Climate Change Quarterly: Fall 2014

Abstracts of Recent Papers on Climate Change and Land Management in the West

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Climate Projections

Abatzoglou, J. T., and R. Barbero. 2014. **Observed and projected changes in absolute temperature records across the contiguous United States.** Geophysical Research Letters 41:6501-6508. DOI: 10.1002/2014GL061441.

Abstract. Changes in the extent of absolute, all-time, daily temperature records across the contiguous United States were examined using observations and climate model simulations. Observations from station data and reanalysis from 1980 to 2013 show increased extent of absolute highest temperature records and decreased extent of absolute lowest temperature records. Conversely, station data from 1920 to 2013 showed decreased extent of absolute highest records with nearly half of such records occurring in the 1930s during exceptional widespread drought. Simulated changes in the extent of absolute temperature records from climate model experiments were in general agreement with observed changes for recent decades. However, fewer lowest temperature records and highest temperature records were observed since 2000 than simulated by most models. Climate models project a continued increase in the occurrence of highest temperature records and decline in lowest temperature records through the mid-21st century.

Jeong, D., L. Sushama, and M. Naveed Khaliq. 2014. **The role of temperature in drought projections over North America.** Climatic Change 127:289-303. DOI: 10.1007/s10584-014-1248-3.

Abstract. The effects of future temperature and hence evapotranspiration increases on drought risk over North America, based on ten current (1970–1999) and ten corresponding future (2040–2069) Regional Climate Model (RCM) simulations from the

North American Regional Climate Change Assessment Program, are presented in this study. The ten pairs of simulations considered in this study are based on six RCMs and four driving Atmosphere Ocean Coupled Global Climate Models. The effects of temperature and evapotranspiration on drought risks are assessed by comparing characteristics of drought events identified on the basis of Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspration Index (SPEI). The former index uses only precipitation, while the latter uses the difference (DIF) between precipitation and potential evapotranspiration (PET) as input variables. As short- and long-term droughts impact various sectors differently, multi-scale (ranging from 1- to 12-month) drought events are considered. The projected increase in mean temperature by more than 2 °C in the future period compared to the current period for most parts of North America results in large increases in PET and decreases in DIF for the future period, especially for low latitude regions of North America. These changes result in large increases in future drought risks for most parts of the USA and southern Canada. Though similar results are obtained with SPI, the projected increases in the drought characteristics such as severity and duration and the spatial extent of regions susceptible to drought risks in the future are considerably larger in the case of SPEI-based analysis. Both approaches suggest that long-term and extreme drought events are affected more by the future increases in temperature and PET than short-term and moderate drought events, particularly over the high drought risk regions of North America.

Watanabe, M., H. Shiogama, H. Tatebe, M. Hayashi, M. Ishii, and M. Kimoto. 2014. **Contribution of natural decadal variability to global warming acceleration and hiatus.** Nature Climate Change 4:893-897. doi:10.1038/nclimate2355

Abstract. Reasons for the apparent pause in the rise of global-mean surface air temperature (SAT) after the turn of the century has been a mystery, undermining confidence in climate projections. Recent climate model simulations indicate this warming hiatus originated from eastern equatorial Pacific cooling associated with strengthening of trade winds5. Using a climate model that overrides tropical wind stress anomalies with observations for 1958–2012, we show that decadal-mean anomalies of global SAT referenced to the period 1961–1990 are changed by 0.11, 0.13 and −0.11 °C in the 1980s, 1990s and 2000s, respectively, without variation in human-induced radiative forcing. They account for about 47%, 38% and 27% of the respective temperature change. The dominant wind stress variability consistent

with this warming/cooling represents the deceleration/acceleration of the Pacific trade winds, which can be robustly reproduced by atmospheric model simulations forced by observed sea surface temperature excluding anthropogenic warming components. Results indicate that inherent decadal climate variability contributes considerably to the observed global-mean SAT time series, but that its influence on decadal-mean SAT has gradually decreased relative to the rising anthropogenic warming signal.

Carbon and Carbon Storage

Gray, A. N., and T. R. Whittier. 2014. **Carbon stocks and changes on Pacific Northwest national forests and the role of disturbance, management, and growth.** Forest Ecology and Management 328:167-178. doi:10.1016/j.foreco.2014.05.015

Abstract. The National Forest System (NFS) of the United States plays an important role in the carbon cycle because these lands make up a large proportion of the forested land in the country and commonly store more wood per unit area than other forest ownerships. In addition to sustaining natural resources, these lands are managed for multiple objectives that do not always align with maximizing carbon (C) sequestration. The objectives of this study were to determine C stocks and flux in measured pools on Pacific Northwest Region NFS lands and the major ecological drivers of C flux. We compiled tree, dead wood, and understory vegetation data from 11,435 systematically-placed inventory plots and estimated growth, mortality, decay, removals, and disturbance events based on two full measurements spanning 1993–2007. The area of NFS-administered lands increased by 0.3% during this period and the area in formally-designated protected status increased by 0.7%. There was 1293 Tg C (±11.2 Tg standard error) in non-soil C stocks at the first measurement, which increased by 45 ± 2.2 Tg (3.4%), with 59% of the increase in the live tree pool and the remainder in the dead tree pools. C stocks followed broad regional patterns in productivity while C flux varied at local scales. Fires affected <1% of the forested area per year and were most prevalent in Wilderness areas. Fires reduced C stocks on burned plots by only 9%, and had a negligible effect on the region as a whole. Most tree harvest on NFS lands in the region consisted of partial harvest and had comparable impacts to fire during this period. C sequestration rates were higher (1.2 ± 0.09 Mg/ha/yr) on the west side of the Cascade Mountains, and primarily stayed in the live tree pool, compared to lower rates (0.5 ± 0.04 Mg/ha/yr) east of the Cascades where most of the increase was seen in the down wood pool. We discuss challenges to estimating forest ecosystem carbon stocks, which requires the application of a large number of equations and parameters for measured and unmeasured components, some with scant empirical support. Improved measurements and biomass models applied to networks of permanent plots would enable improved ground-based estimates of the drivers and components of regional changes in C.

Kelsey, Katharine C, Kallie L Barnes, Michael G Ryan and Jason C Neff. 2014. **Short and long-term carbon balance of bioenergy electricity production fueled by forest treatments.** Carbon Balance and Management 9:6. doi:10.1186/s13021-014-0006-1

Abstract. Background: Forests store large amounts of carbon in forest biomass, and this carbon can be released to the atmosphere following forest disturbance or management. In the western US, forest fuel reduction treatments designed to reduce the risk of high severity wildfire can change forest carbon balance by removing carbon in the form of biomass, and by altering future potential wildfire behavior in the treated stand. Forest treatment carbon balance is further affected by the fate of this biomass removed from the forest, and the occurrence and intensity of a future wildfire in this stand. In this study we investigate the carbon balance of a forest treatment with varying fates of harvested biomass, including use for bioenergy electricity production, and under varying scenarios of future disturbance and regeneration.

Results: Bioenergy is a carbon intensive energy source; in our study we find that carbon emissions from bioenergy electricity production are nearly twice that of coal for the same amount of electricity. However, some emissions from bioenergy electricity production are offset by avoided fossil fuel electricity emissions. The carbon benefit achieved by using harvested biomass for bioenergy electricity production may be increased through avoided pyrogenic emissions if the forest treatment can effectively reduce severity.

Conclusion: Forest treatments with the use of harvested biomass for electricity generation can reduce carbon emissions to the atmosphere by offsetting fossil fuel electricity generation emissions, and potentially by avoided pyrogenic emissions due to reduced intensity and severity of a future wildfire in the treated stand. However, changes in future wildfire and regeneration regimes may affect forest carbon balance

and these climate-induced changes may influence forest carbon balance as much, or more, than bioenergy production.

Smith, P. 2014. **Do grasslands act as a perpetual sink for carbon?** Global Change Biology, 20: 2708–2711. doi: 10.1111/gcb.12561. (Opinion)

Abstract. It is increasingly commonly suggested that grasslands are a perpetual sink for carbon, and that just maintaining grasslands will yield a net carbon sink. I examine the evidence for this from repeated soil surveys, long term grassland experiments and simple mass balance calculations. I conclude that it is untenable that grasslands act as a perpetual carbon sink, and the most likely explanation for observed grassland carbon sinks over short periods is legacy effects of land use and land management prior to the beginning of flux measurement periods. Simply having grassland does not result is a carbon sink, but judicious management or previously poorly managed grasslands can increase the sink capacity. Given that grasslands are a large store of carbon, and that it is easier and faster for soils to lose carbon that it is for them to gain carbon, it is an important management target to maintain these stocks.

