Red Mountain Wetland Restoration: restoring a rare fen to eliminate sediment inputs to Mineral Creek, in San Juan Mountains, San Juan County, Colorado

Final Report

Prepared for: Colorado Watershed Restoration Fund
Attn: Chris Sturm

Grantee:
Mountain Studies Institute
POGG1 PDAA 20160000000000000608

Grant Amount: $14,530

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March 31, 2018

Mountain Studies Institute
SAN JUAN MOUNTAINS COLORADO

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1.0 Introduction

Mountain Studies Institute (MSI), Michigan Technology University (MTU), and the San Juan National Forest Service (SJNF) have continued a long partnership to restore damaged mountain wetlands in the Upper Animas watershed, near Silverton, Colorado. Fens are a special type of wetland that accumulates peat over thousands of years. In the San Juan Mountains, fens are 8,000-10,000 years old; therefore, they are considered irreplaceable (Cooper et al. 2012). However, many the of fens in the San Juan Mountains have been degraded by roads, mining, grazing and other disturbances (Chimner et al. 2010). The funds awarded by the Colorado Watershed Restoration Fund were used, to support site planning and permitting, to enable the restoration of 1.5 ha of fen at Red Mountain Pass (Appendix A, Figure 1). The fen is bisected by an abandoned road (Appendix A, Figure 2) and has two associated ditches running the length of the road (Appendix A, Figure 3, 370m) that drain the wetland. The road and associated ditches are having a severe impact on the fen by (1) lowering the water table, (2) changing plant communities, including weeds invading the degraded part of the fen, and (3) causing a loss of sequestered carbon from the degradation of the peat.

MSI, MTU, and SJMA, are working together to restore damaged mountain wetlands in the Upper Animas watershed, near Silverton, Colorado. As one of our top priority sites, the ultimate goal of this proposal is to restore Red Mountain Pass fen to its natural hydrological and vegetation conditions, by removing the old gravel road, using that material to fill in the two ditches, and replanting the restored road and ditches with sedges and other native plants. In this first phase, support from CWCB enabled MSI and our partners to address key permitting, assessment, and cost analysis needs to inform future phases to seek partners, resources, and funding for the restoration. The funds awarded to MSI by the Colorado Watershed Restoration Fund supported MSI's efforts to: (1) coordinate permitting and federal clearances, (2) determine the depth of gravel and peat, (3) quantify water chemistry and road base, (4) collect native seeds for future revegetation, and (5) coordinate cost estimates, competitive bidding, and volunteer activities. These actions will enable MSI and our partners to utilize techniques developed from our previous successful fen restoration projects at Ophir Pass and Chattanooga fens to improve conditions at Red Mountain Pass fen.

2.0 Background

Fens are a special type of wetland that accumulates peat over thousands of years (Cooper et al. 2012). Fens were thought to be rare in the continental Western U.S. because of the hot and dry climate. However, it has recently become apparent that fens are numerous in the higher elevations of the Rocky Mountains and they support endemic and widely disjunct taxa and unique communities (Cooper and Andrus 1994, Chimner et al. 2010, Cooper et al. 2012). In the San Juan Mountains, fens are 8,000-10,000 years old; therefore, they are considered irreplaceable (Cooper et al. 2012). Fens require perennially saturated soils produced by nearly constant groundwater inflow to accumulate peat. Even small water diversions or groundwater depletions can reverse the process of peat accumulation that has been ongoing in many fens for thousands of years (Chimner and Cooper, 2002) and lead to fen destruction (Chimner and Cooper, 2003). Thousands of fens in the San Juan's have been degraded by roads, mining, grazing and other disturbances (Chimner et al., 2010). This project aims to reverse this trend.

Red Mountain Pass fen is at the headwaters of the North Fork of Mineral Creek in the Upper Animas River basin, a priority watershed of the Southwest Basin Roundtable (Southwest Basin Roundtable Report, 2010). The wetland is immediately adjacent to San Juan Skyway Scenic Byway (Colorado Highway 550), which is the main road that over 500,000 visitors drive from Silverton to Ouray on each year. Red Mountain fen is one of the most damaged fens in the San Juan Mountains and most visible to the public. Red Mountain Pass fen ranked as a very high priority for restoration by the San Juan Assessment of Fens (Chimner et al. 2010). This fen is bisected by an abandoned road with two associated ditches running the length of the road that drain roughly half of the fen. The road and ditches are have a severe impact on the 0.52 ha of fen by: (1) lowering the water table (up to 40 cm lower), (2) changing plant communities, including weeds invading the degraded part of the fen (Figure 4), and (3) causing a loss of sequestered carbon from the degradation of the peat (Chimner unpublished data). Approximately half of the wetland is unaffected by the road because it is upgradient of the abandoned road and ditches (Figure 5). The undrained portion of the fen occupies 0.79 ha, with 0.46 ha being sedge fen and 0.33 ha being wet meadow.

3.0 Accomplishments

MSI fulfilled the goals of the Colorado Watershed Restoration Fund grant by breaking its execution into four tasks: Task 1, permitting coordination; Task 2, site planning and assessment; Task 3, construction planning; and Task 4, monitoring and evaluation.

Task 1 – Permitting Coordination

MSI coordinated with SJNF to engage US Army Corps of Engineers and Colorado Department of Transportation (CDOT) to determine necessary permitting, right of way easements, delineate ownership, and articulate the scope of work to facilitate the National Environmental Policy Act (NEPA) process. SJNF served as lead agency and land owner in the permitting process and conducting the analysis. To accomplish the goals of Task 1, MSI staff maintained regular communication with the agencies, listed above, and served as a conduit of communication between the agencies to facilitate the permitting process. MSI also used these lines of communication to increase the capacity and seek partners to support future phases to fund restoration construction activities and long-term maintenance of the site post-restoration.

The permitting process began in 2016. The SJNF assigned an Inter-Disciplinary Team to the project which included a hydrologist, archaeologist, wildlife biologist, and range/botanist to support the NEPA documentation. Staff initially planned on a Categorical Exclusion (CE) to meet the required permit obligations to be completed by end of the field season in 2017. However, due to delays in field schedule, the final assessment is scheduled to be completed in spring of 2018.

Through consultations with USACE and CDOT, MSI's team learned that CDOT is seeking a mitigation site to meet their requirements for a bridge improvement project that they completed in 2010 near Silverton and in the Mineral Creek drainage. Their previous attempts at mitigation has not met the needed benchmarks. CDOT identified the Red Mountain Pass fen as a potential match for their mitigation credits, as they need to include restoration of fen wetlands for their commitments. MSI is recruiting them as a potential partner for the restoration phase of this project.

All property delineations have been made and the area of restoration is solely on San Juan National forest property. The San Juan National Forest is awaiting specialist access to the site, May/June 2018, to compete final checks with NEPA. As the landowner, the San Juan National Forest is in communication with the US Army Corps of Engineers regarding subsequent permitting. MSI and the San Juan National Forest have been on consultation with the Colorado Department of Transportation (CDOT) regarding any potential right of way conflicts with the current alignment of Colorado/US 550. It has been determined that the restoration will be outside of the CDOT right of way. These conversations have led to a potential match from CDOT of equipment and labor for site restoration activities and staging of materials and equipment during restoration.

Task 2 – Site Planning and Assessment

From previous site visits, it was known that the abandoned road is mostly bare and separates the fen into two sections. Half of the fen remains healthy while the other half has altered hydrology due to two ditches that parallel each side of the road. Ultimately, we will excavate the road, use the road fill and plywood dams to fill the ditches and restore the hydrology, and revegetate bare areas. To do so we need a full assessment of the area. With CWCB funds, we sought to determine the amount of in-situ fill, estimate what additional materials may be needed, understand the current hydrology, and estimate the amount of wetland vegetation needed for revegetating bare areas.

Site planning began with the original San Juan Fen Assessment which identified the extent of fens in the San Juan Mountains and identified priority targets for restoration (Chimner et al. 2010). Early onsite assessments for Red Mountain Pass fen were conducted in conjunction with the planning efforts for MSI's restoration projects at the nearby Ophir Pass and Chattanooga Fens, also in the Mineral Creek watershed. The early assessment included the establishment of two groundwater wells, a survey of vegetation to determine the presence of invasive plant species, and a rough delineation of the fen complex.

In 2015-2016, MSI enlisted the help of alpine ecology students form Prescott College to develop a detailed delineation and mapping of the site as a GIS project (Appendix A, Figure 2). In 2016 soil samples were collected, from the abandoned road bed, to determine if metals or potential contaminates were present. The site was further delineated in 2017 to determine the exact dimensions and depths of the abandoned road bed. In particular, MSI's team was interested in determining the depth of the road material to peat in order to estimate the quantity of material available for use in filling the ditches that transect the site.

To further facilitate and support MSI's restoration construction efforts, MSI tested a novel means of revegetation that involved collecting local seed of native Carex species, sending to a nursery for propagation, and then planting of the propagated plugs at our existing restoration site at the Ophir Pass fen. We collected our initial seed crop in 2015 at our test site at Ophir Pass. The process was piloted in 2016 from seeds collected in the fall of 2015. A second, and expanded, collection was done in the fall of 2016 by volunteer effort, and those pugs were planted in the summer of 2017. A third and further expanded collection was done in the fall of 2017. These seeds are currently at the nursery for propagation.

