation, aspect, or tree stand density.

There could be many reasons for the lack of pine beetle affected trees in the areas sampled at the B-Bar Ranch. The pine beetle levels may have been low due to a minimal presence on lands surrounding the ranch (reducing in-migration), or the area could have been unaffected by recent drought conditions, giving the trees more success in repelling beetle attacks. None of the hypotheses in this study could be tested because of the small number of affected trees. In future studies, areas that have a larger extent of pine beetle attack would be helpful in addition to areas that have higher levels of landscape heterogeneity. Study areas with variation of slope, aspect, elevation, and stand density would allow for a more accurate statistical analysis of bark beetle high risk zones.

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Gene D. Amman - Principal entomologist, U.S. Department of Agriculture, Forest Service,

Intermountain Forest and Range Experiment Station, Ogden, UT.

Mark D. McGregor - Entomologist, U.S. Department of Agriculture, Forest Service, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

Robert E. Dolph, Jr. - Entomologist, U.S. Department of Agriculture, Forest Service, Forest Pest Management, State and Private Forestry, Pacific Northwest Region, Portland, OR.

3. Whirling Disease: A Risk Assessment Model

Sarah Roemer, Zoe Isaacson, Karlee Davenport, Jordan Sweeney

Introduction

Water is an important resource for Montana for drinking, irrigation, and recreation. Montana has several fantastic trout streams that attract anglers worldwide, bringing money to the state. Myxobolus cerebralis, the causative agent of salmonid whirling disease, has the potential to adversely affect this, as it causes the trout population to severely decrease (Kruegar et al. 2006). It infects juvenile trout and causes skeletal deformities, black tail, and swimming in a "whirling" pattern. The life cycle of M. cerebralis alternates between two spore forms, the actinospores and the myxospore (Andree et al. 1997). The parasite also alternates hosts, between the aquatic oligochaete Tubifex tubifex and various species of salmonid fish.

The objective of the whirling disease group was to conceptualize and design a risk assessment model that ranch managers and water quality specialists could use to aid in determining a stream's risk of whirling disease. A risk assessment model is used to evaluate the likeliness of entry, establishment, or spread of a hazard within an area. A risk assessment can be qualitative or quantitative. The prototype model developed in this study is qualitative and based on a descriptive scale of low – moderate – high risk. Tom Miner Creek was used as the study site to develop the prototype risk assessment model. Data from the USGS on the Madison River, Montana was also used to develop the model and provide a comparison value for Tom Miner Creek.

Data Collection

Six sites were chosen along the stretch of Tom Miner Creek; five within the B-Bar Ranch and one at a bridge outside the northern boundary. The sites were chosen by ease of access from the road. Each site had pool and riffle habitats with visible deposition of fines. The sites were numbered 1-6 with site 1 located the furthest downstream and outside the ranch boundaries.

Basic water quality measurements were made. Velocity was measured with a Marsh Mcburney flow meter. Flow measurements were made at both a pool and a riffle for each of our six sites to help characterize the stream. The meter was calibrated to measure flow at 2/3 depth below water surface. The flow was measured at one-foot intervals across the stream. One person recorded the data while another was in the stream reading the velocity meter. Temperature, pH, and electrical conductivity were measured with a Hach Pocket Pal digital meter. A Pocket Pal is a multi-probe which can quantify the aforementioned water characteristics by inserting it into the water for a few seconds. Water samples were made at each site to determine the presence of nitrates. One 100 mL filtered bottle was filled at each study site and then sent to Dr. Mark Skidmore's lab at MSU for analysis.

At each of the six sample areas, pebble counts were made to characterize the stream bottom. Six transects were established at each site perpendicular to water flow, and measurements were taken by randomly collecting 25 pebbles along each transect.

Benthic invertebrates were collected using a surbur sampler at two places within riffle habitats at each site. The second sampling was made upstream from the first, and samples were preserved in Kahle's solution (buffered formalin) in double Ziploc bags, and in the lab identified down to order.

Sediment core samples were made at each site to determine the presence of aquatic annelids. Two pool habitats with fines were located at each site and three samples were collected from each. These samples were put into Whirl-pak bags with Kahle's solution to preserve them until later analysis. Ocular observation of trout was used to determine their presence and species.

Results and Discussion

A prototype risk assessment model was used to determine a stream's risk of obtaining whirling disease based on abiotic and biotic characteristics and land use practices. The first step of using the risk assessment model is to run through the flow chart to determine if use of the model is necessary. The flow chart determines whether both of the hosts necessary for the parasite are present. If the stream in question fails the flow chart (scores 0) then there is no risk of whirling disease and the model is no longer necessary.

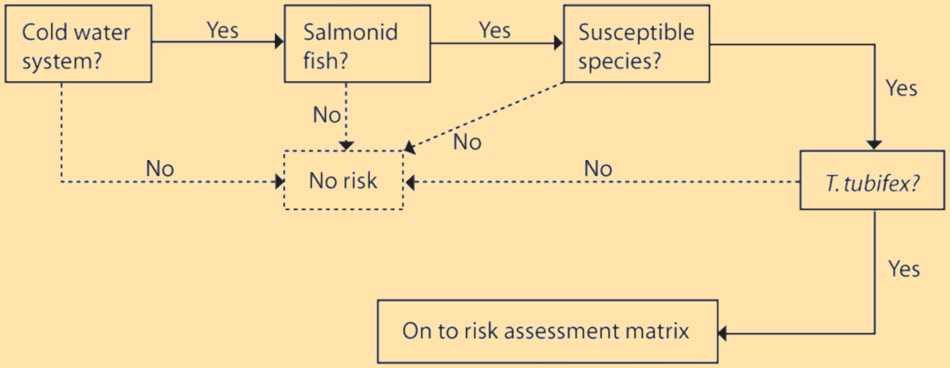

Figure 1: Flow chart used to determine if risk assessment matrix is necessary. Solid lines indicate a "Yes" answer to the question, dashed lines indicated a "No" answer.

The five parameters we selected for predicting the potential of whirling disease were fine sediments, water temperature, water flow, fishing access, and headwaters or stocked ponds. Weights were assigned to parameters based on perceived importance; the weights for all the parameters in the model must total 1.0. Importance was determined after consultation with Kajsa Stromberg of the Whirling Disease Initiative (Stromberg pers. comm.). Y-intercepts are normalizers which allow for a comparison of values of different scales. To obtain the y-intercept, a graph of optimal values is plotted with the y-axis being a normalizing scale of 0-1. The measured values from the field are then graphed and overlaid on the optimal value graph. The y-intercept is the intersection point of the two graphs. This value is used as the normalizing value in the risk assessment matrix and is multiplied by the weight to give each parameter a score. Fishing access and headwaters/stocked ponds are scored on a yes/no basis and therefore are given either a 1 (yes) or 0 (no). The higher the total score, the higher the risk for whirling disease. We assigned the lower third of the scale to be a low risk (0-0.33), the middle third of the scale to indicate a moderate risk (0.34-0.66), and the top end of the scale a high risk (0.67-1.0). As this is a prototype assessment model, the values have not been fully assessed.

Velocity data along with width of stream and height of water at each section were used to calculate discharge. Low flow is preferred by M. cerebralis and T. tubifex (Bartholomew et al. 2005). The flow values along with stream bank vegetation indicators designate this stream to be greater than low flow. Low flow for this study is considered to be any flow less than 10% of normal flow for that particular reach. There is no yearly data of the normal flow of Tom Miner Creek; however, when comparing bankfull to water level within the channel, it was obvious that flow was running at or near capacity.

The temperature of the stream ranged from 7.8 to 16.5 °C, with an average of 12.78 °C. Tubifex tubifex prefer water temperature conditions ranging from 10-13 °C. Myxobolus cerebralis prefers water temperature ranging from 12-17 °C (Bartholomew et al. 2005).

Table 1: Optimal temperatures for T. tubifex, M. cerebralis, and trout with values measured for Tom Miner Creek

	T. tubifex	**M. cerebralis**	**Trout**	**Tom Miner Creek**
Stream Temperature	10 - 13ºC	12 - 17ºC	12 - 16ºC	7.8 – 16.5ºC
Sediment	< 2mm	-------	Fines - Coarse	92% Coarse
Size Class	"Fines"			8% Fines
Velocity	Low	-------	Low - High	?

The average pH of Tom Miner Creek was 8.08, with a range from 7.9 to 8.3. Stream EC ranged from 87 to 110 µs/cm with an average of 99.6 µS/cm. Although pH and EC readings were taken as measurements of water quality; these measurements were not necessary for determining suitable habitat for T. tubifex and M. cerebralis. The water samples had no trace of nitrates, with levels below detection.

Pebble counts were conducted to find the average substrate size of the channel floor. The Wolman Pebble Count computer program was used to generate a logarithmic graph of the data . The program also formats the data into a particle size histogram (Figure 2) to display the distribution of the pebble size classes. Tubifex tubifex prefers a habitat with fine sediment ranging between the silty and sandy classification. Only 8% of the pebble samples were within the <2mm category and thus there is some suitable habitat for T. tubifex in Tom Miner Creek. Ocular observations confirmed the presence of cutthroat and rainbow trout species. These species are more susceptible than other salmonids (Bartholomew et al. 2005).

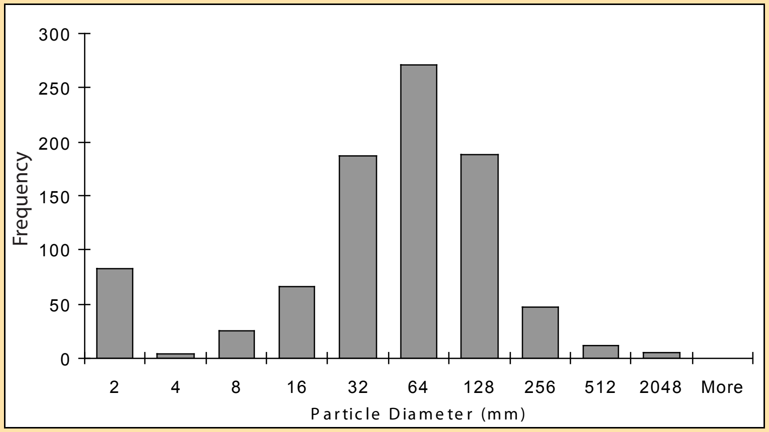

Figure1: Histogram showing the frequency of pebble diameters in millimeters

There were oligochaetes present, but their identity could not be determined because there were no sexually mature specimens. Tubifex tubifex are very common in aquatic environments and so are likely to be in Tom Miner Creek. Invertebrate populations suggest the stream is healthy and productive, due to the high abundance of Plecoptera (stoneflies), Ephemeroptera (mayflies), and Trichoptera (caddisflies) (Merrit and Cummins 1996).

Table 2: Invertebrate counts at each sampling site

	Stonefly	Mayfly	Caddis fly	TRUE Flies	Beetle	Dragon fly	Mite	Oligo	Totals
Site 1	194	439	27	296	22	0	5	13	996
Site 2	159	321	43	133	41	0	0	29	726
Site 3	174	248	35	156	29	2	3	37	684
Site 4	123	187	36	186	34	0	6	16	588
Site 5	156	235	51	213	19	3	1	25	703
Site 6	187	201	49	198	38	0	0	9	682
Totals	993	1631	241	1182	183	5	15	129	4379

Ocular observations confirmed the presence of cutthroat and rainbow trout, two of the more susceptible species of salmonids (Bartholomew et al. 2005).

Conclusions

According to the risk assessment model, Tom Miner Creek obtained a score of 0.615; this falls into the Moderate risk category. However, the ecosystem health and functions of Tom Miner Creek are sustainable and productive and at this point there is no need for concern because a large percentage of their score stemmed from natural parameters that cannot be altered or controlled (i.e., water temperature). However, if the managers of the ranch do not feel comfortable with this score, they may want to talk to a Forest Service official about reducing upstream fishing access.

Parameter	**Weight**	**Y-intercept**	**Score**
Fine sediments	0.15	0.1	0.015
Water temperature	0.35	1	0.35
Water flow	0.1	0	0
Fishing access	0.25	1	0.25
Headwaters/stocked ponds	0.15	0	0

Total: 0.61

Parameter	**Weight**	**Y-intercept**	**Score**
Fine sediments	0.15	0.4	0.06
Water temperature	0.35	1	0.35
Water flow	0.1	0.7	0.07
Fishing access	0.25	1	0.25
Headwaters/stocked ponds	0.15	1	0.15

Total: 0.88

Data from the USGS on the Madison River was entered into the risk assessment matrix. The total score for the Madison River was 0.88. This places the Madison River into the high risk category; this river is already infected with whirling disease. The higher score results from the Madison River having slower water velocity, more fine sediments, and stocked fish.

