Climate Change Quarterly: Spring 2016

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

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Oregon-Washington BLM employees can access some of the papers listed below through the OSO Science Info SharePoint site at: http://teamspace/or/sites/ScienceInfo/Pages/ClimateChange.aspx.

Climate Projections

Abatzoglou, J. T. 2016. **Contribution of cutoff lows to precipitation across the United States.** Journal of Applied Meteorology and Climatology 55:893-899.

Abstract. A chronology of cutoff lows (COL) from 1979 to 2014 alongside daily precipitation observations across the conterminous United States was used to examine the contribution of COL to seasonal precipitation, extreme-precipitation events, and interannual precipitation variability. COL accounted for between 2% and 32% of annual precipitation at stations across the United States, with distinct geographic and seasonal variability. The largest fractional contribution of COL to precipitation totals and precipitation extremes was found across the Great Plains and the interior western United States, particularly during the transition seasons of spring and autumn. Widespread significant correlations between seasonal COL precipitation and total precipitation on interannual time scales were found across parts of the United States, most notably to explain spring precipitation variability in the interior western United States and Great Plains and summer precipitation variability in the northwestern United States. In addition to regional differences, a distinct gradient in the contributions of COL to precipitation was found in the lee of large mountain ranges in the western United States. Differences in orographic precipitation enhancement associated with slow-moving COL resulted in relatively more precipitation at lower elevations and, in particular, east of north–south-oriented mountain ranges that experience a strong rain shadow with progressive disturbances.

Donat, M. G., A. L. Lowry, L. V. Alexander, P. A. Ogorman, and N. Maher. 2016. **More extreme precipitation in the world's dry and wet regions.** Nature Climate Change 6:508-513.

Abstract. Intensification of the hydrological cycle is expected to accompany a warming climate. It has been suggested that changes in the spatial distribution of precipitation will amplify differences between dry and wet regions, but this has been disputed for changes over land. Furthermore, precipitation changes may differ not only between regions but also between different aspects of precipitation, such as totals and extremes. Here we investigate changes in these two aspects in the world's dry and wet regions using observations and global climate models. Despite uncertainties in total precipitation changes, extreme daily precipitation averaged over both dry and wet regimes shows robust increases in both observations and climate models over the past six decades. Climate projections for the rest of the century show continued intensification of daily precipitation extremes. Increases in total and extreme precipitation in dry regions are linearly related to the model-specific global temperature change, so that the spread in projected global warming partly explains the spread in precipitation intensification in these regions by the late twenty-first century. This intensification has implications for the risk of flooding as the climate warms, particularly for the world's dry regions.

Lewandowsky, S., J. S. Risbey, and N. Oreskes. 2016. **The "pause" in global warming: turning a routine fluctuation into a problem for science.** Bulletin of the American Meteorological Society 97:723-733.

Abstract. There has been much recent published research about a putative "pause" or "hiatus" in global warming. We show that there are frequent fluctuations in the rate of warming around a longer-term warming trend, and that there is no evidence that identifies the recent period as unique or particularly unusual. In confirmation, we show that the notion of a pause in warming is considered to be misleading in a blind expert test. Nonetheless, the most recent fluctuation about the longer-term trend has been regarded by many as an explanatory challenge that climate science must resolve. This departs from long-standing practice, insofar as scientists have long recognized that the climate fluctuates, that linear increases in CO2 do not produce linear trends in global warming, and that 15-yr (or shorter) periods are not diagnostic of long-term trends. We suggest that the repetition of the "warming has paused" message by contrarians was adopted by the scientific community in its problem-solving and answer-seeking role

and has led to undue focus on, and mislabeling of, a recent fluctuation. We present an alternative framing that could have avoided inadvertently reinforcing a misleading claim.

Mascioli, N. R., A. M. Fiore, M. Previdi, and G. Correa. 2016. **Temperature and precipitation extremes in the United States: quantifying the responses to anthropogenic aerosols and greenhouse gases.** Journal of Climate 29:2689-2701.

Abstract. Changes in extreme temperatures, heat waves, and heavy rainfall events have adverse effects on human health, air quality, and water resources. With aerosol-only (AER) and greenhouse gas–only (GHG) simulations from 1860 to 2005 in the GFDL CM3 chemistry–climate model, aerosol-induced versus greenhouse gas–induced changes in temperature (summer) and precipitation (all seasons) extremes over the United States are investigated. Small changes in these extremes in the all forcing simulations reflect cancellations between the effects of increasing anthropogenic aerosols and greenhouse gases. In AER, extreme high temperatures and the number of days with temperatures above the 90th percentile decline over most of the United States. The strongest response occurs in the western United States (−2.0°C and −14 days, regionally averaged) and the weakest response occurs in the southeastern United States (−0.6°C and −4.8 days). An opposite-signed response pattern occurs in GHG (+2.3°C and +11.5 days over the western United States and +1.6°C and +7.2 days over the southeastern United States). The similar spatial response patterns in AER versus GHG suggest a preferred regional mode of response that is largely independent of the type of forcing. Extreme precipitation over the eastern United States decreases in AER, particularly in winter, and increases over the eastern and central United States in GHG, particularly in spring. Over the twenty-first century under the representative concentration pathway 8.5 (RCP8.5) emissions scenario, the patterns of extreme temperature and precipitation associated with greenhouse gas forcing dominate.

Otto-Bliesner, B. L., E. C. Brady, J. Fasullo, A. Jahn, L. Landrum, S. Stevenson, N. Rosenbloom, A. Mai, and G. Strand. 2016. **Climate variability and change since 850 CE: an ensemble approach with the community earth system model.** Bulletin of the American Meteorological Society 97:735-754.

Abstract. The climate of the past millennium provides a baseline for understanding the background of natural climate variability upon which current anthropogenic changes are superimposed. As this period also contains high data density from proxy sources (e.g., ice cores, stalagmites, corals, tree rings, and sediments), it provides a unique opportunity for understanding both global and regional-scale climate responses to natural forcing. Toward that end, an ensemble of simulations with the Community Earth System Model (CESM) for the period 850–2005 (the CESM Last Millennium Ensemble, or CESM-LME) is now available to the community. This ensemble includes simulations forced with the transient evolution of solar intensity, volcanic emissions, greenhouse gases, aerosols, land-use conditions, and orbital parameters, both together and individually. The CESM-LME thus allows for evaluation of the relative contributions of external forcing and internal variability to changes evident in the paleoclimate data record, as well as providing a longer-term perspective for understanding events in the modern instrumental period. It also constitutes a dynamically consistent framework within which to diagnose mechanisms of regional variability. Results demonstrate an important influence of internal variability on regional responses of the climate system during the past millennium. All the forcings, particularly large volcanic eruptions, are found to be regionally influential during the preindustrial period, while anthropogenic greenhouse gas and aerosol changes dominate the forced variability of the mid- to late twentieth century.

Schoof, J. T., and S. M. Robeson. 2016. **Projecting changes in regional temperature and precipitation extremes in the United States.** Weather and Climate Extremes 11:28-40.

Abstract. Regional and local climate extremes, and their impacts, result from the multifaceted interplay between large-scale climate forcing, local environmental factors (physiography), and societal vulnerability. In this paper, we review historical and projected changes in temperature and precipitation extremes in the United States, with a focus on strengths and weaknesses of (1) commonly used definitions for extremes such as thresholds and percentiles, (2) statistical approaches to quantifying changes in extremes, such as extreme value

theory, and (3) methods for post-processing (downscaling) global climate models (GCMs) to investigate regional and local climate. We additionally derive regional and local estimates of changes in temperature extremes by applying a quantile mapping approach to high-resolution gridded daily temperature data for 6 U.S. sub-regions. Consistent with the background warming in the parent GCMs, we project decreases in regional and local cold extremes and increases in regional and local warm extremes throughout the domain, but the downscaling approach removes bias and produces substantial spatial variability within the relatively small sub-regions. We finish with recommendations for future research on regional climate extremes, suggesting that focus be placed on improving understanding of extremes in the context of large-scale circulation and evaluating the corresponding cascade of scale interactions within GCMs.

Scott, J. D., M. A. Alexander, D. R. Murray, D. Swales, and J. Eischeid. 2016. **The Climate Change Web Portal: a system to access and display climate and earth system model output from the CMIP5 archive.** Bulletin of the American Meteorological Society 97:523-530. (No Abstract)

Tan, I., T. Storelvmo, and M. D. Zelinka. 2016. **Observational constraints on mixed-phase clouds imply higher climate sensitivity.** Science 352:224-227.

Abstract. Global climate model (GCM) estimates of the equilibrium global mean surface temperature response to a doubling of atmospheric CO_2, measured by the equilibrium climate sensitivity (ECS), range from 2.0° to 4.6°C. Clouds are among the leading causes of this uncertainty. Here we show that the ECS can be up to 1.3°C higher in simulations where mixed-phase clouds consisting of ice crystals and supercooled liquid droplets are constrained by global satellite observations. The higher ECS estimates are directly linked to a weakened cloud-phase feedback arising from a decreased cloud glaciation rate in a warmer climate. We point out the need for realistic representations of the supercooled liquid fraction in mixed-phase clouds in GCMs, given the sensitivity of the ECS to the cloud-phase feedback.

Carbon and Carbon Storage

Argerich, A., R. Haggerty, S. L. Johnson, S. M. Wondzell, N. Dosch, H. Corson-Rikert, L. R. Ashkenas, R. Pennington, and C. K. Thomas. 2016. **Comprehensive multiyear carbon budget of a temperate headwater stream.** Journal of Geophysical Research: Biogeosciences 121:1306-1315.

Abstract. Headwater streams comprise nearly 90% of the total length of perennial channels in global catchments. They mineralize organic carbon entering from terrestrial systems, evade terrestrial carbon dioxide (CO^2), and generate and remove carbon through in-stream primary production and respiration. Despite their importance, headwater streams are often neglected in global carbon budgets primarily because of a lack of available data. We measured these processes, in detail, over a 10 year period in a stream draining a 96 ha forested watershed in western Oregon, USA. This stream, which represents only 0.4% of the watershed area, exported 159 kg C ha^{-1} yr^{-1}, similar to the global exports for large rivers. Stream export was dominated by downstream transport of dissolved inorganic carbon (63 kg C ha^{-1} yr^{-1}) and by evasion of CO2 to the atmosphere (42 kg C ha^{-1} yr^{-1}), leaving the remainder of 51 kg C ha^{-1} yr^{-1} for downstream transport of organic carbon (17 kg C ha^{-1} yr^{-1} and 34 kg C ha^{-1} yr^{-1} in dissolved and particulate form, respectively).