To test the efficacy of planting plugs grown from local seed, MSI has developed a simple experimental design by flagging a subset of plugs planted in both 2016 and 2017. Survivorship was documented by MSI staff, restoration volunteers, and MSI's high school interns. For the 2017 and 2018 seasons we have expanded the species collected to include the native wetland grass species, Deschampsia cespitosa, which is better suited for drier locations on our fen restoration sites. Results of the monitoring of the experiment is included in Task 4 discussion.

Task 3 – Construction Planning

Based on the efforts of Task 2, MSI staff, in coordination with Dr. Rod Chimner, MTU, and SJNF developed a construction plan for the site (Appendix A). This plan has been submitted to several contractors for bid proposals. Due to the Red Mountain location at a high mountain pass, MSI has learned that careful planning with our contractors and volunteers is essential to the effective completion of alpine restoration. In future phases, we plan to utilize a combination of heavy equipment and handwork to accomplish our objectives. Through this task, we drafted construction documents to support a competitive bid process to anticipate the expenses of future phases.

MSI staff prepared a construction plan and bid package for sharing with contractors. On September 25, 2016, we conducted a pre-bid meeting with interested contractors. Three contractors expressed interest and two companies attended the pre-bid onsite meeting. With feedback from the pre-bid meeting, MSI staff and Dr. Rod Chimner made adjustments to the scope of work and collected additional information on the dimensions of the ditches, roads, and fill material.

Based upon past experiences and communication with contractors, estimates for construction are around $13,000- $15,000. Mobilization costs (range $1500-2500) are anticipated to be reasonable, as access from CO/US 550 is immediately next to the site. Wetland plant germination and seedling costs are estimated at $1.25/seedling, and do not include the cost of shipping or delivery. However, shipping the plants via Federal Express or similar company is viable. The construction plan is attached in Appendix A.

Finally, MSI staff will use this information to pursue funding for future phases and partnerships with: San Juan National Forest, National Forest Foundation, Colorado Department of Transportation, US Army Corps of Engineers, Michigan Tech University, Five Rivers Chapter of Trout Unlimited, and various foundations supporting MSI's education programming. The goal of these grants is to fund the restoration construction at Red Mountain Pass, est. $30,000, and to support outreach, monitoring, and volunteer restoration efforts as several other fens in the San Juans.

Task 4 – Monitoring and Evaluation

The efficacy of the future restoration of the Red Mountain Pass Fen requires understanding the feasibility of our restoration methods and the current state of the fen. Fortunately, our previous involvement in multiple fen restoration projects and research provides us confidence in many restoration methods. Through this grant, we were able to test if highly adapted fen plant species can grow in a nursery and be replanted in a high elevation restoration area. The restoration will alter many natural processes in the area. To determine if we have restored those processes to those of a natural fen, we must first understand their current altered state through monitoring.

To test our method, we monitored the health nursery grown plants by documenting the survival/mortality of different seed groups and growing methods. We planted the grown plugs in a test site at Ophir Pass fen, which has similar characteristics of Red Mountain Pass Fen and the NEPA for restoration has already been completed. Those transplants were monitored annually in the summer for mortality. This grant included reviewing vegetation, documenting groundwater, and carbon flux monitoring. Species composition, percent vegetation cover, and the presence/absence of invasives were documented in vegetation plots representative of the entire fen. Two groundwater wells existed at the site and were monitored in 2016-2017. The data was compared to other fen sites with funding from the Colorado Mesa State Water Center. Carbon flux monitoring was conducted with an infrared gas analyzer and custom-built chambers. The data will be analyzed in the future to determine if peat is accumulating once the wetland is restored. The full results of the carbon flux study is attached, Appendix C.

Red Mountain Pass reference site had water table levels that were at 3.3 cm below the surface of the wetland versus the disturbed side at levels of 41.1 cm, on average. Our results indicate that reference fens in comparable sites have water table levels generally above 20–30 cm below the surface, and had the largest plant production and carbon storage of all fens measured (Chimner et al, 2016). The reference fens also had unaltered peat profiles. However, when water tables were lower than 20–30 cm such as at the Red Mountain site, plant production decreased, less carbon was stored, and peat soils subsided and oxidized. This pattern was seen through the carbon flux that data indicates that respiration was increasing more than plant production as the water table dropped. These results are similar to what was found in fens in the Front Range of Colorado where we found that fens stored less carbon when the water tables dropped more than 20 cm below the peat surface (Chimner et al. 2002, Chimner and Cooper 2003a, 2003b).

Regarding the experimentation with Carex plugs propagated from local seed we have seen high success and survivorship. Over 100 plugs were planted in the 2016 pilot planting. 50 of these plugs were marked with pin flags and 49 out of 50 plugs were relocated in summer of 2017, Figure 1. The one “lost” plug was covered by debris during spring melt. These plugs will be located and documented for survivorship in the summer of 2018 as their second year of growth. In 2017 an expanded set of plugs was planted by volunteers. In total in 2017, over 300 Carex and 200 native grasses were planted. A sub set of 50 more Carex and 100 of the grasses were flagged to document survivorship. We expect to see good survivorship when monitored in 2018.

Figure 1. Seedling Planting. A volunteer prepares to plant Carex plugs, grown from local seed, at the Ophir Pass fen. Pin flag are placed to track survivorship.

Long-term site monitoring will be integrated into future restoration plans. Funding for post-construction monitoring has been allocated in agreements with San Juan National Forest and the grant proposal submitted the National Fish and Wildlife Foundation's Five Star Urban Waters Program.

4.0 Lessons Learned and Next Steps

The key lessons learned through this application are:

- Wild carex seed can be collected and germinated in a nursery for use at restoration sites. As our site is at an elevation that is significantly higher than the nursery, we were unsure if the plants would survive the transitions and if the growing conditions would be similar enough to support plant growth. We made several adjustments to the collection process. Monitoring has shown that the plants have a high level of survivorship.

- Planting carex seedlings is much more volunteer friendly than our previous process of digging transplants from nearby wetlands, as digging and carrying plant materials at 12,000 feet is quite physical exercise for volunteers. At the cost of $1.25/seedling, it is also cost effective. Additionally, the practice is more environmentally sensitive than transplants, as it does not have the same level of disturbance (e.g. digging holes) in nearby wetlands.
- Peat production and plant production is reduced in wetlands that have sub-optimal water levels. Therefore, the restoration of wetland fens will contribute to maintaining carbon sequestration in mountain environments.
- The Site assessments has enabled the project to acquire refined estimates for construction quantities for materials and expenses, which will prove valuable in fundraising for future phases.

Next steps for the project will be to (1) continue the NEPA process, and (2) seek funding to complete the restoration plan developed through this project. Future funding will also include outreach programs, workshops, and support for the San Juan Fen Partnership, to promote the advances of alpine wetland restoration to additional sites. Additional steps for Red Mountain Pass will be determined at the conclusion of the NEPA process.

In conclusion, we would like to express our sincere gratitude to Colorado Water Conservation Board and the Healthy Rivers Fund for your support of this important work to protect and restore alpine wetlands!

5.0 Budget

MSI requested $14,530 from Colorado Healthy Rivers Fund (CHRF) to complement $ 11,920 in cash and $17,340 in-kind funding from our partners and volunteers (total budget $40,180, 67% match). The tables below show a comparison of the proposed budget to actual expenses. Cash matching funds were secured from San Juan National Forest Service, Colorado Mesa State, and National Forest Foundation. Sources of in-kind contributions are from MSI interns and volunteers, MTU, and Forest Service. The tables below detail our request, expenditures, matching funds, and sources.

Table 1: Proposed Project Budget and Sources of Matching Funds

Tasks	CWCB	Other Cash	In-Kind	Total	Source of Matching Cash Funds
Task 1: Permitting Coordination	$ 3,090	$ -	$4,400	$ 7,490	MSI, USFS, volunteers
Task 2: Site Plan & Assessment	$ 3,800	$ 6,140	$ 4,000	$ 13,940	CO Mesa State, USFS, NFF
Task 3: Construction Planning-Contractors, Volunteers	$ 7,140	$ 2,480	$ 2,000	$ 11,620	SJMA, MSI, CO Mesa State, volunteers
Task 4: Monitoring & Evaluation	$ 500	$ 3,300	$ 3,330	$ 7,130	CO Mesa State, USFS, MSI, volunteers
TOTALS	**$ 14,530**	**$ 11,920**	**$ 13,730**	**$ 40,180**	

Table 2: Matching Funds by Source

Matching Funds	
National Forest Foundation- volunteer coordination	3,274.10
USFS San Juan National Forest fen restoration funds	4,498.50
Colorado Mesa State Water Center- fen assessment and monitoring	7,859.24
	15,631.84
Inkind Matching Contributions	
Prescott College GIS students	2,492.16
USFS Hydrology and IDT specialists	4,810.00
MSI volunteers, interns	4,153.60
Dr. Chimner, restoration expert	6,600.00
	18,055.76

Table 3: Budget and Actual Expenses Per Task for CWCB Funds

		BUDGET	**ACTUALS**
Task 1 - Permitting Coordination			
	Salaries	2,640.00	3,060.00
	Supplies	250.00	-
	Travel	200.00	-
	Total	***3,090.00***	***3,060.00***
Task 2 - Site Plan/Assessment			
	Salaries	800.00	2,325.00
	Supplies	2,000.00	512.65
	Travel	1,000.00	1,294.34
	Total	***3,800.00***	***4,131.99***
Task 3 - Construction Planning			
	Salaries	5,940.00	4,411.25
	Supplies	1,000.00	2,290.22
	Travel	200.00	261.54
	Total	***7,140.00***	***6,963.01***
Task 4 - Monitoring & Evaluation			
	Salaries	500.00	-
	Supplies	-	-
	Travel	-	-
	Total	***500.00***	***375.00***
TOTALS		**14,530.00**	**14,530.00**

6.0 References

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Simon, W. 2004. Preliminary characterization of fens in iron rich areas of Mineral Creek. Report to San Juan National Forest.

