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Climate Projections

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.pdf.

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/).

Carbon and Carbon Storage

Beckman, N. D., and E. Wohl. 2014. **Carbon storage in mountainous headwater streams: The role of old-growth forest and logjams.** Water Resources Research 50: 2376–2393. doi:10.1002/2013WR014167.

Abstract. We measured wood piece characteristics and particulate organic matter (POM) in stored sediments in 30 channel-spanning logjams along headwater streams in the Colorado Front Range, USA. Logjams are on streams flowing through old-growth (>200 years), disturbed (<200 years, natural disturbance), or altered (<200 years, logged) subalpine conifer forest. We examined how channel-spanning logjams influence riverine carbon storage (measured as the total volatile carbon fraction of stored sediment and instream wood). Details of carbon storage associated with logjams reflect age and disturbance history of the adjacent riparian forest. A majority of the carbon within jams is stored as wood. Wood volume is significantly larger in old-growth and disturbed reaches than in altered reaches. Carbon storage also differs in relation to forest characteristics. Sediment from old-growth streams has significantly higher carbon content than altered streams. Volume of carbon stored in jam sediment correlates with jam wood volume in old-growth and disturbed forests, but not in altered forests. Forest stand age and wood volume within a jam explain 43% of the variation of carbon stored in jam sediment. First-order estimates of the amount of carbon stored within a stream reach show an order of magnitude difference between disturbed and altered reaches. Our first-order estimates of reach-scale riverine carbon storage suggest that the carbon per hectare stored in streams is on the same order of magnitude as the carbon stored as dead biomass in terrestrial subalpine forests of the region. Of particular importance, old-growth forest correlates with more carbon storage in rivers.

Friend, A. D., W. Lucht, T. T. Rademacher, R. Keribin, R. Betts, P. Cadule, P. Ciais, D. B. Clark, R. Dankers, P. D. Falloon, A. Ito, R. Kahana, A. Kleidon, M. R. Lomas, K. Nishina, S. Ostberg, R. Pavlick, P. Peylin, S. Schaphoff, N. Vuichard, L. Warszawski, A. Wiltshire, and F. I. Woodward. 2014. **Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO_2.** Proceedings of the National Academy of Sciences 111:3280-3285. doi: 10.1073/pnas.1222477110

Abstract. Future climate change and increasing atmospheric CO_2 are expected to cause major changes in vegetation structure and function over large fractions of the global land surface. Seven global vegetation models are used to analyze possible responses to future climate simulated by a range of general circulation models run under all four representative concentration pathway scenarios of changing concentrations of greenhouse gases. All 110 simulations predict an increase in global vegetation carbon to 2100, but with substantial variation between vegetation models. For example, at 4 °C of global land surface warming (510–758 ppm of CO_2), vegetation carbon increases by 52–477 Pg C (224 Pg C mean), mainly due to CO_2 fertilization of photosynthesis. Simulations agree on large regional increases across much of the boreal forest, western Amazonia, central Africa, western China, and southeast Asia, with reductions across southwestern North America, central South America, southern Mediterranean areas, southwestern Africa, and southwestern Australia. Four vegetation models display discontinuities across 4 °C of warming, indicating global thresholds in the balance of positive and negative influences on productivity and biomass. In contrast to previous global vegetation model studies, we emphasize the importance of uncertainties in projected changes in carbon residence times. We find, when all seven models are considered for one representative concentration pathway × general circulation model combination, such uncertainties explain 30% more variation in modeled vegetation carbon change than responses of net primary productivity alone, increasing to 151% for non-HYBRID4 models. A change in research priorities away from production and toward structural dynamics and demographic processes is recommended.

Gray, A. N., T. R. Whittier, and D. L. Azuma. 2014. **Estimation of Aboveground Forest Carbon Flux in Oregon: Adding Components of Change to Stock-Difference Assessments.** Forest Science 60:317-326.

Abstract. A substantial portion of the carbon (C) emitted by human activity is apparently being stored in forest ecosystems in the Northern Hemisphere, but the magnitude and cause are not precisely understood. Current official estimates of forest C flux are based on a combination of field measurements and other methods. The goal of this study was to improve on existing methods by directly tracking components of change in tree C across a large region using field measurements. We used repeated Forest Inventory and Analysis (FIA) measurements on permanent plots to quantify aboveground live tree C flux over an 11-year period due to land-use change, disturbance, and harvest, on 1,073 plots across 5.96 million ha of nonfederal forestland in Oregon. Land-use change resulted in a 110,000 ha (1.9%) net increase of forestland between 1986 and 1997. However, there was a net loss of 3.4 Tg of live tree C due to land-use change because the forestland lost was more productive than that gained. Live woody C decreased significantly in eastern Oregon (−14.4 Tg), with mortality and harvest exceeding growth, primarily due to severe defoliation by western spruce budworm. However, C stores increased significantly in western Oregon (19.2 Tg) due primarily to large accumulations from growth on nonfederal public lands. We demonstrate that C accounting that uses remeasured probabilistic field sample data can produce detailed estimates of C flux that identify causes and components of change and produce more consistent estimates than alternative approaches.

Hurteau, M. D., T. A. Robards, D. Stevens, D. Saah, M. North, and G. W. Koch. 2014. **Modeling climate and fuel reduction impacts on mixed-conifer forest carbon stocks in the Sierra Nevada, California.** Forest Ecology and Management 315:30-42.

Abstract. Quantifying the impacts of changing climatic conditions on forest growth is integral to estimating future forest carbon balance. We used a growth-and-yield model, modified for climate sensitivity, to quantify the effects of altered climate on mixed-conifer forest growth

in the Lake Tahoe Basin, California. Estimates of forest growth and live tree carbon stocks were made for low and high emission scenarios using four downscaled general circulation model (GCM) projections. The climate scenarios were coupled with a range of commonly-used fuels reduction treatments to quantify the combined effects of these factors on live tree carbon stocks. We compared mid- (2020–2049) and late-21st (2070–2099) century carbon stock estimates with a baseline period of 1970–1999 using common input data across time periods. Recursive partitioning analysis indicates that GCM, forest composition, and simulation period most influence live tree carbon stock changes. Comparison with the late 20th century baseline period shows mixed carbon stock responses across scenarios. Growth varied by species, often with compensatory responses among dominant species that limited changes in total live tree carbon. The influence of wildfire mitigation treatments was relatively consistent with each GCM by emission scenario combination. Treatments that included prescribed fire had greater live tree carbon gains relative to baseline under the scenarios that had overall live tree carbon gains. However, across GCMs the influence of treatments varied considerably among GCM projections, indicating that further refinement of regional climate projections will be required to improve model estimates of fuel manipulations on forest carbon stocks. Additionally, had out simulations included the effects of projected climate changes on increasing wildfire probability, the effects of management treatments on carbon stocks may have been more pronounced because of the influence of treatment on fire severity.

Shryock, B., K. Littke, M. Ciol, D. Briggs, and R. Harrison. 2014. **The effects of urea fertilization on carbon sequestration in Douglas-fir plantations of the coastal Pacific Northwest.** Forest Ecology and Management 318:341-348.

Abstract. If long-term carbon (C) sequestration can be quantifiably attributed to forest plantation nitrogen (N) fertilization, the net C credits could be used to offset the rising cost of fertilization and C released during the production, transportation, and application of N fertilizer and the effect of NO_x volatilized after application. The purpose of our study was to determine the net change in C sequestration following N fertilization of second-growth Douglas-fir (Psuedotsuga menziesii [Mirb.] Franco) plantations in the Pacific Northwest. The C content of the trees, understory vegetation, forest floor, and mineral soil was quantified at age 26–33 at five sites, each with a fertilized plot that received a total of 896–1120 kg N ha^{-1} as urea over 16 years paired with an unfertilized control plot. Tree biomass was estimated

using biometric equations and by subtracting the difference between treatment and control at the year of site establishment from the difference between treatment and control final measurement. Understory vegetation on the fertilized plots contained significantly more C than on the control plots (0.2 Mg C ha^{-1}, S.D. 0.2). Nitrogen fertilization significantly increased C sequestered per tree by 2.2 Mg C ha^{-1} (S.D. 1.8), but there was no significant increase in C sequestered in trees per plot. No significant change was found in forest floor, A horizon, and subsoil C contents due to fertilization. These results indicate that, while there is a greater amount of C stored per tree after fertilization, there was more difficulty in accessing C sequestration in forest plantations due to tree mortality and assumed soil variability between plots.