This risk assessment model is a preliminary model and is still a work in progress. The members of this research group hope that other scientists may further this research in data collection techniques and parameter modifications.

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4. Mountain Stream Dynamics

Austin Allen, Ashley Bembenek & Kelly Conde

Introduction

The goal of our project was to gain a better understanding of the relationship between channel morphology and solute transport. Solute transport measurements can be used to describe water movement. Water movement in streams can be summarized by two characteristics, advection and dispersion. Advection is transport that is imposed by a current. Dispersion is the sum of advection and molecular diffusion and mechanical dispersion. Molecular diffusion is the movement of a solute in response to a concentration gradient, while mechanical dispersion is driven by mixing that occurs due to variable water velocities and water flow over rough substrates (Hornberger et al., 1998). In addition, solute transport research can determine areas of groundwater loss or gain; such knowledge can be useful to land managers.

To investigate solute transport properties on Tom Miner Creek, we studied two reaches: a straight reach and a bent reach. The first hypothesis was that the meander bend would have more transient storage than the straight reach. Transient storage is the temporary retention of water in eddies and pools. The second hypothesis was that the meander bend would have more dispersion than the straight reach.

Tracer tests

Solute transport is measured with tracer tests. Tracer tests are used in hydrological research to characterize the exchange of surface and sub-surface water (Rieckermann et al. 2005). Tracer tests are based on the assumption that a conservative tracer fully mixed with the stream water will act in the same manner as the stream water. Another assumption of a tracer test is none of the tracer is lost on the reach. Conservative tracers are highly soluble and have little absorption to other elements such as organic matter or other chemicals. The conservative tracer that best suited our needs was NaCl as it is relatively inexpensive, readily available and easy to measure. By injecting salt into the stream, transport paths and transient storage can be measured via the downstream breakthrough curve.

Study Area

We performed our experiment on Tom Miner Creek. We examined two reaches a 30-m straight reach (Fig. 1) and a 30-m meander bend reach (Fig. 2). Reaches had similar slopes, depths, surrounding topography, vegetation and streambed sediments. Both reaches were free of logs, beaver dams and other factors that-may have affected stream characteristics.

Figure 1. Straight Reach.

Figure 2. Meander Bend

Methods

Data Collection

In preparation for the salt injection, salt and water were mixed in a container until the salt was fully dissolved. A mixing zone, characterized by riffles followed by a small pool was selected 5-m above the 30-m reach. Beginning on the straight reach, the concentrated pulse of salt (500 g) was poured into the 5-meter mixing zone. Fluctuations in EC were measured at 7 and 30 m downstream using a hand held EC probe and an EC data logger. Measurement continued until stream EC returned to background levels (~ 92 µs/cm). After the tracer was flushed from the straight reach, the experiment was repeated for accuracy. The same process was then performed in an identical fashion on the bent reach. Cross sectional area was calculated at each measurement location.

Data analysis

Breakthrough curves were generated by graphing concentration versus time from each tracer injection. The shape of each break through curve gives visual cues about solute transport properties. However calculations for each solute transport property is calculated directly from the EC data. Below is a brief definition of each solute transport property and the technique used to calculate it.

<u>Advection</u>: is transport via an imposed current. Advection was calculated by dividing the length of the reach by the time it took to reach the peak concentration of tracer. Advection is a velocity (m/s).

<u>Dispersion</u>: the net result of advection and both mechanical and molecular diffusion. In breakthrough curves, it can be visualized as the width of the curve (Fig. 4). Dispersion is important near the end of the tracer test as EC values return to background concentration. We have estimated dispersion by calculat-

ing a velocity for the 25% and 75% recoveries (Fig. 4). The 25% recovery velocity is divided by the 75% recovery velocity. The ratios are a way of ranking the width of each breakthrough curve. Reaches with a high level of dispersion will have higher ratios than reaches with little dispersion.

Skew: as defined by traditional statistics, a measure of symmetry within a dataset. We borrowed the concept to asses how symmetrical the breakthrough curves are. The advection velocity is divided by the center of mass velocity (Fig. 4). Skew illustrates the impact of both advection and dispersion. If a tracer test could be completed without advection or dispersion, the resulting skew would be one. In reality skew will not be equal to one because both advection and dispersion occur in all streams.

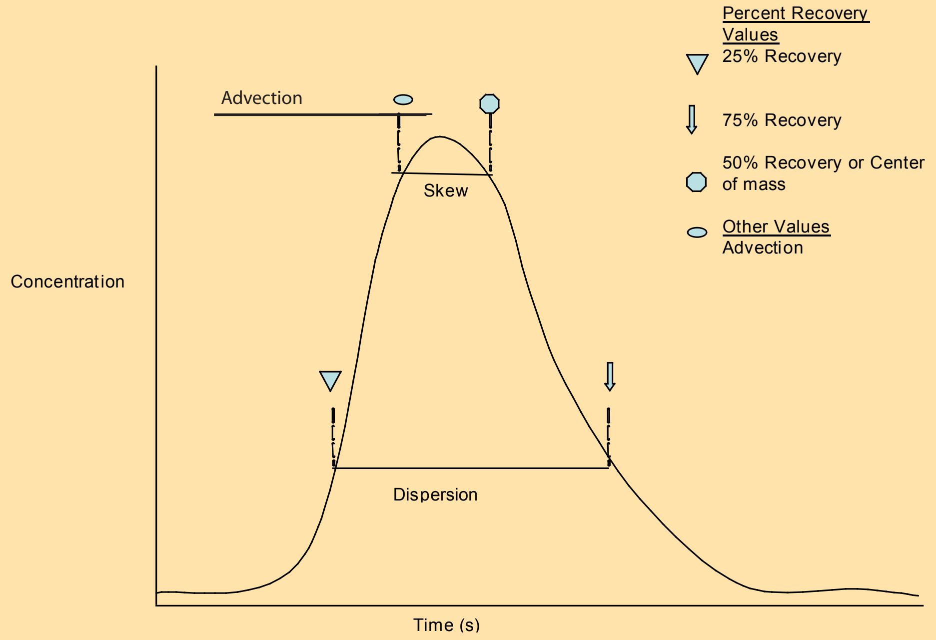

Figure 3. Breakthrough curve assessment techniques.

Discharge was calculated using a technique similar to those presented by Rieckermann et al. (2005). 1) Electrical Conductivity (EC) is converted to concentration (Co; g/L) using a calibration curve generated in the laboratory. 2) Background concentration is subtracted from Co. 3) Concentrations from each time-step in the test are integrated with respect to time. 4) The sum of the concentrations collected during the tracer injection divided by the amount of tracer injected results in discharge. Full tracer recovery is assumed; in addition, complete mixing must occur to successfully measure discharge.

Tom Miner Creek Results

Discharge on the straight reach was 7.9 cubic feet per second (cfs) and discharge on the bent reach was 10.3 cfs (Table 1). These reaches were within 50-m of each other and is very improbable that discharge would have changed that significantly with this distance. Experimental error is the only reasonable explanation for the difference. If the tracer did not fully mix with stream water, i.e. it dissolved and sank to the stream bottom; discharge would have been overestimated because the concentrations measured by the EC probe would be too dilute. Conversely, discharge may have been underestimated if an unmixed and highly concentrated mass of tracer had reached the EC probe. The location of the EC probe was also critical to successful discharge measurement. It should have been located in the main current to avoid tracer passing by unmeasured.

Table 1. Summary of results from two reaches on Tom Miner Creek.

Reach	Discharge (cfs)	Advection (m/s)	Dispersion	Skew
Meander Bend	10.29	0.21	1.11	0.97
Straight Reach	7.94	0.19	1.13	0.97
Percent Difference	22.9	13.9	1.8	0

The breakthrough curves generated from each of the reaches have significant gaps during the rise, peak and fall of EC (Fig. 3). This suggests that we did not accurately characterize the shape of the curve because our time interval was too large.

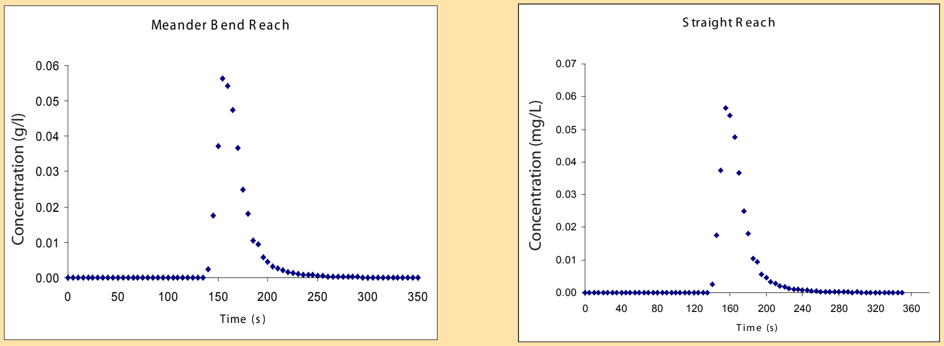

Figure 4. Tom Miner breakthrough curves.

The accumulation of experimental errors meant the results from Tom Miner Creek were not meaningful.

Stringer Creek data analysis

The data was collected in August of 2005 on Stringer Creek in the Tenderfoot Experimental Forest in the Little Belt Mountains of Central Montana by Rob Payne. Dr. Brian McGlynn is a member of Rob Payne's advising committee and was able to supply us with the data from Stringer Creek. Payne used the tracer tests, identical to those described previously, and ran the experiment multiple times over 18 100 m stream reaches.

We established three new hypotheses for the Stringer Creek data set: 1) solute transport is a function of channel morphology; 2) groundwater inflow and outflow is a function of channel morphology; 3) groundwater contributions to stream flow are variable from reach to reach. To test our hypotheses, we used the following, in addition to advection, dispersion and skew:

Groundwater In: The rate (L/s per 100 m reach) of groundwater gain to the stream. This data was supplied by Rob Payne.

Groundwater Out: The rate (L/s per 100 m reach) of stream water loss to the groundwater system. Groundwater out was also collected by Rob Payne.
Net Groundwater: (Groundwater in) - (Groundwater out)

Sinuosity: Measures the curviness of a stream reach. Sinuosity is the ratio of channel distance to valley distance (channel length/ valley length). A completely straight reach will have a sinuosity of 1 and a highly sinuous (or meandering) reach could have an infinitely high sinuosity, however values greater than 1.2 are generally considered high.

Channel Slope: Calculated in the channel, as ((channel elevation1 –channel elevation2) / channel length). This incorporates the sinuosity of the channel. Linear regressions were used to assess the relationships between specific variables.

Stringer Creek Results

1. Solute transport is affected by channel morphology.

In areas where the stream is highly sinuous, there was a decrease in solute advection velocity or a decrease in the speed at which the salt moved down stream (fig. 5). With an R^2 value of 0.49, this relationship shows that advection velocities may be controlled by sinuosity.

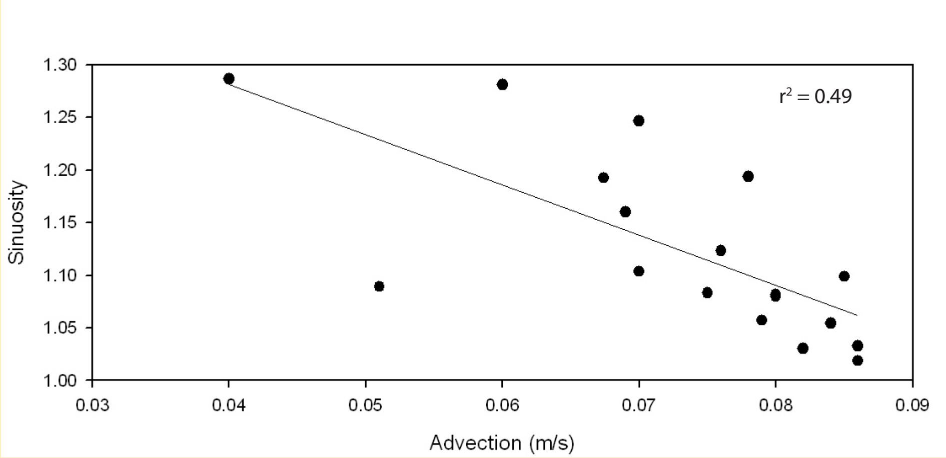

Figure 5. Advection versus sinuosity for 18 reaches along Stringer Creek.