Wolf, E. 2008. Fill volume survey of drainage features at Chattanooga and Ophir fens. Report to Mountain Studies Institute, Durango Mountain Resort, and the San Juan National Forest. 11 pgs.

Appendix A – Construction and Site Plan

RED MOUNTAIN PASS WETLAND RESTORATION PROJECT DESCRIPTION

I. SITE DESCRIPTION

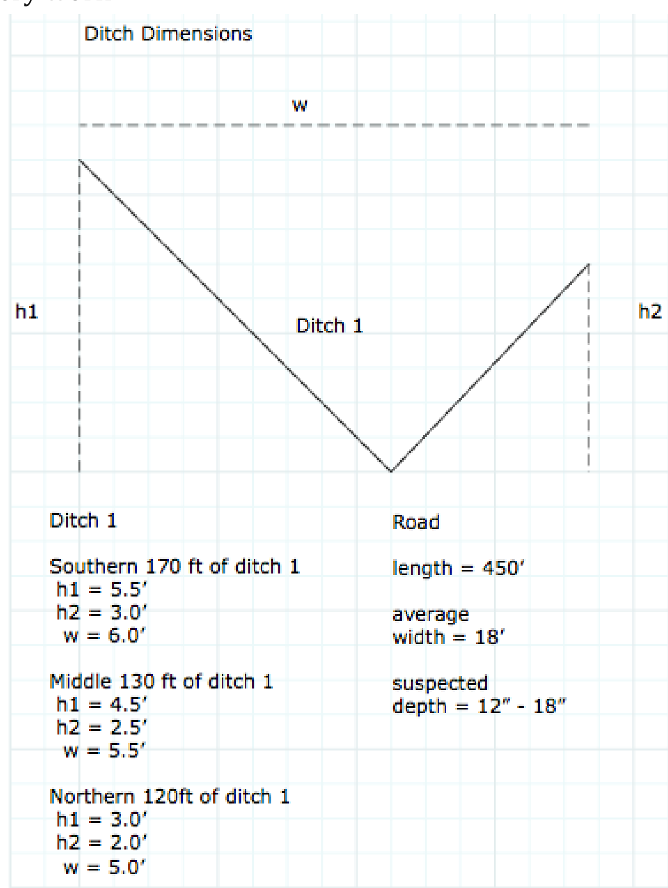
The wetland restoration site is located west of Highway 550 and southeast of Black Bear Pass Road atop Red Mountain Pass. Black Bear Pass Road marks the northern and western edge of the wetland, a forested hill marks the southern edge, and Highway 550 marks the eastern edge. An unused road bisects the three-acre wetland and is flanked by a ditch on each side. Water, which would naturally flow across the entirety of the wetland, is currently rerouted out of the wetland via the ditches.

II. PROJECT DESCRIPTION

The project will entail the excavation of road material, the installation of plywood dams in Ditch 1, and the infilling of two ditches while minimizing the impact to existing vegetation. All existing healthy wetland vegetation, as discerned by the Project Manager, will be excavated and set-aside during construction. The displaced vegetation will be placed atop disturbed areas by the end of the project. Road material will be carefully excavated to the level of healthy peat, and the road material will be used to fill the ditches. At least four plywood dams will be installed in the western ditch. Any project waste will be removed from the site upon completion. To promote revegetation, Excelsior mulch will be placed on any bare areas post heavy machinery work.

Access to the site is provided from Highway 550, in the immediate area of Red Mountain Pass. The United States Forest Service is the land owner. All mechanical equipment on the site will be limited to travel within the ditches or on the gravel road until the point that the road is removed.

The dimensions of the road and vary. Therefore, only estimates are provided. Test pits were dug in the road bed and the depth to peat ranged from 36 – 30 in. The graphic shows the average dimensions for ditch 1 and the road. Ditch 2 (length of 325') is of lower priority for fill and will be dammed using Excelsior bales.



III. SCOPE OF WORK

The subcontractor will provide services, staff, equipment, and otherwise do all things necessary for or incidental to the performance of work, as set forth below and per confirmation by the Project Manager – Anthony Culpepper (mountainstudies.org)

A. Transport the necessary staff and machinery/equipment to the project site.
B. Minimize impact to existing healthy wetland vegetation, as discerned by the Project Manager, by doing the following:
   a. Carefully excavate and displace existing vegetation
   b. Primarily use the existing road as site access
C. Excavate approximately 800 CY of material from the road bisecting the wetland
D. Infill the two ditches along the side of the road
E. Install four plywood dams in the western ditch
F. Revegetate the site
   a. Replace displaced vegetation into original locations
   b. Scarify any bare areas to decrease erosion and promote revegetation
   c. Cover with 4-6" of excelsior mulch
   d. Install erosion control straw wattles every linear 20 feet.
G. Place Excelsior mulch on all bare areas
H. Clean the site and remove any construction waste

IV. BIDS BY TASK

ITEM	DESCRIPTION	QTY	UNIT	UNIT PRICE	AMOUNT
1.	Equipment/staff transport	1	Task	n/a	$__________
2.	Road material excavation	~800	Cubic yards		$__________
3.	Infill two ditches	~300	Cubic yards		$__________
4.	Install plywood dams	4	Dams		$__________
5.	Revegetate	1	Task	n/a	$__________

V. PROJECT CONTACTS

Project Owner Representative:
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VI. FIGURES

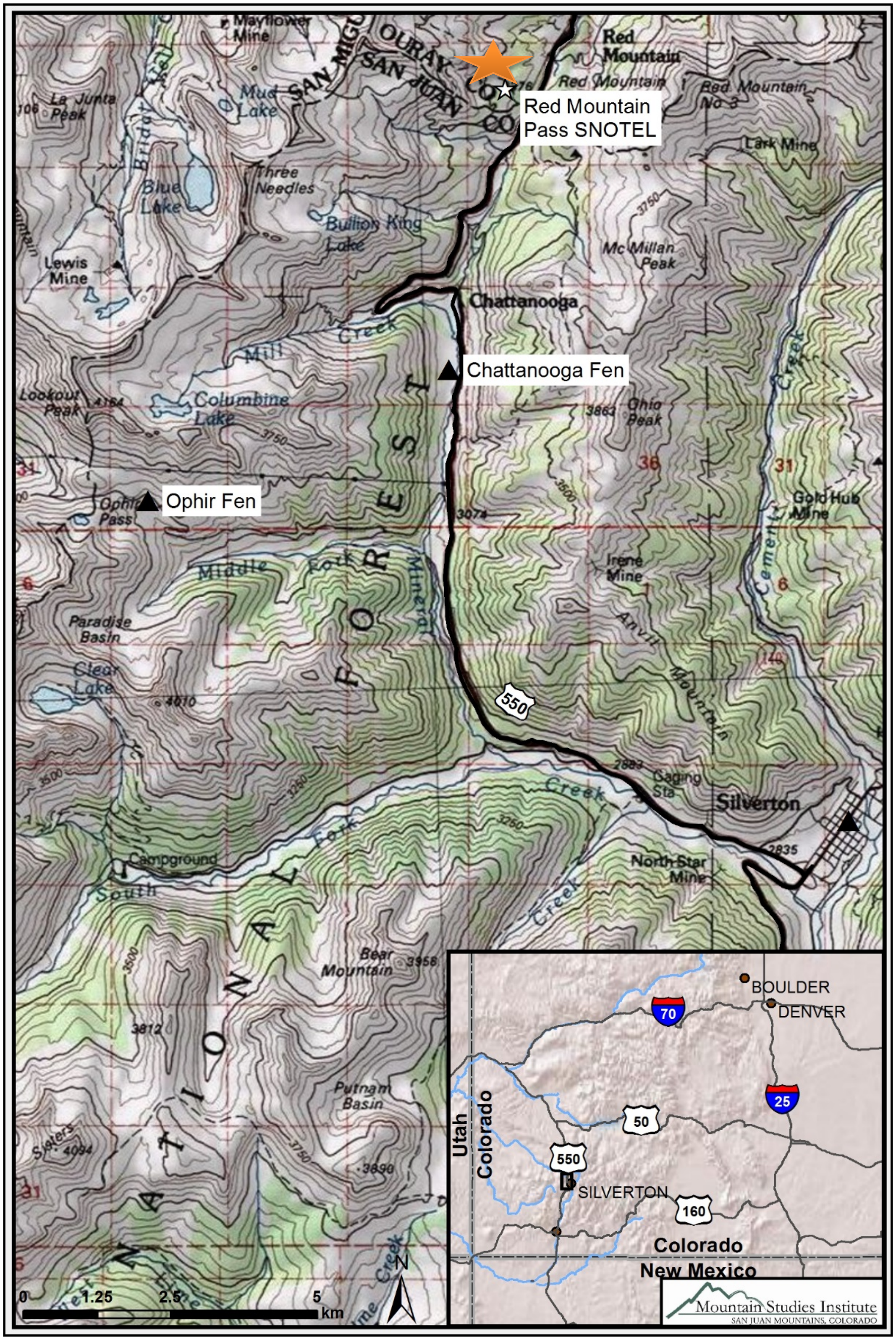

Figure 1. Project Location Map. Red Mountain fen is accessed via Highway 550, at the pass (orange star).