Volkova, L., C. P. Meyer, S. Murphy, T. Fairman, F. Reisen, and C. Weston. 2014. **Fuel reduction burning mitigates wildfire effects on forest carbon and greenhouse gas emission.** International Journal of Wildland Fire 23:771-780. http://dx.doi.org/10.1071/WF14009.

Abstract. A high-intensity wildfire burnt through a dry Eucalyptus forest in south-eastern Australia that had been fuel reduced with fire 3 months prior, presenting a unique opportunity to measure the effects of fuel reduction (FR) on forest carbon and greenhouse gas (GHG) emissions from wildfires at the start of the fuel accumulation cycle. Less than 3% of total forest carbon to 30-cm soil depth was transferred to the atmosphere in FR burning; the subsequent wildfire transferred a further 6% to the atmosphere. There was a 9% loss in carbon for the FR–wildfire sequence. In nearby forest, last burnt 25 years previously, the wildfire burning transferred 16% of forest carbon to the atmosphere and was characterised by more complete combustion of all fuels and less surface charcoal deposition, compared with fuel-reduced forest. Compared to the fuel-reduced forests, release of non-CO_2 GHG doubled following wildfire in long-unburnt forest. Although this is the maximum emission mitigation likely within

a planned burning cycle, it suggests a significant potential for FR burns to mitigate GHG emissions in forests at high risk from wildfires.

Phenology Changes

Diez, Jeffrey M., Inés Ibáñez, John A. Silander, Jr., Richard Primack, Hiroyoshi Higuchi, Hiromi Kobori, Ananda Sen, and Timothy Y. James 2014. **Beyond seasonal climate: statistical estimation of phenological responses to weather.** Ecological Applications 24:1793–1802. http://dx.doi.org/10.1890/13-1533.1

Abstract. Phenological events, such as the timing of flowering or insect emergence, are influenced by a complex combination of climatic and non-climatic factors. Although temperature is generally considered most important, other weather events such as frosts and precipitation events can also influence many species' phenology. Non-climatic variables such as photoperiod and site-specific habitat characteristics can also have important effects on phenology. Forecasting phenological shifts due to climate change requires understanding and quantifying how these multiple factors combine to affect phenology. However, current approaches to analyzing phenological data have a limited ability for quantifying multiple drivers simultaneously. Here, we use a novel statistical approach to estimate the combined effects of multiple variables, including local weather events, on the phenology of several taxa (a tree, an insect, and a fungus). We found that thermal forcing had a significant positive effect on each species, frost events delayed the phenology of the tree and butterfly, and precipitation had a positive effect on fungal fruiting. Using data from sites across latitudinal gradients, we found that these effects are remarkably consistent across sites once latitude and other site effects are accounted for. This consistency suggests an underlying biological response to these variables that is not commonly estimated using data from field observations. This approach's flexibility will be useful for forecasting ongoing phenological responses to changes in climate variability in addition to seasonal trends.

Species Range Changes

Stahl, Ulrike, Björn Reu, and Christian Wirth. 2014. **Predicting species' range limits from functional traits for the tree flora of North America.** Proceedings of the National Academy of Sciences 111(38): 13739-13744. doi:10.1073/pnas.1300673111

Abstract. Using functional traits to explain species' range limits is a promising approach in functional biogeography. It replaces the idiosyncrasy of species-specific climate ranges with a generic trait-based predictive framework. In addition, it has the potential to shed light on specific filter mechanisms creating large-scale vegetation patterns. However, its application to a continental flora, spanning large climate gradients, has been hampered by a lack of trait data. Here, we explore whether five key plant functional traits (seed mass, wood density, specific leaf area (SLA), maximum height, and longevity of a tree)—indicative of life history, mechanical, and physiological adaptations—explain the climate ranges of 250 North American tree species distributed from the boreal to the subtropics. Although the relationship between traits and the median climate across a species range is weak, quantile regressions revealed strong effects on range limits. Wood density and seed mass were strongly related to the lower but not upper temperature range limits of species. Maximum height affects the species range limits in both dry and humid climates, whereas SLA and longevity do not show clear relationships. These results allow the definition and delineation of climatic "no-go areas" for North American tree species based on key traits. As some of these key traits serve as important parameters in recent vegetation models, the implementation of trait-based climatic constraints has the potential to predict both range shifts and ecosystem consequences on a more functional basis. Moreover, for future trait-based vegetation models our results provide a benchmark for model evaluation.

Forest Vegetation

Adams, Hallie R., Holly R. Barnard, and Alexander K. Loomis 2014. **Topography alters tree growth–climate relationships in a semi-arid forested catchment.** Ecosphere 5:art148. http://dx.doi.org/10.1890/ES14-00296.1

Abstract. Topography and climate play an integral role in the spatial variability and annual dynamics of aboveground carbon sequestration.

Despite knowledge of vegetation–climate–topography relationships on the landscape and hillslope scales, little is known about the influence of complex terrain coupled with hydrologic and topoclimatic variation on tree growth and physiology at the catchment scale. Climate change predictions for the semi-arid, western United States include increased temperatures, more frequent and extreme drought events, and decreases in snowpack, all of which put forests at risk of drought induced mortality and enhanced susceptibility to disturbance events. In this study, we determine how species-specific tree growth patterns and water use efficiency respond to interannual climate variability and how this response varies with topographic position. We found that *Pinus contorta* and *Pinus ponderosa* both show significant decreases in growth with water-limiting climate conditions, but complex terrain mediates this response by controlling moisture conditions in variable topoclimates. Foliar carbon isotope analyses show increased water use efficiency during drought for *Pinus contorta*, but indicate no significant difference in water use efficiency of *Pinus ponderosa* between a drought year and a non-drought year. The responses of the two pine species to climate indicate that semi-arid forests are especially susceptible to changes and risks posed by climate change and that topographic variability will likely play a significant role in determining the future vegetation patterns of semi-arid systems.

Crookston, Nicholas L. 2014. **Climate-FVS Version 2: Content, users guide, applications, and behavior.** Gen. Tech. Rep. RMRS-GTR-319. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p. Available at http://www.fs.fed.us/rm/pubs/rmrs_gtr319.html

Abstract. Climate change in the 21st Century is projected to cause widespread changes in forest ecosystems. Climate-FVS is a modification to the Forest Vegetation Simulator designed to take climate change into account when predicting forest dynamics at decadal to century time scales. Individual tree climate viability scores measure the likelihood that the climate at a given location and at a given point in time is consistent with the climate recorded for species' contemporary distribution. These viability scores are input into Climate-FVS. A web-based service is available for providing this input for climate predictions generated by down scaling general circulation model (GCM) outputs run using several models and scenarios from the IPCC third (IPCC 2000) and fifth assessments (IPCC 2013). Climate-FVS contains components that modify mortality and growth rates, plus rules for establishing new trees. Commands are presented that control the model. These commands enable the users to explore the model's sensitivity to model components and parameters, to include pertinent information unknown to the model, and use the model to simulate management alternatives. Model outputs are very sensitive to the mortality component, are moderately sensitive to growth rate modifications, and are sensitive to maximum density adjustment only when a stand's maximum density is being approached. The intended model uses are to provide insights into future forest dynamics that are not otherwise evident, to provide model outputs that are relevant to forest managers, to provide a consistent way to compare management alternatives, and to do so using defensible methods.

Grossiord, Charlotte, André Granier, Sophia Ratcliffe, Olivier Bouriaud, Helge Bruelheide, Ewa Chećko, David Ian Forrester, Seid Muhie Dawud, Leena Finér, Martina Pollastrini, Michael Scherer-Lorenzen, Fernando Valladares, Damien Bonal, and Arthur Gessler. 2014. **Tree diversity does not always improve resistance of forest ecosystems to drought.** Proceedings of the National Academy of Sciences 111(41) 14812-14815. doi:10.1073/pnas.1411970111

Abstract. Climate models predict an increase in the intensity and frequency of drought episodes in the Northern Hemisphere. Among terrestrial ecosystems, forests will be profoundly impacted by drier climatic conditions, with drastic consequences for the functions and services they supply. Simultaneously, biodiversity is known to support a wide range of forest ecosystem functions and services. However, whether biodiversity also improves the resistance of these ecosystems to drought remains unclear. We compared soil drought exposure levels in a total of 160 forest stands within five major forest types across Europe along a gradient of tree species diversity. We assessed soil drought exposure in each forest stand by calculating the stand-level increase in carbon isotope composition of late wood from a wet to a dry year ($\Delta\delta^{13}CS$). $\Delta\delta^{13}CS$ exhibited a negative linear relationship with tree species diversity in two forest types, suggesting that species interactions in these forests diminished the drought exposure of the ecosystem. However, the other three forest types were unaffected by tree species diversity. We conclude that higher diversity enhances resistance to drought events only in drought-prone environments. Managing forest ecosystems for high tree species diversity does not necessarily assure improved adaptability to the more severe and frequent drought events predicted for the future.