The ratio of advection to dispersion (A/D) is an indicator of transient storage. High AD ratios mean little transient storage is occurring and solute transport is more like "plug flow", while lower ratios indicate a larger amount of transient storage (more dispersive flow) occurs on the reach. Transient storage is the temporary retention of water in pools and eddies and in some cases includes water exchange with the bank or sediments. High rates of dispersion occur on reaches with significant transient storage. As channel slope declines the AD ratio also declines (fig. 6). Such a relationship suggests that flat reaches have a greater amount of transient storage than steep reaches.

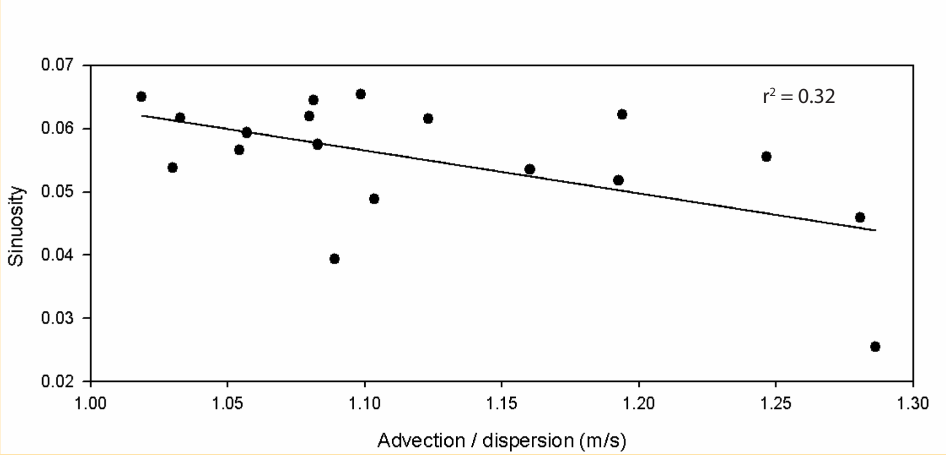

Figure 6. Channel slope versus the ratio of advection to dispersion for 18 points.

Though channel morphology greatly affected solute transport, other factors were involved. With increasing discharge there were increasing advection velocities (Fig. 7). As the stream gains water from tributaries and groundwater, the speed at which the salt moves through the stream increases. This suggests that advection was not only controlled by channel morphology but also by discharge magnitude.

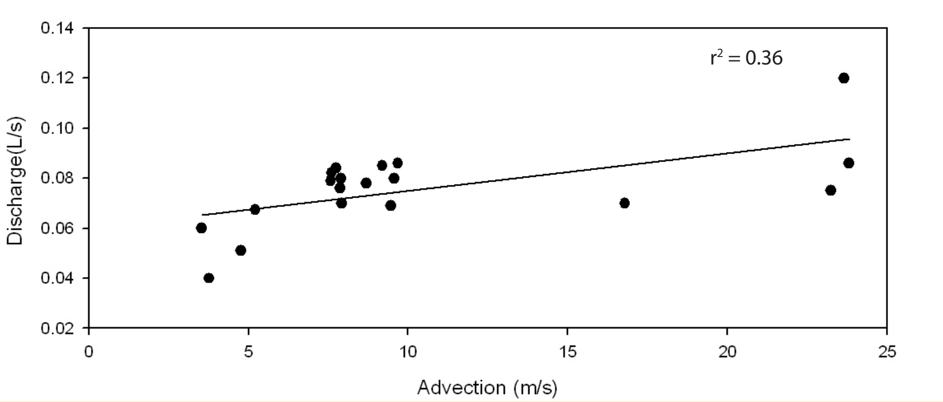

Figure 7. Advection versus discharge for 18 reaches along Stringer Creek.

2. Net groundwater is partially a function of channel morphology.

Our second hypothesis predicted that channel morphology would affect the amount of groundwater coming into the stream and the amount of surface water being lost to the groundwater system. Figure 8 shows one variable of stream morphology, slope versus net groundwater. The graph suggests that with increasing slope, there is decreasing groundwater input. This supports the idea that slope plays a significant role in determining groundwater contributions.

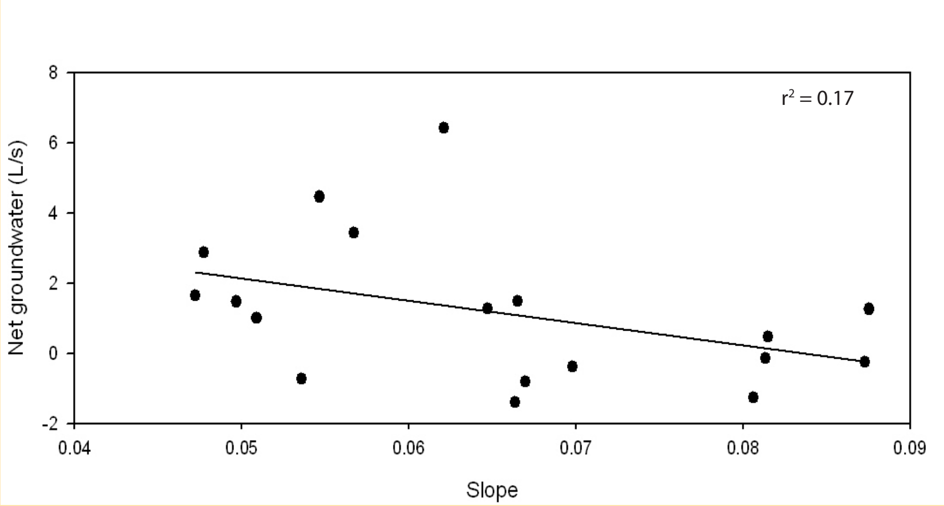

Figure 8. Slope versus net groundwater change on Stringer Creek.

As sinuosity increases there is decreasing groundwater contribution to Stringer Creek (Fig. 9). This suggests that a second channel morphology factor partially controls groundwater contributions. Although both sinuosity and slope negatively correlate to net groundwater, they do not co-vary with one another. That is reaches with low slopes tend to be more sinuous rather than less sinuous. Because the two variables do not work in concert groundwater contributions are difficult to understand based on morphology alone.

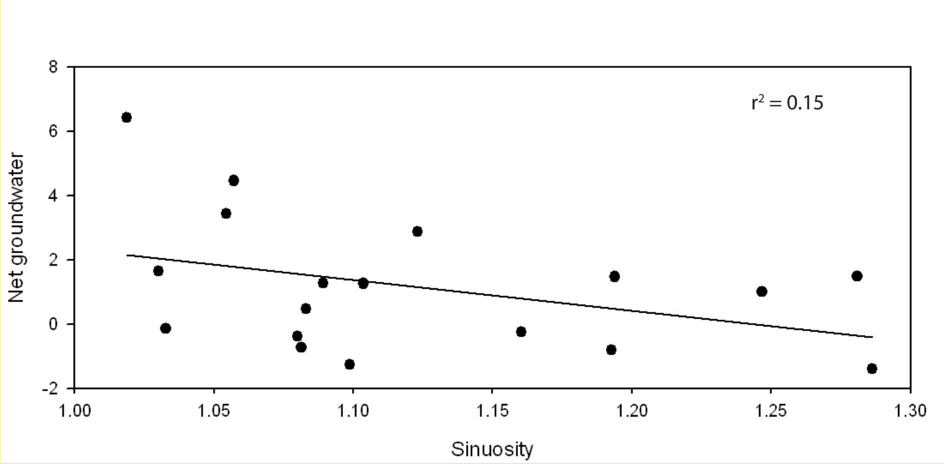

Figure 9. Net groundwater versus sinuosity for 18 points.

3. Groundwater losses and gains are variable from reach to reach.

The gross losses and gains on each reach are tallied along with the net change in stream discharge (Fig. 10). The large degree of variability among reaches suggests that groundwater fluxes are variable from reach to reach. As previously established groundwater losses and gains may be partially controlled by channel morphology. However the r2 values (0.15, 0.17 slope and sinuosity respectively) suggest that there are additional factors involved. The geology over which the stream runs can greatly affect groundwater contribution as well as surface water loss. Different geologies have different hydraulic conductivities (the ability of a material to conduct water). This can affect the ease in which the water enters the ground. On Stringer Creek, there is a change in geology from shale to rhyolite. This change happens at around 1500-m from the stream outlet. There is an increase in groundwater upwelling and surface water loss around this area (Fig. 10). This may be because shale has a much lower hydraulic conductivity than rhyolite. Because of this, water may build up at the interface of the two materials and be forced up into the stream. Geology is an additional factor that increases the variability of groundwater gains and losses on streams.

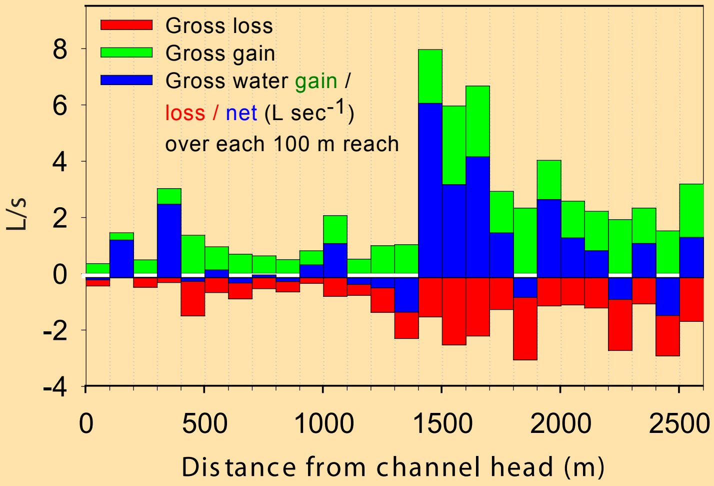

Figure 10. Gross gains and losses for each 100 m reach (Payne, 2006).

Conclusions

Our findings demonstrate channel morphology drives changes in both solute transport and groundwater contributions. Solute transport is affected by both channel slope and sinuosity. Groundwater gains and losses are attributed to two morphological features, slope and sinuosity. Groundwater gains and losses are further complicated by other factors such as geology. The combined effect of geology, channel slope and sinuosity leads to variability of gains and losses in groundwater within each reach.

An improved understanding of the interaction among each of the components, geology, channel slope and sinuosity may allow for better land management decisions. Identifying areas of groundwater gains and losses may assist in habitat conservation decisions. For example, areas of groundwater gain tend to stabilize stream temperature year round and thus may serve as premier habitat for trout and other aquatic species.

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Soil Properties and Irrigation: The Davis Meadow at the B-Bar Ranch
Kris Anderson, Brian Edwards, and Jeff Johnston
LRES capstone 442, December 2006

5. Nutrient Cycling in Mowed & Unmowed Plots

Kevin Barnes, Loren Huggins, Douglas Higgins,

Introduction

Invasive weeds are costly to land managers due to the time, energy, and resources devoted to their eradication. Scientific literature and publications addressing invasive species frequently claim that they impact the environment as well. Some of the most common impacts attributed to invasive weeds are their ability to affect ecosystem-level rates of erosion, water table levels, fire regimes, and nutrient cycling (Gordon 1998).

In regard to nutrient cycling, and specifically nitrogen (N) cycling, invasive species that fix nitrogen have the greatest potential to influence this cycling, since they are able to release N inputs into the system at a greater rate (Vitousek 1987). Nevertheless, non-nitrogen fixing plants can still influence N cycling by differing considerably from co-occurring natives in tissue chemistry. Invasive species that have different carbon to nitrogen ratios (C: N) or lignin to nitrogen ratios can influence rates of mineralization though root and leaf litter. For example, species with lower C: N result in increased mineralization rates (Wedin and Tillman 1990, Vinton and Burke 1995, Evans et al. 2001, Ehrenfeld 2003).

Invasive species can also influence N cycling and uptake by differing from co-occurring native species in phenology, rate of growth, below ground morphology (enabling plants to access different parts of the soil profile), and the amount or chemistry of root exudates. To gauge an invasive species' ability to impact nitrogen cycling, or any other ecosystem function, one must consider its impact in the context of its relative and absolute abundance at a particular site. As such, a given species will not likely impact nutrient cycling unless it is well represented and markedly different from its co-occurring natives with respect to any of the factors listed above.