Arora, V. K., Y. Peng, W. A. Kurz, J. C. Fyfe, B. Hawkins, and A. T. Werner. 2016. **Potential near-future carbon uptake overcomes losses from a large insect outbreak in British Columbia, Canada.** Geophysical Research Letters 43:2590-2598.

Abstract. The current capacity of northern high-latitude forests to sequester carbon has been suggested to be undermined by the potential increase in fire and insect outbreaks. Here we investigate the response of the terrestrial ecosystems in the province of British Columbia (BC), Canada, to the recent large mountain pine beetle (MPB) outbreak that started in 1999 as well as changing climate and continually increasing atmospheric CO_2 concentration up to 2050, in a combined framework, using a process-based model. Model simulations suggest that the recent MPB outbreak results in BC's forests accumulating 328 Tg less carbon over the 1999–2020 period. Over this same period changing climate and increasing atmospheric CO_2 concentration, however, yield enhanced carbon uptake equal to a cumulative sink of around 900–1060 Tg C, depending on the future

climate change scenario, indicating that the reduced carbon uptake by land due to the MPB disturbance may already be surpassed by 2020.

Campbell, J. L., J. B. Fontaine, and D. C. Donato. 2016. **Carbon emissions from decomposition of fire-killed trees following a large wildfire in Oregon, United States.** Journal of Geophysical Research: Biogeosciences 121:718-730.

Abstract. A key uncertainty concerning the effect of wildfire on carbon dynamics is the rate at which fire-killed biomass (e.g., dead trees) decays and emits carbon to the atmosphere. We used a ground-based approach to compute decomposition of forest biomass killed, but not combusted, in the Biscuit Fire of 2002, an exceptionally large wildfire that burned over 200,000 ha of mixed conifer forest in southwestern Oregon, USA. A combination of federal inventory data and supplementary ground measurements afforded the estimation of fire-caused mortality and subsequent 10 year decomposition for several functionally distinct carbon pools at 180 independent locations in the burn area. Decomposition was highest for fire-killed leaves and fine roots and lowest for large-diameter wood. Decomposition rates varied somewhat among tree species and were only 35% lower for trees still standing than for trees fallen at the time of the fire. We estimate a total of 4.7 Tg C was killed but not combusted in the Biscuit Fire, 85% of which remains 10 years after. Biogenic carbon emissions from fire-killed necromass were estimated to be 1.0, 0.6, and 0.4 Mg C ha^{-1} yr^{-1} at 1, 10, and 50 years after the fire, respectively; compared to the one-time pyrogenic emission of nearly 17 Mg C ha^{-1}.

Chambers, A., R. Lal, and K. Paustian. 2016. **Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative.** Journal of Soil and Water Conservation 71:68A-74A. (No Abstract)

Eskelson, B. N. I., V. J. Monleon, and J. S. Fried. 2016. **A 6 year longitudinal study of post-fire woody carbon dynamics in California's forests.** Canadian Journal of Forest Research 46:610-620.

Abstract. We examined the dynamics of aboveground forest woody carbon pools — live trees, standing dead trees, and down wood — during the first 6 years following wildfire across a wide range of conditions, which are characteristic of California forest fires. From repeated measurements of the same plots, we estimated change in

woody carbon pools as a function of crown fire severity as indicated by a post-fire index, years since fire, pre-fire woody carbon, forest type group (hardwood vs. softwood), elevation, and climate attributes. Our analysis relied on 130 U.S. national forest inventory plots measured before and 1 year after fire, with one additional remeasurement within 6 years after fire. There was no evidence of net change in total wood carbon, defined for this study as the wood in standing trees larger than 12.7 cm diameter at breast height and down wood larger than 7.6 cm in diameter, over the post-fire period in any of the three severity classes. Stands that burned at low severity exhibited considerable shifts from live to standing dead and down wood pools. In stands that burned at moderate severity, live wood decreased significantly whereas no net change was detected in standing dead or down wood. High severity fire burning resulted in movement from standing dead to down wood pools. Our results suggest that the carbon trajectories for stand-replacing fires may not be appropriate for the majority of California's forest area that burned at low to moderate severities.

Hurteau, M. D., S. Liang, K. L. Martin, M. P. North, G. W. Koch, and B. A. Hungate. 2016. **Restoring forest structure and process stabilizes forest carbon in wildfire-prone southwestern ponderosa pine forests.** Ecological Applications 26:382-391.

Abstract. Changing climate and a legacy of fire-exclusion have increased the probability of high-severity wildfire, leading to an increased risk of forest carbon loss in ponderosa pine forests in the southwestern USA. Efforts to reduce high-severity fire risk through forest thinning and prescribed burning require both the removal and emission of carbon from these forests, and any potential carbon benefits from treatment may depend on the occurrence of wildfire. We sought to determine how forest treatments alter the effects of stochastic wildfire events on the forest carbon balance. We modeled three treatments (control, thin-only, and thin and burn) with and without the occurrence of wildfire. We evaluated how two different probabilities of wildfire occurrence, 1% and 2% per year, might alter the carbon balance of treatments. In the absence of wildfire, we found that thinning and burning treatments initially reduced total ecosystem carbon (TEC) and increased net ecosystem carbon balance (NECB). In the presence of wildfire, the thin and burn treatment TEC surpassed that of the control in year 40 at 2%/yr wildfire probability, and in year 51 at 1%/yr wildfire probability. NECB in the presence of wildfire showed a similar response to the no-wildfire scenarios: both thin-only and thin and burn treatments increased the C sink. Treatments

increased TEC by reducing both mean wildfire severity and its variability. While the carbon balance of treatments may differ in more productive forest types, the carbon balance benefits from restoring forest structure and fire in southwestern ponderosa pine forests are clear.

Klein, T., R. T. W. Siegwolf, and C. Körner. 2016. **Belowground carbon trade among tall trees in a temperate forest.** Science 352:342-344.

Abstract. Forest trees compete for light and soil resources, but photoassimilates, once produced in the foliage, are not considered to be exchanged between individuals. Applying stable carbon isotope labeling at the canopy scale, we show that carbon assimilated by 40-meter-tall spruce is traded over to neighboring beech, larch, and pine via overlapping root spheres. Isotope mixing signals indicate that the interspecific, bidirectional transfer, assisted by common ectomycorrhiza networks, accounted for 40% of the fine root carbon (about 280 kilograms per hectare per year tree-to-tree transfer). Although competition for resources is commonly considered as the dominant tree-to-tree interaction in forests, trees may interact in more complex ways, including substantial carbon exchange.

McGranahan, D. A., T. J. Hovick, R. Dwayne Elmore, D. M. Engle, Samuel D. Fuhlendorf, S. L. Winter, J. R. Miller, and D. M. Debinski. 2016. **Temporal variability in aboveground plant biomass decreases as spatial variability increases.** Ecology 97:555-560.

Abstract. Ecological theory predicts that diversity decreases variability in ecosystem function. We predict that, at the landscape scale, spatial variability created by a mosaic of contrasting patches that differ in time since disturbance will decrease temporal variability in aboveground plant biomass. Using data from a multi-year study of seven grazed tallgrass prairie landscapes, each experimentally managed for one to eight patches, we show that increased spatial variability driven by spatially patchy fire and herbivory reduces temporal variability in aboveground plant biomass. This pattern is associated with statistical evidence for the portfolio effect and a positive relationship between temporal variability and functional group synchrony as predicted by metacommunity variability theory. As disturbance from fire and grazing interact to create a shifting mosaic of spatially heterogeneous patches within a landscape, temporal

variability in aboveground plant biomass can be dampened. These results suggest that spatially heterogeneous disturbance regimes contribute to a portfolio of ecosystem functions provided by biodiversity, including wildlife habitat, fuel, and forage. We discuss how spatial patterns of disturbance drive variability within and among patches.

Slesak, R. A., T. B. Harrington, D. H. Peter, D. G. DeBruler, S. H. Schoenholtz, and B. D. Strahm. 2016. **Effects of intensive management practices on 10-year Douglas-fir growth, soil nutrient pools, and vegetation communities in the Pacific Northwest, USA.** Forest Ecology and Management 365:22-33.

Abstract. Intensive management practices are commonly used to increase fiber production from forests, but potential tradeoffs with maintenance of long-term productivity and early successional biodiversity have yet to be quantified. We assessed soil and vegetation responses in replicated manipulations of logging debris (LD; either retained or removed) and competing vegetation control (VC; either initial or sustained annually for 5 years) for 10 years at two Douglas-fir sites that contrasted strongly in availability of soil nutrients and water. We evaluated (1) survival and growth of Douglas-fir to determine short-term effectiveness for fiber production, (2) change in soil C and nutrient pools as an indicator of longer-term effects of treatments on soil quality and ecosystem production, and (3) vegetation composition and cover for treatment effects on early successional biodiversity. Annual VC caused large increases in Douglas-fir growth at both sites, but increased survival only at the lower-productivity site. In most instances and regardless of site or treatment, soil C and nutrient pools increased following harvesting, but the increases were generally larger with lower intensity practices (LD retained and initial VC). Effects of LD were small and inconsistent at the higher productivity site, but LD retained increased Douglas-fir survival and growth and soil nutrient pools at the lower productivity site. Species diversity was reduced at both sites with annual VC because of increased Douglas-fir cover, but the magnitude was greater and the timing was earlier at the higher quality site where plant communities in all treatments had converged by year 10. Annual VC can be used to increase growth of planted Douglas-fir while maintaining soil nutrient pools for sustained ecosystem productivity, but a concurrent decrease in early successional diversity will occur with impacts increasing with site quality. Logging debris retention can have positive benefits to Douglas-fir growth and soil nutrient pools, particularly at lower quality sites. Our results demonstrate a need for careful consideration of site

quality to ensure that objectives are realized with regards to fiber production and maintenance of soil productivity and biodiversity with intensive forest management.