Stephenson,N. L., A. J. Das, R. Condit, S. E. Russo, P. J. Baker, N. G. Beckman, D. A. Coomes, E. R. Lines, W. K. Morris, N. Rüger, E. Álvarez, C. Blundo, S. Bunyavejchewin, G. Chuyong, S. J. Davies, Á. Duque, C. N. Ewango, O. Flores, J. F. Franklin, H. R. Grau, Z. Hao, M. E. Harmon, S. P. Hubbell, D. Kenfack, Y. Lin, J.-R. Makana, A. Malizia, L. R. Malizia, R. J. Pabst, N. Pongpattananurak, S.-H. Su, I-F. Sun, S. Tan, D. Thomas, P. J. van Mantgem, X. Wang, S. K. Wiser and M. A. Zavala. 2014. **Rate of tree carbon accumulation increases continuously with tree size.** Nature 507:90-93. doi:10.1038/nature12914.

Abstract. Forests are major components of the global carbon cycle, providing substantial feedback to atmospheric greenhouse gas concentrations. Our ability to understand and predict changes in the forest carbon cycle—particularly net primary productivity and carbon storage—increasingly relies on models that represent biological processes across several scales of biological organization, from tree leaves to forest stands. Yet, despite advances in our understanding of productivity at the scales of leaves and stands, no consensus exists about the nature of productivity at the scale of the individual tree in part because we lack a broad empirical assessment of whether rates of absolute tree mass growth (and thus carbon accumulation) decrease, remain constant, or increase as trees increase in size and age. Here we present a global analysis of 403 tropical and temperate tree species, showing that for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree. The apparent paradoxes of individual tree growth increasing with tree size despite declining leaf-level and stand-level productivity can be explained, respectively, by increases in a tree's total leaf area that outpace declines in productivity per unit of leaf area and, among other factors, age-related reductions in population density. Our results resolve conflicting assumptions about the nature of tree growth, inform efforts to undertand and model forest carbon dynamics, and have additional implications for theories of resource allocation and plant senescence.

Thomey, Michell L.; Ford, Paulette L.; Reeves, Matt C.; Finch, Deborah M.; Litvak, Marcy E.; Collins, Scott L. 2014. **Review of climate change impacts on future carbon stores and management of warm deserts of the United States.** Gen. Tech. Rep. RMRS-GTR-316. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 26 p. Available at http://www.fs.fed.us/rm/pubs/rmrs_gtr316.pdf

Abstract. Reducing atmospheric carbon dioxide (CO2) concentration through enhanced terrestrial carbon storage may help slow or reverse the rate of global climate change. As a result, Federal land management agencies, such as the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior Bureau of Land Management, are implementing management policies to increase carbon storage. However, information on how projected southwestern climate changes might affect the balance between CO2 uptake and loss on semiarid rangelands is not easily accessible to land managers. We summarize studies that focus on key components of carbon exchange, including photosynthesis, soil respiration, and plant productivity, across the warm deserts of North America to determine if common trends exist that can be utilized in management. We also provide an overview of how management practices can influence carbon sequestration in this region and discuss the U.S. Department of Agriculture Forest Service Climate Change Scorecard. Since desertification is projected to increase in the future, management strategies that increase carbon sequestration or decrease carbon loss are especially important. This requires managers to thoughtfully consider management practices that do not impede sequestration during critical times. For a popular version of the GTR see Rangelands February 2014.

Species Range Changes

Anu Eskelinen and Susan Harrison. 2014. **Exotic plant invasions under enhanced rainfall are constrained by soil nutrients and competition.** Ecology 95:682–692. http://dx.doi.org/10.1890/13-0288.1

Abstract. To predict the net impact of climate change on invasions, it is critical to understand how its effects interact with environmental and biotic context. In a factorial field experiment, we examined how increased late-season rainfall influences the growth and reproductive success of two widespread invasive species (*Centaurea solstitialis* and *Aegilops triuncialis*) in heterogeneous Californian grasslands, and, in particular, how its impact depends on habitat type, nutrient addition, and competition with resident species. Rainfall enhancement alone exhibited only weak effects, especially in naturally infertile and relatively uninvaded grasslands. In contrast, watering and fertilization together exhibited highly synergistic effects on both invasive species. However, the benefits of the combined treatment were greatly reduced or offset by the presence of surrounding competitors. Our results highlight the roles of nutrient limitation and biotic resistance by resident competitors in constraining the responses of invasive species to changes in rainfall. In systems with strong environmental control by precipitation, enhanced rainfall may promote invasions mainly under nutrient-rich and disturbed conditions, while having lesser effects on nutrient-poor, native "refuges."

Cahill, A. E., M. E. Aiello-Lammens, M. Caitlin Fisher-Reid, X. Hua, C. J. Karanewsky, H. Y. Ryu, G. C. Sbeglia, F. Spagnolo, J. B. Waldron, and J. J. Wiens. 2014. **Causes of warm-edge range limits: systematic review, proximate factors and implications for climate change.** Journal of Biogeography 41:429-442.

Abstract. *Aim.* The factors that set species range limits underlie many patterns in ecology, evolution, biogeography and conservation. These factors have been the subject of several reviews, but there has been no systematic review of the causes of warm-edge limits (low elevations and latitudes). Understanding these causes is urgent, given that the factors that set these limits might also drive extinction at warm edges as global climate changes. Many authors have suggested that warm-edge limits are set by biotic factors (particularly competition) whereas others have stressed abiotic factors (particularly temperature). We synthesize the known causes of species' warm-edge

range limits, with emphasis on the underlying mechanisms (proximate causes).

Location. Global.

Methods. We systematically searched the literature for studies testing the causes of warm-edge range limits.

Results. We found 125 studies that address the causes of warm-edge limits, from a search including > 4000 studies. Among the species in these studies, abiotic factors are supported more often than biotic factors in setting species range limits at warm edges, in contrast to the widely held view that biotic factors are more important. Studies that test both types of factors support abiotic factors significantly more frequently. In addition, only 23 studies (61 species) identified proximate causes of these limits, and these overwhelmingly support physiological tolerances to abiotic factors (primarily temperature). Only eight species with identified proximate causes were tested for both biotic and abiotic factors, but the majority support abiotic factors.

Main conclusions. Although it is often assumed that warm-edge limits are set by biotic factors, our review shows that abiotic factors are supported more often among the species in these 125 studies. However, few studies both identify proximate causes and test alternative mechanisms, or examine the interaction between biotic and abiotic factors. Filling these gaps should be a high priority as warm-edge populations are increasingly driven to extinction by climate change.

Forest Vegetation

Bigelow, S., M. Papaik, C. Caum, and M. North. 2014. **Faster growth in warmer winters for large trees in a Mediterranean-climate ecosystem.** Climatic Change 123:215-224.

Abstract. Large trees (>76 cm breast-height diameter) are vital components of Sierra Nevada/Cascades mixed-conifer ecosystems because of their fire resistance, ability to sequester large amounts of carbon, and role as preferred habitat for sensitive species such as the California spotted owl. To investigate the likely performance of large trees in a rapidly changing climate, we analyzed growth rings of five conifer species against 20th century climate trends from local weather stations. Over the local station period of record, there were no temporal trends in precipitation, but maximum temperatures increased by 0.10 to 0.13 °C/decade (summer and autumn), and minimum temperatures increased by 0.11 to 0.19 °C/decade in all seasons. All species responded positively to precipitation, but more variation was explained by a significant positive response to minimum winter temperatures. High maximum summer temperature adversely affected growth of two species, and maximum spring temperatures in the year prior to ring formation were negatively associated with growth of one species. The strong coherent response to increasing minimum temperatures bodes well for growth of large trees in Sierra/Cascades region mixed conifer forest under continued climatic warming, but these trees will still be under threat by the increased fire intensity that is a indirect effect of warming.

