Final Status Report

Evaluating Long-term Carbon Storage Potential on Private Rangelands using Dynamic Landscape Modeling

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Introduction:

The Landscape Toolbox project was initiated by The Nature Conservancy because there was no one source that would provide key guidance for rangeland assessment, monitoring, and landscape scale planning. We identified 3 core objectives for the project, 1. Development of a resource for land managers that will provide guidance on rangeland assessment and monitoring to support planning and adaptive management; 2. Outreach and training of professionals on the use of these tools and, 3. Tools for the visualization of the results to empower the communication of complex results. In short, toolbox was developed when the vision of providing one place to obtain guidance and tools necessary to integrate, analyze, and understand monitoring and assessment data and to help rangeland managers develop a coherent picture of landscape health. Over the past four years we believe we have accomplished his goal, yet in the process of we have identified a number of additional challenges to apply scientific tools to rangeland management. We are continuing to adapt methods, and develop new tools with the goal of continuing to provide the rangeland management community the best, and most useful tools, available.

Over the past two decades there has been an explosion in the amount of information available to support the management of rangelands and aridlands. Unfortunately, the vast majority of that information was buried in the scientific literature which made it essentially unavailable to professional land managers. Furthermore, there was no one source that provided an objective assessment of the applicability of tools and methods to different land management challenges. Thus, methods were commonly misapplied, data were commonly misinterpreted, and promising tools (e.g. remote sensing) are abandoned as too difficult. The over-arching goal of the Landscape Toolbox was to overcome these challenges. The key result of this project is the The

Landscape Toolbox website, which integrates existing and emerging field, remote sensing, and ecosystem modeling tools and methods in support of rangeland assessment, monitoring, and planning. The results of these efforts are embodied, in large part, in the Landscape Toolbox website (www.Landscapetoolbox.org).

The United States has about 405 Million acres of rangelands. Changes in rangeland soil carbon can occur in response to a wide range of management and environmental factors. Grazing, fire, and fertilization have been shown to affect soil C storage in rangelands. Grazing lands are estimated to contain 10–30% of the world's soil organic carbon and so it is critical to consider these lands when planning carbon sequestration programs. The sequestration of carbon in soils has been proposed as one way of addressing the changes in our global climate resulting from increased atmospheric CO2. A major challenge in understanding how rangeland management can contribute to goals for offsetting CO2 emissions is that a reliable system must be in place for assigning value to the additional carbon that private rangelands can store. Up to now, models used for estimating carbon sequestration, are only able to provide estimates for small-scale, homogeneous areas. This presents a problem to private livestock producers whose ownership may cover a large, heterogeneous landscape. Our objective was develop a tool – in the Landscape Toolbox – that would link the long-term landscape modeling tools developed by TNC and the CENTURY soil carbon model making it possible to estimate sequestration rates for baseline management and evaluate gains or losses in soil carbon under alternative management scenarios at the scale of entire ranches.

We initiated this project when carbon Cap-and-Trade was predicted to be a significant financial instrument for off-setting carbon emissions and allowing countries to meet their carbon emission goals to limit ongoing climate change. At that time, the Chicago Climate Exchange had opened to great fanfare, and the carbon market was promising to provide significant income to landowners willing to change land management practices to foster carbon sequestration. Unfortunately, the United States' commitment to reducing total carbon monoxide production has largely collapsed and with it the carbon cap-and-trade market. The Chicago Climate Exchange closed at the end of 2011. While there is no longer a financial incentive for land managers to

focus on carbon sequestration, we believe that there remains an interest among conservation-minded operators who are interested in the "carbon footprint" of their operations.

We developed this model using the private lands of the Flat Top Ranch in Blaine County, Idaho as a pilot site (Figure 1). Our general approach consisted of two parts. First, TNC's dynamic landscape modeling tools were used to assess the possible changes to participating producers' lands over a 50-year time period. Second, using these predictions and data on soils, climate, and biomass production from the study area, estimates of soil carbon sequestration were generated for the modeled landscape. Being able to estimate the long-term carbon storage potential of private rangelands is a critical step in being able to measure environmental services of rangeland management.