Smith, P. 2016. **Soil carbon sequestration and biochar as negative emission technologies.** Global Change Biology 22:1315-1324.

Abstract. Despite 20 years of effort to curb emissions, greenhouse gas (GHG) emissions grew faster during the 2000s than in the 1990s, which presents a major challenge for meeting the international goal of limiting warming to <2 °C relative to the preindustrial era. Most recent scenarios from integrated assessment models require large-scale deployment of negative emissions technologies (NETs) to reach the 2 °C target. A recent analysis of NETs, including direct air capture, enhanced weathering, bioenergy with carbon capture and storage and afforestation/deforestation, showed that all NETs have significant limits to implementation, including economic cost, energy requirements, land use, and water use. In this paper, I assess the potential for negative emissions from soil carbon sequestration and biochar addition to land, and also the potential global impacts on land use, water, nutrients, albedo, energy and cost. Results indicate that soil carbon sequestration and biochar have useful negative emission potential (each 0.7 GtCeq. yr^{-1}) and that they potentially have lower impact on land, water use, nutrients, albedo, energy requirement and cost, so have fewer disadvantages than many NETs. Limitations of soil carbon sequestration as a NET centre around issues of sink saturation and reversibility. Biochar could be implemented in combination with bioenergy with carbon capture and storage. Current integrated assessment models do not represent soil carbon sequestration or biochar. Given the negative emission potential of SCS and biochar and their potential advantages compared to other NETs, efforts should be made to include these options within IAMs, so that their potential can be explored further in comparison with other NETs for climate stabilization.

Thurner, M., C. Beer, N. Carvalhais, M. Forkel, M. Santoro, M. Tum, and C. Schmullius. 2016. **Large-scale variation in boreal and temperate forest carbon turnover rate related to climate.** Geophysical Research Letters 43:4576-4585.

Abstract. Vegetation carbon turnover processes in forest ecosystems and their dominant drivers are far from being understood at a broader

scale. Many of these turnover processes act on long timescales and include a lateral dimension and thus can hardly be investigated by plot-level studies alone. Making use of remote sensing-based products of net primary production (NPP) and biomass, here we show that spatial gradients of carbon turnover rate (*k*) in Northern Hemisphere boreal and temperate forests are explained by different climate-related processes depending on the ecosystem. *k* is related to frost damage effects and the trade-off between growth and frost adaptation in boreal forests, while drought stress and climate effects on insects and pathogens can explain an elevated *k* in temperate forests. By identifying relevant processes underlying broadscale patterns in *k*, we provide the basis for a detailed exploration of these mechanisms in field studies, and ultimately the improvement of their representations in global vegetation models (GVMs).

Yu, Z., J. Wang, S. Liu, S. Piao, P. Ciais, S. W. Running, B. Poulter, J. S. Rentch, and P. Sun. 2016. **Decrease in winter respiration explains 25% of the annual northern forest carbon sink enhancement over the last 30 years.** Global Ecology and Biogeography 25:586-595.

Abstract. Aim. Winter snow has been suggested to regulate terrestrial carbon (C) cycling by modifying microclimate, but the impacts of change in snow cover on the annual C budget at a large scale are poorly understood. Our aim is to quantify the C balance under changing snow depth.

Location. Non-permafrost region of the northern forest area.

Methods. Here, we used site-based eddy covariance flux data to investigate the relationship between depth of snow cover and ecosystem respiration (Reco) during winter. We then used the Biome-BGC model to estimate the effect of reductions in winter snow cover on the C balance of northern forests in the non-permafrost region.

Results. According to site observations, winter net ecosystem C exchange (NEE) ranged from 0.028 to 1.53 $gC{\cdot}m^{-2}{\cdot}day^{-1}$, accounting for 44 ± 123% of the annual C budget. Model simulation showed that over the past 30 years, snow-driven change in winter C fluxes reduced non-growing season CO_2 emissions, enhancing the annual C sink of northern forests. Over the entire study area, simulated winter Reco significantly decreased by 0.33 $gC{\cdot}m^{-2}{\cdot}day^{-1}{\cdot}year^{-1}$ in response to decreasing depth of snow cover, which accounts for approximately 25% of the simulated annual C sink trend from 1982 to 2009.

Main conclusion. Soil temperature is primarily controlled by snow cover rather than by air temperature as snow serves as an insulator to prevent chilling impacts. A shallow snow cover has less insulation potential, causing colder soil temperatures and potentially lower respiration rates. Both eddy covariance analysis and model-simulated results show that both Reco and NEE are significantly and positively correlated with variation in soil temperature controlled by variation in snow depth. Overall, our results highlight that a decrease in winter snow cover restrains global warming as less C is emitted to the atmosphere.

Zald, H. S. J., T. A. Spies, R. Seidl, R. J. Pabst, K. A. Olsen, and E. A. Steel. 2016. **Complex mountain terrain and disturbance history drive variation in forest aboveground live carbon density in the western Oregon Cascades, USA.** Forest Ecology and Management 366:193-207.

Abstract. Forest carbon (C) density varies tremendously across space due to the inherent heterogeneity of forest ecosystems. Variation of forest C density is especially pronounced in mountainous terrain, where environmental gradients are compressed and vary at multiple spatial scales. Additionally, the influence of environmental gradients may vary with forest age and developmental stage, an important consideration as forest landscapes often have a diversity of stand ages from past management and other disturbance agents. Quantifying forest C density and its underlying environmental determinants in mountain terrain has remained challenging because many available data sources lack the spatial grain and ecological resolution needed at both stand and landscape scales. The objective of this study was to determine if environmental factors influencing aboveground live carbon (ALC) density differed between young versus old forests. We integrated aerial light detection and ranging (lidar) data with 702 field plots to map forest ALC density at a grain of 25 m across the H.J. Andrews Experimental Forest, a 6369 ha watershed in the Cascade Mountains of Oregon, USA. We used linear regressions, random forest ensemble learning (RF) and sequential autoregressive modeling (SAR) to reveal how mapped forest ALC density was related to climate, topography, soils, and past disturbance history (timber harvesting and wildfires). ALC increased with stand age in young managed forests, with much greater variation of ALC in relation to years since wildfire in old unmanaged forests. Timber harvesting was the most important driver of ALC across the entire watershed, despite occurring on only 23% of the landscape. More variation in forest ALC density was explained in models of young managed forests than in models of old

unmanaged forests. Besides stand age, ALC density in young managed forests was driven by factors influencing site productivity, whereas variation in ALC density in old unmanaged forests was also affected by finer scale topographic conditions associated with sheltered sites. Past wildfires only had a small influence on current ALC density, which may be a result of long times since fire and/or prevalence of non-stand replacing fire. Our results indicate that forest ALC density depends on a suite of multi-scale environmental drivers mediated by complex mountain topography, and that these relationships are dependent on stand age. The high and context-dependent spatial variability of forest ALC density has implications for quantifying forest carbon stores, establishing upper bounds of potential carbon sequestration, and scaling field data to landscape and regional scales.

Greenhouse Gas

Anderson, F. E., B. Bergamaschi, C. Sturtevant, S. Knox, L. Hastings, L. Windham-Myers, M. Detto, E. L. Hestir, J. Drexler, R. L. Miller, J. H. Matthes, J. Verfaillie, D. Baldocchi, R. L. Snyder, and R. Fujii. 2016. **Variation of energy and carbon fluxes from a restored temperate freshwater wetland and implications for carbon market verification protocols**. Journal of Geophysical Research: Biogeosciences 121:777-795.

Abstract. Temperate freshwater wetlands are among the most productive terrestrial ecosystems, stimulating interest in using restored wetlands as biological carbon sequestration projects for greenhouse gas reduction programs. In this study, we used the eddy covariance technique to measure surface energy carbon fluxes from a constructed, impounded freshwater wetland during two annual periods that were 8 years apart: 2002–2003 and 2010–2011. During 2010–2011, we measured methane (CH4) fluxes to quantify the annual atmospheric carbon mass balance and its concomitant influence on global warming potential (GWP). Peak growing season fluxes of latent heat and carbon dioxide (CO_2) were greater in 2002–2003 compared to 2010–2011. In 2002, the daily net ecosystem exchange reached as low as -10.6 g C m^{-2} d^{-1}, which was greater than 3 times the magnitude observed in 2010 (-2.9 g C m^{-2} d^{-1}). CH_4 fluxes during 2010–2011 were positive throughout the year and followed a strong seasonal pattern, ranging from 38.1 mg C m^{-2} d^{-1} in the winter to 375.9 mg C m^{-2} d^{-1} during the summer. The results of this study suggest that the wetland had reduced gross ecosystem productivity in

2010–2011, likely due to the increase in dead plant biomass (standing litter) that inhibited the generation of new vegetation growth. In 2010–2011, there was a net positive GWP (675.3 g C m^{-2} yr^{-1}), and when these values are evaluated as a sustained flux, the wetland will not reach radiative balance even after 500 years.

