Effects of Forest Fire on Submerged Aquatic Macrophytes: Ecosystem Engineers in New Mexico Mountain Streams

Project Completion Report for the New Mexico Water Resources Research Institute (NM WRRI) prepared by:

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INTRODUCTION

Submerged aquatic macrophytes (SAMs) strongly influence surficial aquatic ecosystems by providing multiple ecosystem services including nutrient cycling, geomorphic structure, hydrologic modifications, and provisioning of food and refugia (Dawson 1980, Carignan & Kalff 1980, Carpenter & Lodge 1986, Jeppson et al. 1997, Bolser et al. 1998, Madsen & Cedergreen 2002). SAMs have evolved physiological mechanisms that allow them to acquire vital nutrients (i.e., carbon, nitrogen, phosphorus) from both their roots and the water column, which is key to their role in nutrient cycling in aquatic systems (Carignan & Kalff 1980, Chambers et al. 1989, Madsen & Cedergreen 2002, Cavalli et al. 2012). SAMs are dominant components of some high elevation streams and rivers in New Mexico (NM) (personal observations).

Disturbances, including forest fires, are primary drivers in the structure and function of stream ecosystems. Fires can dramatically increase the availability of biologically important nitrogen and phosphorus compounds in forest soils (Certini 2005), which then are deposited into streams after precipitation events occur over burn scars. Forest fires also have been shown to have major impacts on these aquatic ecosystems including (but not limited to) 1) changes in light regime, 2) increases in temperature, 3) strong effects on water quality (i.e., increased turbidity, enriched inorganic nutrients, and removal of dissolved oxygen), and 4) temporary increases in flows and their accompanying physical effects (Hauer & Spencer 1998; Benda et al. 2003; Earl & Blinn 2003; Rhoads et al. 2006; Smith et al. 2011, Stephan et al. 2012; Verkaik et al. 2013; Dahm et al. 2015; Sherson et al. 2015).

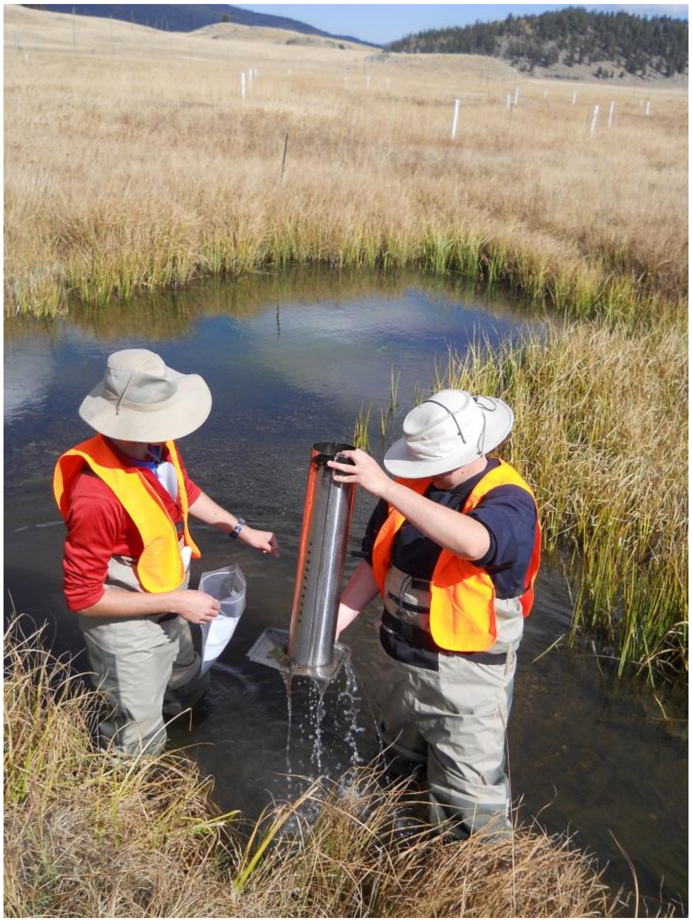
The frequency, intensity, and erratic behavior of forest fires in NM and the southwestern US will increase with climate change (Westerling et al. 2006; Vose et al. 2012, Luo et al. 2013). The 2011 Las Conchas fire, the largest NM forest fire to that point in time, created an excellent opportunity to study the effects of a catastrophic forest fire on SAMs as individual species and as a community.