Figure 2. Overview of Red Mountain Pass Fen Restoration Plan showing location of wetland types, ditches, and road. Abandoned road area=0.2 ha, ditches = 0.04 ha, fen=0.46 ha, wet meadow = 0.33 ha, and degraded fen= 0.53 ha. Western ditch length = 450 ft. Eastern ditch length = 350 ft.

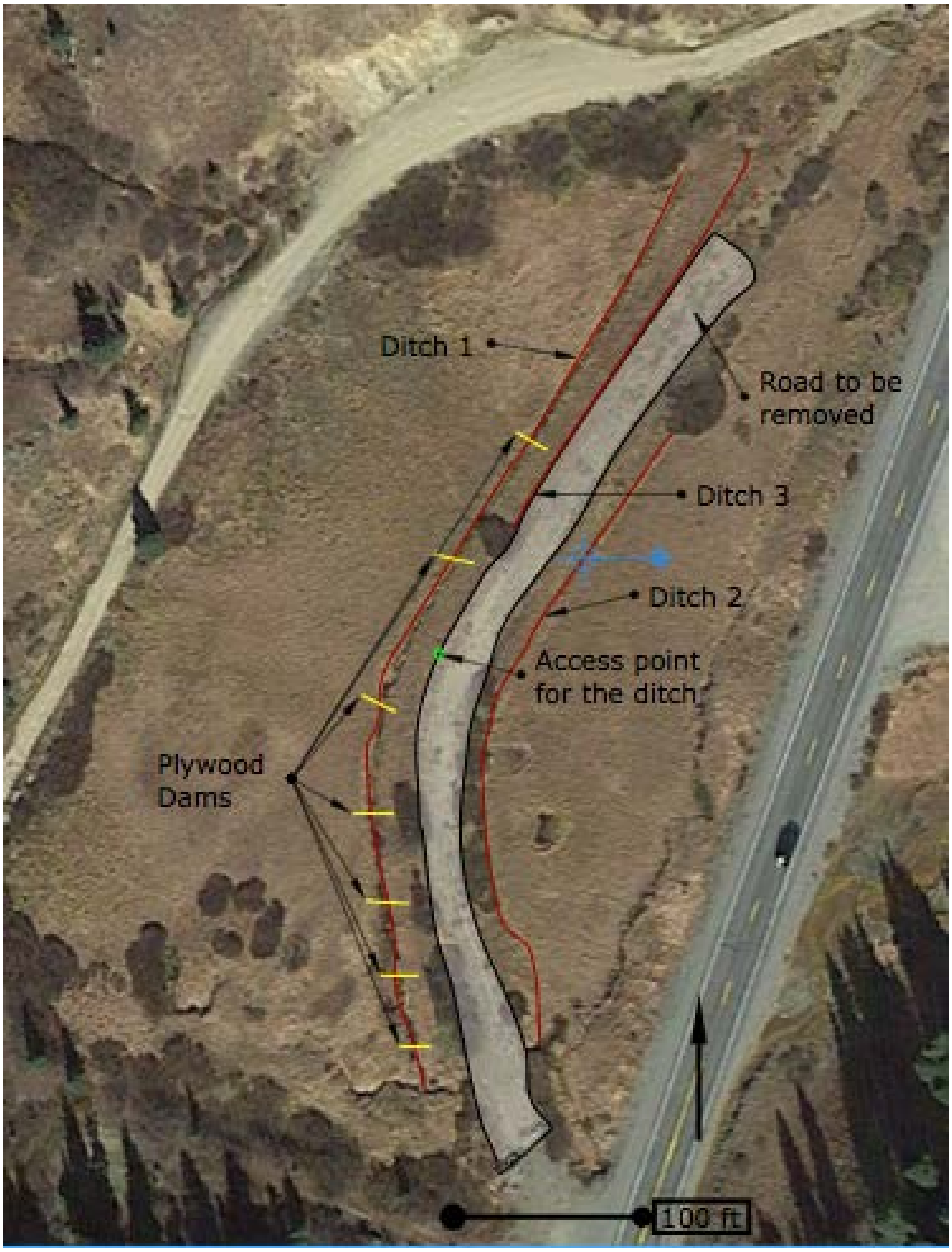

Figure 3. Overview of Proposed Construction Plan showing the location of plywood dams, the section of the road that will need to removed, the possible access for heavy equipment to reach the ditch, and the ditches needing damming. The snow site is not shown but lies just North of the proposed road excavation marked.

Figure 4. Project Photo of Road to Remove. Photo showing the abandoned road bed (gravel base) dissecting the fen that we propose to restore. The linear ditch feature is visible in the right upper corner near the orange star.

Figure 5. Photo of east road side ditch running north.

Appendix B – FEN SEED COLLECTION AND REVEGETATION NOTES AND PROTOCOLS

DESCRIPTION: This guide is created to be a working document adapting to restoration revegetation methods/techniques that evolve with trial, error, and the introduction of new information. The guide is also used to document the methods used each year for seed collection, preparation, growing, and planting. Please ensure the document stays relevant through the years by making edits as our processes improve.

HISTORY: Revegetation in fen restoration sites in the San Juan Mountains is often slow. The conditions are harsh and the growing seasons are short. Annual planting is most often needed to establish significant vegetation cover. Historically, wetland vegetation was excavated from healthy sections of the fen to be planted as "plugs" in bare areas. Plugs would be planted to cover as much area as possible, i.e., plugs were equally distributed across areas of the most need. Caution was taken to excavate vegetation broadly throughout a large portion of healthy fen, but with large-scale revegetation efforts, healthy sections of fen could be impacted. Consequently, new revegetation methods were needed to minimize the impact to the fen while providing ample plugs to plant.

A grant from CWCB for a wetland restoration project on Red Mountain Pass provided funds to determine the feasibility of collecting seeds in the field, growing plugs in a greenhouse, and planting plugs at a restoration site. In 2015, a variety of seeds were collected from Ophir Pass Fen, Chattanooga Fen, and fens on the Grand Mesa. The species of seeds collected included: Carex aquatilis, Carex utriculata, Calamagrostis canadensis, Pedicularis groelandica, and Betula glandulos. The seeds were collected mid September and placed into plastic ziplock bags. Over a week later, they were spread on large surfaces to dry for two weeks. Thereafter, the seeds were separated from the pieces of plants collected, put into brown bags, and refrigerated until being sent to greenhouses for the winter.

Of the multiple bags of seeds collected, only 328 Carex aquatilis seedlings were grown. The seedlings were delivered in early July and were watered in their containers for two weeks before being planted. All 328 plugs were planted at the Ophir Pass Fen on July 27th, 2016. They were planted on the drier steep slopes of the southernmost bare area and the southernmost section of the large bare area. 50 plugs were marked with pink flags to determine the survival rate in 2017.

CURRENT PROTOCOLS

COLLECTION:

Time – September

Technique – Hand pluck seed heads from sedges or use a knife to cut off the seed heads and place in a container (Ziploc bag).

Labels – Label bags with location collected, time collected, species, and the collector's name.

Documentation – Document the process including issues, new techniques used, conditions of the seed collection sites, and any relevant notes.

PREPARATION:

Drying – Spread the material on large surfaces with exposure to sun. Ensure the location is out of reach of rodents.

Separation – Use a soil sieve to separate sedge leaves and seed heads from the seeds (a soil sieve can be found in the Silverton MSI office).

Storage – Store the separated seeds in brown lunch bags in a refrigerator.

Labels – Label bags with location collected, time collected, and species collected.

GROWING:

Schedule – Determine a date the grown seedlings will be planted

Communication – Call Andy Herb (303-859-1475, andyherb@alpine-eco.com) at Alpine Eco to determine when he will need the seed to have the plants grown in time for the planting date. Address any specific pricing, timing, and logistic issues or questions. Check with Andy every month to determine the progress of the seed.

Delivery – Package the seed and send to Alpine Eco's greenhouse growing facilities in Buena Vista, Colorado.

PLANTING:

Delivery – After receiving the seedlings, store them in a safe place and water daily until planting.

Planting – Photograph the area before the addition of the plugs. Distribute the plugs evenly throughout the area for greatest coverage. Pull away any existing mulch and dig a hole the size of the plug. Gently pack the soil around the plug and place 3-5" of Excelsior mulch around each plug.

Documentation – Photograph the process and the final product. Document who planted the plugs, how many volunteers were involved, the condition of the plugs, how many plugs were planted, the conditions of the site where the plugs were planted, and any other relevant details.