Stanley, E. H., N. J. Casson, S. T. Christel, J. T. Crawford, L. C. Loken, and S. K. Oliver. 2016. **The ecology of methane in streams and rivers: patterns, controls, and global significance.** Ecological Monographs 86:146-171

Abstract. Streams and rivers can substantially modify organic carbon (OC) inputs from terrestrial landscapes, and much of this processing is the result of microbial respiration. While carbon dioxide (CO_2) is the major end-product of ecosystem respiration, methane (CH_4) is also present in many fluvial environments even though methanogenesis typically requires anoxic conditions that may be scarce in these systems. Given recent recognition of the pervasiveness of this greenhouse gas in streams and rivers, we synthesized existing research and data to identify patterns and drivers of CH_4, knowledge gaps, and research opportunities. This included examining the history of lotic CH_4 research, creating a database of concentrations and fluxes (MethDB) to generate a global-scale estimate of fluvial CH_4 efflux, and developing a conceptual framework and using this framework to consider how human activities may modify fluvial CH_4 dynamics. Current understanding of CH_4 in streams and rivers has been strongly influenced by goals of understanding OC processing and quantifying the contribution of CH_4 to ecosystem C fluxes. Less effort has been directed towards investigating processes that dictate in situ CH_4 production and loss. CH_4 makes a meager contribution to watershed or landscape C budgets, but streams and rivers are often significant CH_4 sources to the atmosphere across these same spatial extents. Most fluvial systems are supersaturated with CH_4 and we estimate an annual global emission of 26.8 Tg CH_4, equivalent to ~15-40% of wetland and lake effluxes, respectively. Less clear is the role of CH_4 oxidation, methanogenesis, and total anaerobic respiration to whole ecosystem production and respiration. Controls on CH_4 generation and persistence can be viewed in terms of proximate controls that influence methanogenesis (organic matter, temperature, alternative electron acceptors, nutrients) and distal geomorphic and hydrologic drivers. Multiple controls combined with its extreme redox status and low solubility result in high spatial and temporal variance of CH_4 in fluvial environments, which presents a substantial challenge for understanding its larger-scale dynamics. Further understanding of CH_4

production and consumption, anaerobic metabolism, and ecosystem energetics in streams and rivers can be achieved through more directed studies and comparison with knowledge from terrestrial, wetland, and aquatic disciplines.

Teague, W. R., S. Apfelbaum, R. Lal, U. P. Kreuter, J. Rowntree, C. A. Davies, R. Conser, M. Rasmussen, J. Hatfield, T. Wang, F. Wang, and P. Byck. 2016. **The role of ruminants in reducing agriculture's carbon footprint in North America.** Journal of Soil and Water Conservation 71:156-164.

Abstract. Owing to the methane (CH_4) produced by rumen fermentation, ruminants are a source of greenhouse gas (GHG) and are perceived as a problem. We propose that with appropriate regenerative crop and grazing management, ruminants not only reduce overall GHG emissions, but also facilitate provision of essential ecosystem services, increase soil carbon (C) sequestration, and reduce environmental damage. We tested our hypothesis by examining biophysical impacts and the magnitude of all GHG emissions from key agricultural production activities, including comparisons of arable- and pastoral-based agroecosystems. Our assessment shows that globally, GHG emissions from domestic ruminants represent 11.6% (1.58 Gt C y^{-1}) of total anthropogenic emissions, while cropping and soil-associated emissions contribute 13.7% (1.86 Gt C y^{-1}). The primary source is soil erosion (1 Gt C y^{-1}), which in the United States alone is estimated at 1.72 Gt of soil y^{-1}. Permanent cover of forage plants is highly effective in reducing soil erosion, and ruminants consuming only grazed forages under appropriate management result in more C sequestration than emissions. Incorporating forages and ruminants into regeneratively managed agroecosystems can elevate soil organic C, improve soil ecological function by minimizing the damage of tillage and inorganic fertilizers and biocides, and enhance biodiversity and wildlife habitat. We conclude that to ensure long-term sustainability and ecological resilience of agroecosystems, agricultural production should be guided by policies and regenerative management protocols that include ruminant grazing. Collectively, conservation agriculture supports ecologically healthy, resilient agroecosystems and simultaneously mitigates large quantities of anthropogenic GHG emissions.

Air Quality

Shen, L., L. J. Mickley, and E. Gilleland. 2016. **Impact of increasing heat waves on U.S. ozone episodes in the 2050s: Results from a multimodel analysis using extreme value theory.** Geophysical Research Letters 43:4017-4025.

Abstract. We develop a statistical model using extreme value theory to estimate the 2000–2050 changes in ozone episodes across the United States. We model the relationships between daily maximum temperature (T_{max}) and maximum daily 8 h average (MDA8) ozone in May–September over 2003–2012 using a Point Process (PP) model. At ~20% of the sites, a marked decrease in the ozone-temperature slope occurs at high temperatures, defined as ozone suppression. The PP model sometimes fails to capture ozone-T_{max} relationships, so we refit the ozone-T_{max} slope using logistic regression and a generalized Pareto distribution model. We then apply the resulting hybrid-extreme value theory model to projections of T_{max} from an ensemble of downscaled climate models. Assuming constant anthropogenic emissions at the present level, we find an average increase of 2.3 d a^{-1} in ozone episodes (>75 ppbv) across the United States by the 2050s, with a change of +3–9 d a^{-1} at many sites.

Phenology Changes

Elmendorf, S. C., K. D. Jones, B. I. Cook, J. M. Diez, C. A. F. Enquist, R. A. Hufft, M. O. Jones, S. J. Mazer, A. J. Miller-Rushing, D. J. P. Moore, M. D. Schwartz, and J. F. Weltzin. 2016. **The plant phenology monitoring design for The National Ecological Observatory Network.** Ecosphere 7:e01303.

Abstract. Phenology is an integrative science that comprises the study of recurring biological activities or events. In an era of rapidly changing climate, the relationship between the timing of those events and environmental cues such as temperature, snowmelt, water availability, or day length are of particular interest. This article provides an overview of the observer-based plant phenology sampling conducted by the U.S. National Ecological Observatory Network (NEON), the resulting data, and the rationale behind the design. Trained technicians will conduct regular in situ observations of plant phenology at all terrestrial NEON sites for the 30-yr life of the observatory. Standardized and coordinated data across the network of sites can be used to quantify the direction and magnitude of the

relationships between phenology and environmental forcings, as well as the degree to which these relationships vary among sites, among species, among phenophases, and through time. Vegetation at NEON sites will also be monitored with tower-based cameras, satellite remote sensing, and annual high-resolution airborne remote sensing. Ground-based measurements can be used to calibrate and improve satellite-derived phenometrics. NEON's phenology monitoring design is complementary to existing phenology research efforts and citizen science initiatives throughout the world and will produce interoperable data. By collocating plant phenology observations with a suite of additional meteorological, biophysical, and ecological measurements (e.g., climate, carbon flux, plant productivity, population dynamics of consumers) at 47 terrestrial sites, the NEON design will enable continental-scale inference about the status, trends, causes, and ecological consequences of phenological change.

Gezon, Z. J., D. W. Inouye, and R. E. Irwin. 2016. **Phenological change in a spring ephemeral: implications for pollination and plant reproduction.** Global Change Biology 22:1779-1793.

Abstract. Climate change has had numerous ecological effects, including species range shifts and altered phenology. Altering flowering phenology often affects plant reproduction, but the mechanisms behind these changes are not well-understood. To investigate why altering flowering phenology affects plant reproduction, we manipulated flowering phenology of the spring herb *Claytonia lanceolata* (Portulacaceae) using two methods: in 2011–2013 by altering snow pack (snow-removal vs. control treatments), and in 2013 by inducing flowering in a greenhouse before placing plants in experimental outdoor arrays (early, control, and late treatments). We measured flowering phenology, pollinator visitation, plant reproduction (fruit and seed set), and pollen limitation. Flowering occurred approx. 10 days earlier in snow-removal than control plots during all years of snow manipulation. Pollinator visitation patterns and strength of pollen limitation varied with snow treatments, and among years. Plants in the snow removal treatment were more likely to experience frost damage, and frost-damaged plants suffered low reproduction despite lack of pollen limitation. Plants in the snow removal treatment that escaped frost damage had higher pollinator visitation rates and reproduction than controls. The results of the array experiment supported the results of the snow manipulations. Plants in the early and late treatments suffered very low reproduction due either to severe frost damage (early treatment) or low pollinator visitation (late treatment) relative to control plants. Thus, plants face tradeoffs with advanced

flowering time. While early-flowering plants can reap the benefits of enhanced pollination services, they do so at the cost of increased susceptibility to frost damage that can overwhelm any benefit of flowering early. In contrast, delayed flowering results in dramatic reductions in plant reproduction through reduced pollination. Our results suggest that climate change may constrain the success of early-flowering plants not through plant-pollinator mismatch but through the direct impacts of extreme environmental conditions.

Leong, M., L. C. Ponisio, C. Kremen, R. W. Thorp, and G. K. Roderick. 2016. **Temporal dynamics influenced by global change: bee community phenology in urban, agricultural, and natural landscapes.** Global Change Biology 22:1046-1053.

Abstract. Urbanization and agricultural intensification of landscapes are important drivers of global change, which in turn have direct impacts on local ecological communities leading to shifts in species distributions and interactions. Here, we illustrate how human-altered landscapes, with novel ornamental and crop plant communities, result not only in changes to local community diversity of floral-dependent species, but also in shifts in seasonal abundance of bee pollinators. Three years of data on the spatio-temporal distributions of 91 bee species show that seasonal patterns of abundance and species richness in human-altered landscapes varied significantly less compared to natural habitats in which floral resources are relatively scarce in the dry summer months. These findings demonstrate that anthropogenic environmental changes in urban and agricultural systems, here mediated through changes in plant resources and water inputs, can alter the temporal dynamics of pollinators that depend on them. Changes in phenology of interactions can be an important, though frequently overlooked, mechanism of global change.

Toftegaard, T., D. Posledovich, J. A. Navarro-Cano, C. Wiklund, K. Gotthard, and J. Ehrlén. 2016. **Variation in plant thermal reaction norms along a latitudinal gradient – more than adaptation to season length.** Oikos 125:622-628.

Abstract. Little is known about the extent to which observed phenological responses to changes in climate are the result of phenotypic plasticity or genetic changes. We also know little about how plasticity, in terms of thermal reaction norms, vary spatially. We investigated if the thermal reaction norms for flower development of five crucifer species (Brassicaceae) differed among three regions along a south–north latitudinal gradient in replicated experiments. The mean response (elevation) of thermal reaction norms of flowering differed among regions in all study species, while sensitivity of flower development to temperature (slope) differed in only one of the species. Differences in mean responses corresponded to cogradient patterns in some species, but countergradient patterns in other. This suggests that differences among regions were not solely the result of adaptation to differences in the length of the growing season, but that other factors, such as herbivory, play an important role. Differences in development rate within species were mainly explained by variation in early phases of bud formation in some species but by variation in later phases of bud formation in other species. The differences in latitudinal patterns of thermal reaction norms among species observed in this study are important, both to identify agents of selection and to predict short- and long-term responses to a warming climate.