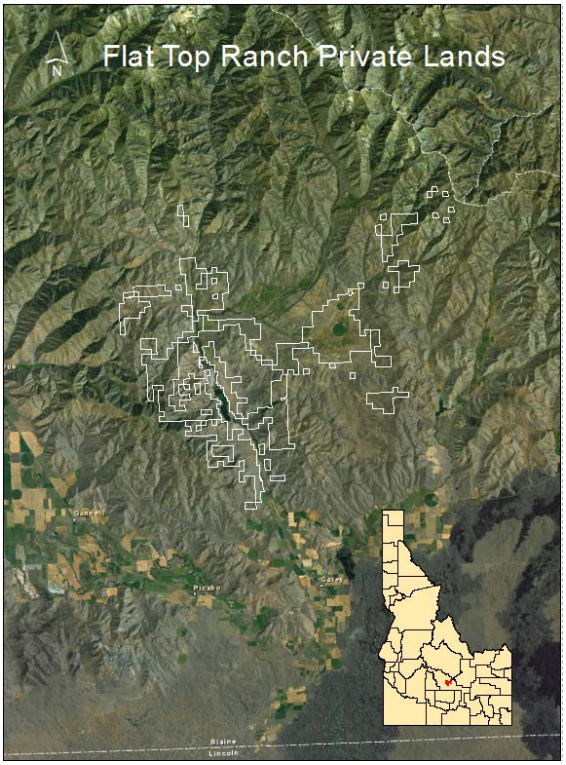

Figure 1. Private lands on the Flat Top Ranch. This ranch was utilized for a pilot of the Landscape Carbon Model.

For this project, we linked state-and-transition models (STMs) of vegetation dynamics with the CENTURY model of soil carbon sequestration to predict the change in soil carbon under alternative management scenarios. STMs were run in the Path Landscape Model, developed by ApexRMS and ESSA Technologies. Figure 2 shows the total modeling process. Carbon sequestration rates are dependent on both the type of vegetation growing on a site and the length of time that vegetation type has been present on that site. In this case, history matters. The vegetation dynamics model must provide results describing the vegetation state (i.e., seral class) for each year so that the Landscape Carbon Modeling tool can create a historical map of vegetation, and vegetation changes throughout the modeling period. The Landscape Carbon

Modeling tool then takes the vegetation models, converts those annual outputs into a matrix of type and duration for each cell for each state class. Annual carbon sequestration is then calculated for each combination of vegetation state – duration for each year. These are then summed to provide an estimate of carbon sequestered, by ecological system, each year.