Joyce, Linda A.; Price, David T.; Coulson, David P.; McKenney, Daniel W.; Siltanen, R. Martin; Papadopol, Pia; Lawrence, Kevin. 2014. **Projecting climate change in the United States: A technical document supporting the Forest Service RPA 2010 Assessment.** Gen. Tech. Rep. RMRS-GTR-320. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p. Available at http://www.fs.fed.us/rm/pubs/rmrs_gtr320.html

Abstract. A set of climate change projections for the United States was developed for use in the 2010 USDA Forest Service RPA Assessment. These climate projections, along with projections for population dynamics, economic growth, and land use change in the United States, comprise the RPA scenarios and are used in the RPA Assessment to project future renewable resource conditions 50 years into the future. This report describes the development of the historical and projected climate data set. The climate variables are monthly total precipitation in millimeters (mm), monthly mean daily maximum air temperature in degrees Celsius (°C), and monthly mean daily minimum air temperature in degrees Celsius (°C). Downscaled climate data were developed for the period 2001-2100 at the 5-arcminute grid scale (approximately 9.3 km by 7.1 km grid size at 40 degree N) for the conterminous United States. These data were also summarized at the U.S. county level. Computed monthly mean daily potential evapotranspiration (mm) and mean grid cell elevation in meters (m) are also included in the data set. The scenarios used here from the IPCC Special Report on Emissions Scenarios are A1B, A2, and B2. The A1B and A2 scenarios were used to drive three climate models: the Third Generation Coupled Global Climate Model, version 3.1, medium resolution; the Climate System Model, Mark 3.5 (T63); and the Model for Interdisciplinary Research on Climate, version 3.2, (T42), all used in the Fourth IPCC Assessment. The B2 scenario was used to drive three earlier generation climate models: the Second Generation Coupled Global Climate Model, version 2, medium resolution; the Climate System Model, Mark 2; and the UKMO Hadley Centre Coupled Model, version 3, all used in the IPCC Third Assessment. Monthly change factors were developed from global climate model output using the delta method. The coarse-resolution change factors were downscaled to a 5-arcminute resolution grid using ANUSPLIN. The 30-year mean historical climatology (1961-1990) was developed using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) data at 2.5-arcminute resolution and aggregated to the 5-arcminute resolution grid. The downscaled change factors were combined with the PRISM observed climatology to develop nine future climate projections for the conterminous United States. These

projection data and the change factor data are available through the U.S. Forest Service data archive website (http://www.fs.usda.gov/rds/archive/).

Oakes, Lauren E., Paul E. Hennon, Kevin L. O'Hara, and Rodolfo Dirzo 2014. **Long-term vegetation changes in a temperate forest impacted by climate change.** Ecosphere 5:art135. http://dx.doi.org/10.1890/ES14-00225.1

Abstract. Pervasive forest mortality is expected to increase in future decades as a result of increasing temperatures. Climate-induced forest dieback can have consequences on ecosystem services, potentially mediated by changes in forest structure and understory community composition that emerge in response to tree death. Although many dieback events around the world have been documented in recent years, yellow-cedar (*Callitropsis nootkatensis*) decline provides an opportunity to study vegetation changes occurring over the past century. Current research identifies climate-related reductions in snow cover as a key driver of this species dieback. To examine the process of forest development post-dieback, we conducted vegetation surveys at 50 plots along the outer coast of southeast Alaska across a chronosequence of mortality. Our main study objectives were to examine changes in seedling and sapling abundance, and community structure of conifer species in the overstory; effects of yellow-cedar mortality on plant diversity and community composition of functional groups in the understory; and volume of key forage species for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) managed throughout the region. The probability of yellow-cedar sapling occurrence was reduced across the chronosequence. Yellow-cedar seedling and sapling abundance also decreased. We observed a turnover from yellow-cedar to western hemlock (*Tsuga heterophylla*) dominated forests. Functional plant diversity increased and the community composition of the understory changed across the chronosequence. Bryophytes became less abundant and grasses more abundant in the early stages of stand development, and shrubs increased in relative abundance in latter stages. Our results demonstrate that yellow-cedar is significantly less likely to regenerate in forests affected by widespread mortality, and a species dieback can dynamically rearrange the plant community over time. These findings emphasize the importance of considering long-term temporal dynamics when assessing the impacts of climate change on biodiversity and ecosystem services, and adapting forest management to a changing climate.

Peterson, David W.; Kerns, Becky K.; Dodson, Erich K. 2014. **Climate change effects on vegetation in the Pacific Northwest: a review and synthesis of the scientific literature and simulation model projections.** Gen. Tech. Rep. PNWGTR-900. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 183 p. Available at http://www.treesearch.fs.fed.us/pubs/46520

Abstract. The purpose of this study was to review scientific knowledge and model projections on vegetation vulnerability to climatic and other environmental changes in the Pacific Northwest, with emphasis on five major biome types: subalpine forests and alpine meadows, maritime coniferous forests, dry coniferous forests, savannas and woodlands (oak and juniper), and interior shrub-steppe. We started by reviewing and synthesizing the scientific literature on past and projected changes in atmospheric carbon dioxide concentrations and climate for the Pacific Northwest (and globally), and how these changes are likely to influence snowpack dynamics, soil water availability, and selected disturbance regimes. We also reviewed and synthesized the scientific literature on plant growth, reproduction, and mortality in response to changing climate and disturbance regimes, and on the ability of plants to adapt to these changes through phenotypic plasticity, local adaptation, and migration. We then reviewed the strengths and weaknesses of several types of simulation models commonly used to project vegetation responses to climate change and discussed recent model projections of vegetation responses to future climate change scenarios in the Pacific Northwest, as well as how these projections might best be used in developing management plans for forests and rangelands. We next reviewed the existing scientific literature on plant sensitivity and adaptation to changing climate and disturbance regimes for five major vegetation biomes in the Pacific Northwest. We concluded with a discussion of current approaches and resources for developing climate change adaptation strategies, including restoring historical vegetation structure and composition, promoting resistance to change, promoting resilience to change, and facilitating anticipated responses to change.

Reich, Peter B., Yunjian Luo, John B. Bradford, Hendrik Poorter, Charles H. Perry, and Jacek Oleksyn. 2014. **Temperature drives global patterns in forest biomass distribution in leaves, stems, and roots**. Proceedings of the National Academy of Sciences 111 (38) 13721-13726. doi:10.1073/pnas.1216053111

Abstract. Whether the fraction of total forest biomass distributed in roots, stems, or leaves varies systematically across geographic gradients remains unknown despite its importance for understanding forest ecology and modeling global carbon cycles. It has been hypothesized that plants should maintain proportionally more biomass in the organ that acquires the most limiting resource. Accordingly, we hypothesize greater biomass distribution in roots and less in stems and foliage in increasingly arid climates and in colder environments at high latitudes. Such a strategy would increase uptake of soil water in dry conditions and of soil nutrients in cold soils, where they are at low supply and are less mobile. We use a large global biomass dataset (>6,200 forests from 61 countries, across a 40 °C gradient in mean annual temperature) to address these questions. Climate metrics involving temperature were better predictors of biomass partitioning than those involving moisture availability, because, surprisingly, fractional distribution of biomass to roots or foliage was unrelated to aridity. In contrast, in increasingly cold climates, the proportion of total forest biomass in roots was greater and in foliage was smaller for both angiosperm and gymnosperm forests. These findings support hypotheses about adaptive strategies of forest trees to temperature and provide biogeographically explicit relationships to improve ecosystem and earth system models. They also will allow, for the first time to our knowledge, representations of root carbon pools that consider biogeographic differences, which are useful for quantifying whole-ecosystem carbon stocks and cycles and for assessing the impact of climate change on forest carbon dynamics.