The main objective of this study is to determine if disturbances and nutrient inputs resulting from the Las Conchas fire and subsequent summer monsoons have caused a change in the nutritional content of SAMs present in the East Fork Jemez River (EFJR), an important headwater area for the Rio Grande in central NM.

A second objective is to document the effects of catastrophic forest fires on SAMs in the context of climate change given that climate change is predicted to have a variety of negative effects on hydrologic systems in the southwestern US including more frequent, higher intensity forest fires.

MATERIALS & METHODS

Samples were collected from a basin strongly affected by the Las Conchas fire, the East Fork Jemez River (EFJR). Samples were taken on transects within an ungulate exclosure. Samples were collected approximately every six weeks during each growing season (May-October) to reduce possible cumulative impacts from sampling to the ecosystem. A sampling device for collecting all of the aboveground plant tissues in a known surface area was created for shallow flowing water use based on the Marshall and Lee (1994) basic design. Samples were preserved on ice and transported to the BioAnnex Analytical Laboratories at the University of New Mexico in Albuquerque for analysis. Upon return to the lab, the plant tissue samples were manually separated, and vegetation samples were sorted by taxa. Each individual sample was then sonicated in an ultrasonic water bath filled with deionized water for at least 10 minutes to remove epiphytic organisms. After sonication, each sample was placed in a drying oven at 60^{o}C for 48 hours, and then weighed. Approximately 250 mg subsamples were retained from the dried samples and stored in 20 mL glass scintillation vials for later carbon, nitrogen, and phosphorus content analyses. The remaining plant tissue was then fired in a muffle furnace at 500^{o}C for two hours to determine the organic and inorganic content of the plant tissues.



Collecting SAMs in the East Fork Jemez River to take back to the lab for further testing.

The retained subsamples were then analyzed for tissue nutrient concentrations of carbon (C), nitrogen (N), and phosphorus (P). Percent C and N were determined using high temperature combustion and gas chromatography using the ThermoQuest Carlo Erba Instrument NC2100 Elemental Analyzer present at the UNM BioAnnex Analytical Laboratories (BAAL). Total P measurements were conducted using the method of Stelzer and Lamberti (2001) that includes combustion of samples and acid dissolution followed by dissolved total phosphate analysis using a Technicon AutoAnalyzer II also present in the UNM BAAL.

RESULTS

The SAM species present at the study site in the EFJR are *Elodea canadensis*, *Ranunculus aquitilis*, *Potamogeton richardsonii*, and *Stuckenia pectinata*. All species are native to the region and the US. *E. canadensis* is the dominant SAM species onsite and accounted for 50% of the total biomass measured over all sampling dates.

Elodea canadensis, the dominant SAM at the site, in bloom.

Elemental composition (carbon, nitrogen and phosphorus) of all the SAM species collected during sampling was measured. For all SAM species combined, the average elemental composition of the plant tissues was 36% carbon, 2% nitrogen, and 0.2% phosphorus (Fig.1, 2 & 3). These findings are consistent with published values for SAM tissues from other systems (Atkinson and Smith 1983; Elser et al. 2000; Demars and Edwards 2007).