Kaiguang Zhao and Robert B. Jackson. 2014. **Biophysical forcings of land-use changes from potential forestry activities in North America.** Ecological Monographs 84:329–353. http://dx.doi.org/10.1890/12-1705.1

Abstract. Land-use changes through forestry and other activities alter not just carbon storage, but biophysical properties, including albedo, surface roughness, and canopy conductance, all of which affect temperature. This study assessed the biophysical forcings and climatic impact of vegetation replacement across North America by comparing satellite-derived albedo, land surface temperature (LST), and evapotranspiration (ET) between adjacent vegetation types. We calculated radiative forcings (RF) for potential local conversions from croplands (CRO) or grasslands (GRA) to evergreen needleleaf (ENF) or deciduous broadleaf (DBF) forests. Forests generally had lower albedo than adjacent grasslands or croplands, particularly in locations with snow. They also had warmer nighttime LST, cooler daily and daytime LST in warm seasons, and smaller daily LST ranges. Darker forest surfaces induced positive RFs, dampening the cooling effect of carbon sequestration. The mean (±SD) albedo-induced RFs for each land conversion were equivalent to carbon emissions of 2.2 ± 0.7 kg C/m^2 (GRA–ENF), 2.0 ± 0.6 kg C/m^2 (CRO–ENF), 0.90 ± 0.50 kg C/m^2 (CRO–DBF), and 0.73 ± 0.22 kg C/m^2 (GRA–DBF), suggesting that, given the same carbon sequestration potential, a larger net cooling (integrated globally) is expected for planting DBF than ENF. Both changes in LST and ET induce longwave RFs that sometimes had values comparable to or even larger than albedo-induced shortwave RFs. Sensible heat flux, on average, increased when replacing CRO with ENF, but decreased for conversions to DBF, suggesting that DBF tends to cool near-surface air locally while ENF tends to warm it. This local temperature effect showed some seasonal variation and spatial dependence, but did not differ strongly by latitude. Overall, our results

show that a carbon-centric accounting is, in many cases, insufficient for climate mitigation policies. Where afforestation or reforestation occurs, however, deciduous broadleaf trees are likely to produce stronger cooling benefits than evergreen needleleaf trees provide.

Rangeland Vegetation

Bansal, S., J. J. James, and R. L. Sheley. 2014. **The effects of precipitation and soil type on three invasive annual grasses in the western United States.** Journal of Arid Environments 104:38-42.

Abstract. Multiple species of annual grasses are invading sagebrush-steppe communities throughout the western United States. Most research has focused on dominant species such as Bromus tectorum (cheatgrass), yet other, less studied annual grasses such as Taeniatherum caput-medusae (medusahead) and Ventenata dubia (ventenata) are spreading rapidly. Future precipitation regimes are expected to have less frequent but more intense rain events, which may affect soil moisture availability and favor these 'newer' invasives over cheatgrass. We conducted a full factorial, growth chamber study examining the effects of two watering regimes (small/frequent, large/infrequent rain pulses) across nine soil types on the growth of cheatgrass, medusahead and ventenata. We tested a hypothesis that medusahead or ventenata would have greater growth than cheatgrass with larger/infrequent rain events. The two watering regimes had relatively strong effects on soil water content, but generally did not impact plant growth. In contrast, variation in soil properties such as clay content, pH and soil N correlated with a two- to four-fold change in plant growth. The three invasive grass species generally respond similarly to changes in precipitation regimes and to edaphic factors. Nevertheless, medusahead had 30–40% overall greater root growth compared to the other species and a 15% increase in root growth in response to the large/infrequent watering treatment. Our findings reveal that 1) greater biomass allocation to roots and 2) greater responsiveness of root growth to differing precipitation regimes of medusahead may favor its ecological success over other invasive annuals under future climate scenarios.

Borer, Elizabeth T., Eric W. Seabloom, Daniel S. Gruner, W. Stanley Harpole, Helmut Hillebrand, Eric M. Lind, Peter B. Adler, Juan Alberti, T. Michael Anderson, Jonathan D. Bakker, Lori Biederman, Dana Blumenthal, Cynthia S. Brown, Lars A. Brudvig, Yvonne M. Buckley, Marc Cadotte, Chengjin Chu, Elsa E. Cleland, Michael J. Crawley, Pedro Daleo, Ellen I. Damschen, Kendi F. Davies, Nicole M. DeCrappeo, Guozhen Du, Jennifer Firn, Yann Hautier, Robert W. Heckman, Andy Hector, Janneke HilleRisLambers, Oscar Iribarne, Julia A. Klein, Johannes M. H. Knops, Kimberly J. La Pierre, Andrew D. B. Leakey, Wei Li, Andrew S. MacDougall, Rebecca L. McCulley, Brett A. Melbourne, Charles E. Mitchell, Joslin L. Moore, Brent Mortensen, Lydia R. O'Halloran, John L. Orrock, Jesús Pascual, Suzanne M. Prober, David A. Pyke, Anita C. Risch, Martin Schuetz, Melinda D. Smith, Carly J. Stevens, Lauren L. Sullivan, Ryan J. Williams, Peter D. Wragg, Justin P. Wright and Louie H. Yang. 2014. **Herbivores and nutrients control grassland plant diversity via light limitation.** Nature 508: 517-520. doi:10.1038/nature13144.

Abstract. Human alterations to nutrient cycles and herbivore communities are affecting global biodiversity dramatically. Ecological theory predicts these changes should be strongly counteractive: nutrient addition drives plant species loss through intensified competition for light, whereas herbivores prevent competitive exclusion by increasing ground-level light, particularly in productive systems. Here we use experimental data spanning a globally relevant range of conditions to test the hypothesis that herbaceous plant species losses caused by eutrophication may be offset by increased light availability due to herbivory. This experiment, replicated in 40 grasslands on 6 continents, demonstrates that nutrients and herbivores can serve as counteracting forces to control local plant diversity through light limitation, independent of site productivity, soil nitrogen, herbivore type and climate. Nutrient addition consistently reduced local diversity through light limitation, and herbivory rescued diversity at sites where it alleviated light limitation. Thus, species loss from anthropogenic eutrophication can be ameliorated in grasslands where herbivory increases ground-level light.

Evans, R. D., A. Koyama, D. L. Sonderegger, T. N. Charlet, B. A. Newingham, L. F. Fenstermaker, B. Harlow, V. L. Jin, K. Ogle, S. D. Smith, and R. S. Nowak. 2014. **Greater ecosystem carbon in the Mojave Desert after ten years exposure to elevated CO_2.** Nature Climate Change 4:394-397. doi:10.1038/nclimate2184

Abstract. Carbon dioxide is the main greenhouse gas inducing climate change. Increased global CO_2 emissions, estimated at 8.4 Pg C yr^{-1} at present, have accelerated from 1% yr^{-1} during 1990–1999 to 2.5% yr^{-1} during 2000–2009. The carbon balance of terrestrial ecosystems is the greatest unknown in the global C budget because the actual magnitude, location and causes of terrestrial sinks are uncertain; estimates of terrestrial C uptake, therefore, are often based on the residuals between direct measurements of the atmospheric sink and well-constrained models of ocean uptake of CO_2. Here we report significant terrestrial C accumulation caused by CO_2 enhancement to net ecosystem productivity in an intact, undisturbed arid ecosystem following ten years of exposure to elevated atmospheric CO_2. Results provide direct evidence that CO_2 fertilization substantially increases ecosystem C storage and that arid ecosystems are significant, previously unrecognized, sinks for atmospheric CO_2 that must be accounted for in efforts to constrain terrestrial and global C cycles.

Hautier, Yann, Eric W. Seabloom, Elizabeth T. Borer, Peter B. Adler, W. Stanley Harpole, Helmut Hillebrand, Eric M. Lind, Andrew S. MacDougall, Carly J. Stevens, Jonathan D. Bakker, Yvonne M. Buckley, Chengjin Chu, Scott L. Collins, Pedro Daleo, Ellen I. Damschen, Kendi F. Davies, Philip A. Fay, Jennifer Firn, Daniel S. Gruner, Virginia L. Jin, Julia A. Klein, Johannes M. H. Knops, Kimberly J. La Pierre, Wei Li, Rebecca L. McCulley, Brett A. Melbourne, Joslin L. Moore, Lydia R. O'Halloran, Suzanne M. Prober, Anita C. Risch, Mahesh Sankaran, Martin Schuetz and Andy Hector. 2014. **Eutrophication weakens stabilizing effects of diversity in natural grasslands.** Nature 508: 521-524. doi:10.1038/nature13014.