Shive K. L., Fulé P. Z., Sieg C. H., Strom B. A., Hunter M. E. 2014. **Managing burned landscapes: evaluating future management strategies for resilient forests under a warming climate.** International Journal of Wildland Fire 23, 915–928. http://dx.doi.org/10.1071/WF13184

Abstract. Climate change effects on forested ecosystems worldwide include increases in drought-related mortality, changes to disturbance regimes and shifts in species distributions. Such climate-induced changes will alter the outcomes of current management strategies, complicating the selection of appropriate strategies to promote forest resilience. We modelled forest growth in ponderosa pine forests that burned in Arizona's 2002 Rodeo–Chediski Fire using the Forest Vegetation Simulator Climate Extension, where initial stand structures were defined by pre-fire treatment and fire severity. Under extreme climate change, existing forests persisted for several decades, but shifted towards pinyon–juniper woodlands by 2104. Under milder scenarios, pine persisted with reduced growth. Prescribed burning at 10- and 20-year intervals resulted in basal areas within the historical range of variability (HRV) in low-severity sites that were initially dominated by smaller diameter trees; but in sites initially dominated by larger trees, the range was consistently exceeded. For high-severity sites, prescribed fire was too frequent to reach the HRV's minimum basal area. Alternatively, for all stands under milder scenarios, uneven-aged management resulted in basal areas within the HRV because of its inherent flexibility to manipulate forest structures. These results emphasise the importance of flexible approaches to management in a changing climate.

Tarancón, Alicia Azpeleta, Peter Z. Fulé, Kristen L. Shive, Carolyn H. Sieg, Andrew Sánchez Meador, and Barbara Strom 2014. **Simulating post-wildfire forest trajectories under alternative climate and management scenarios.** Ecological Applications 24:1626–1637. http://dx.doi.org/10.1890/13-1787.1

Abstract. Post-fire predictions of forest recovery under future climate change and management actions are necessary for forest managers to make decisions about treatments. We applied the Climate-Forest Vegetation Simulator (Climate-FVS), a new version of a widely used forest management model, to compare alternative climate and management scenarios in a severely burned multispecies forest of Arizona, USA. The incorporation of seven combinations of General Circulation Models (GCM) and emissions scenarios altered long-term (100 years) predictions of future forest condition compared to a No Climate Change (NCC) scenario, which forecast a gradual increase to high levels of forest density and carbon stock. In contrast, emissions scenarios that included continued high greenhouse gas releases led to near-complete deforestation by 2111. GCM-emissions scenario combinations that were less severe reduced forest structure and carbon stock relative to NCC. Fuel reduction treatments that had been applied prior to the severe wildfire did have persistent effects, especially under NCC, but were overwhelmed by increasingly severe climate change. We tested six management strategies aimed at

sustaining future forests: prescribed burning at 5, 10, or 20-year intervals, thinning 40% or 60% of stand basal area, and no treatment. Severe climate change led to deforestation under all management regimes, but important differences emerged under the moderate scenarios: treatments that included regular prescribed burning fostered low density, wildfire-resistant forests composed of the naturally dominant species, ponderosa pine. Non-fire treatments under moderate climate change were forecast to become dense and susceptible to severe wildfire, with a shift to dominance by sprouting species. Current U.S. forest management requires modeling of future scenarios but does not mandate consideration of climate change effects. However, this study showed substantial differences in model outputs depending on climate and management actions. Managers should incorporate climate change into the process of analyzing the environmental effects of alternative actions.

Vicente-Serrano, S. M., Camarero, J. J. and Azorin-Molina, C. 2014. **Diverse responses of forest growth to drought time-scales in the Northern Hemisphere.** Global Ecology and Biogeography, 23: 1019–1030. doi: 10.1111/geb.12183

Abstract. Aim: To identify the main spatiotemporal patterns of tree growth responses to different time-scales of drought at a hemispheric scale using a climate drought index and tree-ring records, and to determine whether those patterns are driven by different climate and forest features.

Location: Northern Hemisphere.

Methods: We used a large-scale dendrochronological data set of tree-ring width series from 1657 sites and a time-dependent drought index which incorporates information on precipitation and temperature variability (standardized precipitation–evapotranspiration index, SPEI). Correlation analysis was used to quantify how tree growth responds to different drought time-scales. Variation in the correlations was summarized using principal components analysis (PCA) and the contribution of the various environmental factors was estimated using predictive discriminant analysis (PDA).

Results: The period between the water shortage and the impact on tree growth differs noticeably among forest types and tree families. There is a gradient in the response of growth to drought including: (1) forests that do not respond to drought, such as those located in cold and very humid areas; (2) forests located in semi-arid areas characterized by responses to long-term droughts; (3) forests that

respond to medium- to long-term droughts subjected to subhumid conditions; and (4) forests that dominate humid sites and respond to short-term droughts.

Main conclusion: Forests that experience semi-arid and subhumid conditions tend to respond over longer time-scales than those located in more humid areas. The characteristic time-scale at which forest growth mainly responds to drought is a proxy for drought vulnerability, reflecting the trees' ability to cope with water deficits of different durations and severities.

Rangeland Vegetation

Compagnoni, Aldo and Peter B. Adler. 2014. **Warming, competition, and *Bromus tectorum* population growth across an elevation gradient.** Ecosphere 5:9, art121-art121. http://dx.doi.org/10.1890/ES14-00047.1

Abstract. Cheatgrass (*Bromus tectorum*) is one of the most problematic invasive plant species in North America and climate change threatens to exacerbate its impacts. We conducted a two-year field experiment to test the effect of warming, competition, and seed source on cheatgrass performance across an elevation gradient in northern Utah. We hypothesized that warming would increase cheatgrass performance, but that warming effects would be limited by competing vegetation and by local adaptation of cheatgrass seed sources. The warming treatment relied on open top chambers, we removed vegetation to assess the effect of competition from neighboring vegetation, and we reciprocally sowed cheatgrass seed sources from the three study sites. We quantified performance with per capita growth rate and its components (emergence, survival, and fecundity). The main effect of the warming treatment was significant and positive only at high elevation, where warming triggered a three- to six-fold increase in population growth rate. At the lower elevation sites, main effects of warming were always positive but not significant. Interactions between warming and seed source or competition were inconsistent across sites and years. As expected, competition from resident vegetation had strong and consistent negative effects on cheatgrass population growth rate, but it significantly limited warming effects only at the mid-elevation site in one year, presumably by decreasing soil water availability. High elevation seed sources performed best at all sites. Our results indicate that in northern Utah, warming has the potential to increase cheatgrass densities in years

with normal to high precipitation, especially at high elevations, regardless of cheatgrass seed source. In this region, climate change is likely to increase the impacts associated with high cheatgrass density and biomass, such as shortened fire return intervals, at high elevations where this species is not yet problematic.

Germino, Matthew J., Keith Reinhardt, David Pilliod, Diane Debinski, Ann Marie Raymondi, Martha Brabec, Lar Svenson, Jess Vander Veen, and Alex Suazo. 2014. **Sagebrush ecosystems in a changing climate.** Final Report: 2014-10-21. U.S. Department of the Interior, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center. Available at https://nccwsc.usgs.gov/display-project/4f8c64d2e4b0546c0c397b46/5006eb3ee4b0abf7ce733f5a.

Abstract. Climate responses of sagebrush are needed to inform land managers on the stability and restoration of sagebrush ecosystems, which are an important but threatened habitat type. We evaluated climate responses of sagebrush using two approaches: 1) experimental manipulations of temperature and precipitation for natural plants in the field, and 2) assessment of how climate adaptation and weather have affected sagebrush seeding efforts on nearly 25 large-scale sagebrush seeding projects done over the past several decades. Experimental warming increased growth of sagebrush in high-elevation meadows in the Teton Mountains, but had marginal or no effects at lower elevations sites (near Twin Falls and Boise, Idaho, respectively). Increased precipitation enhanced sagebrush abundance, along with flowering and stem growth, particularly when added in winter on deep soils. In the post-fire seeding study, we found sagebrush abundances to be highly variable across different seeding projects, and the variation was partly related to the climate of seeding and seed-source sites, and weather. Sagebrush seeds typically traveled hundreds of km and nearly 1000 m downhill from seed source/origins to seeding sites, from sites with colder minimum temperatures than the seeding sites. Big sagebrush is comprised of subspecies that differ in their climate adaptation, and many seeding projects received a subspecies that differed from the native type requested by the land managers. These climate transfers appeared important to the success of seedings: successful seedings imported seeds from sites having the same minimum temperatures. In failed seedings, seeds originated from relatively colder sites and, moreover, years having relatively warm minimum temperatures prevailed following planting. These results suggest minimum temperature and

winter precipitation responses are important factors in the climate adaptation and ecology of this desert shrub, and their consideration in climate vulnerability analyses and selection of seed sources is likely to improve land planning and restoration.