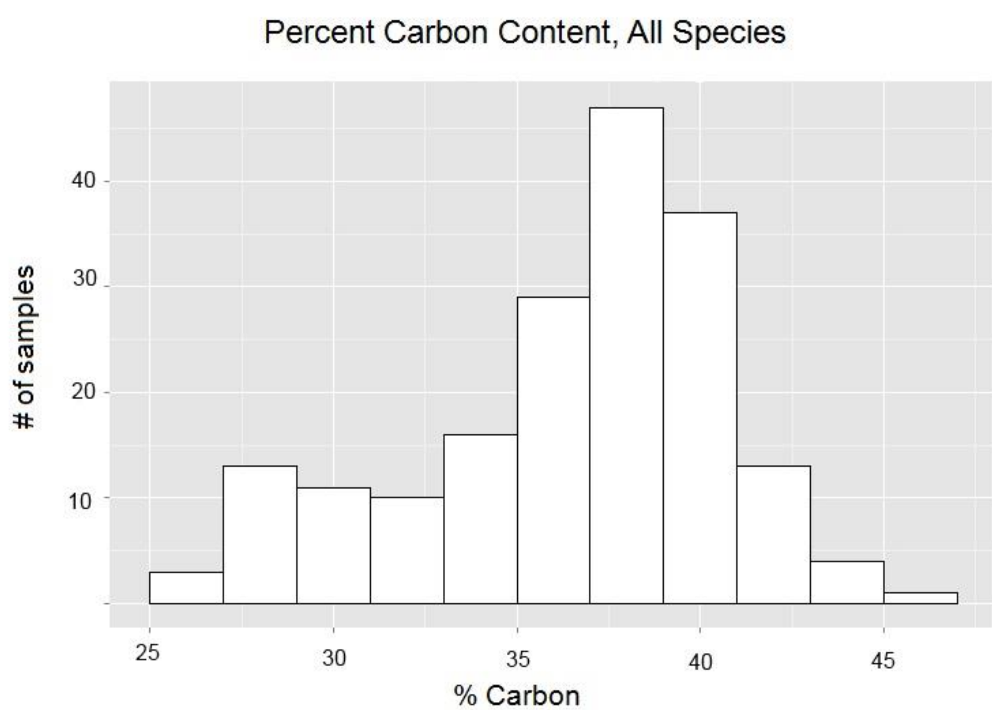


Figure 1. Amount of carbon found in the tested SAM tissue samples that were collected before and after the Las Conchas fire.

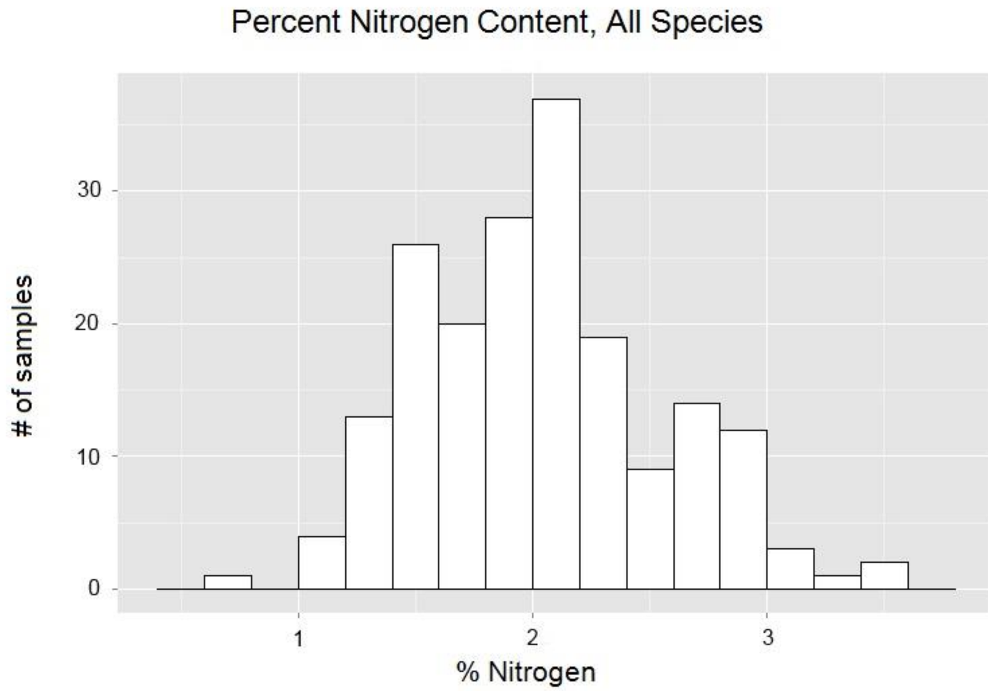


Figure 2**.** Amount of nitrogen found in the tested SAM tissue samples that were collected before and after the Las Conchas fire.