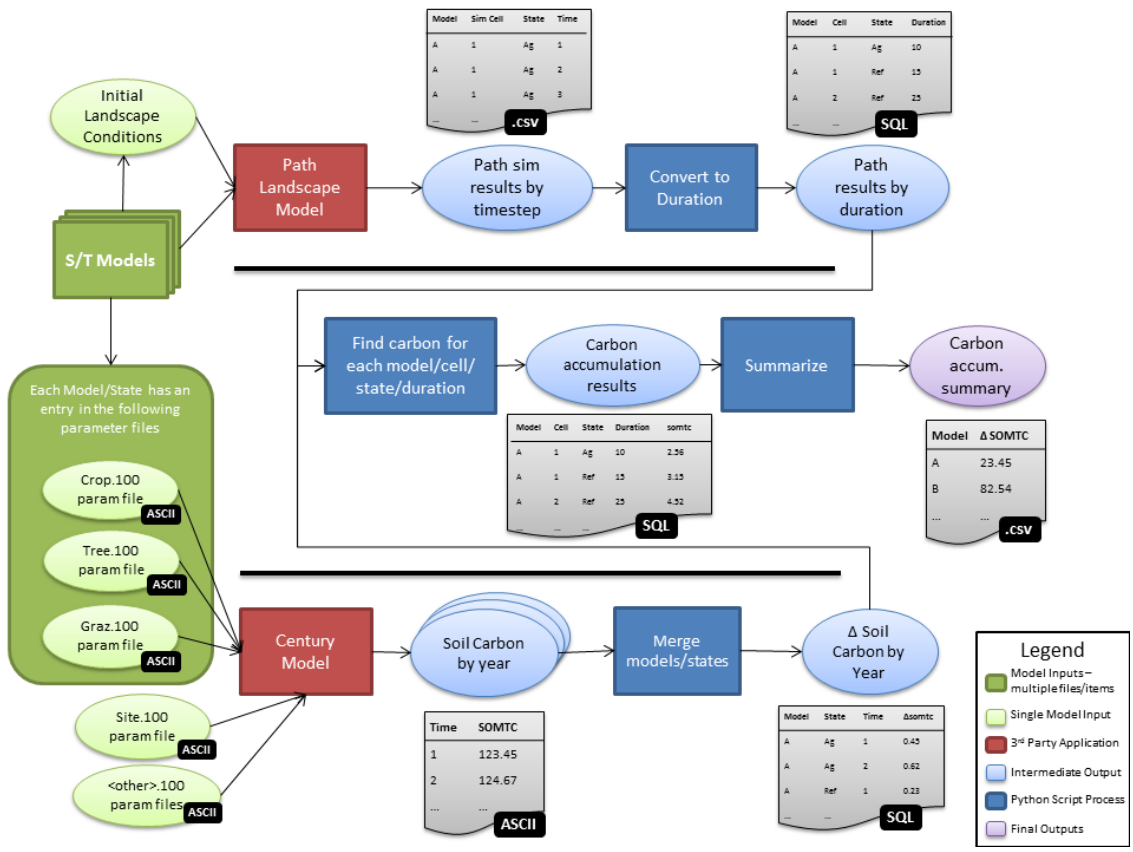

Figure 2. Schematic of how the NRCS/CIG Landscape Carbon Model tool takes outputs from the Path Landscape model and the Century soil carbon model to create landscape-level estimates of soil carbon sequestration for different management scenarios.

The Landscape Carbon Model is available for use on the Landscape Toolbox website. It can be accessed at http://www.landscapetoolbox.org/cumulative_analysis/carbon_model. The first step in modeling sequestration across a landscape requires that the user create a series of PATH Landscape state and transition models (STMs). These models are run under of variety of

management/disturbance scenarios to simulate how a landscape's vegetation may change over time. The Landscape Carbon tool then runs a server-based version of the Century model using this detailed output of the PATH Landscape models to estimate how soil organic carbon changes in the study area in response to a given management scenario.

Figure 3. The Landscape Carbon Model is accessible at: http://www.landscapetoolbox.org/cumulative_analysis/carbon_model.

Estimating soil carbon storage potential for a landscape over time requires two steps prior to running the Landscape Carbon Model:

1) Running the Path Landscape models for user defined management/disturbance scenarios.
2) Defining the parameters for the Century model for each STM and creating parameter files that match the Path Landscape scenarios.

The Landscape Carbon Model takes the output from the Path Landscape model and the corresponding parameter files for Century and automates running of the Century model and compilation of the results. The following provides instructions on running the Path Landscape Model and the creation of the parameter files for the Century model.

<u>Creating and Running a Path Landscape Model</u>

These instructions are written for Path version 3.0.x. Later versions may require slightly different instructions but should be able to produce the type of output required for the carbon sequestration tool using a similar set of steps. Path version 3 requires the Vegetation Dynamics

Development Tool (VDDT) as a simulation engine, but the recently released version 4 is a stand-alone simulation engine that does not require VDDT.

The Path software can be downloaded at: http://www.apexrms.com/path. VDDT 6.0.25 can be downloaded at: http://essa.com/tools/VDDT/. To download the software, register as a user and follow the instructions on the websites. VDDT and Path both create Microsoft Access project files, but to use the carbon sequestration tool you will only need to interact with the Path program, not with VDDT or Microsoft Access.

The Path Landscape Model **Help** menu provides links to the **Online User Guide** and **Getting Started** webpages. You can also refer to the support forum at http://www.apexrms.com/forum, where you can review the questions posed by others and add your own questions.

Instructions for generating Path model output for the carbon sequestration tool:

1. Download the Path software from http://www.apexrms.com/path
2. Open the Path Landscape Model program
3. Open or create a Path database
    a. If you have an existing Path database, open it by navigating to the main **File** menu – **Open Project** and select your Path database.
    b. If you have an existing VDDT database but no Path database, you will need to convert the VDDT database to the Path format. In the Path program, choose **File – New – Project From VDDT**. Navigate to your existing VDDT database and name the new Path database that you will be creating. You may need to uncheck the 'Use VDDT Definition Codes on Import' box if the import fails
    c. If you are creating STMs from scratch or combining multiple STMs from different sources, refer to the **Help** menu for instructions on constructing a model.
4. Set up your management scenarios and Path runs. Refer to the Path example database to view the recommended folder setup. In this database, we have three folders. Note that the names can be changed but it is recommended that users maintain a similar structure to ensure that Path runs are properly implemented. Folders and scenarios can be added by right-clicking and choosing **New**.