Prevéy, J. S., Seastedt, T. R. 2014. **Seasonality of precipitation interacts with exotic species to alter composition and phenology of a semi-arid grassland.** Journal of Ecology, 102: 1549–1561. doi: 10.1111/1365-2745.12320

Abstract. 1. While modelling efforts suggest that invasive species will track climate changes, empirical studies are few. A relevant and largely unaddressed research question is 'How will the presence of exotic species interact with precipitation change to alter ecosystem structure and function?'

2. We studied the effects of changes in seasonal timing of precipitation on species composition and resource availability in a grassland community in Colorado, USA. We examined how seasonal precipitation patterns affect the abundance of historically present (native) and recently arrived (exotic) plant species, as well as soil moisture, nitrogen and above-ground biomass. Over 4 years, we applied four precipitation treatments based on climate model predictions for the study area: winter-wet/summer-ambient, winter-wet/summer-dry, winter-wet/summer-wet and winter-dry/summer-wet.

3. Cover of exotic winter-active grasses was greater in winter-wet treatments than in control or winter-dry treatments. Cover of native warm-season grasses and forbs was greatest in the winter-dry/summer-wet treatment, and lowest in the winter-wet/summer-dry treatment. These results support the expectation that increased winter precipitation benefits new arrivals, whereas increased summer precipitation benefits later-growing native plants.

4. Structural equation models showed that interactive effects of increased winter precipitation and increased cover of winter-active grasses reduced growing season soil water content and species diversity. In addition, the dominant winter-active species, Bromus tectorum, flowered and senesced earlier in plots receiving increased winter precipitation and reduced summer precipitation, suggesting that earlier growth of winter-active grasses decreases available soil resources and impacts later-growing native plants. Peak above-ground biomass was lowest in the treatment receiving reduced summer precipitation, but only in years with dry springs. Plant-available

nitrogen in spring was lower in plots receiving supplemental winter precipitation, and highest in plots with reduced winter precipitation.

5. *Synthesis*. Our results indicate that altering the seasonality of precipitation can have large direct effects on plant community composition and phenology, as well as significant indirect effects, mediated through exotic species, on plant-available resources and plant interactions.

Reeves, M., A. Moreno, K. Bagne, and S. Running. 2014. **Estimating climate change effects on net primary production of rangelands in the United States.** Climatic Change 126:429-442.

Abstract. The potential effects of climate change on net primary productivity (NPP) of U.S. rangelands were evaluated using estimated climate regimes from the A1B, A2 and B2 global change scenarios imposed on the biogeochemical cycling model, Biome-BGC from 2001 to 2100. Temperature, precipitation, vapor pressure deficit, day length, solar radiation, CO_2 enrichment and nitrogen deposition were evaluated as drivers of NPP. Across all three scenarios, rangeland NPP increased by 0.26% $year^{-1}$ (7 kg C ha^{-1} $year^{-1}$) but increases were not apparent until after 2030 and significant regional variation in NPP was revealed. The Desert Southwest and Southwest assessment regions exhibited declines in NPP of about 7% by 2100, while the Northern and Southern Great Plains, Interior West and Eastern Prairies all experienced increases over 25%. Grasslands dominated by warm season (C_4 photosynthetic pathway) species showed the greatest response to temperature while cool season (C_3 photosynthetic pathway) dominated regions responded most strongly to CO_2 enrichment. Modeled NPP responses compared favorably with experimental results from CO_2 manipulation experiments and to NPP estimates from the Moderate Resolution Imaging Spectroradiometer (MODIS). Collectively, these results indicate significant and asymmetric changes in NPP for U.S. rangelands may be expected.

Taylor, K., T. Brummer, L. Rew, M. Lavin, and B. Maxwell. 2014. ***Bromus tectorum* Response to Fire Varies with Climate Conditions.** Ecosystems 17:960-973. DOI: 10.1007/s10021-014-9771-7

Abstract. The invasive annual grass *Bromus tectorum* (cheatgrass) forms a positive feedback with fire in some areas of western North America's sagebrush biome by increasing fire frequency and size, which then increases *B. tectorum* abundance post-fire and dramatically alters ecosystem structure and processes. However, this positive response to fire is not consistent across the sagebrush steppe. Here, we ask whether different climate conditions across the sagebrush biome can explain *B. tectorum's* variable response to fire. We found that climate variables differed significantly between 18 sites where *B. tectorum* does and does not respond positively to fire. A positive response was most likely in areas with higher annual temperatures and lower summer precipitation. We then chose a climatically intermediate site, with intact sagebrush vegetation, to evaluate whether a positive feedback had formed between *B. tectorum* and fire. A chronosequence of recent fires (1–15 years) at the site created a natural replicated experiment to assess abundance of *B. tectorum* and native plants. *B. tectorum* cover did not differ between burned and unburned plots but native grass cover was higher in recently burned plots. Therefore, we found no evidence for a positive feedback between *B. tectorum* and fire at the study site. Our results suggest that formation of a positive *B. tectorum*-fire feedback depends on climate; however, other drivers such as disturbance and native plant cover are likely to further influence local responses of *B. tectorum*. The dependence of *B. tectorum's* response to fire on climate suggests that climate change may expand *B. tectorum's* role as a transformative invasive species within the sagebrush biome.

Fish and Wildlife

Hansson, Lars-Anders, Mattias K. Ekvall, Mikael T. Ekvall, Johan Ahlgren, William Sidemo Holm, Lisa Dessborn, and Christer Brönmark. 2014. **Experimental evidence for a mismatch between insect emergence and waterfowl hatching under increased spring temperatures.** Ecosphere 5:art120. http://dx.doi.org/10.1890/ES14-00133.1

Abstract. By combining a large-scale experimental assessment on timing of insect emergence with long-term monitoring of waterfowl hatching date, we here show that insect emergence is mainly driven by temperature, whereas there is only a weak effect of increasing spring temperatures on inter-annual variability in observations of waterfowl chicks. Hence, a change in timing of the mass-emergence of insects from lakes and wetlands, which is the crucial food source for waterfowl chicks, will likely result in a consumer/resource mismatch in a future climate change perspective. Specifically, we experimentally

show that a moderate increase in temperature of 3°C above ambient, expected to occur within 25–75 years, leads to a considerably (2 weeks) earlier, and more pronounced, peak in insect emergence (*Chironomus* sp). Moreover, by utilizing long-term Citizen Science databases, ranging over several decades, we also show that common waterfowl species are unable to significantly adjust their reproduction to fit future temperature increase. Hence, based on our data we predict a future mismatch between insect emergence and waterfowl species basing their reproduction on temperature. This will have a profound impact on reproductive success and population dynamics of many aquatic birds, as well as on freshwater biodiversity.

Illán, J. G., Thomas, C. D., Jones, J. A., Wong, W.-K., Shirley, S. M. and Betts, M. G. 2014. **Precipitation and winter temperature predict long-term range-scale abundance changes in Western North American birds.** Global Change Biology, 20: 3351–3364. doi: 10.1111/gcb.12642

Abstract. Predicting biodiversity responses to climate change remains a difficult challenge, especially in climatically complex regions where precipitation is a limiting factor. Though statistical climatic envelope models are frequently used to project future scenarios for species distributions under climate change, these models are rarely tested using empirical data. We used long-term data on bird distributions and abundance covering five states in the western US and in the Canadian province of British Columbia to test the capacity of statistical models to predict temporal changes in bird populations over a 32-year period. Using boosted regression trees, we built presence-absence and abundance models that related the presence and abundance of 132 bird species to spatial variation in climatic conditions. Presence/absence models built using 1970–1974 data forecast the distributions of the majority of species in the later time period, 1998–2002 (mean AUC = 0.79 ± 0.01). Hindcast models performed equivalently (mean AUC = 0.82 ± 0.01). Correlations between observed and predicted abundances were also statistically significant for most species (forecast mean Spearman's ρ = 0.34 ± 0.02, hindcast = 0.39 ± 0.02). The most stringent test is to test predicted changes in geographic patterns through time. Observed changes in abundance patterns were significantly positively correlated with those predicted for 59% of species (mean Spearman's ρ = 0.28 ± 0.02, across all species). Three precipitation variables (for the wettest month, breeding season, and driest month) and minimum temperature of the coldest month were the most important predictors of bird distributions and abundances in this region, and hence of abundance

changes through time. Our results suggest that models describing associations between climatic variables and abundance patterns can predict changes through time for some species, and that changes in precipitation and winter temperature appear to have already driven shifts in the geographic patterns of abundance of bird populations in western North America.