Abstract. Studies of experimental grassland communities have demonstrated that plant diversity can stabilize productivity through species asynchrony, in which decreases in the biomass of some species are compensated for by increases in others. However, it remains unknown whether these findings are relevant to natural ecosystems, especially those for which species diversity is threatened by anthropogenic global change. Here we analyse diversity–stability relationships from 41 grasslands on five continents and examine how these relationships are affected by chronic fertilization, one of the strongest drivers of species loss globally. Unmanipulated communities with more species had greater species asynchrony, resulting in more stable biomass production, generalizing a result from biodiversity experiments to real-world grasslands. However, fertilization weakened the positive effect of diversity on stability. Contrary to expectations, this was not due to species loss after eutrophication but rather to an increase in the temporal variation of productivity in combination with a decrease in species asynchrony in diverse communities. Our results demonstrate separate and synergistic effects of diversity and eutrophication on stability, emphasizing the need to understand how drivers of global change interactively affect the reliable provisioning of ecosystem services in real-world systems.

Peek, James M. 2014. **Annual Changes in Bluebunch Wheatgrass Biomass and Nutrients Related to Climate and Wildfire.** Northwest Science 88(2): 129-139.

Abstract. Current year's growth (biomass) and nutrient levels of bluebunch wheatgrass (*Pseudoroegneria spicata*), a highly palatable bunchgrass in western North America, were evaluated over 20-year and 10-year periods, respectively. Three study sites representing a range of variation in conditions were located on south-facing slopes. Annual biomass ranged from 5.6 to 109.0 gm m^{-2} on individual sites with means for all sites of 42.7 gm m^{-2} (range 17.5–73.3 gm m^{-2}), with April and May precipitation best predicting the variation. Variation was highest on the site lowest in elevation and highest in biomass. A fire in August 2000 that burned all study sites suppressed biomass for the following two years, aided by lower than average precipitation. The highest elevation site had higher mean values of Cu, Mg, N, K, P, S, and Zn than the two lower sites, but the greatest range of values occurred on one of the two lower sites for Ca, Fe, K, Mg, N, P, and S. Combinations of temperature and precipitation predicted Ca, K, N, P, and Zn values, while Cu and Fe were predicted with total monthly precipitation, and Mg and S were predicted with mean monthly temperature. Values of Cu, Fe, K, N, P, S, and Zn were higher than expected for one to two years following the 2000 fire, while Ca and Mg did not show any responses to the fire. Predictions for biomass and nutrient content apply to the range of conditions, temperatures and precipitation observed over the study period. The predictions may be useful in assessing responses to changes in climate, and are helpful in explaining variation in herbivore populations relative to changes in forage quality and quantity.

Poulter, B., D. Frank, P. Ciais, R. B. Myneni, N. Andela, J. Bi, G. Broquet, J. G. Canadell, F. Chevallier, Y. Y. Liu, S. W. Running, S. Sitch, and G. R. van der Werf. 2014. **Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle.** Nature 509:600-603.

Abstract. The land and ocean act as a sink for fossil-fuel emissions, thereby slowing the rise of atmospheric carbon dioxide concentrations. Although the uptake of carbon by oceanic and terrestrial processes has kept pace with accelerating carbon dioxide emissions until now, atmospheric carbon dioxide concentrations exhibit a large variability on interannual timescales, considered to be driven primarily by terrestrial ecosystem processes dominated by tropical rainforests. We use a terrestrial biogeochemical model, atmospheric carbon dioxide inversion and global carbon budget accounting methods to investigate the evolution of the terrestrial carbon sink over the past 30 years, with a focus on the underlying mechanisms responsible for the exceptionally large land carbon sink reported in 2011. Here we show that our three terrestrial carbon sink estimates are in good agreement and support the finding of a 2011 record land carbon sink. Surprisingly, we find that the global carbon sink anomaly was driven by growth of semi-arid vegetation in the Southern Hemisphere, with almost 60 per cent of carbon uptake attributed to Australian ecosystems, where prevalent La Niña conditions caused up to six consecutive seasons of increased precipitation. In addition, since 1981, a six per cent expansion of vegetation cover over Australia was associated with a fourfold increase in the sensitivity of continental net carbon uptake to precipitation. Our findings suggest that the higher turnover rates of carbon pools in semi-arid biomes are an increasingly important driver of global carbon cycle inter-annual variability and that tropical rainforests may become less relevant drivers in the future. More research is needed to identify to what extent the carbon stocks accumulated during wet years are vulnerable to rapid decomposition or loss through fire in subsequent years.

Sheley, R. L., and J. J. James. 2014. **Simultaneous intraspecific facilitation and interspecific competition between native and annual grasses.** Journal of Arid Environments 104:80-87.

Abstract. Invasive annual grasses tend to construct thinner and less dense root and leaf tissue than native perennial grasses. This allows invasive annuals to grow faster and produce more biomass in the arid grasslands of the United States. Based on these differences we tested

the hypotheses that: 1) Competitive effects of the native perennial on the invasive annual will increase as plant developmental stage increases and as drought stress increases. 2) Drought stress will reduce the competitive effect of invasive annuals on native perennials proportionately more than drought stress reduces the competitive effect of native perennials on the invasive annual. 3) Facilitation among native perennial grass seedlings will decrease as developmental stage increases. Competitive effects of native squirreltail, on invasive medusahead, increased as the initial developmental stage of squirreltail increased, but not vice versa. Drought stress reduced the competitive effect of medusahead on squirreltail target biomass more than drought stress reduced the competitive effect of squirreltail on medusahead target biomass. While both squirreltail and medusahead displayed intraspecific facilitation, the net effect of their interspecific interaction was negative for both species. Habitat amelioration manifests itself differently depending on species traits, and can create conditions that simultaneously benefit one species while hindering another.

Simon Chollet, Serge Rambal, Adeline Fayolle, Daniel Hubert, Didier Foulquié, and Eric Garnier. 2014. **Combined effects of climate, resource availability, and plant traits on biomass produced in a Mediterranean rangeland.** Ecology 95:737–748. http://dx.doi.org/10.1890/13-0751.1

Abstract. Biomass production in grasslands, a key component of food provision for domestic herbivores, is known to depend on climate, resource availability, and on the functional characteristics of communities. However, the combined effects of these different factors remain largely unknown. The aim of the present study was to unravel the causes of variations in the standing biomass of plant communities using a long-term experiment conducted in a Mediterranean rangeland of Southern France. Two management regimes, sheep grazing and grazing associated with mineral fertilization, were applied to different areas of the study site over the past 25 years. Abiotic (temperature, available water, nutrients) and biotic (components of the functional structure communities) factors were considered to explain interannual and spatial variations in standing biomass in these rangelands.

Standing biomass was highly predictable, with the best model explaining ~80% of variations in the amount of biomass produced, but the variation explained by abiotic and biotic factors was dependent on the season and on the management regime. Abiotic factors were found to have comparable effects in both management regimes: The amount

of biomass produced in the spring was limited by cold temperatures, while it was limited by water availability and high temperatures in the summer. In the fertilized community, the progressive change in the functional structure of the communities had significant effects on the amount of biomass produced: the dominance of few productive species which were functionally close led to higher peak standing biomass in spring.

Scasta, J. D., and B. S. Rector. 2014. **Drought and Ecological Site Interaction on Plant Composition of a Semi-Arid Rangeland.** Arid Land Research and Management 28:197-215.

Abstract. Fluctuating climatic patterns are increasing the frequency and severity of drought, a concern for native plant communities on grazed semi-arid rangelands. Vegetation successional models have focused on the impact of management and have failed to quantify the effects of extreme drought. From 2001 to 2011, plant community composition was sampled on ecological sites in a semi-arid rangeland managed with conservative grazing and frequent fire since 1937. Ordination and classification were used to assess the interactive effects of ecological site and extreme drought on plant species composition, holding all other external drivers constant. Deeper soil clay loam sites had 4x greater beta diversity than shallower and rockier low stony hill sites, an indication of greater species turnover and instability in response to extreme drought. Cumulative effects of drought years explained similarity between sites and species composition. Response to extreme drought varied by species; no response (*Bouteloua curtipendula*), decreased (*Nassella leucotricha*), and increased (*Bouteloua rigidiseta* and *Eriochloa sericea*). Annual C3 plant responses were explained by short-term drought and perennial C3 and C4 plant responses were explained by long-term drought. Clay loam sites had maximum species richness and diversity values during neutral periods with quadratic declines associated with climatic extremes (dry or wet) compared to the more xeric sites which had minimum species richness and diversity during neutral periods with quadratic increases during climatic extremes. The interaction between site and drought, holding all other external drivers constant, can enhance our understanding of plant community dynamics and secondary plant succession of degraded semi-arid rangelands.