Species Range Changes

Chan, W.-P., I.-C. Chen, R. K. Colwell, W.-C. Liu, C.-y. Huang, and S.-F. Shen. 2016. **Seasonal and daily climate variation have opposite effects on species elevational range size.** Science 351:1437-1439.

Abstract. The climatic variability hypothesis posits that the magnitude of climatic variability increases with latitude, elevation, or both, and that greater variability selects for organisms with broader temperature tolerances, enabling them to be geographically widespread. We tested this classical hypothesis for the elevational range sizes of more than 16,500 terrestrial vertebrates on 180 montane gradients. In support of the hypothesis, mean elevational range size was positively correlated with the scope of seasonal temperature variation, whereas elevational range size was negatively correlated with daily temperature variation among gradients. In accordance with a previous life history model and our extended versions of it, our findings indicate that physiological specialization may be favored under shorter-term climatic variability.

Gutiérrez, A. G., R. S. Snell, and H. Bugmann. 2016. **Using a dynamic forest model to predict tree species distributions.** Global Ecology and Biogeography 25:347-358.

Abstract. Aim. It has been suggested that predicting species distributions requires a process-based and preferably dynamic

approach. If dynamic models are to contribute towards understanding species distributions, uncertainties related to their spatial extrapolation and bioclimatic parameters need to be addressed. Here, we analyse the potential of a forest gap model for predicting species distributions.

Location. Pacific Northwest of North America (PNW).

Methods. We used the dynamic forest gap model ForClim, which includes climate, competition and demographic processes, to simulate the distribution of 18 tree species outside the domain of the data used for fitting. We explored model accuracy for species distributions at the regional scale by: (1) estimating species climatic tolerances so as to maximize agreement with regional distribution maps versus (2) employing a bioclimatic parameter set that produces high accuracy at the local scale. We then performed the opposite tests and simulated local forest composition in a small area in the PNW, using (3) the local bioclimatic parameters and (4) the bioclimatic parameters that produced the highest accuracy at the regional scale. We also compared the ForClim results with predictions from a standard correlative species distribution model (SDM).

Results. ForClim produced regional species distributions with fair to very good agreement for 12 tree species. The optimized bioclimatic parameters consistently improved the accuracy of regional predictions compared with simulations run with the local parameters, and were consistent with SDM results. At the local scale, predictions using the local parameters conformed to descriptions of forest composition, but accuracy decreased strongly when using the regionally calibrated parameters.

Main conclusions. Forest gap models can predict regional species distributions, but at the cost of reduced accuracy at the local scale. Future applications of gap models to understand regional species distributions should include robust parameterization schemes and additional ecological processes that are important at large spatial scales (e.g. dispersal, disturbances).

Wolf, A., N. B. Zimmerman, W. R. L. Anderegg, P. E. Busby, and J. Christensen. 2016. **Altitudinal shifts of the native and introduced flora of California in the context of 20th-century warming.** Global Ecology and Biogeography 25:418-429.

Abstract. Aim. The differential responses of plant species to climate change are of great interest and grave concern for scientists and conservationists. One underexploited resource for better understanding these changes are the records held by herbaria. Using these records to assess the responses of different groups of species across the entire flora of California, we sought to quantify the magnitude of species elevational shifts, to measure differences in shifts among functional groups and between native and introduced species, and to evaluate whether these shifts were related to the conservation of thermal niches.

Location. California.

Methods. To characterize these shifts in California, we used 681,609 georeferenced herbarium records to estimate mean shifts in elevational and climatic space of 4426 plant taxa. We developed and employed a statistical method to robustly analyse the data represented in these records.

Results. We found that 15% of all taxa in California have ranges that have shifted upward over the past century. There are significant differences between range shifts of taxa with different naturalization statuses: 12% of endemic taxa show significant upward range shifts, while a greater proportion (27%) of introduced taxa have shifted upward. We found significant differences between the proportion of significant range shifts across taxa with different seed sizes, but did not find evidence for differences in shift based on life-form (annual versus perennial, herbaceous versus woody).

Main conclusions. Our analyses suggest that introduced species have disproportionately expanded their ranges upward in elevation over the past century when compared with native species. While these shifts in introduced species may not be exclusively driven by climate, they highlight the importance of considering the interacting factors of climate-driven range shifts and invasion to understand how floras are responding in the face of anthropogenic change.

Forest Vegetation

Anderegg, W. R. L., T. Klein, M. Bartlett, L. Sack, A. F. A. Pellegrini, B. Choat, and S. Jansen. 2016. **Meta-analysis reveals that hydraulic traits explain cross-species patterns of drought-induced tree mortality across the globe.** Proceedings of the National Academy of Sciences 113:5024-5029.

Abstract. Drought-induced tree mortality has been observed globally and is expected to increase under climate change scenarios, with large potential consequences for the terrestrial carbon sink. Predicting mortality across species is crucial for assessing the effects of climate extremes on forest community biodiversity, composition, and carbon sequestration. However, the physiological traits associated with elevated risk of mortality in diverse ecosystems remain unknown, although these traits could greatly improve understanding and prediction of tree mortality in forests. We performed a meta-analysis on species' mortality rates across 475 species from 33 studies around the globe to assess which traits determine a species' mortality risk. We found that species-specific mortality anomalies from community mortality rate in a given drought were associated with plant hydraulic traits. Across all species, mortality was best predicted by a low hydraulic safety margin—the difference between typical minimum xylem water potential and that causing xylem dysfunction—and xylem vulnerability to embolism. Angiosperms and gymnosperms experienced roughly equal mortality risks. Our results provide broad support for the hypothesis that hydraulic traits capture key mechanisms determining tree death and highlight that physiological traits can improve vegetation model prediction of tree mortality during climate extremes.

Assal, T. J., P. J. Anderson, and J. Sibold. 2016. **Spatial and temporal trends of drought effects in a heterogeneous semi-arid forest ecosystem.** Forest Ecology and Management 365:137-151.

Abstract. Drought has long been recognized as a driving mechanism in the forests of western North America and drought-induced mortality has been documented across genera in recent years. Given the frequency of these events are expected to increase in the future, understanding patterns of mortality and plant response to severe drought is important to resource managers. Drought can affect the functional, physiological, structural, and demographic properties of forest ecosystems. Remote sensing studies have documented changes in forest properties due to direct and indirect effects of drought; however, few studies have addressed this at local scales needed to characterize highly heterogeneous ecosystems in the forest-shrubland ecotone. We analyzed a 22-year Landsat time series (1985–2012) to determine changes in forest in an area that experienced a relatively dry decade punctuated by two years of extreme drought. We assessed the relationship between several vegetation indices and field measured characteristics (e.g. plant area index and canopy gap fraction) and applied these indices to trend analysis to uncover the location, direction and timing of change. Finally, we assessed the interaction of climate and topography by forest functional type. The Normalized

Difference Moisture Index (NDMI), a measure of canopy water content, had the strongest correlation with short-term field measures of plant area index (R^2 = 0.64) and canopy gap fraction (R^2 = 0.65). Over the entire time period, 25% of the forested area experienced a significant (p-value < 0.05) negative trend in NDMI, compared to less than 10% in a positive trend. Coniferous forests were more likely to be associated with a negative NDMI trend than deciduous forest. Forests on southern aspects were least likely to exhibit a negative trend while north aspects were most prevalent. Field plots with a negative trend had a lower live density, and higher amounts of standing dead and down trees compared to plots with no trend. Our analysis identifies spatially explicit patterns of long-term trends anchored with ground based evidence to highlight areas of forest that are resistant, persistent or vulnerable to severe drought. The results provide a long-term perspective for the resource management of this area and can be applied to similar ecosystems throughout western North America.

Case, M. J., and J. J. Lawler. 2016. **Relative vulnerability to climate change of trees in western North America.** Climatic Change 136:367-379.

Abstract. Many recent changes in tree species distributions, mortality, and growth rates have been linked to changes in climate. Managing forests in the face of climate change will require a basic understanding of which tree species will be most vulnerable to climate change and in what ways they will be vulnerable. We assessed the relative vulnerability to climate change of 11 tree species in western North America using a multivariate approach to quantify elements of sensitivity to climate change, exposure to climate change, and the capacity to adapt to climate change. Our assessment was based on a combination of expert knowledge, published studies, and projected changes in climate. Of the 11 species, Garry oak (*Quercus garryana*) was determined to be the most vulnerable, largely because of its relatively high sensitivity. Garry oak occupies some of the driest low woodland and savanna sites from British Columbia to California and is highly dependent on disturbances, such as periodic, low intensity fire. Big leaf maple (*Acer macrophyllum*) was determined to be the least vulnerable, largely because of its adaptive capacity. Big leaf maple can reproduce quickly after disturbances and its seeds can disperse long distances potentially allowing it to move in response to a changing climate. Our analyses provide a framework for assessing vulnerability and for determining why some species will likely be more vulnerable than others. Such information will be critical as natural resource

managers and conservation practitioners strive to address the impacts of climate change with limited funds.

Loehle, C., C. Idso, and T. Bently Wigley. 2016. **Physiological and ecological factors influencing recent trends in United States forest health responses to climate change.** Forest Ecology and Management 363:179-189.

Abstract. The health of United States forests is of concern for biodiversity conservation, ecosystem services, forest commercial values, and other reasons. Climate change, rising concentrations of CO_2 and some pollutants could plausibly have affected forest health and growth rates over the past 150 years and may affect forests in the future. Multiple factors must be considered when assessing present and future forest health. Factors undergoing change include temperature, precipitation (including flood and drought), CO_2 concentration, N deposition, and air pollutants. Secondary effects include alteration of pest and pathogen dynamics by climate change. We provide a review of these factors as they relate to forest health and climate change. We find that plants can shift their optimum temperature for photosynthesis, especially in the presence of elevated CO_2, which also increases plant productivity. No clear national trend to date has been reported for flood or drought or their effects on forests except for a current drought in the US Southwest. Additionally, elevated CO_2 increases water use efficiency and protects plants from drought. Pollutants can reduce plant growth but concentrations of major pollutants such as ozone have declined modestly. Ozone damage in particular is lessened by rising CO_2. No clear trend has been reported for pathogen or insect damage but experiments suggest that in many cases rising CO_2 enhances plant resistance to both agents. There is strong evidence from the United States and globally that forest growth has been increasing over recent decades to the past 100+ years. Future prospects for forests are not clear because different models produce divergent forecasts. However, forest growth models that incorporate more realistic physiological responses to rising CO_2 are more likely to show future enhanced growth. Overall, our review suggests that United States forest health has improved over recent decades and is not likely to be impaired in at least the next few decades.