Soils and Hydrology

Bradford, J. B., Schlaepfer, D. R., Lauenroth, W. K., Burke, I. C. 2014. **Shifts in plant functional types have time-dependent and regionally variable impacts on dryland ecosystem water balance.** Journal of Ecology, 102: 1408–1418. doi: 10.1111/1365-2745.12289

Abstract. 1. Terrestrial vegetation influences hydrologic cycling. In water-limited, dryland ecosystems, altered ecohydrology as a consequence of vegetation change can impact vegetation structure, ecological functioning and ecosystem services. Shrub steppe ecosystems dominated by big sagebrush (Artemisia tridentata) are widespread across western North America, and provide a range of ecosystem services. While sagebrush abundance in these ecosystems has been altered over the past century, and changes are likely to continue, the ecohydrological consequences of sagebrush removal and reestablishment remain unclear.

2. To characterize the immediate and medium-term patterns of water cycling and availability following sagebrush plant community alteration, we applied the SOILWAT ecosystem water balance model to 898 sites across the distribution of sagebrush ecosystems, representing the three primary sagebrush ecosystem types: sagebrush shrublands, sagebrush steppe and montane sagebrush. At each site, we examined three vegetation conditions representing intact sagebrush, recently disturbed sagebrush and recovered but grass-dominated vegetation.

3. Transition from shrub to grass dominance decreased precipitation interception and transpiration and increased soil evaporation and deep drainage. Relative to intact sagebrush vegetation, simulated soils in the herbaceous vegetation phases typically had drier surface layers and wetter deep layers.

4. Our simulations suggested that alterations in ecosystem water balance may be most pronounced in vegetation representing recently

disturbed conditions (herbaceous vegetation with low biomass) and only modest in conditions representing recovered, but still grass-dominated vegetation. Furthermore, the ecohydrological impact of simulated sagebrush removal depended on climate; while short-term changes in water balance were greatest in wet areas represented by the montane sagebrush ecosystem type, medium-term impacts were greatest in dry areas of sagebrush shrublands and sagebrush steppe.

5. *Synthesis*. This study provides a novel, regional-scale assessment of how plant functional type transitions may impact ecosystem water balance in sagebrush-dominated ecosystems of North America. Results illustrate that the ecohydrological consequences of changing vegetation depend strongly on climate and suggest that decreasing woody plant abundance may have only limited impact on evapotranspiration and water yield.

Cong, W.-F., van Ruijven, J., Mommer, L., De Deyn, G. B., Berendse, F., Hoffland, E. 2014. **Plant species richness promotes soil carbon and nitrogen stocks in grasslands without legumes.** Journal of Ecology, 102: 1163–1170. doi: 10.1111/1365-2745.12280

Abstract. 1. The storage of carbon (C) and nitrogen (N) in soil is important ecosystem functions. Grassland biodiversity experiments have shown a positive effect of plant diversity on soil C and N storage. However, these experiments all included legumes, which constitute an important N input through N_2-fixation. Indeed, the results of these experiments suggest that N_2 fixation by legumes is a major driver of soil C and N storage.

2. We studied whether plant diversity affects soil C and N storage in the absence of legumes. In an 11-year grassland biodiversity experiment without legumes, we measured soil C and N stocks. We further determined above-ground biomass productivity, standing root biomass, soil organic matter decomposition and N mineralization rates to understand the mechanisms underlying the change in soil C and N stocks in relation to plant diversity and their feedbacks to plant productivity.

3. We found that soil C and N stocks increased by 18% and 16% in eight-species mixtures compared to the average of monocultures of the same species, respectively. Increased soil C and N stocks were mainly driven by increased C input and N retention, resulting from enhanced plant productivity, which surpassed enhanced C loss from decomposition. Importantly, higher soil C and N stocks were

associated with enhanced soil N mineralization rates, which can explain the strengthening of the positive diversity–productivity relationship observed in the last years of the experiment.

4. *Synthesis*. We demonstrated that also in the absence of legumes, plant species richness promotes soil carbon (C) and nitrogen (N) stocks via increased plant productivity. In turn, enhanced soil C and N stocks showed a positive feedback to plant productivity via enhanced N mineralization, which could further accelerate soil C and N storage in the long term.

Creed, I. F., Spargo, A. T., Jones, J. A., Buttle, J. M., Adams, M. B., Beall, F. D., Booth, E. G., Campbell, J. L., Clow, D., Elder, K., Green, M. B., Grimm, N. B., Miniat, C., Ramlal, P., Saha, A., Sebestyen, S., Spittlehouse, D., Sterling, S., Williams, M. W., Winkler, R. and Yao, H. 2014. **Changing forest water yields in response to climate warming: results from long-term experimental watershed sites across North America.** Global Change Biology, 20: 3191–3208. doi: 10.1111/gcb.12615

Abstract. Climate warming is projected to affect forest water yields but the effects are expected to vary. We investigated how forest type and age affect water yield resilience to climate warming. To answer this question, we examined the variability in historical water yields at long-term experimental catchments across Canada and the United States over 5-year cool and warm periods. Using the theoretical framework of the Budyko curve, we calculated the effects of climate warming on the annual partitioning of precipitation (P) into evapotranspiration (ET) and water yield. Deviation (d) was defined as a catchment's change in actual ET divided by P [AET/P; evaporative index (EI)] coincident with a shift from a cool to a warm period – a positive d indicates an upward shift in EI and smaller than expected water yields, and a negative d indicates a downward shift in EI and larger than expected water yields. Elasticity was defined as the ratio of interannual variation in potential ET divided by P (PET/P; dryness index) to interannual variation in the EI – high elasticity indicates low d despite large range in drying index (i.e., resilient water yields), low elasticity indicates high d despite small range in drying index (i.e., nonresilient water yields). Although the data needed to fully evaluate ecosystems based on these metrics are limited, we were able to identify some characteristics of response among forest types. Alpine sites showed the greatest sensitivity to climate warming with any warming leading to increased water yields. Conifer forests included catchments with lowest elasticity and stable to larger water yields.

Deciduous forests included catchments with intermediate elasticity and stable to smaller water yields. Mixed coniferous/deciduous forests included catchments with highest elasticity and stable water yields. Forest type appeared to influence the resilience of catchment water yields to climate warming, with conifer and deciduous catchments more susceptible to climate warming than the more diverse mixed forest catchments.

Delgado-Baquerizo, M., Maestre, F. T., Escolar, C., Gallardo, A., Ochoa, V., Gozalo, B., Prado-Comesaña, A. 2014. **Direct and indirect impacts of climate change on microbial and biocrust communities alter the resistance of the N cycle in a semiarid grassland.** Journal of Ecology, 102: 1592–1605. doi: 10.1111/1365-2745.12303

Abstract. 1. Climate change will raise temperatures and modify precipitation patterns in drylands worldwide, affecting their structure and functioning. Despite the recognized importance of soil communities dominated by mosses, lichens and cyanobacteria (biocrusts) as a driver of nutrient cycling in drylands, little is known on how biocrusts will modulate the resistance (i.e., the amount of change caused by a disturbance) of the N cycle in response to climate change.

2. Here, we evaluate how warming (ambient vs. ˜2.5 °C increase), rainfall exclusion (ambient vs. ˜30% reduction in total annual rainfall) and biocrust cover (incipient vs. well-developed biocrusts) affect multiple variables linked to soil N availability (inorganic and organic N and potential net N mineralization rate) and its resistance to climate change during 4 years in a field experiment. We also evaluate how climate change-induced modifications in biocrust and microbial communities indirectly affect such resistance.