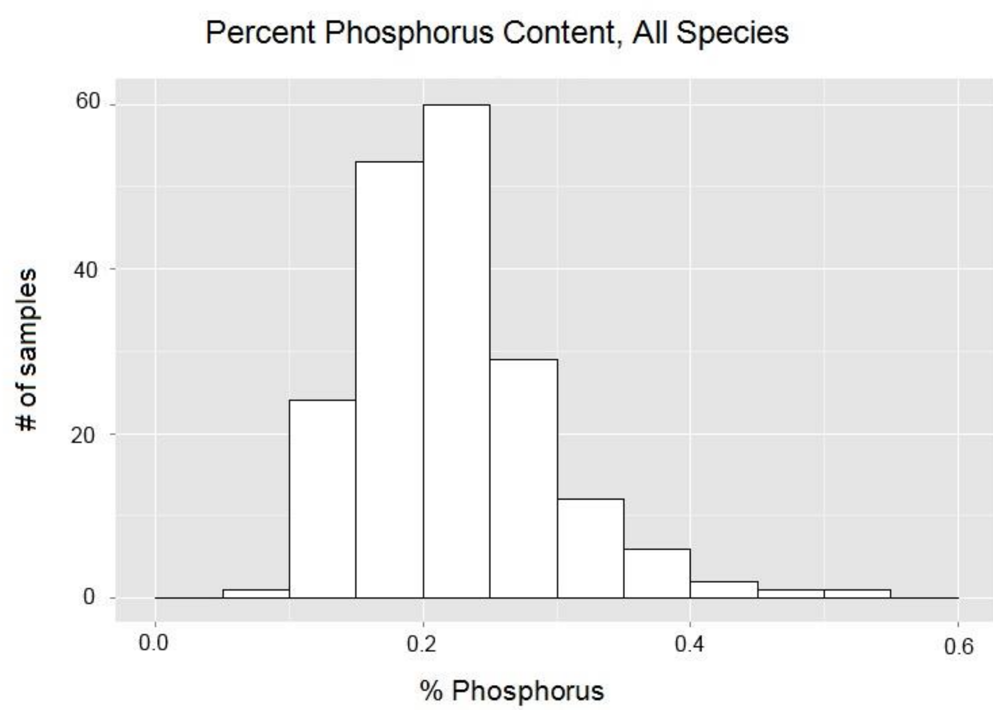


Figure 3. Amount of phosphorus found in the tested SAM tissue samples that were collected before and after the Las Conchas fire.

Ratios of the amount of specific elements present in a sample (molar ratios) were calculated to see if there were patterns of changes in the amount of these key elements in the plant tissues over the growing season due to the inputs of nutrients into the streams from precipitation events over the Las Conchas burn scars. Much of the flood debris introduced into the EFJR in August 2011 included fine sediments, charcoal and ash, which increased the amounts of dissolved nitrate and phosphate in the water column (Sherson et al. 2015). Molar ratios for carbon (C) and nitrogen (N) followed a steady pattern in 2011 and 2012 (Fig. 4), seemingly unchanged by these nutrient inputs. Molar ratios for carbon (C) and phosphorus (P) (Fig. 5) showed a reduction in the months immediately after major debris flow events (September and October 2011). This indicates an increase in the amount of phosphorus in their tissues in relation to carbon. The ratios were much higher the same time the following year (September and October 2012), indicating less phosphorous in relation to carbon. Molar ratios for nitrogen (N) and phosphorus (P) (Fig. 6) were also lower in Sept/Oct 2011 than in Sept/Oct 2012, also indicating there was an increase in the amount of phosphorus in the SAM tissues in relation to nitrogen in Sept/Oct 2011.