Fish and Wildlife

Boucher-Lalonde, V., F. L. Thériault, and D. J. Currie. 2014. **Can climate explain interannual local extinctions among bird species?** Journal of Biogeography 41:443-451.

Abstract. *Aim.* Geographical variations in species richness are strongly related to temperature and precipitation. On ecological time-scales, these variations in species richness should reflect rates of immigration and local extinction (extirpation). Here we ask whether the probability of local extinction in passerine birds covaries with climate. Specifically, we test whether local extinctions increase with climatic harshness or with the climatic distance from a species' optimal climate.

Location. USA and Canada.

Methods. We obtained bird counts from the North American Breeding Bird Survey (BBS) from 1967 to 2012. For each BBS route, we calculated the probability of interannual local extinction for each of 206 passerine birds. We then used linear mixed-effects models and structural equation modelling to relate local extinction rates to our hypothesized predictor variables: temperature, precipitation and their distance from the species' most occupied temperature and precipitation.

Results. We found that local extinctions are nearly independent of temperature and precipitation: no climate is inherently more extinction-prone than any other. Similarly, the climatic distance from a species' maximally occupied temperature and precipitation has only an extremely weak positive effect on the probability of local extinction. We found that only abundance has a strong negative effect on the probability of local extinction.

Main conclusions. Although variations in local extinctions are typically spatially structured, we conclude that they are not related to contemporary climate in a consistent way among species. Broad-scale geographical gradients of species richness are unlikely to be driven by higher extinction rates in climatically harsh areas.

Pearson, R. G., J. C. Stanton, K. T. Shoemaker, M. E. Aiello-Lammens, P. J. Ersts, N. Horning, D. A. Fordham, C. J. Raxworthy, H. Y. Ryu, J. McNees, and H. R. Akcakaya. 2014. **Life history and spatial traits predict extinction risk due to climate change.** Nature Climate Change 4:217-221. doi:10.1038/nclimate2113

Abstract. There is an urgent need to develop effective vulnerability assessments for evaluating the conservation status of species in a changing climate. Several new assessment approaches have been proposed for evaluating the vulnerability of species to climate change based on the expectation that established assessments such as the IUCN Red List need revising or superseding in light of the threat that climate change brings. However, although previous studies have identified ecological and life history attributes that characterize declining species or those listed as threatened, no study so far has undertaken a quantitative analysis of the attributes that cause species to be at high risk of extinction specifically due to climate change. We developed a simulation approach based on generic life history types to show here that extinction risk due to climate change can be predicted using a mixture of spatial and demographic variables that can be measured in the present day without the need for complex forecasting models. Most of the variables we found to be important for predicting extinction risk, including occupied area and population size, are already used in species conservation assessments, indicating that present systems may be better able to identify species vulnerable to climate change than previously thought. Therefore, although climate change brings many new conservation challenges, we find that it may not be fundamentally different from other threats in terms of assessing extinction risks.

Ryan, Maureen E, Wendy J Palen, Michael J Adams, and Regina M Rochefort. 2014. **Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US.** Frontiers in Ecology and the Environment 12: 232–240. http://dx.doi.org/10.1890/130145

Abstract. Wetlands in the remote mountains of the western US have undergone two massive ecological “experiments” spanning the 20th century. Beginning in the late 1800s and expanding after World War II, fish and wildlife managers intentionally introduced millions of predatory trout (primarily Oncorhynchus spp) into fishless mountain ponds and lakes across the western states. These new top predators, which now occupy 95% of large mountain lakes, have limited the habitat distributions of native frogs, salamanders, and wetland

invertebrates to smaller, more ephemeral ponds where trout do not survive. Now a second “experiment” – anthropogenic climate change – threatens to eliminate many of these ephemeral habitats and shorten wetland hydroperiods. Caught between climate-induced habitat loss and predation from introduced fish, native mountain lake fauna of the western US – especially amphibians – are at risk of extirpation. Targeted fish removals, guided by models of how wetlands will change under future climate scenarios, provide innovative strategies for restoring resilience of wetland ecosystems to climate change.

Sacha M. O'Regan, Wendy J. Palen, and Sean C. Anderson. 2014. **Climate warming mediates negative impacts of rapid pond drying for three amphibian species.** Ecology 95:845–855. http://dx.doi.org/10.1890/13-0916.1

Abstract. Anthropogenic climate change will present both opportunities and challenges for pool-breeding amphibians. Increased water temperature and accelerated drying may directly affect larval growth, development, and survival, yet the combined effects of these processes on larvae with future climate change remain poorly understood. Increased surface temperatures are projected to warm water and decrease water inputs, leading to earlier and faster wetland drying. So it is often assumed that larvae will experience negative synergistic impacts with combined warming and drying. However, an alternative hypothesis is that warming-induced increases in metabolic rate and aquatic resource availability might compensate for faster drying rates, generating antagonistic larval responses. We conducted a mesocosm experiment to test the individual and interactive effects of pool permanency (permanent vs. temporary) and water temperature (ambient vs. +~3°C) on three anurans with fast-to-slow larval development rates (Great Basin spadefoot [*Spea intermontana*], Pacific chorus frog [*Pseudacris regilla*], and northern red-legged frog [*Rana aurora*]). We found that although tadpoles in warmed pools reached metamorphosis 15–17 days earlier, they did so with little cost (<2 mm) to size, likely due to greater periphyton growth in warmed pools easing drying-induced resource competition. Warming and drying combined to act antagonistically on early growth ($P = 0.06$) and survival ($P = 0.06$), meaning the combined impact was less than the sum of the individual impacts. Warming and drying acted additively on time to and size at metamorphosis. These nonsynergistic impacts may result from cotolerance of larvae to warming and drying, as well as warming helping to offset negative impacts of drying. Our results indicate that combined pool warming and drying may not always be harmful for larval amphibians. However, they also demonstrate that antagonistic responses are difficult to predict, which poses a challenge to proactive conservation and management. Our study highlights the importance of considering the nature of multiple stressor interactions as amphibians are exposed to an increasing number of anthropogenic threats.

Zimova, M., L. S. Mills, P. M. Lukacs, and M. S. Mitchell. 2014. **Snowshoe hares display limited phenotypic plasticity to mismatch in seasonal camouflage.** Proceedings of the Royal Society B: Biological Sciences 281. doi: 10.1098/rspb.2014.0029

Abstract. As duration of snow cover decreases owing to climate change, species undergoing seasonal colour moults can become colour mismatched with their background. The immediate adaptive solution to this mismatch is phenotypic plasticity, either in phenology of seasonal colour moults or in behaviours that reduce mismatch or its consequences. We observed nearly 200 snowshoe hares across a wide range of snow conditions and two study sites in Montana, USA, and found minimal plasticity in response to mismatch between coat colour and background. We found that moult phenology varied between study sites, likely due to differences in photoperiod and climate, but was largely fixed within study sites with only minimal plasticity to snow conditions during the spring white-to-brown moult. We also found no evidence that hares modify their behaviour in response to colour mismatch. Hiding and fleeing behaviours and resting spot preference of hares were more affected by variables related to season, site and concealment by vegetation, than by colour mismatch. We conclude that plasticity in moult phenology and behaviours in snowshoe hares is insufficient for adaptation to camouflage mismatch, suggesting that any future adaptation to climate change will require natural selection on moult phenology or behaviour.

Soils and Hydrology

Coopersmith, E. J., B. S. Minsker, and M. Sivapalan. 2014. **Patterns of regional hydroclimatic shifts: An analysis of changing hydrologic regimes.** Water Resources Research 50: 1960–1983. doi:10.1002/2012WR013320.

Abstract. Temporal shifts in precipitation and runoff regime curves appear throughout the continental United States, but differ from region to region. This paper explores these regime shifts by building upon a

hydroclimatic classification system that partitions the United States into clusters of similarly behaved catchments using four simple hydroclimatic indicators. Hydroclimate data from over four hundred catchments over a 55 year period (belonging to the MOPEX data set) are analyzed to reveal how the indicators have shifted before and after 1970, before and after 1975, and before and after 1980. Statistically significant hydroclimatic changes in these indicators are explored qualitatively, suggesting which catchments today might resemble other catchments tomorrow. Thus, a preview of current locations in one class under future conditions is provided by observing existing locations of another class. The classification system structure enables organization of these data, allowing patterns of regime change to emerge without highly specified models at each individual site. Regional analyses explore changes in mean seasonal precipitation/runoff regimes, including shifts in the daily variability of precipitation and runoff. Additionally, changes in regime curves of minimum and maximum precipitation/runoff observations are analyzed and discussed. Results indicate that after 1980, classifications typically found in the southeastern quarter of the United States have expanded northward and westward. Regionally, the Midwest and Rocky Mountains seem to demonstrate more frequent, but less intense storms after 1980, while southeastern catchments receive much less water in the form of precipitation and runoff than in previous years.