a. User Scenarios folder, containing the models that will be run. This folder and its scenario containing the models are created by default upon creation of a Path database from VDDT. Models can be viewed under the **Transitions** tab. In the example Path database, we also specify the model run parameters (**General** tab) and the initial conditions (**Advanced – Initial Conditions**). Initial conditions are not necessary to implement a Path run, but model run parameters in the General tab are required.

b. Grazing Scenarios folder, containing a separate scenario for each transition multiplier file that is used to adjust grazing transitions for each management scenario. These need to be manually built by the user by entering values in the **Advanced** tab under **Transition Multipliers**. These files are created by adding a new scenario and entering transition multiplier values for each model (called a Stratum) and transition type. If no multiplier is entered, the transition probability of an event specified in the model will not be altered. If a multiplier of zero is entered, the transition will be deactivated. Any other number will adjust the existing transition probability upward or downward, depending on whether the value is >1 or <1. Note that these scenarios can also adjust other management transitions, such as juniper cutting or seeding of native species, but for simplicity we only adjust grazing levels in this example and deactivate all other management transitions in all scenarios.

c. Scenario Runs folder, containing the models that will actually be run in Path. The model information and grazing multipliers are added as dependencies by dragging and dropping scenarios from the User Scenarios and Grazing Scenarios folders.

5. Set the output type required for the carbon sequestration tool

a. In the scenario containing the models (located in the User Scenarios folder, navigate to the **Advanced** tab and choose **Output Options**. Under **Output Control**, check the box labeled **Save output in VDDT CSV format…**. Under **Detailed Output (for VDDT CSV output files only)**, check **State classes every** and specify **1** timesteps. This will write detailed state class output to a .csv file for each time step of the simulation in the format required for the carbon

sequestration tool. No summary output is necessary for the carbon sequestration tool, but may be useful to the user to explore vegetation model projections.

b. Specify the folder for the model output. In the main Path window, choose **File – Preferences – VDDT** and navigate to a folder under **Folder for VDDT Model Output.** If no folder is specified, Path will create and write to a default location, and may overwrite existing files (if any).

6. Check that the scenarios in the 'Scenario Runs' folder have been set up correctly by viewing the dependencies for each scenario in the Scenario Runs folder. You can also check the **Data Sources** tab to make sure that all of the intended pieces are present for each run. At a minimum, you should have information the General, Transition Multipliers, Output Options, Transitions -> Deterministic Transitions, and Transitions -> Probabilistic Transitions tabs, indicated by a check mark in the Data Sources tab.
7. Highlight the scenario(s) that you want to run under the Scenario Runs folder, right-click, and choose **Run**. Make sure that the VDDT program is closed before running the Path model (it will open each time a model is run but cannot be previously open).
8. Once the Path runs have finished, the ClassesDetailed.csv file should be populated with model results for each scenario. Several other files will also be created but will contain no results unless an additional type of output is specified. The ClassesDetailed.csv files will be input directly into the carbon sequestration tool.

Landscape Carbon Model Century Inputs

The stand-alone Century soil carbon model can be used to estimate the potential for carbon sequestration in rangeland soils. However, parameterizing the Century model is not a trivial task. While the stand-alone Century software comes with tools to help construct the necessary parameter files, using these files to set up, execute, and compile results over different scenarios is cumbersome and time consuming. Additionally, the stand alone Century model is difficult to apply to large, diverse landscapes that may experience significant changes in land cover over the course of a model simulation due to management or disturbance events. While these kinds of changes can be modeled to a degree within Century, it involves complex parameter and scenario

files.

The NRCS/CIG Landscape Carbon Model (LCM) web tool was created to make it easier to implement Century in the context of dynamic landscape modeling. In this modified modeling environment, a series of PATH Landscape state and transition models (STMs) are applied to management/disturbance scenarios to simulate how a landscape may change over time. Century is run on the detailed output of the PATH Landscape models to estimate how soil organic carbon changes in the study area in response to a given management scenario.

Estimating soil carbon storage potential for a landscape over time requires running: 1) the Path Landscape models for user defined management/disturbance scenarios, and 2) the Century model for each STM state with parameter files that match the Path Landscape scenarios (Figure 1). The LCM simplifies this process by taking the output from the Path Landscape model and the corresponding parameter files for Century and automating the running of the Century model and compilation of the results.