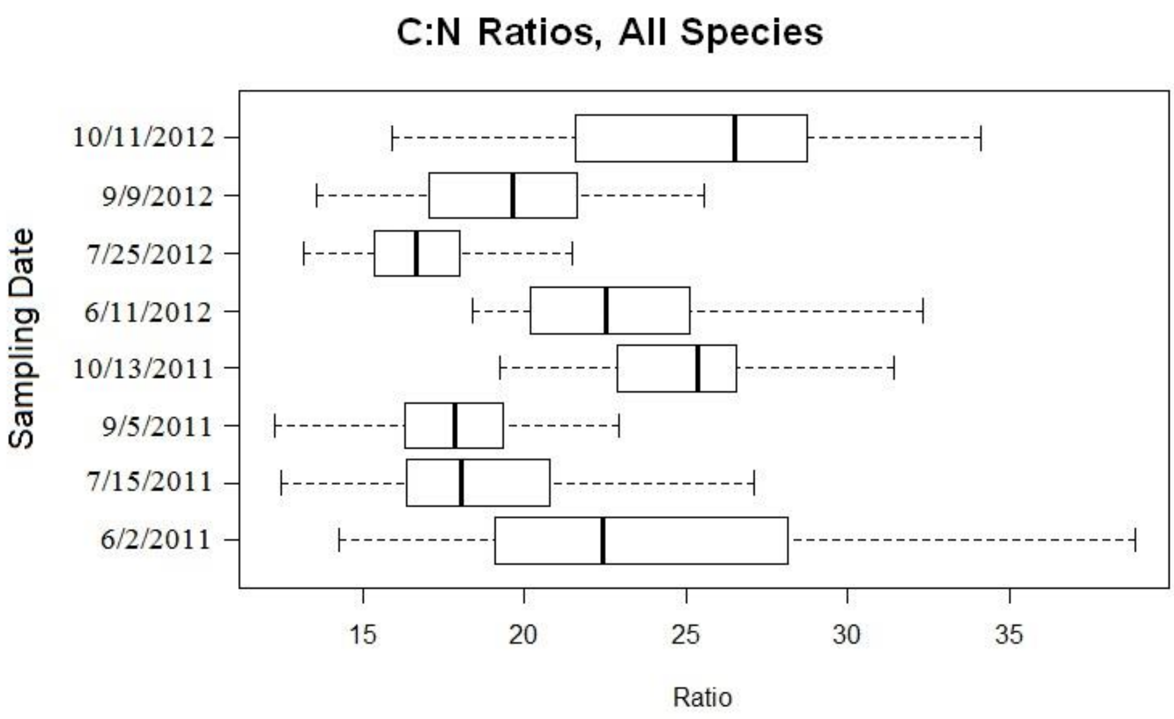


Figure 4. The ratio of carbon (C) to nitrogen (N) found in the SAM tissues that were collected before and after the Las Conchas fire, separated by sampling date.

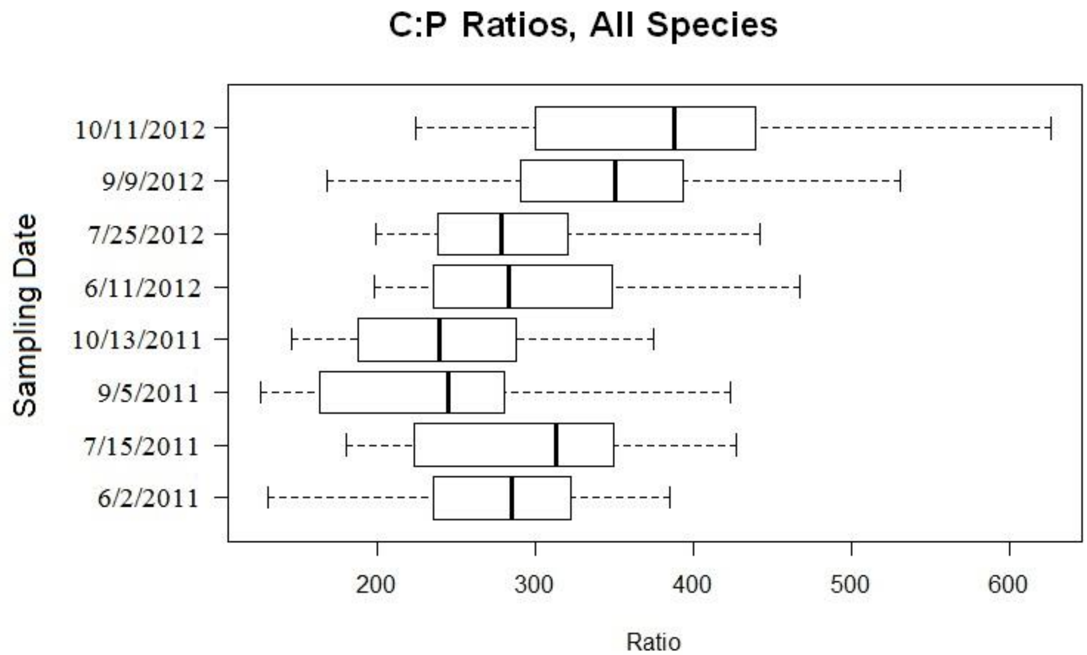


Figure 5. The ratio of carbon (C) to phosphorus (P) found in the SAM tissues that were collected before and after the Las Conchas fire, separated by sampling date.