ADDITIONAL NOTES:

With additional research, it may be beneficial to attempt growing drier adapted species (e.g., Calamagrostis) again for sites like Red Mountain Fen and Ophir Pass Fen. Seeds were collected in 2017 for these additional species. Planting is anticipated in 2018.

Appendix C – Colorado Mesa State University Water Center

Final Report: Monitoring Water Table and Carbon Storage to Assess Mountain Fen Restoration Potential

Final Report: Monitoring Water Table and Carbon Storage to Assess Mountain Fen Restoration Potential

Rod A. Chimner, John A. Hribljan, Tim Cutter, Marcie Bidwell

Abstract

Mountain Studies Institute and Michigan Technological University used the carbon cycle to quantify the upper and lower limits of fen water table position as an indicator for fen functioning and need for restoration. We compared carbon dynamics from 14 sites, representing fens ranging from natural to disturbed conditions. This effort leveraged long-term data collected in the San Juan Mountain fens, established new carbon monitoring sites in Grand Mesa, and built upon many years of collaborative research on mountain fens in southwest Colorado. Our findings indicate that peatland water table levels have a strong influence on fen carbon cycling. Our results indicate that reference fens have water table levels generally above 20–30 cm below the soil surface, and have the largest plant production and carbon storage of all fens measured. The reference fens also had unaltered peat profiles. However, when water tables were lower than 20–30 cm below the soil surface, plant production decreased, less carbon was stored, and peat soils subsided and oxidized. Plant production and carbon cycling measurements also indicate that fen functioning is impaired when the fen water table levels are consistently greater than ~10–30 cm above the soil surface. Another issue besides depth of water that is important to fen functioning is the duration of deep standing water on the fen from reservoirs. Our plant biomass data indicates that locations flooded into late summer did not allow plants to grow properly, and changed species composition. In summary, water table levels can be used to indicate long-term fen functioning, help with managing fens, and indicate restoration potential.

Introduction

Peatlands (fens and bogs) are important ecosystems because their vast peat deposits store substantial amounts of carbon as peat (Gorham 1991). Peat accumulates when long-term net primary productivity exceeds decay and other losses, resulting in the accumulation of incompletely decomposed organic matter, or peat. Peat can only accumulate because anaerobic conditions develop from perennially high water table levels. Therefore, the level of the water table is the most important factor in forming and maintaining a peatland. While peatlands cover only 3 to 5 % of the global land area, they store between 20 to 30 % of the global soil carbon pool (270–455 petagrams (Pg)) (Gorham 1991) and also provide important water quality and habitat function for streams (Bedford and Godwin 2002).

Peatlands are very widespread, occurring from the tropics to the arctic, and are also numerous in mountain ranges (Maltby and Proctor 1996, Patterson and Cooper 2007, Chimner et al. 2010). For example, there are approximately 2,000 peatlands in the San Juan Mountains of Colorado (Chimner et al. 2010), and over 13,000 km^2 of peatlands occur in Canadian mountains (Warner and Asada 2006). Mountain peatlands in the southern Rocky Mountains have all been found to be minerotrophic fens, with no ombrotrophic bogs identified (Cooper and Andrus 1994, Chimner et al. 2010). In addition, seventy five percent of fens analyzed in the San Juan Mountains were found to be sloping fens (Chimner et al. 2010). Because these mountain fens are supported predominantly by groundwater, watershed geology strongly influences groundwater chemistry and plant community structure (Cooper and Andrus 1994, Bedford and Godwin 2002, Chimner et al. 2010).

Disturbances to peatlands are common. For example, approximately 10 % of fens in the San Juan Mountains of Colorado were found to be in need of restoration due largely to hydrologic alterations (Chimner et al. 2010). Additionally, 42 % of 88 fens that were surveyed on Grand Mesa were recommended for restoration due to human alterations (Austin and Cooper 2015). In many cases, water tables are lowered from ditches, roads, gullies, or other water diversions. However, some fens have water tables greatly increased though impeded drainage by roads or reservoir building. Hydrologic alterations can reverse the process of peat accumulation that has been ongoing in many fens for thousands of years (Chimner and Cooper 2003a, Ballentyne et al. 2014, Schimelpfenig et al. 2014), greatly alter ecosystem functioning, and eventually could lead to fen destruction (Chimner and Cooper 2003a). **However, what we do not fully understand is to what extent does a peatland's water table need to be altered before ecosystem functioning is significantly impaired and the fen requires restoration.**

For instance, we know that highly drained wetlands lose carbon and require restoration (Chimner and Cooper 2003a, Schimelpfenig et al. 2014), but we do not know how low the water table needs to be before significantly affecting peatland function (Figure 1). Chimner (2000) took the first attempt at defining the lower limit from work done in Rocky Mountain National Park; he estimated that fens became impaired when the summer

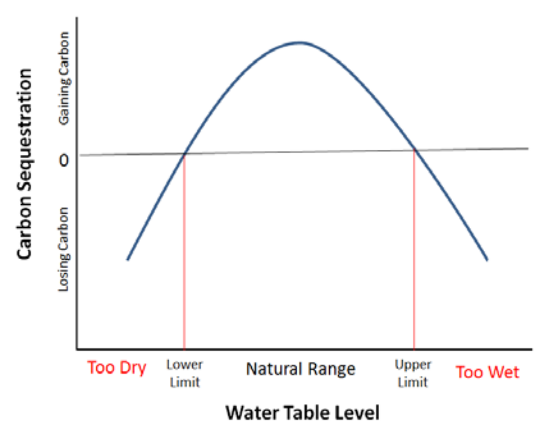

Figure 1. Conceptual model of water table level controlling carbon storage in mountain fens

Figure 2. Kennicott Fen. Notice the displaced peat laying on the surface.

water table dropped below 20 cm below the peat surface for two weeks. However, this estimate was developed with a small dataset and it was never validated. Additionally, we know that when wetlands are flooded too deep, they also become impaired, but we have no estimates where this upper water table limit might be located. **This study better defines the natural upper and lower limits of fen water table position to determine when a fen requires restoration.**

This relationship between water table level and fen function was recently tested in a *Sphagnum* peatland in Michigan. Chimner et al. (paper in review) quantified the carbon budget of a peatland that had sections drained (water table ~15 cm lower) and areas that were inundated (water table ~15 cm higher) as the result of a road crossing. We found that the inundated section of the peatland actually increased in carbon storage, while the dried section lost carbon. After completing this research, land managers realized that restoration was needed on the drained section to restore wetland function, so they retrofitted the road to allow cross drainage and rewetted the peatland. **Therefore, the objective of this study was to use carbon cycling measurements to define the upper and lower limits of natural fen water table position, which if crossed would indicate that restoration is needed (**Figure 1). This work took advantage of long-term carbon data collected from undisturbed fens of the San Juan Mountains, in addition to new data from hydrologically altered fens (drained and inundated fens) in the Grand Mesa and San Juan Mountains. The goal is to develop a simple water table relationship that can be used to determine if a fen needs to be restored from hydrologic alterations.

Methods

***Study Sites* –** To leverage data on this project, we combed data collected from other studies, and collected new data from additional sites (Table 1). Historical data used in this study is from five sites (two fens) from Prospect Basin near Telluride that are used as control sites (Chimner unpublished data). We are also using reference and restored data collected from restoration projects done in the Grand Mesa and the San Juan's (Schimelpfenig et al. 2014). We are using collected data at four additional sites in the San Juan's (Table 1). Ophir Fen and Chattanooga Fen are restoration sites where we have been working at for 10 years and were recently restored from ditching by MSI and Dr. Chimner. We have CO_2 flux data from before the restoration that was incorporated into this study, plus CO_2 measurements collected for this study from areas that were not fully restored that have lower water table levels. We also added additional fen sites from Red Mountain Pass and Silverton Lakes that are drained.

During the summer of 2014, we picked three additional sites (indicated by asterisks in Table 1) in the Grand Mesa to incorporate sites that have been flooded to expand our water table gradient to sites with higher than normal water table levels. We chose two sites that are impacted by reservoirs (Kennecott Fen: 39.029165N, 107.958309W (Figure 2); Womack Fen: 39.020237N, 107.962650W) and one very wet natural fen/marsh wetland near Womack Fen. We started collecting data from the new sites in 2015.

Table 1. Location, status, and average water table of study sites used in this study. Sites in italics indicate where data has already been collected and un-italic sites are additional locations were new data was collected.