McDowell, N. G., A. P. Williams, C. Xu, W. T. Pockman, L. T. Dickman, S. Sevanto, R. Pangle, J. Limousin, J. Plaut, D. S. Mackay, J. Ogee, J. C. Domec, C. D. Allen, R. A. Fisher, X. Jiang, J. D. Muss, D. D. Breshears, S. A. Rauscher, and C. Koven. 2016. **Multi-scale predictions of massive conifer mortality due to chronic temperature rise.** Nature Climate Change 6:295-300.

Abstract. Global temperature rise and extremes accompanying drought threaten forests and their associated climatic feedbacks. Our ability to accurately simulate drought-induced forest impacts remains highly uncertain in part owing to our failure to integrate physiological measurements, regional-scale models, and dynamic global vegetation models (DGVMs). Here we show consistent predictions of widespread mortality of needleleaf evergreen trees (NET) within Southwest USA by 2100 using state-of-the-art models evaluated against empirical data sets. Experimentally, dominant Southwest USA NET species died when they fell below predawn water potential (Ψ_{pd}) thresholds (April–August mean) beyond which photosynthesis, hydraulic and stomatal conductance, and carbohydrate availability approached zero. The evaluated regional models accurately predicted NET Ψ_{pd}, and 91% of predictions (10 out of 11) exceeded mortality thresholds within the twenty-first century due to temperature rise. The independent DGVMs predicted ≥50% loss of Northern Hemisphere NET by 2100, consistent with the NET findings for Southwest USA. Notably, the global models underestimated future mortality within Southwest USA, highlighting that predictions of future mortality within global models may be underestimates. Taken together, the validated regional predictions and the global simulations predict widespread conifer loss in coming decades under projected global warming.

Minckley, T. A., and C. J. Long. 2016. **Paleofire severity and vegetation change in the Cascade Range, Oregon, USA.** Quaternary Research 85:211-217.

Abstract. Paleoecological research has expanded our knowledge of the relationships between climate, fire and vegetation. Fire can be a significant driver of forest composition and structure change, but identifying and quantifying fire regimes has been elusive. Using high-resolution charcoal analysis and pollen analysis we reconstructed a 13,200-year-old fire and vegetation history from Breitenbush Lake, Oregon, located in the central Cascade Range, USA. Our objective was to examine if fire occurrence and severity may have been a driver of Holocene forest-composition change. The data from this study suggests that while fire can create opportunities for successional

process to occur, fire events were not significant catalysts for forest change. Instead, most major transitions at Breitenbush Lake occurred during prolonged fire-free intervals. Our results reinforce the view that climate is the major control of vegetation composition change in the Cascade Range.

van Mantgem, P. J., A. C. Caprio, N. L. Stephenson, and A. J. Das. 2016. **Does prescribed fire promote resistance to drought in low elevation forests of the Sierra Nevada, California, USA?** Fire Ecology 12:13-25.

Abstract. Prescribed fire is a primary tool used to restore western forests following more than a century of fire exclusion, reducing fire hazard by removing dead and live fuels (small trees and shrubs). It is commonly assumed that the reduced forest density following prescribed fire also reduces competition for resources among the remaining trees, so that the remaining trees are more resistant (more likely to survive) in the face of additional stressors, such as drought. Yet this proposition remains largely untested, so that managers do not have the basic information to evaluate whether prescribed fire may help forests adapt to a future of more frequent and severe drought.

During the third year of drought, in 2014, we surveyed 9950 trees in 38 burned and 18 unburned mixed conifer forest plots at low elevation (<2100 m a.s.l.) in Kings Canyon, Sequoia, and Yosemite national parks in California, USA. Fire had occurred in the burned plots from 6 yr to 28 yr before our survey. After accounting for differences in individual tree diameter, common conifer species found in the burned plots had significantly reduced probability of mortality compared to unburned plots during the drought. Stand density (stems ha-1) was significantly lower in burned versus unburned sites, supporting the idea that reduced competition may be responsible for the differential drought mortality response. At the time of writing, we are not sure if burned stands will maintain lower tree mortality probabilities in the face of the continued, severe drought of 2015. Future work should aim to better identify drought response mechanisms and how these may vary across other forest types and regions, particularly in other areas experiencing severe drought in the Sierra Nevada and on the Colorado Plateau.

Zhang, J., S. E. Nielsen, L. Mao, S. Chen, and J.-C. Svenning. 2016. **Regional and historical factors supplement current climate in shaping global forest canopy height.** Journal of Ecology 104:469-478.

Abstract. Canopy height is a key factor that affects carbon storage, vegetation productivity and biodiversity in forests, as well as an indicator of key processes such as biomass allocation. However, global variation in forest canopy height and its determinants are poorly known.

We used global data on Light Detection and Ranging-derived maximum forest canopy height (H_{max}) to test hypotheses relating H_{max} to current climate (water availability, ambient energy and water–energy dynamics), regional evolutionary and biogeographic history, historical climate change, and human disturbance.

We derived H_{max} for 32 304 forested 55-km grid cells using 1-km global canopy height data (maximum height of 1-km cells within a 55-km grid). Variation in H_{max} was related to latitude and biomes, along with environmental and historical variables. Both spatial and non-spatial linear models were used to assess the relative importance of the different hypothesized factors.

H_{max} was inversely related to latitude (i.e. tall canopies at the equator), but with high geographical variability. Actual evapotranspiration and annual precipitation were the factors most correlated to H_{max} globally, thus supporting the water–energy dynamics hypothesis. However, water limitation emerged as a key factor in tropical and temperate biomes within specific geographic regions, while energy limitation was a more important factor in boreal regions where temperature is more limiting to trees than water.

H_{max} exhibited strong variation among biogeographic regions, supporting the role of regional evolutionary and biogeographic history in structuring broad-scale patterns in canopy height. Furthermore, there were divergent relationships between climate and H_{max} between the Southern and Northern Hemispheres, consistent with historical evolutionary contingencies modulating these relationships. Historical climate change was also related to H_{max}, albeit not as strongly, with shorter canopy heights where late-Quaternary climate has been less stable. In contrast, human disturbance was only weakly related to H_{max} at the scale (55 km) examined here.

Synthesis. This study confirms that forest canopy height is strongly controlled by current climate, but also provides evidence for an important supplementary role for regional–historical factors. This

highlights the importance of considering evolutionary and biogeographic history for achieving a comprehensive understanding of forest ecosystem properties.

Rangeland Vegetation

Biederman, J. A., R. L. Scott, M. L. Goulden, R. Vargas, M. E. Litvak, T. E. Kolb, E. A. Yepez, W. C. Oechel, P. D. Blanken, T. W. Bell, J. Garatuza-Payan, G. E. Maurer, S. Dore, and S. P. Burns. 2016. **Terrestrial carbon balance in a drier world: the effects of water availability in southwestern North America.** Global Change Biology 22:1867-1879.

Abstract. Global modeling efforts indicate semiarid regions dominate the increasing trend and interannual variation of net CO_2 exchange with the atmosphere, mainly driven by water availability. Many semiarid regions are expected to undergo climatic drying, but the impacts on net CO_2 exchange are poorly understood due to limited semiarid flux observations. Here we evaluated 121 site-years of annual eddy covariance measurements of net and gross CO_2 exchange (photosynthesis and respiration), precipitation, and evapotranspiration (ET) in 21 semiarid North American ecosystems with an observed range of 100 – 1000 mm in annual precipitation and records of 4–9 years each. In addition to evaluating spatial relationships among CO_2 and water fluxes across sites, we separately quantified site-level temporal relationships, representing sensitivity to interannual variation. Across the climatic and ecological gradient, photosynthesis showed a saturating spatial relationship to precipitation, whereas the photosynthesis–ET relationship was linear, suggesting ET was a better proxy for water available to drive CO_2 exchanges after hydrologic losses. Both photosynthesis and respiration showed similar site-level sensitivity to interannual changes in ET among the 21 ecosystems. Furthermore, these temporal relationships were not different from the spatial relationships of long-term mean CO_2 exchanges with climatic ET. Consequently, a hypothetical 100-mm change in ET, whether short term or long term, was predicted to alter net ecosystem production (NEP) by 64 $gCm^{-2}\ yr^{-1}$. Most of the unexplained NEP variability was related to persistent, site-specific function, suggesting prioritization of research on slow-changing controls. Common temporal and spatial sensitivity to water availability increases our confidence that site-level responses to interannual weather can be extrapolated for prediction of

CO_2 exchanges over decadal and longer timescales relevant to societal response to climate change.

Gornish, E. S., and P. Ambrozio dos Santos. 2016. **Invasive species cover, soil type, and grazing interact to predict long-term grassland restoration success.** Restoration Ecology 24:222-229.

Abstract. Grasslands are undergoing tremendous degradation as a result of climate change, land use, and invasion by non-native plants. However, understanding of the factors responsible for driving reestablishment of grassland plant communities is largely derived from short-term studies. In order to develop an understanding of the factors responsible for longer term restoration outcomes in California annual grasslands, we surveyed 12 fields in Davis, CA, U.S.A., in 2015 that were seeded with native species mixtures starting in 2004. Using field surveys, we investigated how invasive plant richness and cover, native plant richness and cover, aboveground biomass, grazing, soil type, and restoration species identity might provide utility for explaining patterns of restoration success. We found a negative relationship between invasive cover and restoration cover, which was attributed to the slow establishment of seeded species and subsequent dominance by weeds. The relationship between invasive cover and restoration cover was modified by grazing, likely due to a change in the dominance of exotic forbs, which have a more similar growing season to restoration species, and therefore compete more strongly for late season moisture. Finally, we found that soil type was responsible for differences in the identity and abundance of invasive plants, subsequently affecting restoration cover. This work highlights the value of focusing resources on reducing invasive species cover, limiting grazing to periods of adequate moisture, and considering soil type for successful long-term restoration in California annual grasslands. Moreover, observations of long-term restoration outcomes can provide insight into the way mechanisms driving restoration outcomes might differ through time.