Our group investigated whether or not the invasive species houndstongue (Cynoglossum officinale L.) affects nitrogen cycling. Houndstongue is a non-indigenous biennial common to disturbed areas. We chose houndstongue due to its common occurrence at a particular site and hoped to determine whether its presence within designated plots affected available nitrogen (NO3-, NH4+) over the course of a growing season. Initially we intended to focus exclusively on plots with houndstongue versus plots without houndstongue. However, given the high occurrence of houndstongue at the site and the fact that plot designations were made in early May (a period when establishment was indefinite), we were concerned that houndstongue might emerge in plots designated as having no houndstongue. Therefore, we added an additional hypothesis regarding the effect of mowing on available N. This addition afforded an opportunity to investigate how management choices, such as mowing, might influence the availability of N.

Objectives

The objectives of this study were:

1. To determine the effect of houndstongue and mowing on available and mineralizable nitrogen (N).

2. To determine whether community composition affects available N.

Objective one was addressed by measuring available, total, and mineralizable N through the use of resin capsules and soil cores. Objective two was addressed by measuring percent cover by species, density, and C: N ratio of aboveground biomass. We hypothesized that:

H_1: Available and mineralizable N will be higher in houndstongue plot than plots without houndstongue.

H_2: Available N will be greater on the unmowed portion of the field rather than the mowed portion.

H_3: C:N of houndstongue will be lower than its co-occurring neighbors.

H_4: As houndstongue cover increases available N will also increase.

Study Site

The study site was located in Styers 1 field (45° 08′ 22″ N 111° 0′ 59″ W) near Tom Miner Creek. The site was level and bisected by a fence. The east side of the fence had been mowed and contained a mix of grasses and forbs including smooth brome (Bromus inermis), Timothy (Phleum pretense), bluegrass (Poa sp.), yarrow (Achillea millefolium), Canada thistle (Cirsium arvense), common dandelion (Taraxacum officinale), and houndstongue. The west side of the fence was dominated by smooth brome and houndstongue, but also contained traces of yarrow, bluegrass and dandelion. Both sides had been recently grazed prior to our August visit.

Field Methods

On May 4, 2006 at the beginning of the growing season, houndstongue plots were identified based on a minimum of two houndstongue rosettes or stems per 0.5 m^2 (1 m x 0.5 m). Ten houndstongue plots were identified in the Styers mowed field (STM) using this criterion. Three of the ten plots were randomly chosen and paired with plots of the same size, within 1 meter of each, which contained no houndstongue. In the Styers non-mowed field (STN), three houndstongue plots were located, along with adjacent plots not containing houndstongue.

Three resin capsules were buried 10 cm below the surface within each plot. In houndstongue plots, capsules were placed below a houndstongue rosette and in non-houndstongue containing plots resin capsules were randomly placed. A meter of fishing line was attached to each capsule prior to placement to aid in recovery. Three 2 cm diameter x 10 cm deep soil cores were extracted from each plot and three from the outside perimeter of the frames, to minimize disturbance within the frames. Soil cores were taken back to MSU and stored near -10° C until analysis in the fall.

On August 29, 2006 the 12 plots were revisited. Percent cover for each species was recorded and aboveground biomass was harvested in each plot. Density of houndstongue and Canada thistle flowering stems and/or stalks were recorded. Soil capsules were extracted, rinsed with deionized water, placed in individually labeled plastic bags, and immediately put on ice. Soil cores were extracted as previously described for the month of May.

Lab Methods

Resin capsules extracted from the plots were refrigerated until analysis. Following refrigeration each capsule was placed into a 60 ml bottle and available N was desorbed by shaking with 20 ml 2 M KCl for 20 minutes on a reciprocal shaker. This was repeated 3 times and combined into a 60 mL solution per capsule (Skogely et al. 1996). A sub-sample of each 60 ml sample was analyzed by the Lachat Flow 8000 injection analyzer (Lachat Instruments, Milwaukee, WI).

May soils were air dried and sieved using a 2 mm sieve. Available N was desorbed by shaking 5 g of soil from each plot with 50 ml of 2 M KCl in beakers for 30 minutes. The solution was filtered using acid washed Watman 934-AH filter paper and the solute was analyzed using the Lachat flow injection analyzer. Potentially mineralizable N (PMN) was extracted from three 5g sub-samples per plot (Bundy and Meisinger 1994). Each 5g sub-sample was placed into a 30 mL Erlenmeyer flask with 12.5 ml of de-ionized water. The flasks were stoppered and incubated at 40 °C for 7 days. After incubation, 12.5 mL of 4 M KCl was added to each flask and shaken for 1 hour. The resulting solution was filtered through acid washed Watman no. 934-AH filter paper and analyzed by the Lachat flow injection analyzer (Lachat Instruments, Milwaukee, WI). Total N and C were measured using the Leco Truespec C/N Analyzer (Lachat Instruments, Milwaukee, WI) after oven drying the soil at 50 °C overnight and milling with a ball mill. Three replicate samples were completed for each plot.

August soils were analyzed for available N, and total C and N using the same protocol as explained above. August soils were not incubated for an index of PMN. Plant samples were oven dried and milled using a Wiley mill followed by a UDY mill to attain finely ground samples. Milled samples were analyzed for total C and N using the Leco Truespec C/N Analyzer (Lachat Instruments, Milwaukee, WI).

Statistical Methods

Statistical analyses of soil and capsule N levels were conducted using ANOVA (SPSS: Statistical Package for the Social Sciences). In addition, we conducted an ANOVA with a LSD post-hoc test to determine the difference in C:N between species. N levels were compared between houndstongue plots versus plots without houndstongue and between mowed versus un-mowed management schemes. SPSS was used on plant C:N data to determine differences between the species, while a histogram was produced to display the dominant species within the field and their respective carbon to nitrogen ratios (C:N).

Results/Discussion

Paired Houndstongue Plots

Available N measured from May soil samples did not differ between plots with or without houndstongue (F= 1.93, p= 0.17). Mean available N for plots with houndstongue was 20.91g N/kg while available N for plots without houndstongue was 20.90g N/kg. However, in August available N was higher in houndstongue plots (F= 1.43, $p < 0.01$). Mineralizable N measured by resin capsules over the growing season did not differ between plots with or without houndstongue (F=0.60, p = 0.94). Mean mineralizable N for plots with houndstongue was 1.12mmol N/cm2 resin and for plots without houndstongue was 1.14mmol N/cm2 resin. Potentially mineralizable N (PMN) measured by anaerobic incubation was not different between plots (F=2.11, p =0.14), even though the mean for plots containing houndstongue was 103.78g N/kg and the mean for plots without houndstongue was 114.42g N/kg.

Table 1. Available and mineralizable N in houndstongue (HT) and non-houndstongue (NHT) plots

	Available N May (g N/kg)	Available N August (g N/kg)	Mineralizable N resin (mmol N/cm^2)	PMN (g N/kg)
HT	20.91	16.74	1.12	103.78
NHT	20.9	13.16	1.14	114.42

The difference between plots with and without houndstongue from August soil samples is likely the result of a simple difference in phenology. Vegetation within almost all of the frames was dominated by grasses, and in August most of the grasses appeared to have gone dormant or senesced. Houndstongue, on the other hand, was not likely actively growing, but was still green and therefore photosynthesizing. A possible result of this difference in phenology might be that houndstongue, through its root exudates, provided the microbial community with a viable carbon source and thereby enhanced N mineralization. Root exudates increase during water stress and temperature extremes, conditions that were visibly present during August sampling (Sylvia et al. 2005).

Mowed Versus Unmowed

Available N from the May and August samples were higher in the unmowed portion of the field (May: F=3.98, $p < 0.01$; August: F=1.43, $p < 0.01$). The mean for the mowed portion of the field in May was 15.66g N/kg, while the mean for the unmowed portion was 26.16g N/kg. The mean for the mowed portion of the field in August was 14.95g N/kg and the mean for the unmowed portion was 20.18g N/kg. Mineralizable N absorbed by resin capsules was not different between mowed and unmowed portions of the field (F=0.60, p= 0.40). Mean mineralizable N from the mowed portion of the field was 2.13mmol N/cm^2 resin, and from the unmowed portion of the field was 1.32mmol N/cm^2 resin. PMN measured by anaerobic incubation did not differ between mowed and unmowed portions of the field (F=2.11, p=0.15). The mean for the mowed portion of the field was 114.26g N/kg and the mean for the unmowed portion was 103.94g N/kg.

Table 2 Available and mineralizable N in mowed (M) vs. unmowed (UM) portions of the field.

	Available N May (g N/kg)	Available N August (g N/kg)	Mineralizable N resin (mmol N/cm^2)	PMN (g N/kg)
M	15.66	14.95	2.13	114.26
UM	26.16	20.18	1.32	103.94

The difference in Available N between the mowed and unmowed sides of the field (Figure 1) may be attributed to the differences in overall plant growth. More intensive growth on the mowed portion most likely resulted in greater uptake of nitrogen during the early to mid growing season, hence lower measured levels of soil available N during August sampling. On the unmowed portion of the field there was more leaf litter, and less growth, hence less N uptake. Both sides appeared to have the same levels of PMN over the entire growing season. Therefore, mowing does not affect the release of available N to the soil over an entire growing season (mineralizable N) but it does have a short term effect on where nitrogen is sequestered, whether its within plant tissue or the soil.

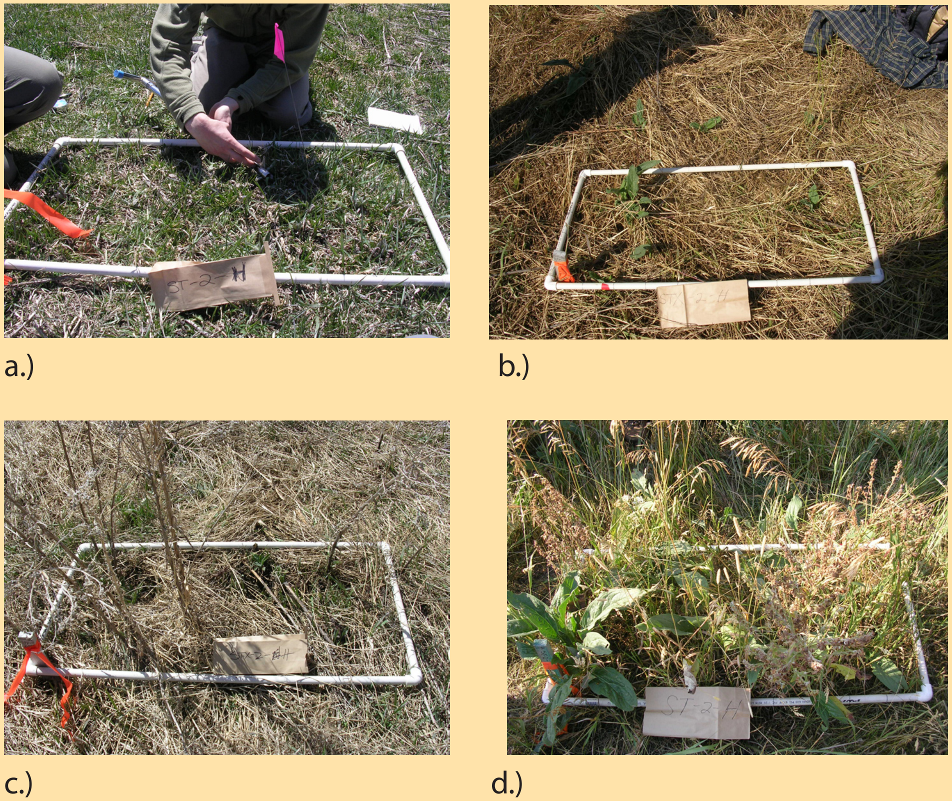

a.) b.) c.) d.)

Figure 1 Houndstongue plots: a) mowed May; b) mowed August; c) unmowed May; d) unmowed August.