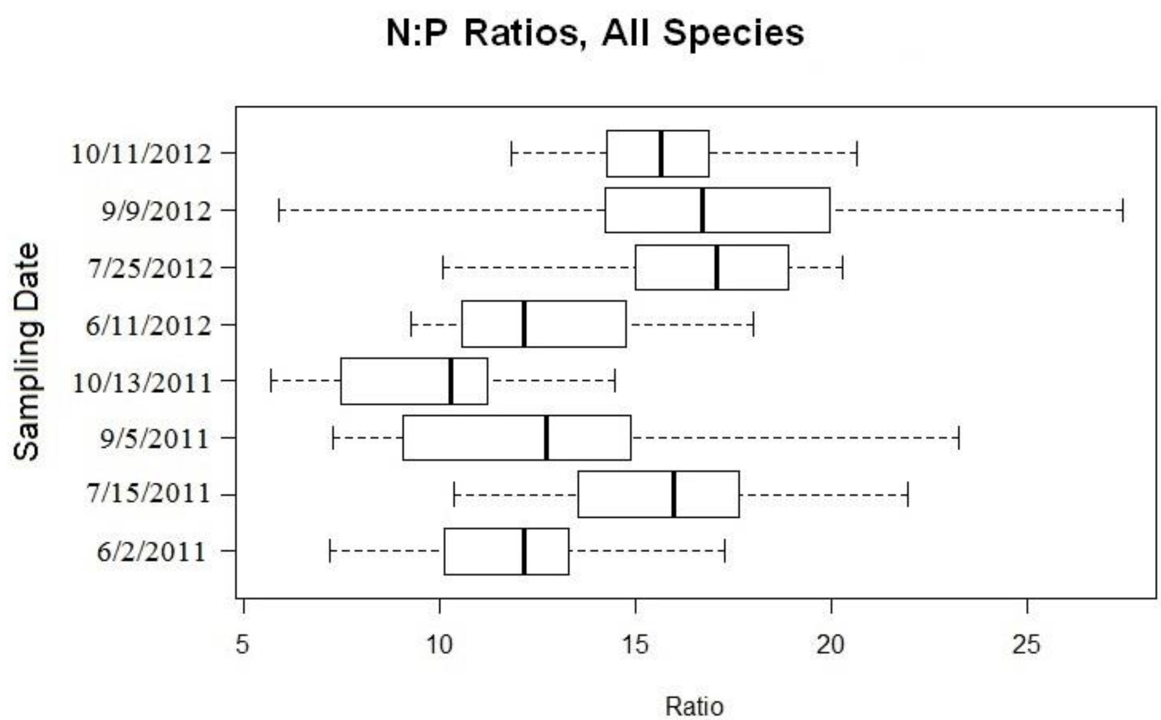


Figure 6. The ratio of nitrogen (N) to phosphorus (P) found in the SAM tissues that were collected before and after the Las Conchas fire, separated by sampling date.

DISCUSSION

Phosphorus is known to be a limiting nutrient in both terrestrial and aquatic ecosystems, and the EFJR is known to have very low levels of key nutrients including dissolved phosphate under normal conditions (Sherson et al. 2015). Ash and solutes that entered the EFJR in August 2011 increased the amount of these key nutrients in the water column and in the sediments as the ash and fine sediments settled out of the water column. The lower C:P and N:P molar ratios in Sept/Oct 2011 than in Sept/Oct 2012 indicate that there was an increase of phosphorus in the EFJR that the SAMs were able to utilize, reflecting a change in the environment and supporting previous findings that nutrient ratios in macrophyte tissues are known to change under differing environmental conditions (Frost et al. 2002). These fine sediments acted as a fertilizer, temporarily increasing both the biomass (unpublished data) as well as the amount of phosphorus in the SAM tissues.