Manea, A., D. R. Sloane, and M. R. Leishman. 2016. **Reductions in native grass biomass associated with drought facilitates the invasion of an exotic grass into a model grassland system.** Oecologia 181:175-183.

Abstract. The invasion success of exotic plant species is often dependent on resource availability. Aspects of climate change such as

rising atmospheric CO_2 concentration and extreme climatic events will directly and indirectly alter resource availability in ecological communities. Understanding how these climate change-associated changes in resource availability will interact with one another to influence the invasion success of exotic plant species is complex. The aim of the study was to assess the establishment success of an invasive exotic species in response to climate change-associated changes in resource availability (CO_2 levels and soil water availability) as a result of extreme drought. We grew grassland mesocosms consisting of four co-occurring native grass species common to the Cumberland Plain Woodland of western Sydney, Australia, under ambient and elevated CO_2 levels and subjected them to an extreme drought treatment. We then added seeds of a highly invasive C_3 grass, *Ehrharta erecta*, and assessed its establishment success (biomass production and reproductive output). We found that reduced biomass production of the native grasses in response to the extreme drought treatment enhanced the establishment success of *E. erecta* by creating resource pulses in light and space. Surprisingly, CO_2 level did not affect the establishment success of *E. erecta*. Our results suggest that the invasion risk of grasslands in the future may be coupled to soil water availability and the subsequent response of resident native vegetation therefore making it strongly context- dependent.

Reed, C. C., and M. E. Loik. 2016. **Water relations and photosynthesis along an elevation gradient for *Artemisia tridentata* during an historic drought.** Oecologia 181:65-76.

Abstract. Quantifying the variation in plant–water relations and photosynthesis over environmental gradients and during unique events can provide a better understanding of vegetation patterns in a future climate. We evaluated the hypotheses that photosynthesis and plant water potential would correspond to gradients in precipitation and soil moisture during a lengthy drought, and that experimental water additions would increase photosynthesis for the widespread evergreen shrub Artemisia tridentata ssp. vaseyana. We quantified abiotic conditions and physiological characteristics for control and watered plants at 2135, 2315, and 2835 m near Mammoth Lakes, CA, USA, at the ecotone of the Sierra Nevada and Great Basin ecoregions. Snowfall, total precipitation, and soil moisture increased with elevation, but air temperature and soil N content did not. Plant water potential (Ψ), stomatal conductance (g_s), maximum photosynthetic rate (A_{max}), carboxylation rate (V_{cmax}), and electron transport rate (J_{max}) all significantly increased with elevations. Addition of water increased Ψ, g_s, J_{max}, and A_{max} only at the lowest elevation; g s

contributed about 30 % of the constraints on photosynthesis at the lowest elevation and 23 % at the other two elevations. The physiology of this foundational shrub species was quite resilient to this 1-in-1200 year drought. However, plant water potential and photosynthesis corresponded to differences in soil moisture across the gradient. Soil re-wetting in early summer increased water potential and photosynthesis at the lowest elevation. Effects on water relations and photosynthesis of this widespread, cold desert shrub species may be disproportionate at lower elevations as drought length increases in a future climate.

Rysavy, A., M. Seifan, M. Sternberg, and K. Tielbörger. 2016. **Neighbour effects on shrub seedling establishment override climate change impacts in a Mediterranean community.** Journal of Vegetation Science 27:227-237.

Abstract. Questions. Can theory about plant–plant interactions along climate gradients help us predict how climate change will affect shrub establishment? How does a predicted reduction in rainfall affect the outcome of the interactions between shrub seedlings and herbaceous plants in a dryland ecosystem?

Location. Three field sites along a rainfall gradient and an adjacent experimental site at the Botanical Gardens of Tel Aviv University, Israel.

Method. We measured seedling survival of a dominant shrub species in response to the presence of herbaceous neighbours and to rainfall amount using two approaches: First, we employed a space-for-time approach and studied seedling survival along an aridity gradient that was shown to mimic the predicted rainfall changes. Second, we monitored seedling survival in a common garden experiment in which we simulated drought using rainout shelters. In both experiments we contrasted the importance of water availability relative to the presence of herbaceous neighbours and the origin of the shrub seedlings.

Results. Our results showed that neighbours always had a negative effect on shrub seedling survival. In contrast to theoretical predictions, the intensity of competition increased with reduction in water availability. Shrub seedlings originating from drier conditions showed higher survival than seedlings from mesic origin.

Conclusions. These results emphasize the importance of incorporating biotic interactions in studies predicting changes in plant dynamics under climate change. Moreover, plant species growing in ecosystems prone to high rainfall variability showed a greater ability to cope with

dry conditions, which suggests more nuanced origin-specific predictions than suggested by recent climate models.

Sullivan, M. J. P., M. A.Thomsen, and K. B. Suttle. 2016. **Grassland responses to increased rainfall depend on the timescale of forcing.** Global Change Biology 22:1655-1665.

Abstract. Forecasting impacts of future climate change is an important challenge to biologists, both for understanding the consequences of different emissions trajectories and for developing adaptation measures that will minimize biodiversity loss. Existing variation provides a window into the effects of climate on species and ecosystems, but in many places does not encompass the levels or timeframes of forcing expected under directional climatic change. Experiments help us to fill in these uncertainties, simulating directional shifts to examine outcomes of new levels and sustained changes in conditions. Here, we explore the translation between short-term responses to climate variability and longer-term trajectories that emerge under directional climatic change. In a decade-long experiment, we compare effects of short-term and long-term forcings across three trophic levels in grassland plots subjected to natural and experimental variation in precipitation. For some biological responses (plant productivity), responses to long-term extension of the rainy season were consistent with short-term responses, while for others (plant species richness, abundance of invertebrate herbivores and predators), there was pronounced divergence of long-term trajectories from short-term responses. These differences between biological responses mean that sustained directional changes in climate can restructure ecological relationships characterizing a system. Importantly, a positive relationship between plant diversity and productivity turned negative under one scenario of climate change, with a similar change in the relationship between plant productivity and consumer biomass. Inferences from experiments such as this form an important part of wider efforts to understand the complexities of climate change responses.

Fish and Wildlife

Bateman, B. L., A. M. Pidgeon, V. C. Radeloff, J. VanDerWal, W. E. Thogmartin, S. J. Vavrus, and P. J. Heglund. 2016. **The pace of past climate change vs. potential bird distributions and land use in the United States.** Global Change Biology 22:1130-1144.

Abstract. Climate change may drastically alter patterns of species distributions and richness, but predicting future species patterns in occurrence is challenging. Significant shifts in distributions have already been observed, and understanding these recent changes can improve our understanding of potential future changes. We assessed how past climate change affected potential breeding distributions for landbird species in the conterminous United States. We quantified the bioclimatic velocity of potential breeding distributions, that is, the pace and direction of change for each species' suitable climate space over the past 60 years. We found that potential breeding distributions for landbirds have shifted substantially with an average velocity of 1.27 km yr^{-1}, about double the pace of prior distribution shift estimates across terrestrial systems globally (0.61 km yr^{-1}). The direction of shifts was not uniform. The majority of species' distributions shifted west, northwest, and north. Multidirectional shifts suggest that changes in climate conditions beyond mean temperature were influencing distributional changes. Indeed, precipitation variables that were proxies for extreme conditions were important variables across all models. There were winners and losers in terms of the area of distributions; many species experienced contractions along west and east distribution edges, and expansions along northern distribution edges. Changes were also reflected in the potential species richness, with some regions potentially gaining species (Midwest, East) and other areas potentially losing species (Southwest). However, the degree to which changes in potential breeding distributions are manifested in actual species richness depends on landcover. Areas that have become increasingly suitable for breeding birds due to changing climate are often those attractive to humans for agriculture and development. This suggests that many areas might have supported more breeding bird species had the landscape not been altered. Our study illustrates that climate change is not only a future threat, but something birds are already experiencing.

Isaak, D. J., M. K. Young, C. H. Luce, S. W. Hostetler, S. J. Wenger, E. E. Peterson, J. M. Ver Hoef, M. C. Groce, D. L. Horan, and D. E. Nagel. 2016. **Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity.** Proceedings of the National Academy of Sciences. 113:4374-4379.

Abstract. The imminent demise of montane species is a recurrent theme in the climate change literature, particularly for aquatic species that are constrained to networks and elevational rather than latitudinal retreat as temperatures increase. Predictions of widespread species losses, however, have yet to be fulfilled despite decades of climate change, suggesting that trends are much weaker than anticipated and may be too subtle for detection given the widespread use of sparse water temperature datasets or imprecise surrogates like elevation and air temperature. Through application of large water-temperature databases evaluated for sensitivity to historical air-temperature variability and computationally interpolated to provide high-resolution thermal habitat information for a 222,000-km network, we estimate a less dire thermal plight for cold-water species within mountains of the northwestern United States. Stream warming rates and climate velocities were both relatively low for 1968–2011 (average warming rate = 0.101 °C/decade; median velocity = 1.07 km/decade) when air temperatures warmed at 0.21 °C/decade. Many cold-water vertebrate species occurred in a subset of the network characterized by low climate velocities, and three native species of conservation concern occurred in extremely cold, slow velocity environments (0.33–0.48 km/decade). Examination of aggressive warming scenarios indicated that although network climate velocities could increase, they remain low in headwaters because of strong local temperature gradients associated with topographic controls. Better information about changing hydrology and disturbance regimes is needed to complement these results, but rather than being climatic cul-de-sacs, many mountain streams appear poised to be redoubts for cold-water biodiversity this century.

La Sorte, F. A., W. M. Hochachka, A. Farnsworth, A. A. Dhondt, and D. Sheldon. 2016. **The implications of mid-latitude climate extremes for North American migratory bird populations.** Ecosphere 7:e01261.