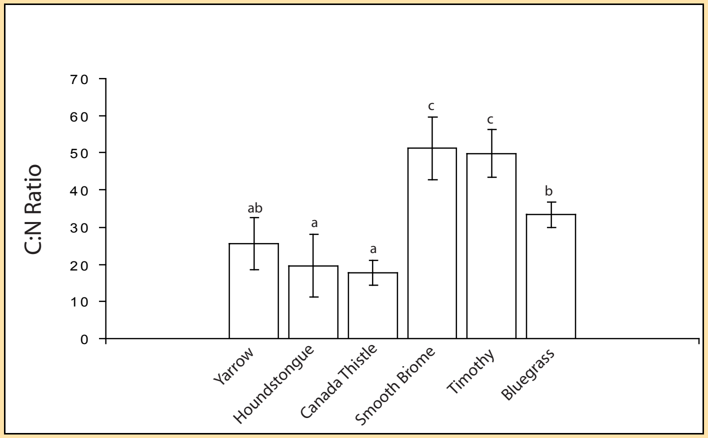
C:N of houndstongue compared to co-occurring neighbors.

While average C:N of houndstongue was different from co-occurring smooth brome, timothy, and bluegrass, it was not markedly different than Canada thistle, yarrow (F= 2.09, p= 0.092, Figure 2). The two other forbs that had nearly equal cover also had similar C:N (Figure 2). As mentioned above, for houndstongue to influence N cycling based on its tissue C:N, it must be clearly different than other species that occur in similar abundance.

Houndstongue cover effect on available N

We used a simple linear regression to estimate the effect of houndstongue cover on available N. Percent cover of houndstongue and available N were poorly correlated (r= 0.14). We acknowledge the limitation of using cover rather than biomass to estimate potential impact of houndstongue on available N; unfortunately we lost our houndstongue biomass data. Nevertheless, given the poor correlation in cover, we would likely have had similar results had biomass been used. Although the C:N of houndstongue was different than grasses, it was not abundant enough to affect a change.

Figure 2: C:N of above-ground plant material for 3 forbs and three grasses



Conclusion

Initially we expected to see differences in available nitrogen due to the presence of houndstongue. The main reason for expecting a difference in available N was a perceived difference in tissue chemistry in houndstongue compared to co-occurring species. However, in order for houndstongue to affect available nitrogen, it has to be substantially different than its co-occurring neighbors in tissue chemistry as well as relative abundance. Based on our results, houndstongue was not different in C:N than other plants within a similar niche or functional group found at the site, nor was it abundant enough to affect available N over the course of a growing season. Even if houndstongue had been different from its neighbors, we had no way of knowing how long it had been established on the site and whether that period was long enough to instigate a change. In addition, rooting depth, especially between houndstounge and grasses, differed. By limiting our sampling depths to 10 cm we may have missed differences in available and/or mineralizable N at deeper rooting depths.

The one observed difference in available N (August soil samples) was most likely due to a difference in phenology of houndstongue compared to other plants within the plots. A possible explanation for this would be that houndstongue, through its root exudates, provided the microbial community with a carbon source and thereby enhanced N mineralization.

The higher available N in unmowed plots compared to mowed plots is easily explained by the lower amount of overall growth observed on the mowed side of the field. While both sides of the fence had similar amounts of N mineralized over the course of the growing season, the side with greater overall plant growth took up more available N. Management decisions can, therefore, influence whether available N is taken up and incorporated into aboveground biomass, or whether it remains in the soil profile.

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6. Weed Distribution on the B-Bar

Nancy Case, Kelley House, Brenda Sanchez & Katie Tillerson

Introduction

The B-Bar Ranch is approximately 18km north of Gardiner, Montana and located in the Tom Miner Basin. The sub-alpine habitat and semi-arid climate is typical of high elevation valleys (~2000 m) and orthographic influences of the contiguous Gallatin Mountain Range. The growing season (late May through August) lasts about 90 days and averages 33cm of rainfall with cool temperatures of around 19 °C during the day and as low as 0 °C at night. Wind speeds average 50-60m/s and the research area primarily consists of aquic, cryic mollisols of variable textures (Capstone 2005).

The livestock industry spends a large amount of time and money managing rangelands, including the control of undesired plant populations within grazing pastures. The approach of range and land managers is to use science-based strategies to control the spatial growth of undesired plant populations to reduce the impact on desired plant species (Maxwell 2006). Management objectives can be achieved by understanding the relationship between weed population dynamics and the negative impacts caused by these populations on surrounding vegetation (Mack et al. 1999). The methodology used to propose these management tactics begins with an inventory of plant populations followed by monitoring. This course of action can initiate the understanding of a weed's potential to threaten management goals (Maxwell 2006).

Weed management can be applied to the restoration of mis-managed or overgrazed rangelands. Overgrazed areas can begin a process of decreasing desired plant species by replacing them with undesired species as a result of a shift in an "eco-system's physical features and nutrient cycling" functions (Mack et al. 1999). The practice of integrated weed management can be a valuable tool in restoring the productivity of rangelands (Maxwell 2006).

One goal of this project was to gather baseline information and establish a data bank of cover, density, and the occurrence of populations of houndstongue (*Cynoglossum officinale*) and Canada thistle (*Cirsium arvense*) from three pastures on the B-Bar Ranch. In combination with future monitoring, this data could be used to track possible trends of spatial distribution of these species. Furthermore, this initial data could be used to look at the potential threshold of where weedy plants may displace desired plant populations and communities. A second goal is to discuss the results of this project in the context of management objectives and monitoring plans for future control of these two undesired species. Maps of density and cover for both of these species were produced using GIS, while frequency distribution graphs were created to support our hypotheses. The proposed hypotheses are:

1. Houndstongue frequency is greater near Tom Miner Creek in Styers I.

2. Houndstongue frequency and Canada thistle frequency are greater near the gravel pile in Styers I.

3. Canada thistle frequency is greater near Tom Miner Creek in Styers II.

4. Houndstongue frequency and Canada thistle frequency are greater near the road in Styers IV.

Species Description

The weedy species that we decided to assess were houndstongue and Canada thistle, due to their relative abundance on site and the fact that both of these species are on the Montana noxious weed list (USDA Plants Database 2006). These species are a nuisance in rangeland and detrimental to livestock and management. Both are highly capable of establishing in disturbed areas, thereby potentially out-competing native vegetation for available resources (Kershaw 1998). Forage potential is reduced in fields where these species are found due to competition for resources and livestock's distaste for them.

Houndstongue (CYNOFF), a member of the Boraginaceae family, is a non-native biennial completing its life cycle in two years. It generally exists as a basal rosette for the first year, then flowers in the second year and dies. CYNOFF produces numerous flowers along a helicoidal cyme inflorescence. In Montana, CYNOFF seed production ranges from 300-675 seeds per plant each year (Webb and Sheley 2002). Fruits are composed of 4 barbed nutlets, allowing for easy transport by attaching to the fur of animals or the clothing of passers-by for effective dispersal. Seeds over winter in the soil and are viable for up to three years. Cattle can be the largest vectors of CYNOFF by attaching approximately 65% of the total burrs in grazed paddocks (Webb and Sheley 2002). CYNOFF infests about 36,000 acres of land in Montana (Webb and Sheley 2002) and contains pyrrolizidine alkaloids that are toxic to livestock, causing liver failure and possible death if enough is consumed (Dosland 2001).

Canada thistle (CIRARV) is a colony forming, aggressive perennial of the Asteraceae family (Kershaw 1998). It is a rhizomatous species, therefore able to reproduce vegetatively and by seed. Rhizomes (underground stems) send up shoots allowing for the colony forming ability and hardiness of this species. Fruits consist of small achenes attached to a feathery pappus, which aids in wind dispersal. In spite of this, the greater part of the seeds will settle within a few meters of the parent plant (DeJong and Klinkhamer 1988). CIRARV is a difficult species to manage due to its ability to reproduce vegetativley.

Materials and Methods

Site Preparation

B-Bar Ranch management provided us with a map delineating pastures as either "pastures of concern" or "pastures in good condition". We surveyed these classified pastures to determine characteristics common to each type. We chose three pastures, Styers I and II considered "pastures of concern" and Styers IV considered in "good condition" (Fig. 1).

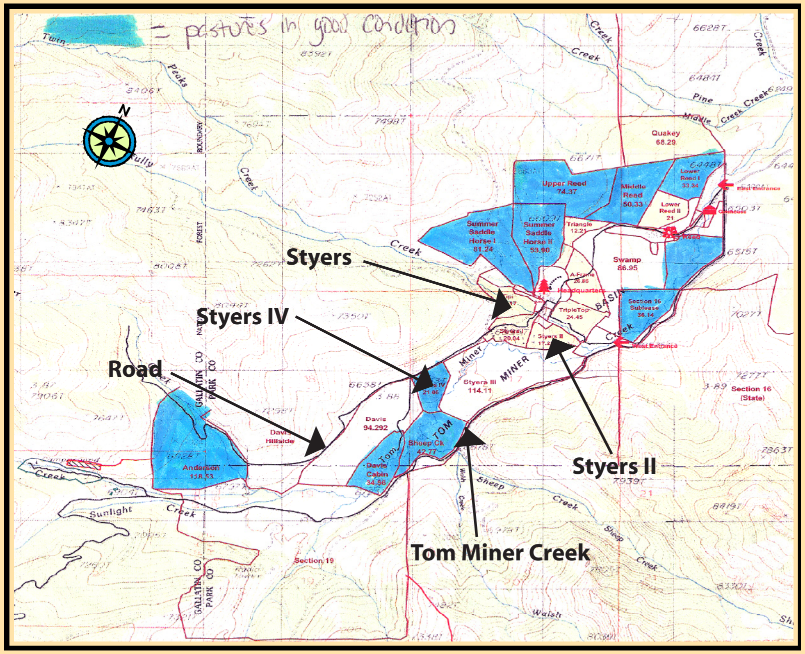

Figure 1: Map of the B-Bar Ranch displaying categorized pastures, pastures chosen for study, and their proximity to the main access road and Tom Miner Creek (B-Bar Ranch 2006).

The pastures are all in the same geomorphological context of a flat valley floor along an alluvial stream plain. All three pastures are located along the main road through the southwest corner of the ranch and all have a boundary that is influenced by Tom Miner Creek.

Dominant vegetation in the meadows is the desired rangeland species of the Poaceae family including Timothy (Phleum pratense) and crested wheatgrass (Agropyron cristatum), both of which were planted for current land use. Additionally, Styers I had an observable presence of weedy species. Height, richness, and density of undesired plant species during initial inspection appeared remarkably different than other pastures.

Study Design

For each pasture, we surveyed these species along 4-6 transects established at 25 m intervals approximately perpendicular to the stream, with the exception of Styers IV in which the stream ran parallel to the transects. In Styers I, transects went from the southern fenceline to the road. In Styers II, transects ran from the southern fenceline to the northern fenceline. Styers IV has a large riparian area near its center, therefore transects began at the edge of the willows and ran to the fenceline on each side of the riparian area.

Data Collection

Quadrats were randomly located along each transect. Within each 1m x 1m quadrat, density of each weedy species was recorded as the number of stems within the frame. Cover was estimated by cover classes 1-5 (Table 1). To allow for continued monitoring of these plots in the future, GPS positions were taken at each quadrat and at the beginning and end of each transect using a Trimble Geo XT GPS receiver. Additionally, points were gathered along the irrigation ditches in Styers II and finally at the gravel pile located in Styers I. Notes were taken of general observations of other flora and site conditions.

Maps were created using a GIS from GPS positions collected in the field (Appendix A). Tom Miner Creek, the ranch access road, and the gravel pile were digitized in ArcMap and used to determine the distance of quadrats from these features to test for a trend between species' frequency and distance. These maps also offer a visual representation for management of weedy species.

Data was organized by species and field ID: Styers I, II, and IV. Distances of quadrats from a feature were grouped into ranges of ten meters. Features consist of Tom Miner Creek, the gravel pile near Styers I, and the ranch access road. The total number of quadrats sampled for each distance range was summed and the total number of quadrats within these ranges that one of the species was present was summed. Frequency of each species was calculated per distance range by dividing the total number of quadrats in which a species was present by the total number of quadrats per field. A frequency distribution was then graphed by species per field for each feature, with distance as the x-axis and frequency as the y-axis.

Cover Class	Percent Cover
0	No cover
1	0 – 1 %
2	2 – 10 %
3	11 – 25 %
4	26 – 50 %
5	51 – 100 %

Results

In Styers I, there was an initial increase followed by a gradual decline in CYNOFF frequency with distance from Tom Miner Creek (Fig. 2). The pattern was the same for CIRARV frequency, with an initial increase followed by a gradual decline with distance from Tom Miner Creek (Fig. 3). The frequency of both species peaked at approximately 50-60m. CYNOFF and CIRARV frequency gradually increased with distance from the road then decreased (Figs. 4 and 5). CYNOFF and CIRARV frequency initially increased with distance from the gravel pile and then gradually decreased, with peak frequencies at 100-110m for CYNOFF and 110-130m / 140-150m for CIRARV (Figs. 6 and 7).