Location	Name	Status	Average Water Table
San Juan's	*Prospect Basin (Cal can)*	Control	-11.2
San Juan's	*Prospect Basin (Car aqu)*	Control	-8.8
San Juan's	*Prospect Basin (Car sax)*	Control	-2.5
San Juan's	*Prospect Basin (Car utr)*	Control	-20.1
San Juan's	*Prospect Basin (Sal Pla)*	Control	-5.2
San Juan's	Ophir Fen	Reference	-27.0
San Juan's	Ophir Fen	Bare	-30.0
San Juan's	Ophir Fen	Restored	-10.3
San Juan's	Chattanooga	Reference	-21.8
San Juan's	Chattanooga	Drained	-30.7
San Juan's	Chattanooga	Restored	-10.2
San Juan's	Red Mountain Pass	Reference	-3.3
San Juan's	Red Mountain Pass	Drained	-41.1
San Juan's	Silverton Fen	Bare	-19.5
San Juan's	Silverton Fen	Drained	-67.4
San Juan's	*Pirate Ship Fen*	Reference	-12.0
San Juan's	*Pirate Ship Fen*	Restored	-31.9
San Juan's	*Lateral Moraine*	Drained	-39.2
San Juan's	*Lateral Moraine*	Restored	-1.0
San Juan's	*Lateral Moraine*	Reference	-8.0
Grand Mesa	*Eggelston Fen*	Reference	-11.6
Grand Mesa	*Eggelston Fen*	Restored	-23.0
Grand Mesa*	Kennecott Fen	Inundated	45.0
Grand Mesa*	Womack Fen	Inundated	45.0
Grand Mesa*	Womack Marsh	Inundated	-5.0

***CO_2 and CH_4 fluxes* –** Within each study site we measured CO_2 flux measurements to begin understanding the dynamics of water table position on carbon storage and to develop restoration priorities for impacted fens. Manual CO_2 measurements were conducted biweekly in the San Juan sites during the summer of 2014 with an Infrared Gas Analyzer (IRGA) (EGM-4, PP-Systems, England) and portable custom built chambers (Chimner *et al.* 2010). The clear chambers were placed on permanent collars and used to measure net ecosystem exchange (NEE) with chamber design following (Ballentyne et al. 2014). Ecosystem respiration (ER) was measured under a dark shroud (cloth cover). Carbon dioxide fluxes were calculated by measuring the change in CO_2 concentrations (adjusted for chamber volume and area) during the sampling period using the built in quadratic line equation (Ballentyne et al. 2014). Chamber measurements were initiated after a steady mixing of air is established, determined when CO_2 concentration increases or decreases at a constant rate (typically 20-30 seconds). Chamber NEE was measured for two minutes (short measurement period minimizes temperature and water vapor increases inside the chamber Ballentyne et al. 2014); the chamber was then vented for 20–30 seconds and subsequently fitted with an opaque reflective white cloth to arrest photosynthesis. Lastly, ER was measured for two minutes. Calculation of gross primary production (GPP) was performed by subtracting ER from NEE. In conjunction with CO_2 concentrations, we also measured relative humidity, photosynthetically active radiation (PAR), and air and soil temperature inside the chamber using EGM-4 standard probes.

Plant Biomass- Above ground plant biomass was measured in the summer of 2015 to provide additional information on how plant growth varied along the water table gradient. Plant biomass was clipped at ground height in 0.25 x 0.25 m^2 quadrats that were randomly located in study sites. After cutting, plant samples were placed in paper bags, air dried, then shipped to Michigan Tech Wetlands lab. In the lab, plant samples were oven dried (80 °C) for two days and weighed. Biomass was scaled to meters square by multiplying the quadrat values by four. Plant biomass samples were then averaged by treatment (reference, restored, drained, and flooded).

Soil Sampling- Soil samples were collected across sites to determine if bulk density and carbon content of soils changed due to hydrological alterations. Peat cores were taken from areas where CO_2 fluxes are currently being measured. Peat cores were collected with a 6.3 cm diameter open-faced gouge auger down to a depth of 75 cm below the soil surface. After collection in the field, soils were sectioned into 15 cm sections and placed in plastic whirl-pak bags and frozen. Soils were then shipped to Michigan Tech Wetlands lab. Soils were oven dried until a constant weight was obtained at (80 °C). After cooling, soils were weighed and ashed to calculate loss on ignition. Dry bulk density g $cm^{-3}$was calculated as the mass of the 15 cm long sample divided by the volume of the auger for the sample. Percent carbon was calculated by using equations developed for converting loss on ignition to % C (Chimner unpublished data).

Table 2. Average environmental and gas flux parameters by treatment type. Reference sites have never been impacted by water table alterations, drained fen sites have a lowered water table due to ditches, bare fen sites contain no vegetation cover, restored sites were previously drained and then restored to pre-disturbance water table levels, and flooded sites are located in reservoirs. Negative flux values indicate carbon uptake by the wetland.

Treatments	**Soil T ©**	**WT (cm)**	**NEE (μmol m^{-2} s^{-1})**	**GPP (μmol m^{-2} s^{-1})**	**ER (μmol m^{-2} s^{-1})**	**GPP:ER**
Bare peat	16.0	-28.5	0.4	-0.6	0.8	0.7
Reference fen sites	13.7	-11.4	-5.0	-9.4	4.4	2.3
Drained sites	17.0	-41.3	-2.5	-5.5	2.9	2.3
Restored sites	18.8	-12.1	-3.3	-5.1	1.8	2.9
Reference marsh site	9.4	-6.7	-3.0	-10.4	7.3	1.5
Shallow flooding <30 cm	14.2	0	-2.3	-5.2	2.9	1.4
Deep flooding >30 cm	10.8	60.0	0.5	-0.4	0.9	0.3
Average	**14.3**	**-5.7**	**-2.2**	**-5.2**	**2.2**	**1.6**

Results and Discussion

Gas Flux- Combining data from all the sites and years, we have a large water table gradient ranging from average water table levels 45 cm above the wetland soil surface to 60 cm below the surface (Table 1). The reference sites were the wettest with a three year average of ~11 cm below the soil surface. The drained sites had the lowest average water table levels, averaging 41 cm below the soil surface. The restored sites were similar to the control sites. The bare sites were dry, but not as dry as the drained sites.

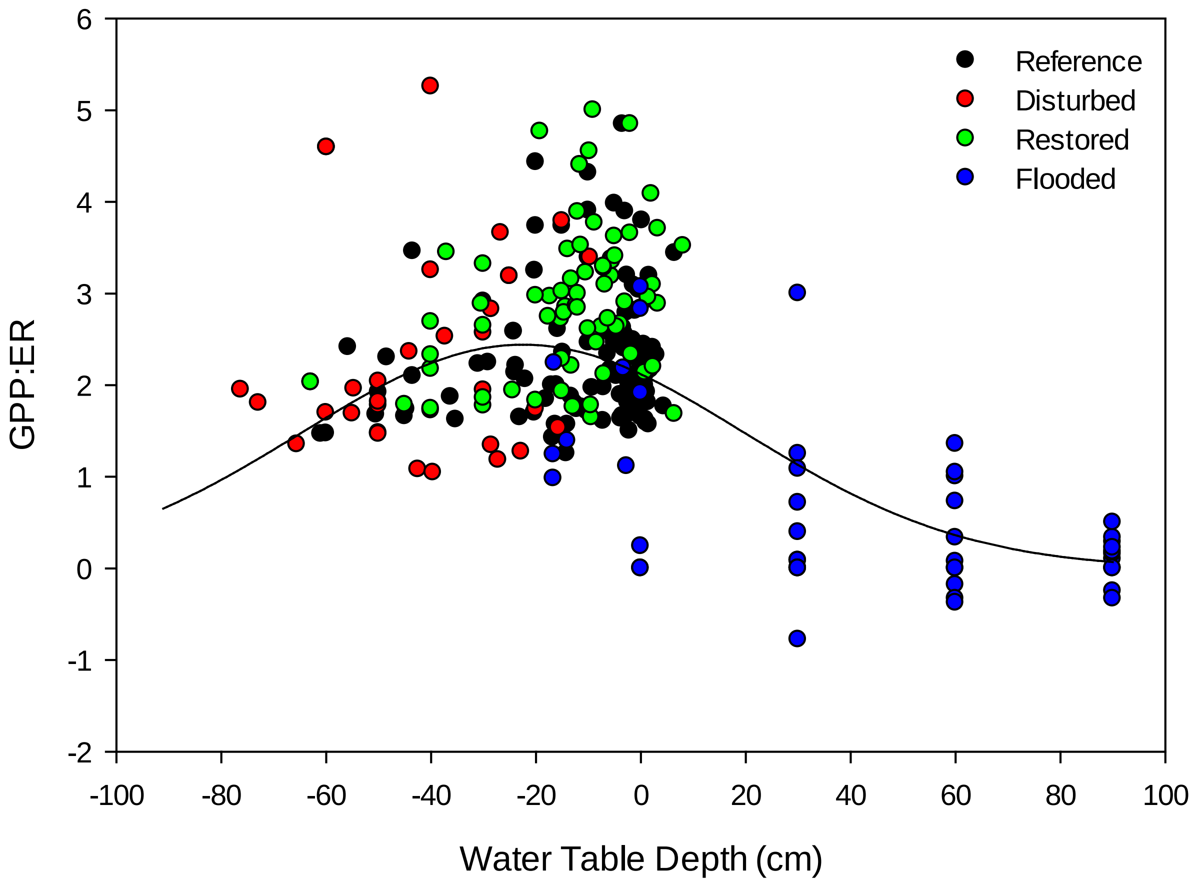

Figure 3. Correlation between GPP:ER and water table level.