Dore, S., D. L. Fry, and S. L. Stephens. 2014. **Spatial heterogeneity of soil CO2 efflux after harvest and prescribed fire in a California mixed conifer forest.** Forest Ecology and Management 319:150-160.

Abstract. Spatial variability is a key factor when quantifying soil CO_2 efflux and punctual measurements need to be extended to larger stand, ecosystem, or regional scales. Spatial variation also affects comparisons among ecosystems, as when quantifying effects of disturbances on ecosystem carbon dynamics. However, spatial variability of soil CO_2 efflux is still unknown and difficult to predict. We quantified the effects of silvicultural practices (prescribed fire and harvesting) on spatial variability of soil CO_2 efflux in a mixed conifer forest from the central Sierra Nevada in California, USA. Soil CO_2 efflux was measured using a portable chamber system, on 20–29 locations in four treatment sites: an untreated control, a prescribed fire site (burned in 2002 and 2009) and two clear cut sites harvested in 2010. In one of the harvested sites the soils were mechanically ripped to reduce soil compaction, a common practice done on industrial timber forest lands in the Sierra Nevada. Results showed that disturbance

increased spatial variability of soil CO_2 efflux. Coefficient of variability increased from an annual average of 32% at the control site to 37% at the burned site, and 49–51% at the harvested sites (without and with soil ripping, respectively), mirroring post-disturbance increases in spatial variability of soil temperature and soil water content. Because of the post-harvest increase in spatial variability, the ability to detect differences became lower, and the number of samples needed to obtain a value representative of the full population mean (within a 10% range) increased by 100%, from 60 to 120 samples. To reduce uncertainty in our soil CO_2 efflux treatment estimates, more than 10–15 randomly selected locations per study site were necessary. Spatial variability of soil CO_2 efflux at our sites was not affected by distance between measurement locations, was correlated to fine root and litter biomass at the control site, negatively correlated to soil bulk density at the fire site, and un-correlated to soil temperature and water content at all sites. The increase of spatial variability in soil CO_2 efflux after disturbance and the requirement for a sufficient number of measurement locations should be considered when quantifying carbon dynamics of disturbed ecosystems, or assessing effects of different forest management practices.

Holsinger, L., R. Keane, D. Isaak, L. Eby, and M. Young. 2014. **Relative effects of climate change and wildfires on stream temperatures: a simulation modeling approach in a Rocky Mountain watershed.** Climatic Change 124:191-206.

Abstract. Freshwater ecosystems are warming globally from the direct effects of climate change on air temperature and hydrology and the indirect effects on near-stream vegetation. In fire-prone landscapes, vegetative change may be especially rapid and cause significant local stream temperature increases but the importance of these increases relative to broader changes associated with air temperature and hydrology are not well understood. We linked a spatially explicit landscape fire and vegetation model (FireBGCv2) to an empirical regression equation that predicted daily stream temperatures to explore how climate change and its impacts on fire might affect stream thermal conditions across a partially forested, mountainous landscape in the western U.S. We used the model to understand the roles that wildfire and management actions such as fuel reduction and fire suppression could play in mitigating stream thermal responses to climate change. Results indicate that air temperature increases associated with future climates could account for a much larger proportion of stream temperature increases (as much as 90 % at a basin scale) than wildfire. Similarly, land management scenarios that

limited wildfire prevalence had negligible effects on future stream temperature increases. These patterns emerged at broader spatial scales because wildfires typically affected only a subset of a stream's network. However, at finer spatial and temporal scales stream temperatures were sensitive to wildfire. Although wildfires will continue to cause local, short-term effects on stream temperatures, managers of aquatic systems may need to find other solutions to cope with the larger impact from climate change on future stream warming that involves adapting to the increases while developing broad strategies for riparian vegetation restoration.

Lute, A. C., and J. T. Abatzoglou. 2014. **Role of extreme snowfall events in interannual variability of snowfall accumulation in the western United States.** Water Resources Research 50: 2874–2888. doi:10.1002/2013WR014465.

Abstract. Water resources in the western United States are contingent on interannual variations in snowpack. Interannual snowpack variability has been attributed to large-scale climate patterns including the El Niño-Southern Oscillation (ENSO), however, the contribution of snowfall frequency and extreme snowfall events to this variability are less well quantified. Long-term records from Snowpack Telemetry and Cooperative Observer Program stations in the 11 western states were used to investigate these relationships by considering the number of snowfall days and snowfall water equivalent (SFE) of extreme snowfall events. The top decile of snowfall events contributed 20–38% of annual SFE, depending on the region. An average of 65% and 69% of the interannual variability in annual SFE was explained by snowfall days and SFE of top decile snowfall events, respectively, with extreme events being a more significant predictor at most stations. The latitudinal dipole in SFE during ENSO phases results from changes in snowfall frequency and extreme events. In the Pacific Northwest, above normal SFE during La Niña winters was a product of both larger contributions from extremes and more snowfall days, while below normal SFE during El Niño winters was primarily associated with a substantial reduction in extremes. Conversely, annual SFE during ENSO phases in the mountains of Arizona was more closely linked to fluctuations in snowfall days than extremes. Results indicate the importance of extreme snowfall events in shaping interannual variability in water resources and suggest that improved predictive ability may inform better water resource management now and in the coming decades.

Rocheta, E., M. Sugiyanto, F. Johnson, J. Evans, and A. Sharma. 2014. **How well do general circulation models represent low-frequency rainfall variability?** Water Resources Research 50: 2108–2123. doi:10.1002/2012WR013085.

Abstract. General circulation models (GCMs) provide reliable simulations of global- and continental-scale atmospheric variables, yet have limited skill in simulating variables important for water resource management at regional to catchment scales. GCM simulations suffer from a range of uncertainties leading to transient (changing over time) and systemic (consistent over time) biases in the output when compared to observed records. An important GCM bias in managing water resources infrastructure is the underrepresentation of low-frequency variability a characteristic central to the simulation of floods and droughts. This study presents a performance metric, the aggregated persistence score (APS), which is used to assess the reliability of GCMs in simulating low-frequency rainfall variability. The APS identifies regions where GCMs poorly represent the amount of variability seen in the observed precipitation. This study calculated the APS at monthly aggregations for GCM precipitation as well as GCM precipitation that was bias-corrected to better represent low-frequency variability. It was found that there were (1) large spatial variations in the skill of GCMs to capture observed rainfall persistence, (2) widespread undersimulation of rainfall persistence characteristics in GCMs, and (3) substantial improvement in rainfall persistence after applying bias correction.

Sanchez-Mejia, Z. M., S. A. Papuga, J. B. Swetish, W. J. D. van Leeuwen, D. Szutu, and K. Hartfield. 2014. **Quantifying the influence of deep soil moisture on ecosystem albedo: The role of vegetation.** Water Resources Research 50: 4038–4053. doi:10.1002/2013WR014150.

Abstract. As changes in precipitation dynamics continue to alter the water availability in dryland ecosystems, understanding the feedbacks between the vegetation and the hydrologic cycle and their influence on the climate system is critically important. We designed a field campaign to examine the influence of two-layer soil moisture control on bare and canopy albedo dynamics in a semiarid shrubland ecosystem. We conducted this campaign during 2011 and 2012 within the tower footprint of the Santa Rita Creosote Ameriflux site. Albedo field measurements fell into one of four Cases within a two-layer soil moisture framework based on permutations of whether the shallow and deep soil layers were wet or dry. Using these Cases, we identified

differences in how shallow and deep soil moisture influence canopy and bare albedo. Then, by varying the number of canopy and bare patches within a gridded framework, we explore the influence of vegetation and soil moisture on ecosystem albedo. Our results highlight the importance of deep soil moisture in land surface-atmosphere interactions through its influence on aboveground vegetation characteristics. For instance, we show how green-up of the vegetation is triggered by deep soil moisture, and link deep soil moisture to a decrease in canopy albedo. Understanding relationships between vegetation and deep soil moisture will provide important insights into feedbacks between the hydrologic cycle and the climate system.