In Styers II, there was no observable trend in CYNOFF frequency with distance from Tom Miner Creek (FIG 8). However, there was an initial increase and drastic decrease in CIRARV frequency with distance from Tom Miner Creek, with peak frequency occurring at 70-80m (FIG 9).

In Styers IV, there was an initial peak in frequency of CYNOFF at 30-40m from the road and a drastic decrease with distance from the road (Fig.10). The pattern was the same for CIRARV frequency, peaking at 30-40m from the road and again at 50-60m from the road with no occurrence in between these two distance ranges (Fig. 11).

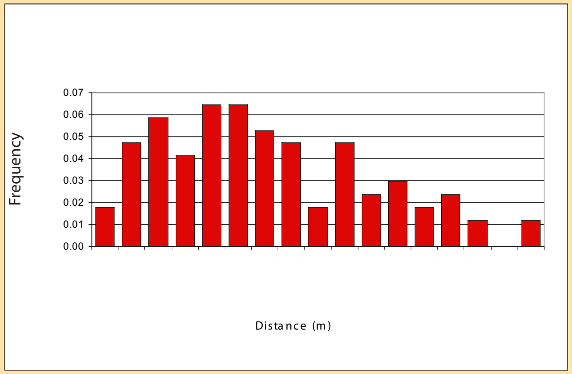

Figure 2: Graph of CYNOFF frequency vs. distance from Tom Miner Creek in Styers I.

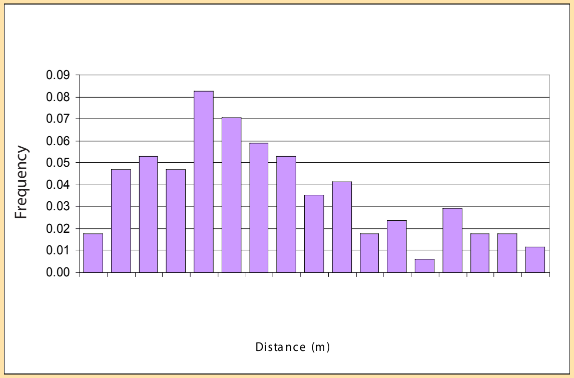

Figure 3: Graph of CIRARV frequency vs. distance from Tom Miner Creek in Styers I.

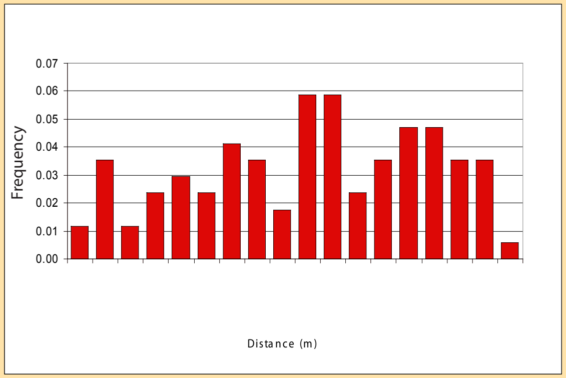

Figure 4: Graph of CYNOFF frequency vs. distance from the road in Styers I.

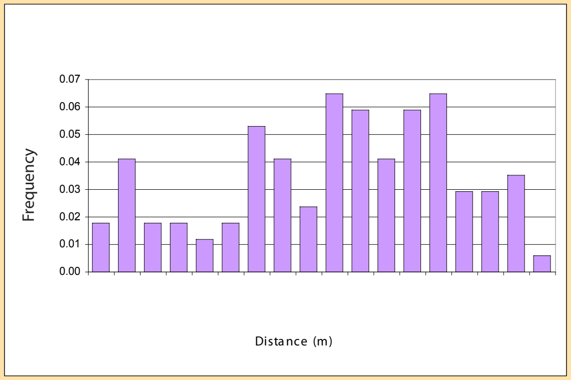

Figure 5: Graph of CIRARV frequency vs. distance from the road in Styers I.

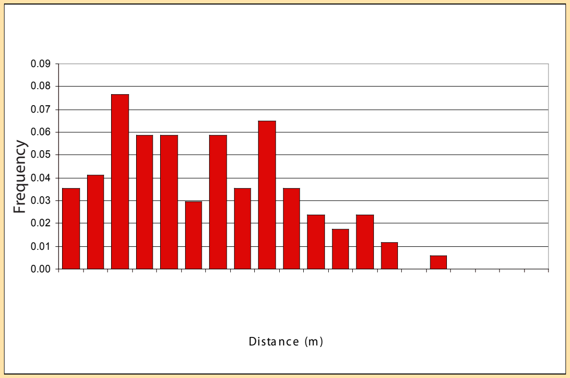

Figure 6: Graph of CYNOFF frequency vs. distance from the gravel pile in Styers I.

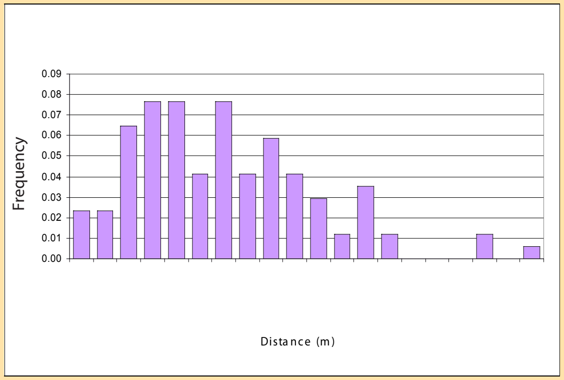

Figure 7: Graph of CIRARV frequency vs. distance from the gravel pile in Styers I.

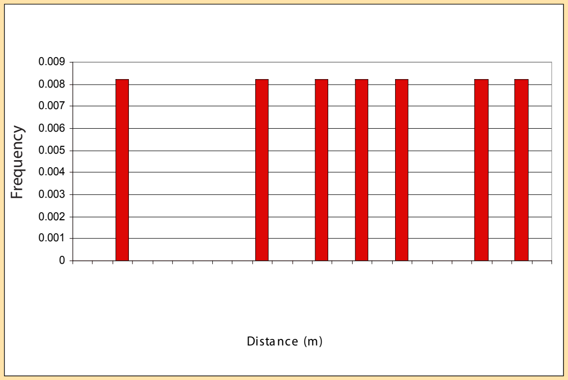

Figure 8: Graph of CYNOFF frequency vs. distance from Tom Miner Creek in Styers II.

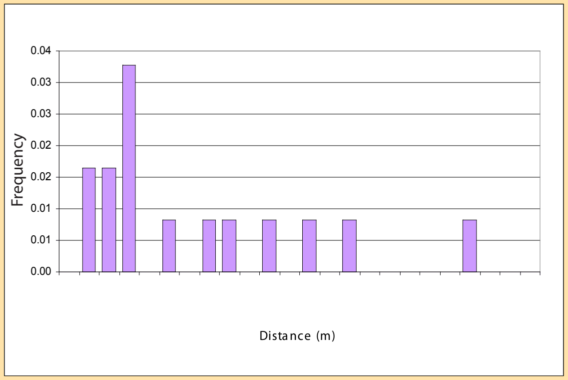

Figure 9: Graph of CIRARV frequency vs. distance from Tom Miner Creek in Styers II.

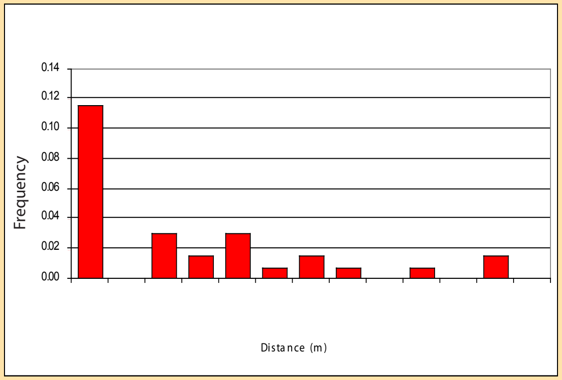

Figure 10: Graph of CYNOFF frequency vs. distance from the road in Styers IV.

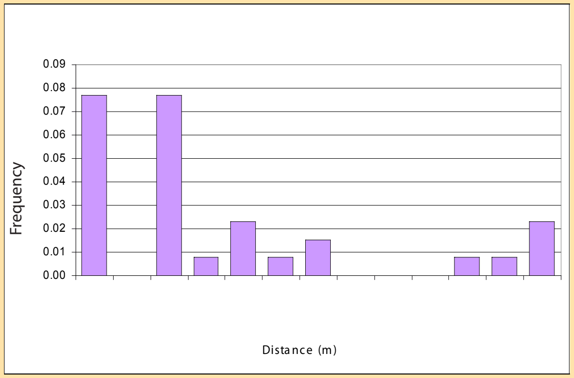

Figure 11: Graph of CIRARV frequency vs. distance from the road in Styers IV.

Conclusions

In Styers I CYNOFF frequency decreased with distance from Tom Miner Creek, after an initial increase adjacent to the creek, therefore we support hypothesis 1. It was expected that frequency of this species would be associated with the use and movement patterns of the primary dispersal vector (cattle) because it has a bur for a fruit that sticks to the animal hair. In addition, the seeds must have a source and the distribution of plants would be assumed to be associated with this source or decline with distance from the source, but modified by the animal behavior. The greatest potential seed source was the disturbed soil area associated with the gravel pile on the edge of Styers I. The observed distribution (Fig. 2, 4, and 6) could be explained by cows moving from the gravel pile to the stream upon entering the field. However, the frequency is lower directly adjacent to the creek and generally increases with distance up until around 50 meters, where it appears to decrease. This may be due to competition from other established plants in close proximity to the creek and the likelihood that many of these riparian species are well-established shrub species capable of out-competing herbaceous species like CYNOFF.

Both species were expected to have a greater frequency near the gravel pile in Styers I, due to the ease of establishment for weedy species in disturbed areas and the abundance of seed available from already established plants (Mack et al. 1999). This was found to be the case, therefore we support hypothesis 2. However, once again the frequency of both species was lower in the vicinity of the gravel pile and increased with distance from the gravel pile up until approximately 110 meters for CYNOFF and 150 meters for CIRARV. This again is assumed to occur because of the relative abundance of other weedy species within this area and the competition for resources or due to a greater amount of general activity in this area, thus more disturbance and less overall vegetation.

Styers II had fewer occurrences of weeds than Styers I. We hypothesized that there would be a greater frequency of CIRARV near the stream in Styers II due to a large patch of established and flowering CIRARV near the stream and this species' ability to reproduce vegetatively as well as sexually. CIRARV frequency is greater near the stream, therefore we can support hypothesis 3. CYNOFF in Styers II was not very prevalent. There were small single plants observed, but no considerable population and no observable trend in the data.

Styers IV is marked by ranch management as a pasture in good condition. There was a substantial greater frequency of CYNOFF and CIRARV near the road in this pasture, therefore we can support hypothesis 4. The higher frequency of CYNOFF is thought to occur due to proximity to the road and the ease of transport of this species by animal and human vectors. CIRARV frequency was expected to be greater due to disturbance and exposure along the roadway and the ease of weedy species establishment under these circumstances.

One method of determining dispersal distances for CIRARV is through the calculated d50. This is based on the theory that the height at which the seed is released, the seeds' terminal velocity and the horizontal wind speed will determine the distance at which 50% of the seeds will travel (Cousens et al. 1995). CIRARV dispersal was estimated to be 51m at a maximum wind speed of 17.9m/s (Brown 2006). This suggests a possible rate of spread for this species over time. If spread and establishment is successful in early years, then dispersal possibilities for CIRARV could be endless and give greater reason for the management and containment of this species. Over time, due to the wind dispersing capabilities of CIRARV, this species could be a serious problem for management and encroachment into areas lightly affected. For instance with Styers IV, which is lightly influenced and within 500m of the gravel pile and thus established patches, it could take around 10 years only, under optimal conditions, for this species to spread and contaminate this field.