These data show that aquatic plants that are not directly burned by fire can be indirectly affected by forest fire through both scour and nutrient enrichment. Being completely submerged in the water column is advantageous for the SAMs when the fire first passes over to avoid the immediate impacts of fire such as scorching and combustion. However, they are not immune to the effects that occur later, especially precipitation events that introduce fire debris and altered soils into the system. In short, SAMs are affected by forest fires. These key ecosystem components can be impacted in both positive and negative ways by forest fire. We know that forest fires have already increased in severity in NM in the last few years, and a greater understanding of the impacts that these catastrophic fires have on our headwater streams will allow us to better anticipate and mitigate the negative impacts in the future.

In the future, I will be comparing continuous water quality data (temperature, turbidity, pH, DO, NO_3-N and PO_4-P) collected by colleagues using in situ instruments at the study site to these patterns of nutrient content as well as the biomass that was collected and measured at the same time. I also will be comparing the different SAM species to see if different species have fundamental differences in the composition of the nutrients in their tissues. I will also investigate if the molar ratios differ between species over time. I also will be combining this water quality information with data I have collected regarding other characteristics of the SAMs in the East Fork, including biomass, to present a more holistic view on the impacts this catastrophic wildfire had on these key ecosystem components.

BROADER IMPACTS

Fires are known to have significant effects on the water quality of surface water systems, including increasing the levels of turbidity and nutrients present in the system. These SAMs are potential biofilters that could clean the water by removing nutrients and reducing turbidity when present in the ecosystems affected by these fire inputs. Since water quality is of great concern for downstream surface water users and water managers, organizations like the Albuquerque Bernalillo County Water Authority would be interested in these results as they might dictate resource management choices. Land managers that monitor headwater surface water systems and/or fire prone areas may be concerned with changes in water quality after fires as they will dictate management choices that could affect fish and wildlife populations and that are important to outdoor enthusiasts, including hunters, anglers, ranchers and tourists/recreational users. Agencies/organizations such as the US Forest Service, the Bureau of Land Management, private land managers, the Valles Caldera National Preserve staff and the NM Department of Fish and Wildlife could potentially use this information to make informed decisions to mitigate potential post-fire effects.

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RESOURCES CITED

Atkinson, M. J., and S. V. Smith. 1983. C:N:P ratios of benthic marine plants. Limnology and Oceanography **28(3)**:568–574. doi:10.2307/2835836.

Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management **178**:105–119.

Bolser, R. C., Hay, M. E., Lindquist, N., Fenical, W. and D. Wilson. 1998. Chemical defenses of freshwater macrophytes against crayfish herbivory. Journal of Chemical Ecology **24**:1639-1658.

Carignan, R., and J. Kalff. 1980. Phosphorus sources for aquatic weeds: water or sediment? Science **207**:987-989.

Carpenter S. R., and D. M. Lodge. 1986. Effects of submersed aquatic macrophytes on ecosystem processes. Aquatic Botany **26**:341-370.

Cavalli, G., T. Riis, and A. Baattrup-Pedersen. 2012. Bicarbonate use in three aquatic plants. Aquatic Botany **98(1)**:57–60.

Certini, G., 2005. Effects of fire on properties of forest soils: A review. Oecologia **143**:1–10.

Chambers, P. A., E. E. Prepas, M. L. Bothwell, and H. R. Hamilton. 1989. Roots versus shoots in nutrient uptake by aquatic macrophytes in flowing waters. Canadian Journal of Fisheries and Aquatic Sciences **46(3)**:435–439.

Dahm, C. N., R. I. Candelaria-Ley, C. S. Reale, J. K. Reale, & D. J. Van Horn. 2015. Extreme water quality degradation following a catastrophic forest fire. Freshwater Biology doi: 10.1111/fwb.12548.

Demars, B. O. L., and A. C. Edwards. 2007. Tissue nutrient concentrations in freshwater aquatic macrophytes: high inter-taxon differences and low phenotypic response to nutrient supply. Freshwater Biology **52(11)**: 2073–2086. doi:10.1111/j.1365-2427.2007.01817.x.