Average gas flux measurements also differed by site and treatment. Reference fen sites stored the most carbon across all the wetlands measured, as indicated by the highest NEE values (negative NEE = carbon storage). Bare sites and areas flooded with deep water (> 30 cm) actually lost carbon in the middle of the day (positive NEE value). Shallow flooded (<30 cm) and drained fens had the next lowest NEE values. Restored sites had larger NEE values than drained and flooded sites, but are not yet comparable to reference/control sites. As shown for NEE, GPP (plant production) was also largest in the reference sites. GPP was almost twice as large as the drained, shallow flooded and restored sites. As expected, bare plots had almost no GPP because lack of plant cover, so measured GPP was likely from algae growth on the peat surface. GPP was also very low in deep flooded plots. Ecosystem respiration (ER) was highest in the reference plots. Whereas, the bare and deep flooded plots had very low ER. The drained, flooded and restored sites also had lower ER than the reference plots. ER is a combination of plant and soil respiration, so the large ER rates in the reference plots is likely due to the high plant respiration as indicated by the high GPP measurements.

The GPP:ER ratio is the ratio of plant production to ecosystem respiration. Simply, it shows the amount of carbon gained by plant growth divided by the amount of carbon lost due to plant and soil respiration. Since it is a ratio, it is easier to look at mechanisms than using NEE. A GPP:ER ratio of 1 indicates that plant production is equal to carbon loss by ER and a ratio of 2 indicates that GPP is twice as large is ER. Peatlands are carbon accumulating ecosystem where GPP is annually larger then ER, this is what forms peat. Our data indicate that the GPP:ER ratio was greatest (between 2 and 6) when the water table was between 0–20 cm beneath the soil surface. The GPP:ER ratio dropped quickly when the wetland water table levels dropped past 20–30 cm below the soil surface (Figure 3). Calculation from diurnal measurements at Prospect Basin considering lower winter ER rates indicates that a GPP:ER ratio greater than 1.8–2.0 is needed to produce a seasonal net accumulation of peat for the peatland (Figure 4).

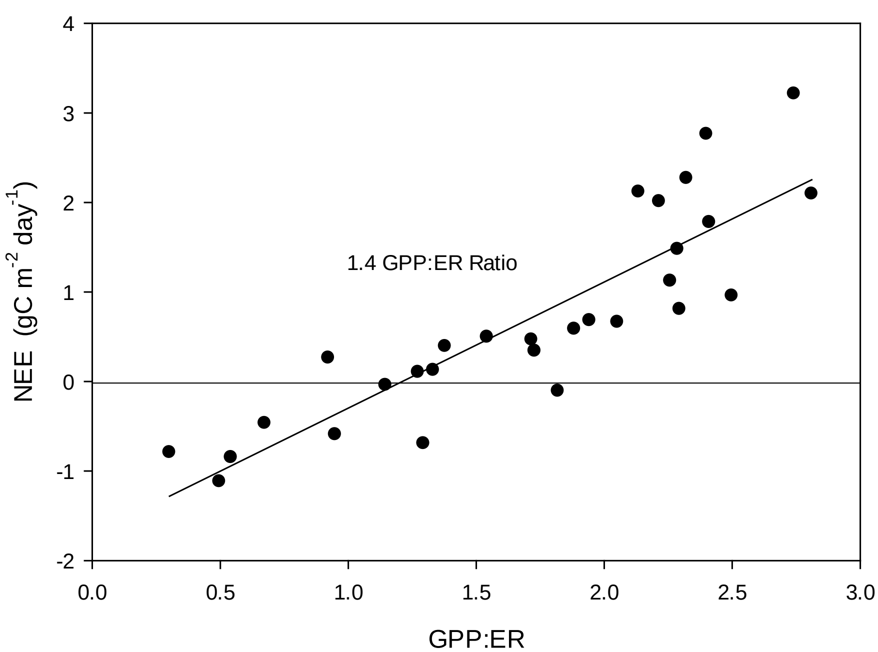

Figure 4. Correlation between daily NEE and GPP:ER and water table depth from diurnal measurements conducted at Prospect Basin. A GPP:ER ratio of 1.4 is required to have a daily NEE of zero. Correcting for winter ER rates, we estimate that GPP:ER ratios of 1.8–2.0 is required to have a seasonal carbon budget of zero.

Plant Biomass- Aboveground plant biomass from the reference and restored fens were not significantly different from each other, averaging 117.8 and 109.7 g m^{-2}, respectively (Figure 6). However, aboveground plant biomass was significantly lower at the deeply flooded reservoir sites that had deep water (> 30 cm above the soil surface) and retained this standing water until September (Figure 6). These long-duration flooded sites had an average biomass of only 45 g m^{-2}. However, aboveground plant biomass at reservoir sites that were only shallowly flooded (< 30 cm) with standing water only until August were similar to reference and restored fens (Figure 6).

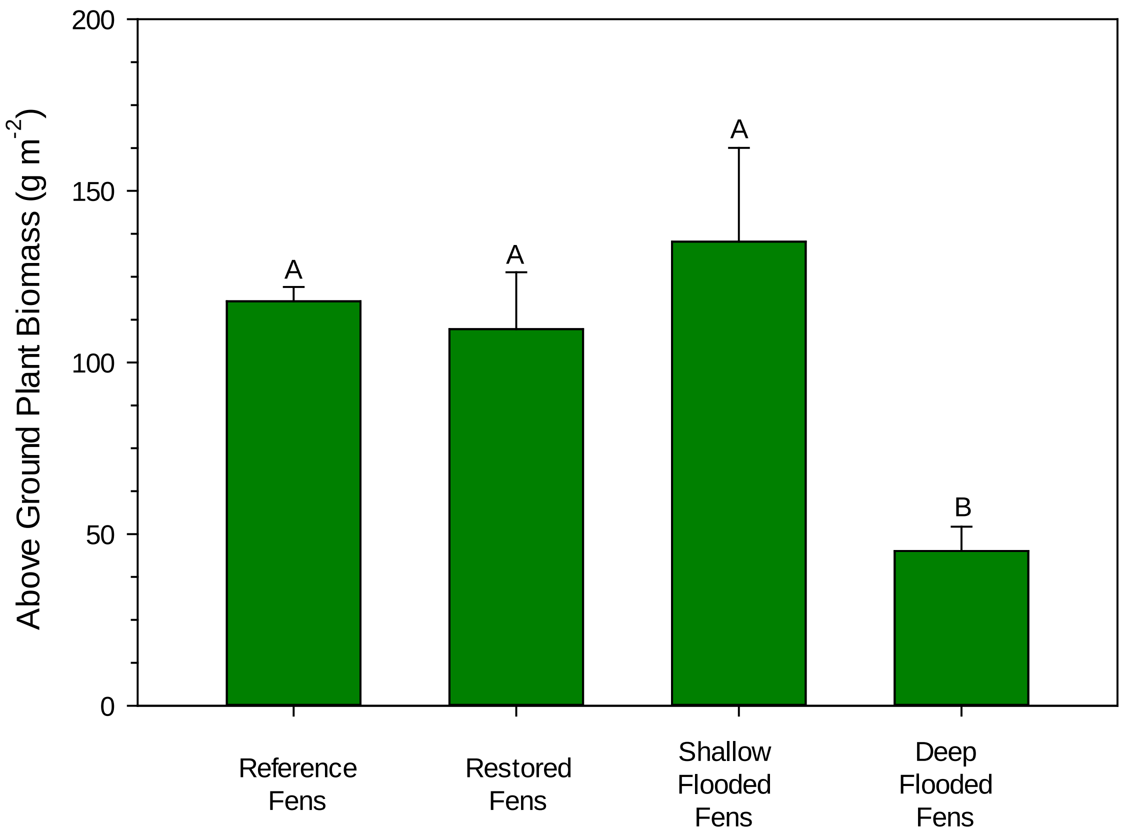

Figure 5. Average above ground plant biomass from 2015. Shallow submerged fens refers to fens shallowly flooded (< 30 cm) from reservoirs, which became unflooded by August. Deep submerged fens refers to fens deeply flooded (> 30 cm) from reservoirs, which did not become unflooded until September.

Soils- Soils data showed strong differences across fen types. Bulk density is a measure of soil compaction with higher values indicating denser soils. Our reference fens had an average bulk density around 0.2 gcm^{-3} and did not vary much with depth (Figure 6A). These are normal bulk density values reported for sedge fens (Chimner and Cooper 2003, Chimner et al. 2014). Bulk density values of restored fens matched the reference fens. Bulk density of the drained fen shows a typical pattern of drainage. The upper surface of the peat was denser due to subsidence and oxidation (Schimelpfenig et al. 2014). The soils below 15 cm had bulk densities that were similar to the reference fens, which is an indication that the soils at these deeper depths are kept wet enough to have not undergone significant oxidation and subsidence. Fens in the reservoirs showed a very distinctive pattern (Figure 6A). In the surface soils (0–30 cm), bulk density was very low. However, the deeper soils were much denser compared to the reference fens.