Montana's goal is to control existing infestations and prevent or minimize the further spread of CYNOFF and CIRARV (Webb and Sheley 2002). CIRARV can be a difficult species to manage because it is able to reproduce sexually and vegetatively, while CYNOFF is difficult to manage due the fact that it is closely associated with animal behavior and source populations, therefore management can focus on these factors to reduce further invasion. This understanding is why more than one method must be applied to prevent their spread. CYNOFF and CIRARV could be a future management issue in pastures II and IV from influences of the present condition of Styers I. Future strategies should insure the control of these two species. Adoption of a long-term, integrated management plan could prevent the spread and establishment of existing and potential populations (Appendix B).

Annual monitoring of all three fields, paying special attention to Styers I, would be recommended to prevent the spread of these noxious weeds and a further decline in forage quality. Baseline information gathered through this study could lead future endeavors of weed management. Due to the fact that the B-Bar Ranch is aiming for organic ranching/cropping status, herbicide use is not an option.

In the end we were able to fulfill our goals and support our hypotheses. This project, brought upon by quick wits in a disappointing start, has evolved into what could be a useful and highly beneficial tool for the B-Bar Ranch, and at the same time a valuable and educational journey for its researchers; by aiding them in the practice of scientific research and writing.

The idea that weed management is integrated and used in conjunction with conservation and science-based methods is exciting. These tools can be used to enhance the productivity of either a presently healthy range or a once degraded area. The knowledge of certain species' demographics will conduct management through the process of understanding how plants persist and how they perish. In addition, their effects on surrounding plant communities and the biodiversity of these areas can be fully ascertained (Wilson 2003). This familiarity will enable range and land mangers to have more productive ranges and enhance the skills needed to spend less time and money on weed management.

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Other Sources:

B-Bar Ranch management. Park County, Montana. Map of pastures. (Figure 1).
The MSU LRES Faculty: Dr. Rick Lawrence, Dr. Bruce Maxwell, Dr. Lisa Rew, Dr. Cathy Zabinski, and T.A. Hillary Parkinson.

All graphs and maps provided in this project were produced by Nancy Case, Kelley House, Brenda Sanchez, and Katie Tillerson. 2005-2006

<http://www.wunderground.com/US/MT/Bozeman.html>Climate(March 2006).
<http://www.windpowermaps.com/windmaps/states.asp#montana>Wind speed (November 2006).

7. Irrigation in Davis Meadow

Kris Anderson, Brian Edwards & Jeff Johnston

Introduction:

The study of soil water characteristics is important when attempting to maximize irrigation efficiency within an agricultural setting. The B-Bar Ranch has changed its irrigation practices to reduce the impact on Tom Miner Creek. Our group's objective was to gain a better understanding of soil water characteristics to aid the B-Bar with managing their irrigation practices for maximum efficiency of water as well as crop productivity.

Successful irrigation should maintain soil water content at between one half and full field capacity to avoid reducing crop growth. Field capacity is defined as the water left in an undisturbed soil allowed to freely drain for a full day after wetting, which is conventionally recognized as –1/3 bars. Wilting point is conventionally defined as –15 bars, and while soil at wilting point does contain water, the water is held so tightly within the soil that is not plant-available (Brady and Weil 2002). We hypothesize that there will be a significant difference in soil properties between the two irrigation pivots. If this is true, then the two areas will benefit from separate management to maintain optimal soil water content across the pasture.

Determining water content at one point in time only gives a snapshot of moisture conditions in the soil. This snapshot, however, gives the B-Bar an idea of the variation across the field. Once the variation in the field has been determined, water content from the selected places in the field can represent the entire field. By determining field capacity and wilting point through laboratory analysis, an irrigation schedule based on recent and expected precipitation, evapotransportation, and crop stage can be created. Evapotransportation (ET) is the sum of evaporation and plant transpiration, the major process of water loss from soil. Vegetation types and land use significantly affect evapotransportation. Soil water content can easily be estimated in the field by the B-Bar Ranch using a Paul Brown Probe. In combination with a weather station (which would have to be installed) these tools can ensure that the watering schedule is appropriate for their crops.

Methods:

After visually surveying and measuring the length of the pivot, the field was divided roughly into thirds. Three north to south transects were established about 50 meters apart. Starting at the edge of the field, we used a large tape measure to place wire flags every 50 m to define sampling points. At each sampling point, crop height, GPS position, and a brief weed survey were taken. Soil cores were also collected at each point using a truck-mounted hydraulic soil corer, sampled at 0-30 cm depth. After soil samples were taken from 0-30 cm, each transect was divided into quarter lengths and additional soil cores were taken. These cores consisted of a soil sample from 0-30cm and another sample from 30-60 cm, in order to separately characterize the two sample depths.

GPS data was collected in order to construct a map of the field. Each sample position was logged using a Trimble GEO-XT GPS unit. The center of each pivot and wheel tracks of both pivots were mapped, as well as the perimeter of the Davis Meadow. A database was created linking measured soil properties to their corresponding sample points. Arcview 9.3 was used to create a spatial interpolation of the soil properties between sample points. (See Maps A and C below)

Soil samples were weighed in the field to determine wet weight, then dried for 48 hours in an oven at 105° C, and re-weighed. The equations used to determine bulk density and water content (Brady and Weil 2002) were:

$$\textbf{Bulk Density} = \frac{\text{Oven Dry Soil Mass (kg)}}{\text{Soil Sample Volume}}$$

$$\textbf{Water Weight} = \text{Wet Soil Weight} - \text{Dry Soil Weight (kg)}$$

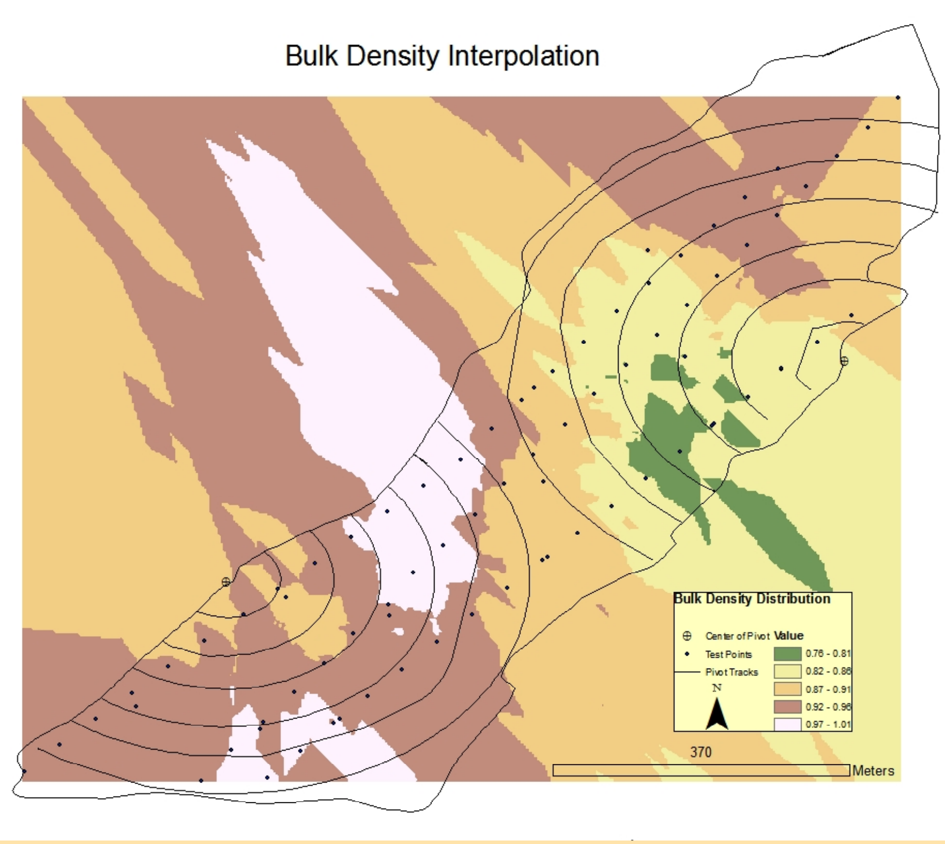
$$\textbf{Water Content} = \text{(Water Weight/ Dry Soil Weight) (Mg/m}^3\text{)}$$

Particle size distribution was determined using a standard hydrometer method to determine the percentages of sand, silt and clay within the samples (LRES 201 lab manual). One third of the samples were sent to Midwest Laboratories to determine wilting point and field capacity (-1/3 and -15 bar) water content.

There was no evapotransportation (ET) data for the B-Bar ranch, but we found data from Gardiner, MT and Ashton, ID on the AgriMet online climate data base. These two sites are similar to the B-Bar with respect to elevation and precipitation.

Results and Discussion:

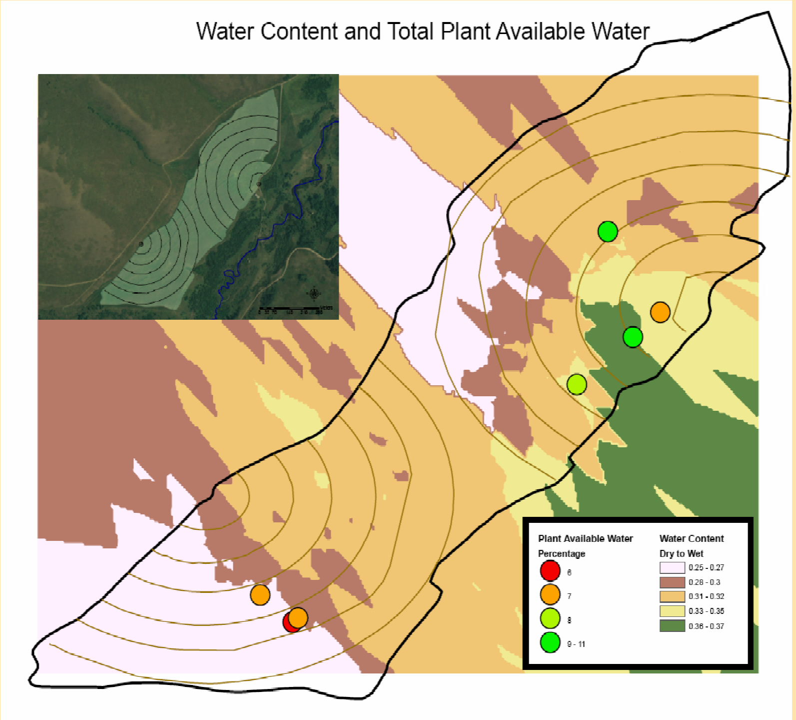
Spatial interpolation results show that Davis Meadow varies in regard to bulk density and water content, suggesting that each pivot should be managed independently of one another. These spatial differences were consistent with the soil water-holding capacity results from Midwest Laboratories. This also implies that watering and irrigation scheduling for each pivot should be specific for the pivot area in order to maximize efficiency (See Figures 1 and 2).



Bulk Density Interpolation

Figure 1. Bulk density (Mg/m^3) in Davis Meadow

It should be noted that the bulk density measurements from Davis Meadow were lower than the values expected from agricultural soils. The majority of the bulk density readings that were acquired from Davis Meadow were between 0.7 and 1.1 Mg/m^3. The north pivot had an average bulk density of 0.89 Mg/m^3, and the south pivot had an average bulk density of 0.98 Mg/m^3. Typically, the bulk density would be expected to be between 1.1 and 1.3 Mg/m^3 (see Table 1; Brady and Weil 2002). This is most likely explained because the soils within Davis Meadow were recently tilled and our measurement of the corer volume may have been incorrectly measured. When soils are tilled the bulk density decreases because the soil is 'fluffed up'. Alternatively, if we over-estimated the volume of the corer, then our bulk density calculations would be systematically lower than the actual soil bulk density.



Water Content and Total Plant Available Water

Figure 2. Water content (%) on August 29th, 2006 and plant available water (%) in Davis Meadow.

Initial results from particle size distribution of 14 soil samples show a slight variation in the texture of the soils. When the two pivots are compared based on the fraction of clay, soils under the north pivot had lower clay content than soils under the south pivot. The average clay content of the soil within the boundary of the north pivot was 28%, while the clay content under the south pivot was 33%. While not an extremely large increase in clay content, it is enough that the consistent patterns of bulk density, water content, and water-holding capacity between the two pivots can be explained by the differences in soil texture (Table 2).

Field Water Balance:

The soil water balance equation can help to determine the amount of water that is needed at any given time to maintain proper soil moisture conditions (http://www.usbr.gov/gp/agrimet/).