Century uses a number of text files to specify its myriad parameters. Basic parameter files that do not change over the course of a Century model simulation (i.e., they are fixed parameters within the model run) all have the .100 file extension. Table 1 lists the Century parameter files that must be defined for the study area. The remaining .100 files that Century requires are generally not modified and do not need to be included in the file upload for the NRCS/CIG Landscape Carbon Model web tool.

In addition to the .100 files, a series of schedule files (with the .sch file extension) define the different management scenarios for each STM state. In other words, a separate .sch file must be created for each STM state. The .sch file dictates the type of vegetation in the state (by referencing the crop.100 and tree.100 files) whether or not management activities like grazing can occur for the STM state, in what months the management occurs, in what months plant growth occurs. See Appendix Y for an example .sch file from the Flattop Ranch. The .sch files must match the management scenario used in the Path Landscape model. So, a different set of .sch files will be created for each management scenario. The .sch files should be named to correspond to the Path Landscape model states (e.g., flat_clayloam_l24012.sch).

Table 1. Minimum Century parameter files that must be defined for the study area to use the NRCS/CIG Landscape Carbon Model.

File Name	Description
Crop.100	Grass and forb growth and production parameters for each STM state. Century uses this file to estimate the monthly production of herbaceous vegetation in each STM state (i.e., vegetation type).
Tree.100	Tree and shrub growth and production parameters for each STM state. Century uses the parameters in this file to estimate monthly production of woody vegetation.
Graz.100	Parameter file that specifies the effects that different types of grazing have on the vegetation in a STM state.
Site.100	Basic site parameters that describe the climate (average monthly temperature and precipitation), and soils of the site and define the initial conditions of soil nutrients and carbon. Generally, there is one Site.100 file per Path Landscape model.

The .100 files listed above and the set of .sch files related to the Path Landscape model scenario are all added to a .ZIP file along with the Path Landscape model detailed results file and uploaded to the LCM web tool.

The LCM web tool runs the Century model for each of the STM states using the .sch and .100 files and creates an output file showing how soil organic carbon changes over the simulation time period. The web tool then examines the Path Landscape model results and constructs a summary file that lists, in order, the different states that occurred in a given simulation cell and

the duration of that state (see Table 2 for an example). For each simulation cell, the change in soil organic carbon over that given duration and STM state is found from the Century model results. This process is iterated over all the simulation cells and Path Landscape model runs. The results are tabulated for the entire landscape and presented as change in soil organic carbon for each STM in the landscape.

Table 2. Detailed Path Landscape model results for a 20-year run of single simulation cell. The detailed results are collapsed into summary results that show the duration of the time in the STM state

TimeStep	STM State Code
1	34010
2	34010
3	34010
4	34010
5	34010
6	34010
7	34010
8	34011
9	34011
10	34011
11	34011
12	34011
13	34011
14	34011
15	34011
16	34011
17	34011
18	34011
19	34011

20 34011

Exemplary Pilot on the Flat Top Ranch.

We used the Flat Top Ranch in Blaine County, Idaho as a pilot test case for the use of the LCM. This ranch is located in Idaho's southern Pioneer Mountains. The majority of the valley bottomlands have been converted to alfalfa or mixed hay. The ranch's rangelands are located on the mountain slopes and ridge tops. We focused our efforts on these rangelands, and excluded the cultivated/irrigated bottomlands from the analyses.