Dawson, F. H. 1980. The origin, composition, and downstream transport of plant material in a small chalk stream. Freshwater Biology **10**:419-435.

Earl, R. S. and D. W. Blinn. 2003. Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. streams. Freshwater Biology **48**:1015-1030.

Elser, J. J., W. F. Fagan, R. F. Denno, D. R. Dobberfuhl, A. Folarin, A. Huberty, S. Interlandi, S. S. Kilham, E. McCauley, K. L. Schulz, E. H. Siemann, and R. W. Sterner. 2000. Nutritional constraints in terrestrial and freshwater food webs. Nature **408**:578–580. doi:10.1038/35046058.

Frost, P. C., R. S. Stelzer, G. A. Lamberti, and J. J. Elser. 2002. Ecological stoichiometry of trophic interactions in the benthos: understanding the role of C:N:P ratios in lentic and lotic habitats. Journal of the North American Benthological Society **21(4)**:515–528. doi:10.2307/1468427.

Hauer, F. R., and C. N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: a study of immediate and long-term effects. International Journal of Wildland Fire **8(4)**:183–198.

Luo, L., Y. Tang, S. Zhong, X. Bian, and W. E. Heilman. 2013. Will future climate favor more erratic wildfires in the western United States? Journal of Applied Meteorology and Climatology **52(11)**:2410–2417.

Jeppesen, E., Jensen, J. P., Sondergaard, M., Lauridsen, T., Pedersen, L. J., and L. Jensen. 1997. Top-down control in freshwater lakes: the role of nutrient state, submerged macrophytes and water depth. Hydrobiologia **342/343**:151-164.

Madsen, T. V., and N. Cedergreen. 2002. Sources of nutrients to rooted submerged macrophytes growing in a nutrient-rich stream. Freshwater Biology **47(2)**: 283–291.

Marshall, T. R. and P. F. Lee, 1994. An inexpensive and lightweight sampler for the rapid collection of aquatic macrophytes. Journal of Aquatic Plant Management **32**:77-79.

Rhoads, C., D. Entwistle, and D. Butler. 2006. Initial stream water response to the Hayman Fire, Colorado front range. In *Elder, K., Dwire, K, Hubbard, R., Rhoades, C., Ryan, S., Young, M., Porth, L., Dixon, M., Goodbody, A., Proceedings of the Second Interagency Conference on Research in the Watersheds,* 89–98. Coweeta Hydrologic Laboratory, Otto, NC.

Sherson, L. R., D. J. Van Horn, J. D. Gomez-Velez, L. J. Crossey and C. N. Dahm. 2015. Nutrient dynamics in an alpine headwater stream: use of continuous water quality sensors to examine responses to wildfire and precipitation events. Hydrological Processes doi:10.1002/hyp10426.

Smith, H. G., G. J. Sheridan, P. N. J. Lane, P. Nyman, and S. Haydon. 2011. Wildfire effects on water quality in forest catchments: a review with implications for water supply. Journal of Hydrology **396(1–2)**:170–192.

Stelzer, R. S. and G. A. Lamberti. 2001. Effects of N: P ratio and total nutrient concentration on stream periphyton community structure, biomass, and elemental composition. Limnology and Oceanography **46(2)**:356-367 doi: 10.4319/lo.2001.46.2.0356.

Stephan, K., K. L. Kavanagh, and A. Koyama. 2012. Effects of spring prescribed burning and wildfires on watershed nitrogen dynamics of central Idaho headwater areas. Forest Ecology and Management **263**:240-252.

Verkaik, I., M. Rieradeval, S. D. Cooper, J. M. Melack, T. L. Dudley, and N. Prat. 2013. Fire as a disturbance in Mediterranean climate streams. Hydrobiologia **719**:353–382.

Vose, J. M., D. L. Peterson, and T. Patel-Weynand. 2012. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. U.S. Department of Agriculture, Pacific Northwest Research Station, United States Forest Service: Portland, Oregon. General Technical Report PNW-GTR-870**.**

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science **313**:940-943.