3. Biocrusts promoted the resistance of soil N availability regardless of the climatic conditions considered. However, the dynamics of N availability diverged progressively from their original conditions with warming and/or rainfall exclusion, as both treatments enhanced N availability and promoted the dominance of inorganic over organic N. In addition, the increase in fungal:bacterial ratio and the decrease in biocrust cover observed under warming had a negative indirect effect on the resistance of N cycle variables.

4. *Synthesis*. Our results indicate that climate change will have negative direct and indirect (i.e. through changes in biocrust and microbial communities) impacts on the resistance of the N cycle in dryland soils. While biocrusts can play an important role slowing down

the impacts of climate change on the N cycle due to their positive and continued effects on the resistance of multiple variables from the N cycle, such change will progressively alter N cycling in biocrust-dominated ecosystems, enhancing both N availability and inorganic N dominance.

Girvetz, E., and C. Zganjar. 2014. **Dissecting indices of aridity for assessing the impacts of global climate change.** Climatic Change 126:469-483. DOI: 10.1007/s10584-014-1218-9.

Abstract. There is great interest in understanding how climate change will impact aridity through the interaction of precipitation changes with rising temperatures. The Aridity Index (AI), Climatic Moisture Deficit (CMD), and Climatic Moisture Surplus (CMS) are metrics commonly used to quantify and map patterns in aridity and water cycling. Here we show that these metrics have different patterns of change under future climate—based on an ensemble of nine general circulation climate models—and the different metrics are appropriate for different purposes. Based on these differences between the metrics, we propose that aridity can be dissected into three different types—hydrological (CMS), agricultural (CMD), and meteorological. In doing this, we propose a novel modified version of the Aridity Index, called AI+, that can be useful for assessing changes in meteorological aridity. The AI + is based on the same ratio between precipitation and evapotranspiration as the traditional AI, but unlike the traditional AI, the AI + only accounts for changes to precipitation during months when precipitation is less than reference/potential evapotranspiration (i.e. there is a deficit). Moreover, we show that the traditional AI provides a better estimate of change in moisture surplus driven by changes to precipitation during the wet season, rather than changes in deficit that occur during the drier seasons. These results show that it is important to select the most appropriate metric for assessing climate driven changes in aridity.

Hao, G., Q. Zhuang, J. Pan, Z. Jin, X. Zhu, and S. Liu. 2014. **Soil thermal dynamics of terrestrial ecosystems of the conterminous United States from 1948 to 2008: an analysis with a process-based soil physical model and AmeriFlux data.** Climatic Change 126:135-150. DOI: 10.1007/s10584-014-1196-y.

Abstract. The spatiotemporal distribution characteristics of soil temperature are a significant, but seldom described signal of climate

warming. This study examines the spatiotemporal trends in soil temperature at depths of 10, 20, and 50 cm in the conterminous US during 1948–2008. We find a warming trend of between 0.2 and 0.4 °C at all depths from 1948 to 2008. The lowest soil temperatures are in Colorado and the area where Wyoming, Idaho, and Montana meet. The coastal areas, such as Texas, Florida, and California, experienced the highest soil temperature. In addition, areas that experienced weak cooling in summer soil temperature include Texas, Oklahoma, and Arkansas. Warming was recorded in Arizona, Nevada, and Oregon. In winter, Mississippi, Alabama, and Georgia show a cooling trend, and Montana, North Dakota, and South Dakota have been warming over the 61-year period. Additionally, mix-forest areas experience slightly cooler soil temperature in comparison with air temperature. Shrubland areas experience slightly warmer soil temperature in comparison with air temperature. This study is among the first to analyze the spatiotemporal distribution characteristics of soil temperature in the conterminous US by using multiple site observational data. Improved understanding of the spatially complex responses of soil temperature shall have significant implications for future studies in climate change over the region.

McCabe, G. J., and D. M. Wolock. 2014. **Spatial and temporal patterns in conterminous United States streamflow characteristics.** Geophysical Research Letters 41:6889-6897. doi:10.1002/2014GL061980.

Abstract. Spatial and temporal patterns in annual and seasonal minimum, mean, and maximum daily streamflow values were examined for a set of 516 reference stream gauges located throughout the conterminous United States for the period 1951–2009. Cluster analysis was used to classify the stream gauges into 14 groups based on similarity in their temporal patterns of streamflow. The results indicated that the temporal patterns in flow metrics (1) have strong spatial coherence within each region, (2) are similar among the three annual flow metrics and the four seasonal flow metrics within each region, (3) indicate some small magnitude trends over time, and (4) are only weakly associated with well-known climate indices. We conclude that most of the temporal variability in flow is unpredictable in terms of relations to climate indices and infer that, for the most part, future changes in flow characteristics cannot be predicted by these indices.

Wang, X., Liu, L., Piao, S., Janssens, I. A., Tang, J., Liu, W., Chi, Y., Wang, J. and Xu, S. 2014. **Soil respiration under climate warming: differential response of heterotrophic and autotrophic respiration.** Global Change Biology, 20: 3229–3237. doi: 10.1111/gcb.12620

Abstract. Despite decades of research, how climate warming alters the global flux of soil respiration is still poorly characterized. Here, we use meta-analysis to synthesize 202 soil respiration datasets from 50 ecosystem warming experiments across multiple terrestrial ecosystems. We found that, on average, warming by 2 °C increased soil respiration by 12% during the early warming years, but warming-induced drought partially offset this effect. More significantly, the two components of soil respiration, heterotrophic respiration and autotrophic respiration showed distinct responses. The warming effect on autotrophic respiration was not statistically detectable during the early warming years, but nonetheless decreased with treatment duration. In contrast, warming by 2 °C increased heterotrophic respiration by an average of 21%, and this stimulation remained stable over the warming duration. This result challenged the assumption that microbial activity would acclimate to the rising temperature. Together, our findings demonstrate that distinguishing heterotrophic respiration and autotrophic respiration would allow us better understand and predict the long-term response of soil respiration to warming. The dependence of soil respiration on soil moisture condition also underscores the importance of incorporating warming-induced soil hydrological changes when modeling soil respiration under climate change.

Fire

Guyette, Richard P.; Thompson, Frank R.; Whittier, Jodi; Stambaugh, Michael C.; Dey, Daniel C. 2014. **Future Fire Probability Modeling with Climate Change Data and Physical Chemistry.** Forest Science 60(5): 862-870.

Abstract. Climate has a primary influence on the occurrence and rate of combustion in ecosystems with carbon-based fuels such as forests and grasslands. Society will be confronted with the effects of climate change on fire in future forests. There are, however, few quantitative appraisals of how climate will affect wildland fire in the United States. We demonstrated a method for estimating changes in fire probability based on future climate simulations of temperature and precipitation.

The probability of a fire occurring in a particular climate was extracted from the Physical Chemistry Fire Frequency Model (PC2FM) and represented the rate of change in fire due to climate. Climate output data from two global climate models (GCMs) were applied to the PC2FM to estimate changes in fire probability. We calculated change in fire frequency and probabilities from the difference between current and future climates and mapped climate-forced percentage change in fire probability under each GCM for the nation at a 1.2 km^2 scale. Future fire probability estimates increased in cooler northern and high elevation regions but decreased slightly in some hotter and drier regions of the southwestern United States. Our approach's greatest strength may be reliance on only climate data and the simple principles of physical chemistry; many other nonclimatic factors that affect fire are often difficult to predict in the distant future.

Pausas, J., and J. Keeley. 2014. **Abrupt Climate-Independent Fire Regime Changes.** Ecosystems 17:1109-1120. DOI: 10.1007/s10021-014-9773-5

Abstract. Wildfires have played a determining role in distribution, composition and structure of many ecosystems worldwide and climatic changes are widely considered to be a major driver of future fire regime changes. However, forecasting future climatic change induced impacts on fire regimes will require a clearer understanding of other drivers of abrupt fire regime changes. Here, we focus on evidence from different environmental and temporal settings of fire regimes changes that are not directly attributed to climatic changes. We review key cases of these abrupt fire regime changes at different spatial and temporal scales, including those directly driven (i) by fauna, (ii) by invasive plant species, and (iii) by socio-economic and policy changes. All these drivers might generate non-linear effects of landscape changes in fuel structure; that is, they generate fuel changes that can cross thresholds of landscape continuity, and thus drastically change fire activity. Although climatic changes might contribute to some of these changes, there are also many instances that are not primarily linked to climatic shifts. Understanding the mechanism driving fire regime changes should contribute to our ability to better assess future fire regimes.