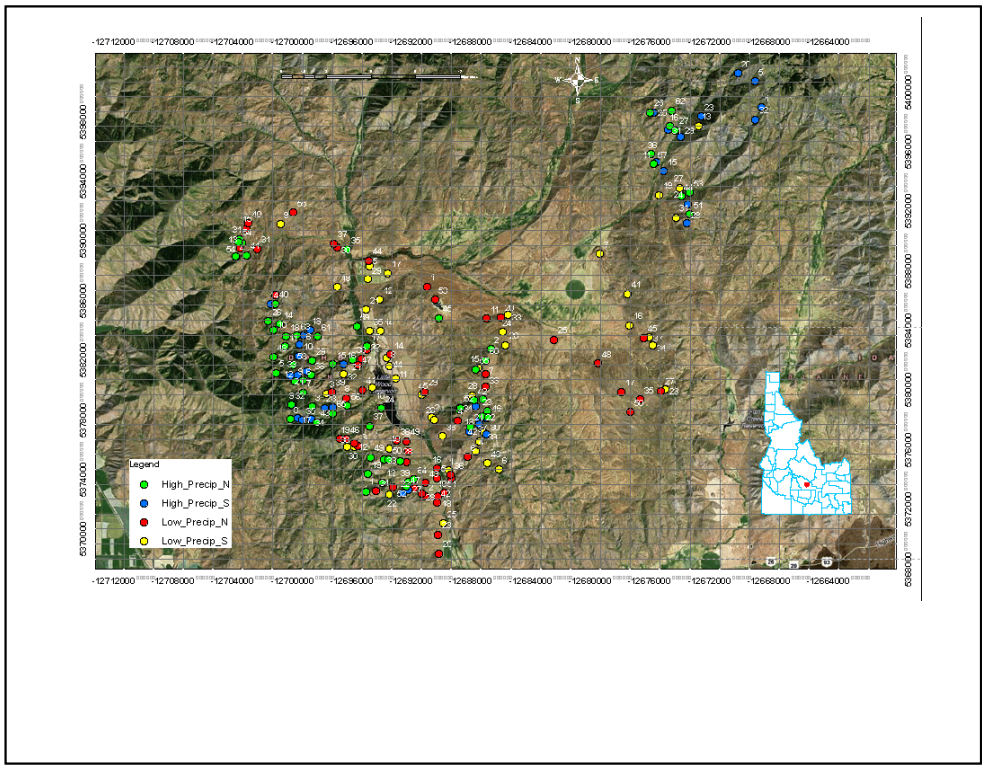

Figure 4 shows the location of the field sampling points. We stratified the ranch based on aspect (i.e., N&W, S&E) and annual precipitation ("high" and "low"), and randomly located sample points within each of the 4 strata. Within each stratum, we randomly chose points to sample. At each visited point field staff collected data on the species composition, and physiognomic structure of the vegetation. These data were used to identify and map ecological community types.

We identified two dominant ecological community types on the Flat Top, Low Sagebrush and Mountain Sagebrush. Figure 5 shows the location of each of these ecological communities on the ranch's private lands. We identified 782 hectares (1932 acres) of low sagebrush and 7758 hectares (19170 acres) in mountain sagebrush.

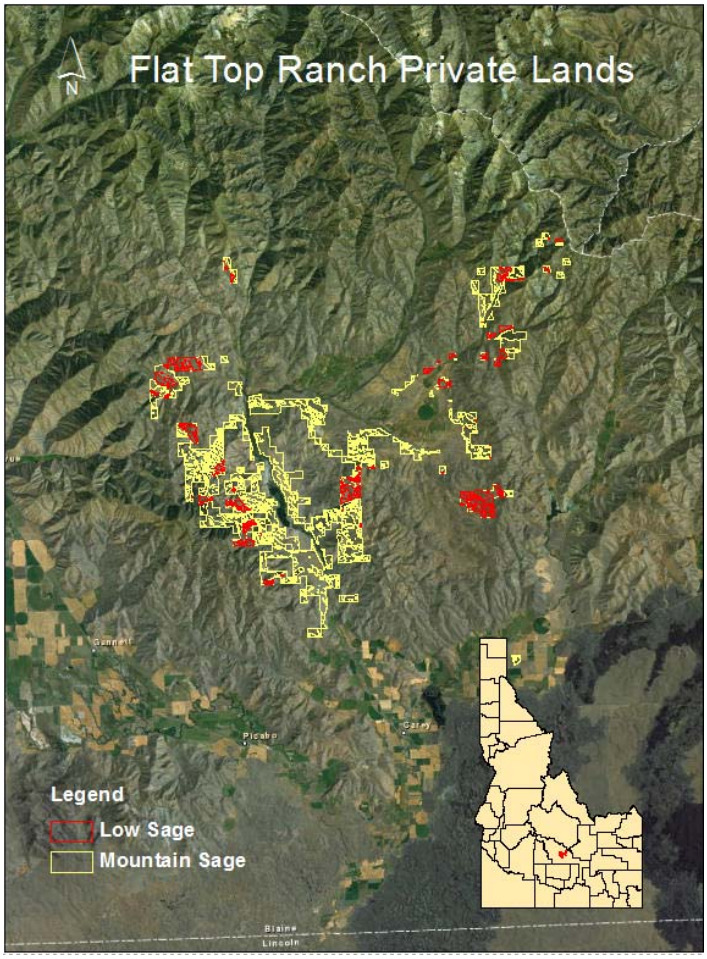

Figure 5. Low sagebrush and mountain sagebrush communities on the private lands of the Flat Top Ranch.