Wagg, C., S. F. Bender, F. Widmer, and M. G. A. van der Heijden. 2014. **Soil biodiversity and soil community composition determine ecosystem multifunctionality.** Proceedings of the National Academy of Sciences 111:5266-5270. doi: 10.1073/pnas.1320054111

Abstract. Biodiversity loss has become a global concern as evidence accumulates that it will negatively affect ecosystem services on which society depends. So far, most studies have focused on the ecological consequences of above-ground biodiversity loss; yet a large part of Earth's biodiversity is literally hidden below ground. Whether reductions of biodiversity in soil communities below ground have consequences for the overall performance of an ecosystem remains unresolved. It is important to investigate this in view of recent observations that soil biodiversity is declining and that soil communities are changing upon land use intensification. We established soil communities differing in composition and diversity and tested their impact on eight ecosystem functions in model grassland communities. We show that soil biodiversity loss and simplification of soil community composition impair multiple ecosystem functions, including plant diversity, decomposition, nutrient retention, and nutrient cycling. The average response of all measured ecosystem functions (ecosystem multifunctionality) exhibited a strong positive linear relationship to indicators of soil biodiversity, suggesting that soil community composition is a key factor in regulating ecosystem functioning. Our results indicate that changes in soil communities and the loss of soil biodiversity threaten ecosystem multifunctionality and sustainability.

Fire

Boulanger, Y., S. Gauthier, and P. J. Burton. 2014. **A refinement of models projecting future Canadian fire regimes using homogeneous fire regime zones.** Canadian Journal of Forest Research 44:365-376.

Abstract. Broad-scale fire regime modelling is frequently based on large ecological and (or) administrative units. However, these units may not capture spatial heterogeneity in fire regimes and may thus lead to spatially inaccurate estimates of future fire activity. In this study, we defined homogeneous fire regime (HFR) zones for Canada based on annual area burned (AAB) and fire occurrence (FireOcc), and we used them to model future (2011–2040, 2041–2070, and 2071–2100) fire activity using multivariate adaptive regression splines (MARS). We identified a total of 16 HFR zones explaining 47.7% of the heterogeneity in AAB and FireOcc for the 1959–1999 period. MARS models based on HFR zones projected a 3.7-fold increase in AAB and a 3.0-fold increase in FireOcc by 2100 when compared with 1961–1990, with great interzone heterogeneity. The greatest increases would occur in zones located in central and northwestern Canada. Much of the increase in AAB would result from a sharp increase in fire activity during July and August. Ecozone- and HFR-based models projected relatively similar nationwide FireOcc and AAB. However, very high spatial discrepancies were noted between zonations over extensive areas. The proposed HFR zonation should help providing more spatially accurate estimates of future ecological patterns largely driven by fire in the boreal forest such as biodiversity patterns, energy flows, and carbon storage than those obtained from large-scale multipurpose classification units.

Hao, W. M., and N. K. Larkin. 2014. **Wildland fire emissions, carbon, and climate: Wildland fire detection and burned area in the United States.** Forest Ecology and Management 317:20-25.

Abstract. Biomass burning is a major source of greenhouse gases, aerosols, black carbon, and atmospheric pollutants that affects regional and global climate and air quality. The spatial and temporal extent of fires and the size of burned areas are critical parameters in the estimation of fire emissions. Tremendous efforts have been made in the past 12 years to characterize the variability of fire locations and burned areas using high frequency satellite observations (e.g., MODIS, GOES) and improved ground-based reports. We describe and compare the major global and regional (e.g., western United States) burned area products and summarize their major findings. The various ground-based reporting systems and the data quality on fire characteristics and burned areas are examined, and we summarize the major knowledge gaps and recommend further improvements in our understanding of fire activity and burned areas.

Larkin, N. K., S. M. Raffuse, and T. M. Strand. 2014. **Wildland fire emissions, carbon, and climate: U.S. emissions inventories.** Forest Ecology and Management 317:61-69.

Abstract. Emissions from wildland fire are both highly variable and highly uncertain over a wide range of temporal and spatial scales. Wildland fire emissions change considerably due to fluctuations from year to year with overall fire season severity, from season to season as different regions pass in and out of wildfire and prescribed fire periods, and from day to day as weather patterns affect large wildfire growth events and prescribed fire windows. Emissions from wildland fire are highly uncertain in that every component used to calculate wildland fire emissions is uncertain – including how much fire occurs and at what time during the year, assessments of available fuel stocks, consumption efficiency, and emissions factors used to calculate the final emissions. As shown here, these component uncertainties result in large-scale differences between estimation methods of wildland fire emissions including greenhouse gas totals, particulate matter totals, and other emissions. Four recent emissions inventories for the contiguous United States are compared to determine inter-inventory differences and to examine how methodological choices result in different annual totals and patterns of temporal and spatial variability. Inter-model variability is detailed for several current models, and current knowledge gaps and future directions for progressing fire emissions inventories are discussed.

Liu, Y., S. Goodrick, and W. Heilman. 2014. **Wildland fire emissions, carbon, and climate: Wildfire–climate interactions.** Forest Ecology and Management 317:80-96.

Abstract. Increasing wildfire activity in recent decades, partially related to extended droughts, along with concern over potential impacts of future climate change on fire activity has resulted in increased attention on fire–climate interactions. Findings from studies published in recent years have remarkably increased our understanding of fire–climate interactions and improved our capacity

to delineate probable future climate change and impacts. Fires are projected to increase in many regions of the globe under a changing climate due to the greenhouse effect. Burned areas in the western US could increase by more than 50% by the middle of this century. Increased fire activity is not simply an outcome of the changing climate, but also a participant in the change. Smoke particles reduce overall solar radiation absorbed by the Earth's atmosphere during individual fire events and fire seasons, leading to regional climate effects including reduction in surface temperature, suppression of cloud and precipitation, and enhancement of climate anomalies such as droughts. Black carbon (BC) in smoke particles displays some different radiation and climate effects by warming the middle and lower atmosphere, leading to a more stable atmosphere. BC also plays a key role in the smoke-snow feedback mechanism. Fire emissions of CO_2, on the other hand, are an important atmospheric CO_2 source and contribute substantially to the global greenhouse effect. Future studies should generate a global picture of all aspects of radiative forcing by smoke particles. Better knowledge is needed in space and time variability of smoke particles, evolution of smoke optical properties, estimation of smoke plume height and vertical profiles and their impacts on locations of warming layers, stability structure, clouds and smoke transport, quantification of BC emission factors and optical properties from different forest fuels, and BC's individual and combined roles with organic carbon. Finally, understanding the short- and long-term greenhouse effect of fire CO_2 emissions, increased capacity to project future fire trends (especially mega-fires), with consideration of climate–fuel–human interactions, and improved fire weather and climate prediction skills (including exploring the SST-fire relations) remain central knowledge needs.

Loehman, R. A., E. Reinhardt, and K. L. Riley. 2014. **Wildland fire emissions, carbon, and climate: Seeing the forest and the trees – A cross-scale assessment of wildfire and carbon dynamics in fire-prone, forested ecosystems.** Forest Ecology and Management 317:9-19.

Abstract. Wildfires are an important component of the terrestrial carbon cycle and one of the main pathways for movement of carbon from the land surface to the atmosphere. Fires have received much attention in recent years as potential catalysts for shifting landscapes from carbon sinks to carbon sources. Unless structural or functional ecosystem shifts occur, net carbon balance in fire-adapted systems at steady state is zero when assessed over the entire post-fire successional sequence and at landscape scales. When evaluated at fine

spatial scales and over short periods of time, however, wildfires may seem to release more carbon to the atmosphere than remains on site. Measurements of wildfire carbon emissions are thus highly biased by the spatial and temporal scales that bound them, and may over- or under-estimate carbon source-sink dynamics that provide critical feedbacks to the climate system. This synthesis paper provides a description of the ecological drivers of wildfires and carbon in forested ecosystems across the spatial and temporal scales at which system drivers (e.g., climate, weather), behaviors (e.g., wildfire occurrence, spread, intensity), and resulting patterns (e.g., vegetation composition and structure, carbon emissions) occur and interact. Improved understanding of these relationships is critical if we are to anticipate and respond to major changes in the global earth system expected in the coming decades and centuries.