Evapotransportation cannot easily be measured directly. Pan evaporation data can be used to estimate ET at a given time frame. The general approach to estimate evapotransportation indirectly is by means of a field soil water balance. We used historic reference evapotranspiration and crop coef-

Sample number, pivot	Sand	Silt	Clay
3, North	0.46	0.36	0.18
5, North	0.44	0.36	0.2
12, South	0.42	0.34	0.24
15, South	0.4	0.34	0.26
19, South	0.32	0.26	0.42
21, South	0.28	0.22	0.5
35, North	0.4	0.34	0.26
38, North	0.38	0.32	0.3
41, North	0.34	0.3	0.36
66, North	0.38	0.32	0.3
68, South	0.36	0.3	0.34
69, South	0.42	0.36	0.22
72, North	0.34	0.24	0.42

Table 1. Soil texture from the Davis Meadow. Numbers indicate proportion of each size class per sample

ficients to predict ET on the B-Bar Ranch; understanding the crops planted are important in how water is utilized.

Current soil water content may be estimated by balancing inputs and losses of water from Davis Meadow. The equation balances the change in water stored within the soil (ΔS) with inputs and losses: Δ

$$S = P + I - ET - D$$

(http://en.wikipedia.org, http://www.irrigationbc.com, http://www.usbr.gov/gp/agrimet/). The inputs are precipitation (P) and irrigation (I). Losses include evapotransportation (ET) and deep percolation (D). Storm water runoff and run-on will be assumed to be zero for Davis Meadow, due to the topography and the fact that these are difficult to measure or estimate.

ID	1/3 BAR (%)	15 BAR (%)	Available Soil Water (%)
3	35.9	24.59	11.31
5	34.26	25.93	8.33
15	34.45	27.65	6.8
21	34.76	28.3	6.46
35	34.26	23.88	10.38
66	29.25	21.69	7.56
69	30.11	23.42	6.69

Table 2. Soil water content, in percentage. Samples 3, 5, 35, and 66 are from the north pivot, and 15, 21, and 69 are from the south pivot.

Historic ArgiMet data was used to predict seasonal evapotransportation. Evapotransportation is the loss of water from the root zone by plant transpiration and evaporation from the soil surface. A 7 year record (12 months/year) of evapotransportation from Ashton, ID was used as a reference. Figure 3 shows the predicted pattern expected for ET rated from the 10th week of the year to the 43rd week. The highest ET was seen in mid summer, about the 26th week.

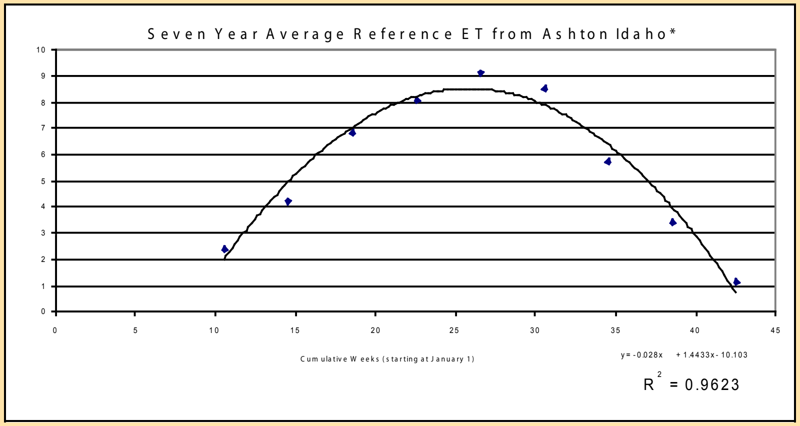


Figure3: The yearly trend in ET averaged over 7 years in Ashton, ID from AgriMet database

When the soil profile is full of water, reaching what is called field capacity (FC), the profile is at about -1/3 bars of water potential. Water potential is a measurement of how tightly the soil water is held in the soil. The tighter it is held, the more negative the water potential. At FC, with a potential of only -1/3 bars, the water is not being held very tightly and it is easy for plants to extract water from the soil. As water content of the soil decreases, the water becomes more tightly held. Figure 4 shows three typical curves for sand, clay and loam soils (Martin 2001). Plants will use the water in the soil until the moisture level reaches permanent wilting point (PWP). Once the soil dries down to the PWP, plants can no longer extract water from the soil at a rate sufficient to sustain them (http://cals.arizona.edu). However, plant growth is significantly reduced by the time the soil water is reduced to about halfway between FC and PWP.

The B-Bar Ranch grows *Avena sativa* (domesticated oats) in Davis meadow. Evapotranspiration from *Avena sativa* is estimated by multiplying the crop coefficient by reference ET. The crop coefficient is a function of growth stage in relation to the reference crop and predicts water demand. The reference ET is derived from *Medicago Sativa* (alfalfa) grown under ideal soil conditions. Oats use about 80% of the water that alfalfa requires to have 100% growth. In Figure 5 the growth of *Avena sativa* is predicted from AgriMet data. Using the equation for lines fitted to historic ET from Ashton, Idaho and crop coefficients, ET can be estimated on a weekly basis for Davis Meadow.

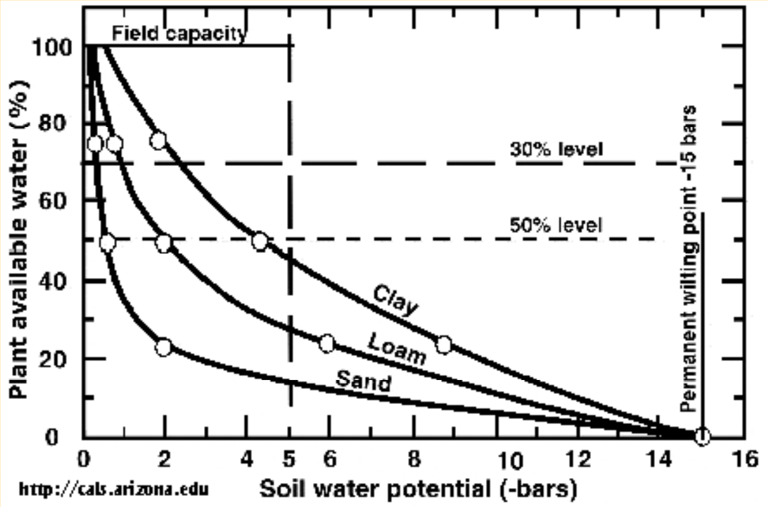


Figure 4. Plant available water in relation to soil water potential

Conclusion:

We measured a slight difference in the clay content between the two irrigation pivots as well as consistent soil water-holding capacity and bulk density values. These values are enough to justify a difference in management between the two irrigation systems, and support our original hypothesis. The B-Bar Ranch can use the AgriMet data to predict evapotranspiration for Avena sativa grown at Davis Meadow. This equation can be used during different times of the growing season to maximize water use efficiency and keep impacts on the Tom Miner Creek as environmentally friendly as possible until the B-Bar can set up their own water monitoring equipment to gather real time data for their area.

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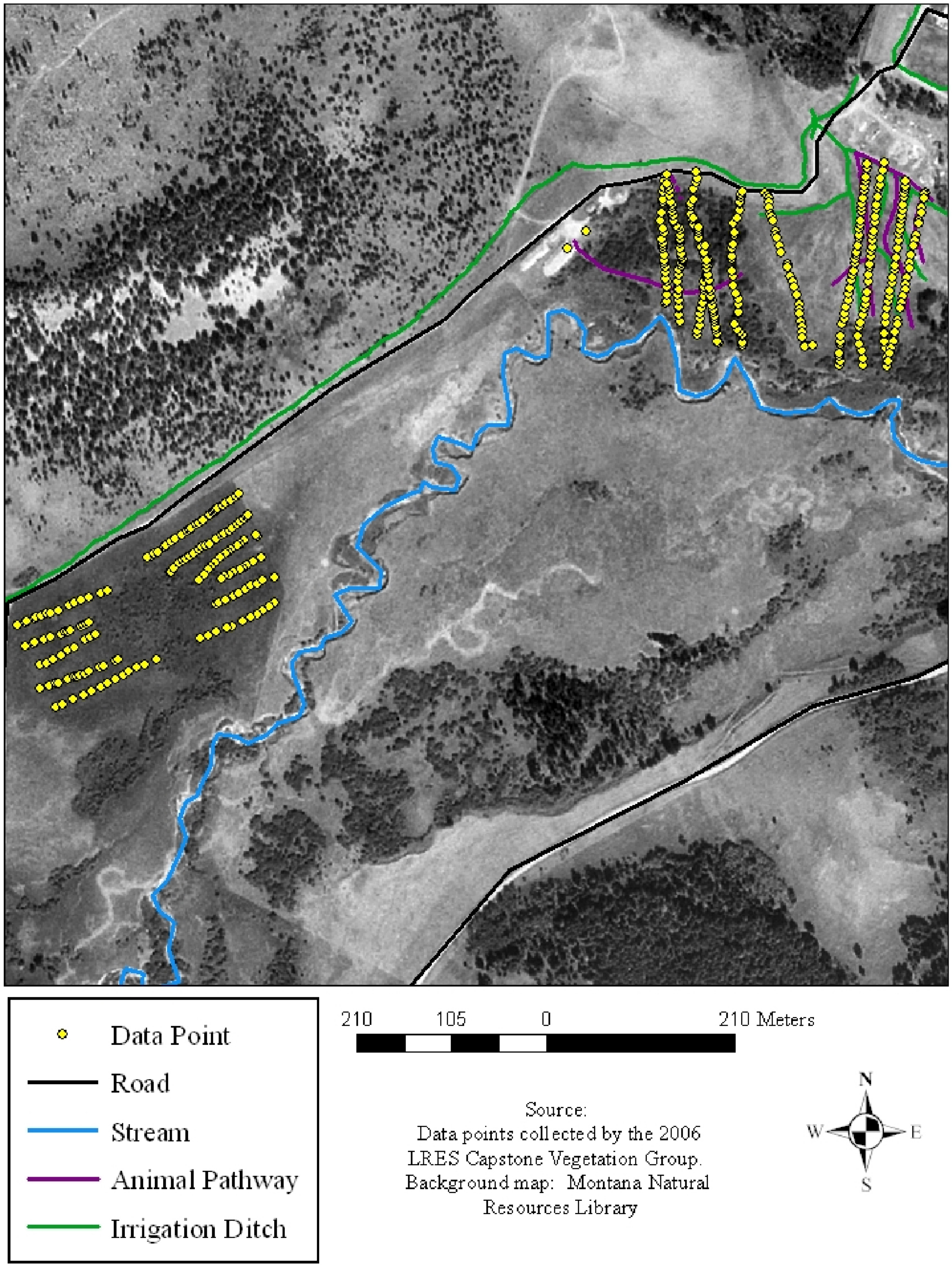
8. Conclusion

The experience of the 2006 LRES Capstone Class at the B-Bar Ranch provided many valuable insights and hands-on opportunities for the graduating class of seniors. The research performed emphasized the difficulty of rigorous scientific study and true understanding of natural ecosystems. With a limited amount of time in the field, this class found valuable results that may be of use to the B-Bar ranch.

9. Appendix A

Weed Inventory Locations



Source:
Data points collected by the 2006
LRES Capstone Vegetation Group.
Background map: Montana Natural
Resources Library

Appendix B

Suggested methods to regain the desired condition of Styers I pasture

- Close the pasture until management is deemed successful; this will keep animals from spreading seed, minimize soil disturbance and allow for competitive grass species to establish.
- The gravel pile is a place of seed collection. Cover the gravel pile with a tarp while not in use; this will keep existing seeds from dispersing and germinating and keep new seeds from migrating into the gravel pile where they could be dispersed through use of the gravel for regrading roadways.
- Mow the pasture in early spring before flower head production. Frequent intervals of mowing may be needed throughout the growing season to prevent these species from reaching the flowering stage and seed production, which in turn reduces all factors of dispersal and contains the population by a possible reduction of 60% (Webb and Sheley 2002). This will also reduce aboveground biomass and thus production of photoassimilates (Graglia et al. 2006).
- Till the pasture in the fall, when CIRARV is actively transferring carbohydrate reserves to the root system for over-wintering, to weaken this species' substantial root system and reduce vegetative reproduction (Graglia et al. 2006).
- Seed the pasture with a "suppressive crop" to offer competition for resources and to suppress shoot regrowth (Graglia et al. 2006).

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Nutrient Cycling Group

Weed Distribution Group

Irrigation Group

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