Models were created for each ecological community under three grazing management scenarios; no grazing, moderate grazing, and heavy grazing. The current grazing management fits within the moderate grazing regime. Each model was run for 50 years.

The Path modeling tool creates models based on stochastic disturbances (i.e., disturbances occur at random intervals). Therefore, no two model runs produce exactly the same results. Thus, we ran every model 5 times to estimate the variability in results.

Figure 6 and 7 show the results of these simulations. Figure 6 show the total, per acre, accumulation (or loss) of soil carbon during the 50 year simulation period.

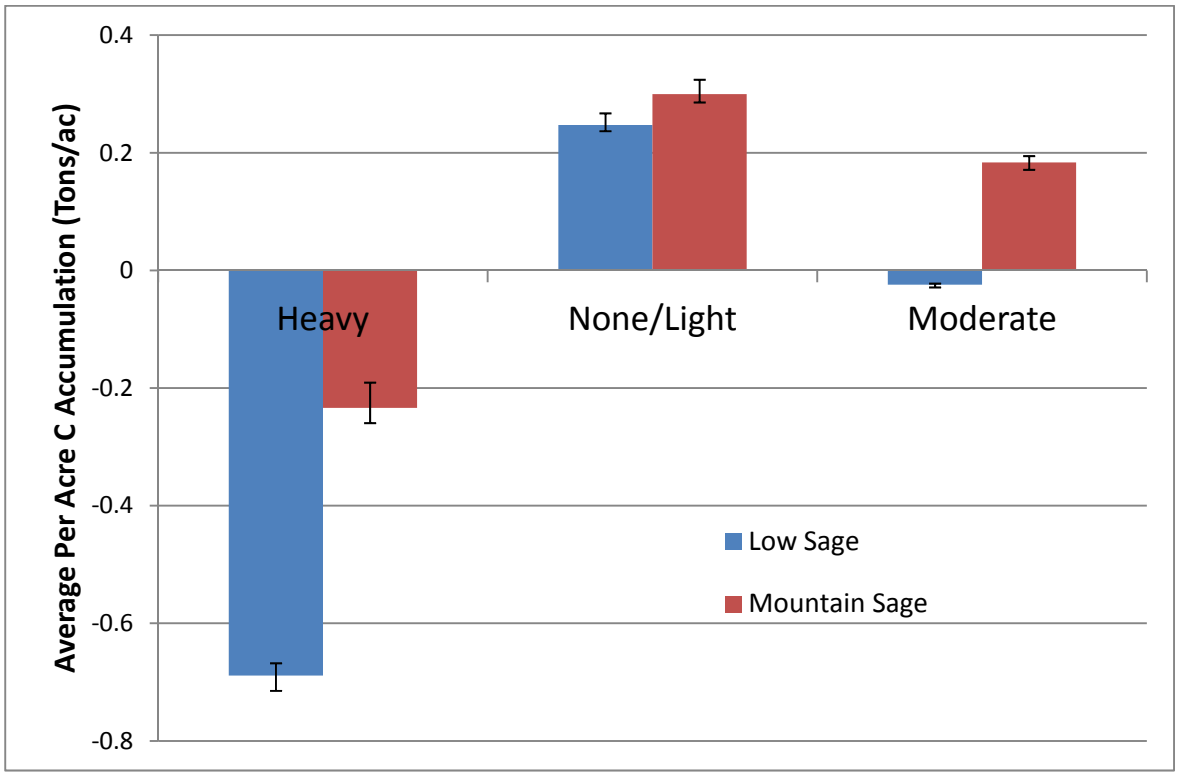

Figure 6. The average carbon accumulation, per acre, during the 50 year simulation period. Error bars are the max/min value for the 5 simulations. Note that heavy grazing results in significant soil carbon loss. Similarly, moderate grazing on the low sagebrush communities results in the loss of soil carbon.