Ottmar, R. D. 2014. **Wildland fire emissions, carbon, and climate: Modeling fuel consumption.** Forest Ecology and Management 317:41-50.

Abstract. Fuel consumption specifies the amount of vegetative biomass consumed during wildland fire. It is a two-stage process of pyrolysis and combustion that occurs simultaneously and at different rates depending on the characteristics and condition of the fuel, weather, topography, and in the case of prescribed fire, ignition rate and pattern. Fuel consumption is the basic process that leads to heat absorbing emissions called greenhouse gas and other aerosol emissions that can impact atmospheric and ecosystem processes, carbon stocks, and land surface reflectance. It is a critical requirement for greenhouse gas emission inventories. There are several fuel consumption models widely used by scientists and land managers including the First Order Fire Effects Model, Consume, and CanFIRE. However, these models have not been thoroughly evaluated with an independent, quality assured, fuel consumption data set. Furthermore, anecdotal evidence indicates the models have limited ability to predict consumption of specific fuel bed categories such as tree crowns, deep organic layers, and rotten logs that can contribute significantly to greenhouse gases. If we are to move forward in our ability to assess the contribution of wildland fire to greenhouse gas to the atmosphere, our current fuel consumption models must be evaluated and modified to improve their predictive capabilities. Finally, information is lacking on how much black and brown carbon from wildland fire is generated during the combustion process and how much remains on site becoming sequestered in soils, partially offsetting greenhouse gas emissions. This synthesis focuses on the process and modeling of fuel

consumption and knowledge gaps that will improve our ability to predict fuel consumption and the resulting greenhouse gas emissions.

Urbanski, S. 2014. **Wildland fire emissions, carbon, and climate: Emission factors.** Forest Ecology and Management 317:51-60.

Abstract. While the vast majority of carbon emitted by wildland fires is released as CO_2, CO, and CH_4, wildland fire smoke is nonetheless a rich and complex mixture of gases and aerosols. Primary emissions include significant amounts of CH_4 and aerosol (organic aerosol and black carbon), which are short-lived climate forcers. In addition to CO_2 and short-lived climate forcers, wildland fires release CO, non-methane organic compounds (NMOC), nitrogen oxides ($NO_x = NO + NO_2$), NH_3, and SO_2. These species play a role in radiative forcing through their photochemical processing, which impacts atmospheric levels of CO_2, CH_4, tropospheric O_3, and aerosol. This paper reviews the current state of knowledge regarding the chemical composition of emissions and emission factors for fires in United States vegetation types as pertinent to radiative forcing and climate. Emission factors are critical input for the models used to estimate wildland fire greenhouse gas and aerosol emission inventories.

Weise, D. R., and C. S. Wright. 2014. **Wildland fire emissions, carbon and climate: Characterizing wildland fuels.** Forest Ecology and Management 317:26-40.

Abstract. Smoke from biomass fires makes up a substantial portion of global greenhouse gas, aerosol, and black carbon (GHG/A/BC) emissions. Understanding how fuel characteristics and conditions affect fire occurrence and extent, combustion dynamics, and fuel consumption is critical for making accurate, reliable estimates of emissions production at local, regional, national, and global scales. The type, amount, characteristics, and condition of wildland fuels affect combustion and emissions during wildland and prescribed fires. Description of fuel elements has focused on those needed for fire spread and fire danger prediction. Knowledge of physical and chemical properties for a limited number of plant species exists. Fuel beds with potential for high impact on smoldering emissions are not described well. An assortment of systems, methods, analytical techniques, and technologies have been used and are being developed to describe, classify, and map wildland fuels for a variety of applications. Older systems do not contain the necessary information to describe realistically the wildland fuel complex. While new tools provide needed

detail, cost effectiveness to produce a reliable national fuels inventory has not been demonstrated. Climate change-related effects on vegetation growth and fuel distribution may affect the amount of GHG/A/BC emissions from wildland fires. A fundamental understanding of the relationships between fuel characteristics, fuel conditions, fire occurrence, combustion dynamics, and GHG/A/BC emissions is needed to aid strategy development to mitigate the expected effects of climate change.

Sea Level Rise

Cazenave, A., H.-B. Dieng, B. Meyssignac, K. von Schuckmann, B. Decharme, and E. Berthier. 2014. **The rate of sea-level rise.** Nature Climate Change 4:358-361. doi:10.1038/nclimate2159

Abstract. Present-day sea-level rise is a major indicator of climate change. Since the early 1990s, sea level rose at a mean rate of ~3.1 mm yr^{-1}. However, over the last decade a slowdown of this rate, of about 30%, has been recorded. It coincides with a plateau in Earth's mean surface temperature evolution, known as the recent pause in warming. Here we present an analysis based on sea-level data from the altimetry record of the past ~20 years that separates interannual natural variability in sea level from the longer-term change probably related to anthropogenic global warming. The most prominent signature in the global mean sea level interannual variability is caused by El Niño–Southern Oscillation, through its impact on the global water cycle. We find that when correcting for interannual variability, the past decade's slowdown of the global mean sea level disappears, leading to a similar rate of sea-level rise (of 3.3 ± 0.4 mm yr^{-1}) during the first and second decade of the altimetry era. Our results confirm the need for quantifying and further removing from the climate records the short-term natural climate variability if one wants to extract the global warming signal.

Paleoclimate

Lyman, R. L. 2014. **Terminal Pleistocene change in mammal communities in southeastern Washington State, USA.** Quaternary Research 81:295-304. DOI: 10.1016/j.yqres.2013.10.019

Abstract. Small mammal communities in western North America experienced declines in taxonomic richness across the late Pleistocene to Holocene transition (PHT), a recent natural global warming event. One community also experienced a decline in evenness and others replaced one species with a congener. Variability in response of small mammal communities to PHT warming is apparent. At the presently arid and xeric Marmes site in the Columbia Basin of southeastern Washington State, megafauna were absent by about 13,000 cal yr BP, evenness of small mammals declined about 11,700 cal yr BP and again about 11,400 cal yr BP whereas richness declined about 11,400 cal BP. Regional faunal turnover was, however, minimal among small-bodied taxa. Local mammal communities are depauperate as a result of megafaunal extinctions and subsequent decreases in small-mammal richness and evenness. The latter chronologically corresponds with a decrease in primary productivity driven by increasing warmth and aridity. More faunas must be studied in order to fully document the range of variability in the responses of mammalian communities to PHT warming. Documentation of patterns in those responses will facilitate understanding and enhance predictive accuracy with respect to responses of mammalian communities to modern global warming.

Mitigation

Gollan, J. R., Ramp, D. and Ashcroft, M. B. 2014. **Assessing the Distribution and Protection Status of two Types of Cool Environment to Facilitate Their Conservation under Climate Change.** Conservation Biology, 28: 456–466. doi: 10.1111/cobi.12212

Abstract. Strategies to mitigate climate change can protect different types of cool environments. Two are receiving much attention: protection of ephemeral refuges (i.e., places with low maximum temperatures) and of stable refugia (i.e., places that are cool, have a stable environment, and are isolated). Problematically, they are often treated as equivalents. Careful delineation of their qualities is needed to prevent misdirected conservation initiatives; yet, no one has determined whether protecting one protects the other. We mapped both types of cool environments across a large (~3.4M ha) mixed-use landscape with a geographic information system and conducted a patch analysis to compare their spatial distributions; examine relations between land use and their size and shape; and assess their current protection status. With a modest, but arbitrary, threshold for

demarcating both types of cool environments (i.e., values below the 0.025 quantile) there were 146,523 ha of ephemeral refuge (62,208 ha) and stable refugia (62,319 ha). Ephemeral refuges were generally aggregated at high elevation, and more refuge area occurred in protected areas (55,184 ha) than in unprotected areas (7,024 ha). In contrast, stable refugia were scattered across the landscape, and more stable-refugium area occurred on unprotected (40,135 ha) than on protected land (22,184 ha). Although sensitivity analysis showed that varying the thresholds that define cool environments affected outcomes, it also exposed the challenge of choosing a threshold for strategies to address climate change; there is no single value that is appropriate for all of biodiversity. The degree of overlap between ephemeral refuges and stable refugia revealed that targeting only the former for protection on currently unprotected land would capture ~17% of stable refugia. Targeting only stable refugia would capture ~54% of ephemeral refuges. Thus, targeting one type of cool environment did not fully protect the other.