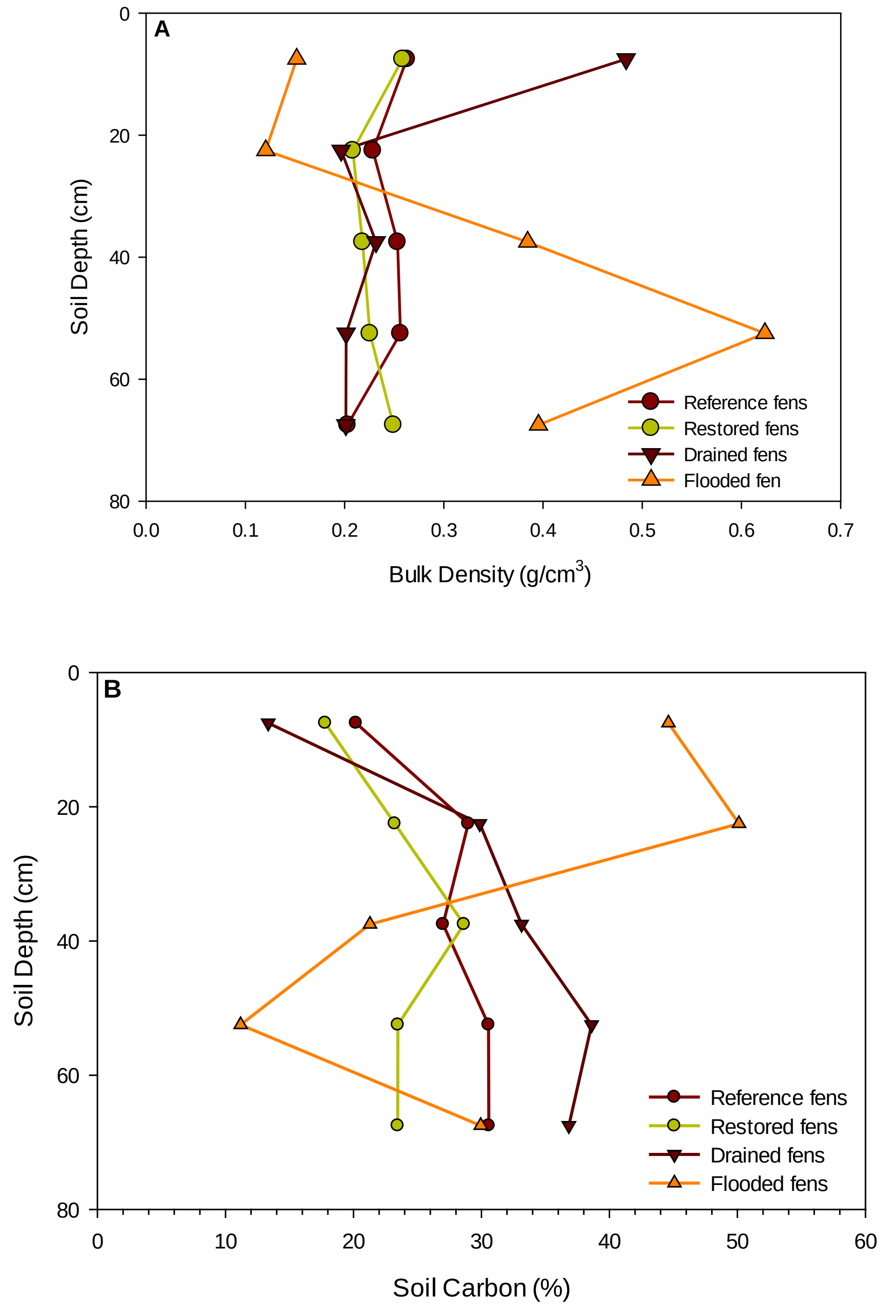

Figure 6. Average soil bulk density (g cm^{-3}) (A) and soil % carbon (B) across fen types.

Soil carbon values for the references fens averaged approximately 30 % (Figure 6B). This value is in line with reference fens in the San Juan's and Grand Mesa fens (Chimner et al. 2010, Austin and Cooper 2015). The restored and drained fen showed similar patterns to the reference fens. However, similar to the bulk density measurements, the reservoir sites showed distinct differences in soil carbon compared to the reference fens. Soil carbon was very high in the surface soils (0–30 cm), then dropped to lower levels in the deeper soils (30–60 cm), compared to the reference fens. The carbon content in the deepest sample from the reservoir site was comparable to levels measured in the reference fens (Figure 6B). The distinctive pattern of the bulk density and carbon concentration displayed by the soils in the reservoir sites likely indicates that the original peat soil underwent compaction and oxidation from reservoir construction. Then, ~30 cm of new low density peat was formed on top of the original peat soil from sedimentation. This type of peat is called limnic or aquatic peat. Limnic peat can form from settling out of peat material in aquatic systems, including reservoirs (Yeloff et el. 2005). The new peat that has settled out on top of the original peat likely formed from the degradation of peat mats that were floating on the water.

Summary

It is clear from this study that peatland water table levels have a strong influence on fen carbon cycling. Our results indicate that reference fens have water table levels generally above 20–30 cm, and had the largest plant production and carbon storage of all fens measured. The reference fens also had unaltered peat profiles. However, when water tables were lower than 20–30 cm, plant production decreased, less carbon was stored, and peat soils subsided and oxidized. This pattern was seen with the NEE and GPP:ER data. The lower GPP:ER data indicates that respiration was increasing more than plant production as the water table dropped. These results are similar to what was found in fens in the Front Range of Colorado where we found that fens stored less carbon when the water tables dropped more than 20 cm below the peat surface (Chimner et al. 2002, Chimner and Cooper 2003a, 2003b).

Furthermore, our data indicates that conditions can also become too wet for natural fen functioning. Plant production and carbon cycling measurements indicate that fen functioning is impaired when the fen water table levels are consistently greater than ~10–30 cm above the soil surface. Another issue besides depth of water that is important to fen functioning is the duration of deep standing water on the fen from reservoirs. Our plant biomass data indicates that locations flooded into late summer did not allow plants to grow properly, and changed species composition. However, locations where flooding disappeared earlier had plant production that was similar to reference fens. This might indicate that reservoirs could be managed to minimize impacts to fens.

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Figure A1. Location of plots in Red Mountain Pass Fen. P2 is the drained location.

Figure A2. Location of sampling plots in Chattanooga Fen. White lines are restored ditches.

Figure A3. Location of sampling plots in Ophir Fen. White lines are restored ditches.

Figure A3. Location of sampling plots in Silverton Lakes fen. The entire site is drained.

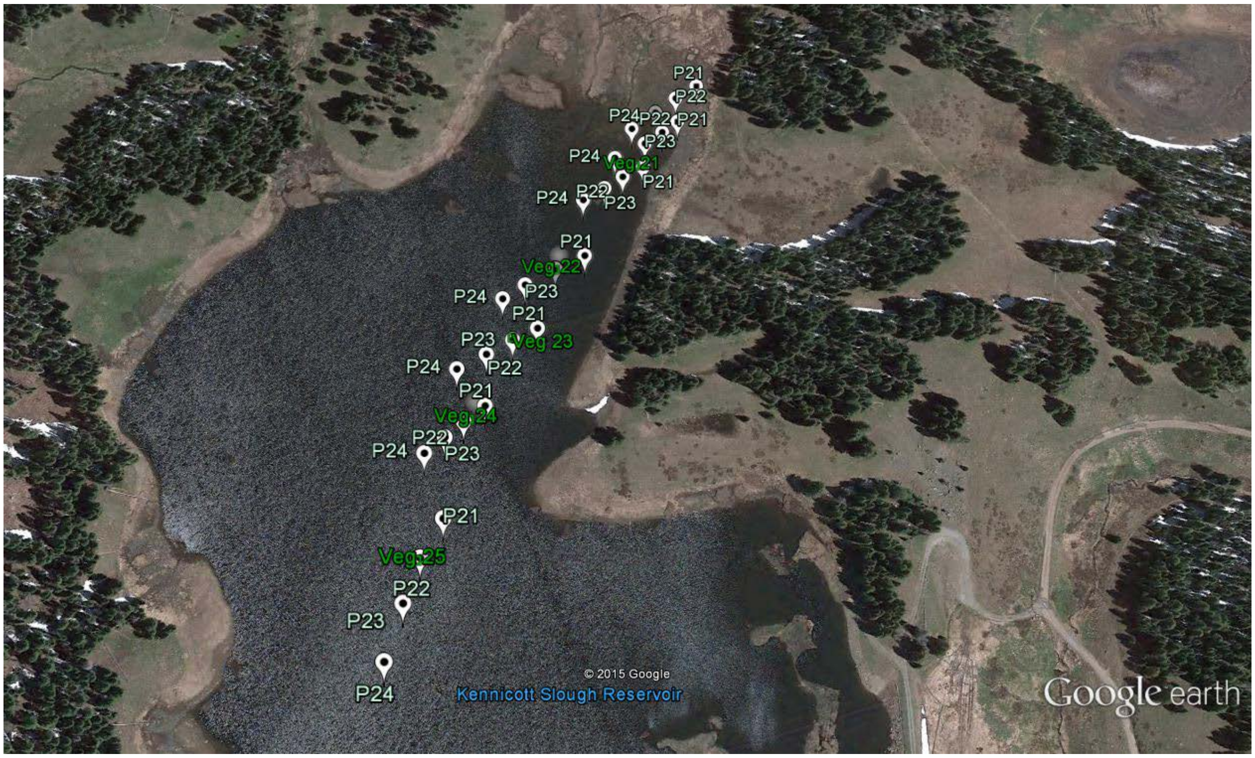

Figure A5. Location of sampling plots in Kennecott Fen.

Figure A6. Location of sampling plots in Womack Fen.