Figure 7 shows the total accumulation, by ecological community type, for the Flat Top Ranch over the 50 year simulation period. In all cases, the models suggest that domestic livestock grazing limits the capacity of low sagebrush communities to sequester carbon. Even moderate grazing intensity results in the loss of soil carbon. Only the "no grazing" scenarios predict carbon accumulation in these systems. Similarly, heavy grazing results in a significant and dramatic loss of soil carbon in both communities.

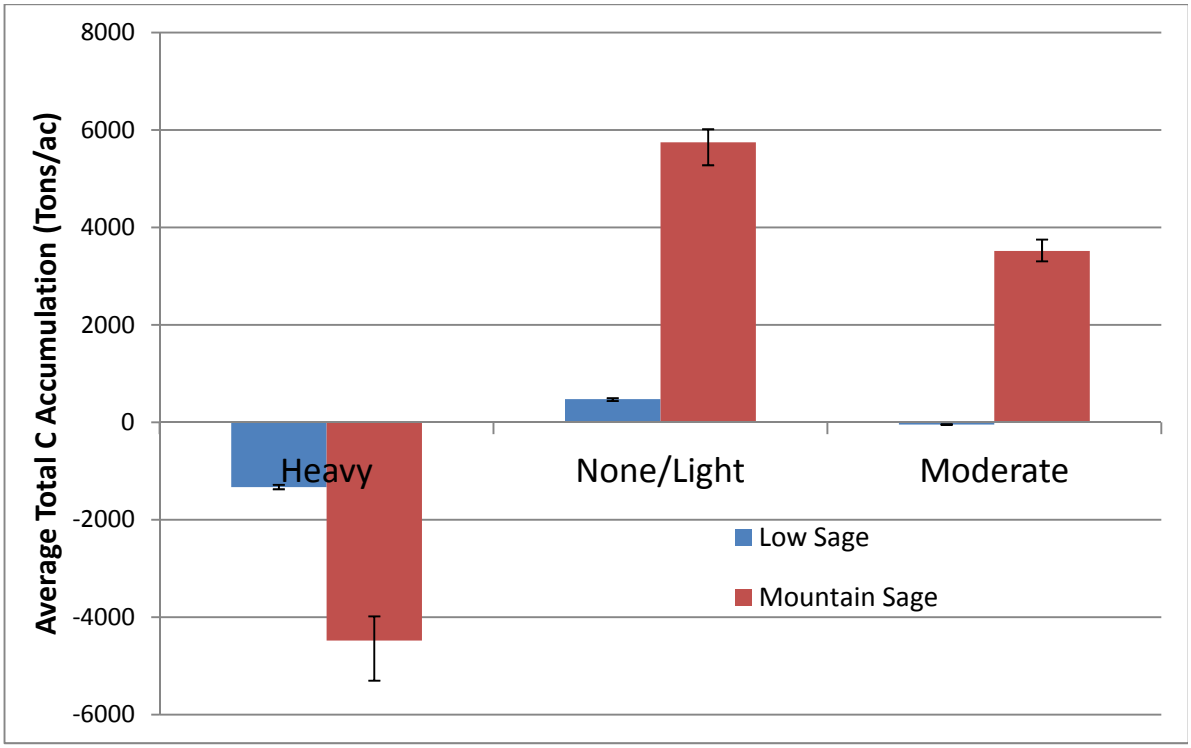

Figure 7. Average total carbon accumulation for the private rangelands on the Flat Top Ranch for the 50 year simulation period. Error bars are the max/min value for the 5 simulations.

In Conclusion:

In 2008 Carbon credits were predicted to exceed $100/metric ton within two years. At that price the market value of the carbon sequestered in the soil of the Flat Top Ranch, under current grazing management, would have been ~$315.000. If all domestic livestock were removed, the estimated value would have increased to ~$565,000, or $11,200 / year. While not a huge sum, it would be substantive enough to encourage rangeland managers to enter the carbon market.

Unfortunately, carbon credits are currently selling in the US for $0.25/metric ton. This pencils out to an approximate value of ~$15.75 / year of income for marketing those credits. However,

from a carbon neutrality perspective, every year the carbon sequestered by the Flat Top Ranch's rangelands would compensate for the annual carbon emissions of approximately70 vehicles.

In conclusion, while this project has proven to be an interesting intellectual exercise, forces beyond our control – in the form of carbon market collapse – prevented us from producing a tool that will be widely used by the ranching community.