Romps, D. M., J. T. Seeley, D. Vollaro, and J. Molinari. 2014. **Projected increase in lightning strikes in the United States due to global warming.** Science 346:851-854. DOI: 10.1126/science.1259100

Abstract. Lightning plays an important role in atmospheric chemistry and in the initiation of wildfires, but the impact of global warming on lightning rates is poorly constrained. Here we propose that the lightning flash rate is proportional to the convective available potential energy (CAPE) times the precipitation rate. Using observations, the product of CAPE and precipitation explains 77% of the variance in the time series of total cloud-to-ground lightning flashes over the contiguous United States (CONUS). Storms convert CAPE times precipitated water mass to discharged lightning energy with an efficiency of 1%. When this proxy is applied to 11 climate models, CONUS lightning strikes are predicted to increase 12 ± 5% per degree Celsius of global warming and about 50% over this century.

Stavros, E. N., J. Abatzoglou, D. McKenzie, and N. Larkin. 2014. **Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous Western United States.** Climatic Change 126:455-468. DOI: 10.1007/s10584-014-1229-6.

Abstract. Seasonal changes in the climatic potential for very large wildfires (VLWF ≥ 50,000 ac ~ 20,234 ha) across the western contiguous United States are projected over the 21st century using generalized linear models and downscaled climate projections for two representative concentration pathways (RCPs). Significant ($p \leq 0.05$) increases in VLWF probability for climate of the mid-21st century (2031–2060) relative to contemporary climate are found, for both RCP 4.5 and 8.5. The largest differences are in the Eastern Great Basin, Northern Rockies, Pacific Northwest, Rocky Mountains, and Southwest. Changes in seasonality and frequency of VLWFs d7epend on changes in the future climate space. For example, flammability-limited areas such as the Pacific Northwest show that (with high model agreement) the frequency of weeks with VLWFs in a given year is 2–2.7 more likely. However, frequency of weeks with at least one VLWF in fuel-limited systems like the Western Great Basin is 1.3 times more likely (with low model agreement). Thus, areas where fire is directly associated with hot and dry climate, as opposed to experiencing lagged effects from previous years, experience more change in the likelihood of VLWF in future projections. The results provide a quantitative foundation for management to mitigate the effects of VLWFs.

Stavros, E. N., J. Abatzoglou, N. K. Larkin, D. McKenzie, and E. A. Steel. 2014. **Climate and very large wildland fires in the contiguous western USA.** International Journal of Wildland Fire 23:899-914.

Abstract. Very large wildfires can cause significant economic and environmental damage, including destruction of homes, adverse air quality, firefighting costs and even loss of life. We examine how climate is associated with very large wildland fires (VLWFs ≥50,000 acres, or ~20,234 ha) in the western contiguous USA. We used composite records of climate and fire to investigate the spatial and temporal variability of VLWF–climatic relationships. Results showed quantifiable fire weather leading up and up to 3 weeks post VLWF discovery, thus providing predictors of the probability that VLWF occurrence in a given week. Models were created for eight National Interagency Fire Center Geographic Area Coordination Centers (GACCs). Accuracy was good (AUC > 0.80) for all models, but significant fire weather predictors of VLWFs vary by GACC, suggesting that broad-scale ecological mechanisms associated with wildfires also vary across regions. These mechanisms are very similar to those found by previous analyses of annual area burned, but this analysis provides a means for anticipating VLWFs specifically and thereby the timing of substantial area burned within a given year, thus providing a quantifiable justification for proactive fire management practices to mitigate the risk and associated damage of VLWFs.

Adaptation

Dymond, Caren C., Sinclair Tedder, David L. Spittlehouse, Brian Raymer, Katherine Hopkins, Katharine McCallion, and James Sandland. 2014. **Diversifying managed forests to increase resilience.** Canadian Journal of Forest Research 44:1196-1205. DOI: 10.1139/cjfr-2014-0146

Abstract. In British Columbia, Canada, a recent epidemic of mountain pine beetle (*Dendroctonus ponderosae* Hopkins, 1902) caused widespread forest mortality. This epidemic was due in part to the changing climate, and damage from pests and diseases is expected to increase in the future. Therefore, we used a historical retrospective

approach as a proxy to evaluate management options on reducing the forest health damage that may occur under a future changing climate. We assessed two landscape-scale strategies, intended to increase tree species diversity, for the response in ecosystem resilience and compared the results with the business-as-usual strategy. The assessment was based on simulation modelling of the Merritt Timber Supply Area for 1980–2060. We applied a strategy to increase the harvest of the most dominant tree species, plant more diverse species, and increase natural regeneration. This strategy resulted in greater ecological resilience (higher diversity and growing stocks), higher harvest rates, and higher, more consistent net revenue over time than the business-as-usual strategy or the strategy that only employed a diversity of planting. A sensitivity analysis indicated a high level of robustness in the results. Our study showed that it may not be necessary to compromise economic viability to reduce forest health risks and consequently improve socio-ecological resilience.

Rannow, Sven, Nicholas A. Macgregor, Juliane Albrecht, Humphrey Q. P. Crick, Michael Förster, Stefan Heiland, Georg Janauer, Mike D. Morecroft, Marco Neubert, Anca Sarbu, and Jadwiga Sienkiewicz. **Managing Protected Areas Under Climate Change: Challenges and Priorities.** Environmental Management 54(4): 732-743. DOI: 10.1007/s00267-014-0271-5

Abstract. The implementation of adaptation actions in local conservation management is a new and complex task with multiple facets, influenced by factors differing from site to site. A transdisciplinary perspective is therefore required to identify and implement effective solutions. To address this, the International Conference on Managing Protected Areas under Climate Change brought together international scientists, conservation managers, and decision-makers to discuss current experiences with local adaptation of conservation management. This paper summarizes the main issues for implementing adaptation that emerged from the conference. These include a series of conclusions and recommendations on monitoring, sensitivity assessment, current and future management practices, and legal and policy aspects. A range of spatial and temporal scales must be considered in the implementation of climate-adapted management. The adaptation process must be area-specific and consider the ecosystem and the social and economic conditions within and beyond protected area boundaries. However, a strategic overview is also needed: management at each site should be informed by conservation priorities and likely impacts of climate change at regional or even wider scales. Acting across these levels will be a long and continuous process, requiring coordination with actors outside the "traditional" conservation sector. To achieve this, a range of research, communication, and policy/legal actions is required. We identify a series of important actions that need to be taken at different scales to enable managers of protected sites to adapt successfully to a changing climate.

Wimberly, M. C., and Z. Liu. 2014. **Interactions of climate, fire, and management in future forests of the Pacific Northwest.** Forest Ecology and Management 327:270-279. doi:10.1016/j.foreco.2013.09.043

Abstract. A longer, hotter, and drier fire season is projected for the Pacific Northwest under future climate scenarios, and the area burned by wildfires is projected to increase as a result. Fuel treatments are an important management tool in the drier forests of this region where they have been shown to modify fire behavior and fire effects, yet we know relatively little about how treatments will interact with changing climate and expanding human populations to influence fire regimes and ecosystem services over larger area and longer time periods. As a step toward addressing this knowledge gap, this paper synthesizes the recent literature on climate, fire, and forest management in the Pacific Northwest to summarize projected changes and assess how forest management can aid in adapting to future fire regimes and reducing their negative impacts. Increased wildfire under future climates has the potential to affect many ecosystem services, including wildlife habitat, carbon sequestration, and water and air quality. Fuel treatments in dry forest types can reduce fire severity and size, and strategically-placed treatments can help to protect both property and natural resources from wildfire. Although increased rates of burning are projected to reduce carbon stocks across the region, research to date suggests that fuel treatments are unlikely to result in significant increases in carbon storage. Prescribed burning combined with thinning has been demonstrated to be effective at reducing fire severity across a variety of dry forest types, but there is uncertainty about whether changing climate and increasing human encroachment into the wildland–urban interface will limit the use of prescribed fire in the future. Most fire research has focused on the dry forest types, and much less is known about the ecological impacts of increased wildfire activity in the moist forests and the potential for adapting to these changes through forest management. To address these knowledge gaps, future research efforts should build on the Pacific Northwest's legacy of integrated regional assessments to incorporate broad-scale climatic drivers with processes operating at the stand and landscape

levels, including vegetation succession, fire spread, treatment effects, and the expansion of human populations into wildland areas. An important outcome of this type of research would be the identification of localized "hot spots" that are most sensitive to future changes, and are where limited resources for fire management should be concentrated.