Abstract. Mid-latitude climate extremes are projected to increase in frequency under global climate change. How this may affect migratory bird populations is not well understood. The mid-latitudes of North

America experienced an extreme warming event during March 2012 that advanced the spring phenology of ecological productivity, resulting in lower levels of productivity during the summer. Here, we test the predictions that: (1) short-distance migratory birds, due to geographic proximity and more flexible migratory behavior, should advance their spring migration phenology; and (2) breeding populations, due to lower summer productivity, should have reduced occurrences. We used occurrence data for 353 bird species from the eBird database to calculate weekly occurrence anomalies for 2012 relative to the 2010–2014 average. We identified species having unusually large positive occurrence anomalies during March 2012 and species having unusually large negative occurrence anomalies during July–August 2012. For each category, we summarized migration strategies, geographic distributions, and annual associations with temperature and ecological productivity. Short-distance migrants whose winter and breeding ranges intersect the mid-latitudes advanced their spring migration phenology during March (n = 21). Long-distance migrants whose winter and breeding distributions were weakly associated with the mid-latitudes had lower occurrences during the summer (n = 32). Five species were shared between the two categories. Within species' winter ranges, temperature and ecological productivity were higher than expected during March; within species' breeding ranges, ecological productivity was lower than expected during the summer. These differences were strongest for the 21 short-distance migrants. Following our expectations, mid-latitude climate extremes and associated ecological consequences broadly affected avian migration and breeding activities within the region. Our findings suggest short-distance migrants are more flexible and resilient, whereas populations of long-distance migrants are at a distinct disadvantage, which may intensify if the frequency of these events increases.

Ohlberger, J., M. D. Scheuerell, and D. E. Schindler. 2016. **Population coherence and environmental impacts across spatial scales: a case study of Chinook salmon.** Ecosphere 7:e01333.

Abstract. A central problem in understanding how species respond to global change is in parsing the effects of local drivers of population dynamics from regional and global drivers that are shared among populations. Management and conservation efforts that typically focus on a particular population would benefit greatly from being able to separate the effects of environmental processes at local, regional, and global scales. One way of addressing this challenge is to integrate data

across multiple populations and use multivariate time series approaches to estimate shared and independent components of dynamics among neighboring populations. Here, we use a data set of 15 populations of Chinook salmon (*Oncorhynchus tshawytscha*) covering a broad geographical range in the eastern North Pacific Ocean to show how Dynamic Factor Analysis (DFA) can be used to estimate temporal coherence in population dynamics and to detect environmental drivers across spatial scales. Our results show that productivity dynamics of Chinook salmon populations strongly covary at the regional scale, but to a lesser degree at larger spatial scales. The timing of river ice break-up in spring was identified as an important driver of regional productivity dynamics. In addition, broad-scale variability in population productivity was linked to the North Pacific Gyre Oscillation, a dominant pattern of sea surface height variability. These broad-scale patterns in productivity dynamics may be associated with recent regime shifts in the Northeast Pacific Ocean. However, our results also demonstrate that populations within regions do not always respond consistently to the same environmental drivers, thus suggesting location-specific impacts. Overall, this study illustrates the use of DFA for quantifying the spatial and temporal complexity of multiple population responses to environmental change, thereby providing insights to processes that affect populations across large geographic areas, but that might be filtered by local habitat conditions.

Soykan, C. U., J. Sauer, J. G. Schuetz, G. S. LeBaron, K. Dale, and G. M. Langham. 2016. **Population trends for North American winter birds based on hierarchical models.** Ecosphere 7:e01351.

Abstract. Managing widespread and persistent threats to birds requires knowledge of population dynamics at large spatial and temporal scales. For over 100 yrs, the Audubon Christmas Bird Count (CBC) has enlisted volunteers in bird monitoring efforts that span the Americas, especially southern Canada and the United States. We employed a Bayesian hierarchical model to control for variation in survey effort among CBC circles and, using CBC data from 1966 to 2013, generated early-winter population trend estimates for 551 species of birds. Selecting a subset of species that do not frequent bird feeders and have ≥25% range overlap with the distribution of CBC circles (228 species) we further estimated aggregate (i.e., across species) trends for the entire study region and at the level of states/provinces, Bird Conservation Regions, and Landscape Conservation Cooperatives. Moreover, we examined the relationship between ten biological traits—range size, population size, migratory strategy, habitat affiliation, body size, diet, number of eggs per clutch, age at sexual maturity, lifespan, and tolerance of urban/suburban settings—and CBC trend estimates. Our results indicate that 68% of the 551 species had increasing trends within the study area over the interval 1966–2013. When trends were examined across the subset of 228 species, the median population trend for the group was 0.9% per year at the continental level. At the regional level, aggregate trends were positive in all but a few areas. Negative population trends were evident in lower latitudes, whereas the largest increases were at higher latitudes, a pattern consistent with range shifts due to climate change. Nine of 10 biological traits were significantly associated with median population trend; however, none of the traits explained >34% of the deviance in the data, reflecting the indirect relationships between population trend estimates and species traits. Trend estimates based on the CBC are broadly congruent with estimates based on the North American Breeding Bird Survey, another large-scale monitoring program. Both of these efforts, conducted by citizen scientists, will be required going forward to ensure robust inference about population dynamics in the face of climate and land cover changes.

Stephens, P. A., L. R. Mason, R. E. Green, R. D. Gregory, J. R. Sauer, J. Alison, A. Aunins, L. Brotons, S. H. M. Butchart, T. Campedelli, T. Chodkiewicz, P. Chylarecki, O. Crowe, J. Elts, V. Escandell, R. P. B. Foppen, H. Heldbjerg, S. Herrando, M. Husby, F. Jiguet, A. Lehikoinen, Å. Lindström, D. G. Noble, J.-Y. Paquet, J. Reif, T. Sattler, T. Szép, N. Teufelbauer, S. Trautmann, A. J. van Strien, C. A. M. van Turnhout, P. Vorisek, and S. G. Willis. 2016. **Consistent response of bird populations to climate change on two continents.** Science 352:84-87.

Abstract. Global climate change is a major threat to biodiversity. Large-scale analyses have generally focused on the impacts of climate change on the geographic ranges of species and on phenology, the timing of ecological phenomena. We used long-term monitoring of the abundance of breeding birds across Europe and the United States to produce, for both regions, composite population indices for two groups of species: those for which climate suitability has been either improving or declining since 1980. The ratio of these composite indices, the climate impact indicator (CII), reflects the divergent fates of species favored or disadvantaged by climate change. The trend in CII is positive and similar in the two regions. On both continents, interspecific and spatial variation in population abundance trends are well predicted by climate suitability trends.

Sultaire, S. M., J. N. Pauli, K. J. Martin, M. W. Meyer, M. Notaro, and B. Zuckerberg. 2016. **Climate change surpasses land-use change in the contracting range boundary of a winter-adapted mammal.** Proceedings of the Royal Society of London B: Biological Sciences 283: 1827.

Abstract. The effects of climate change on biodiversity have emerged as a dominant theme in conservation biology, possibly eclipsing concern over habitat loss in recent years. The extent to which this shifting focus has tracked the most eminent threats to biodiversity is not well documented. We investigated the mechanisms driving shifts in the southern range boundary of a forest and snow cover specialist, the snowshoe hare, to explore how its range boundary has responded to shifting rates of climate and land cover change over time. We found that although both forest and snow cover contributed to the historical range boundary, the current duration of snow cover best explains the most recent northward shift, while forest cover has declined in relative importance. In this respect, the southern range boundary of snowshoe hares has mirrored the focus of conservation research; first habitat loss and fragmentation was the stronger environmental constraint, but climate change has now become the main threat. Projections of future range shifts show that climate change, and associated snow cover loss, will continue to be the major driver of this species' range loss into the future.

Invertebrates

Boulanger, Y., D. R. Gray, B. J. Cooke, and L. De Grandpré. 2016. **Model-specification uncertainty in future forest pest outbreak.** Global Change Biology 22:1595-1607.

Abstract. Climate change will modify forest pest outbreak characteristics, although there are disagreements regarding the specifics of these changes. A large part of this variability may be attributed to model specifications. As a case study, we developed a consensus model predicting spruce budworm (SBW, *Choristoneura fumiferana* [Clem.]) outbreak duration using two different predictor data sets and six different correlative methods. The model was used to project outbreak duration and the uncertainty associated with using different data sets and correlative methods (=model-specification uncertainty) for 2011–2040, 2041–2070 and 2071–2100, according to

three forcing scenarios (RCP 2.6, RCP 4.5 and RCP 8.5). The consensus model showed very high explanatory power and low bias. The model projected a more important northward shift and decrease in outbreak duration under the RCP 8.5 scenario. However, variation in single-model projections increases with time, making future projections highly uncertain. Notably, the magnitude of the shifts in northward expansion, overall outbreak duration and the patterns of outbreaks duration at the southern edge were highly variable according to the predictor data set and correlative method used. We also demonstrated that variation in forcing scenarios contributed only slightly to the uncertainty of model projections compared with the two sources of model-specification uncertainty. Our approach helped to quantify model-specification uncertainty in future forest pest outbreak characteristics. It may contribute to sounder decision-making by acknowledging the limits of the projections and help to identify areas where model-specification uncertainty is high. As such, we further stress that this uncertainty should be strongly considered when making forest management plans, notably by adopting adaptive management strategies so as to reduce future risks.

Kneitel, J. M. 2016. **Climate-driven habitat size determines the latitudinal diversity gradient in temporary ponds.** Ecology 97:961-968.

Abstract. The latitudinal diversity gradient (LDG) has been one of the most documented patterns in ecology, typically showing decreasing species diversity with increasing latitude. Studies of these patterns also used different spatial scales and dispersal traits to better understand the underpinning ecological factors. Seasonal freshwater ecosystems are less studied and may exhibit different patterns because they are more sensitive to climatic variation, which result in an inundation–desiccation cycle. In California, precipitation increases and temperature decreases with increasing latitude and thus the LDG pattern may be associated with this climatic gradient. Using collected data and United States Fish and Wildlife Service reports across seven degrees of latitude, analysis of California vernal pool invertebrate community (total richness and richness of passive and active dispersers) was conducted using correlations (Spearman rank and partial). Alpha diversity (total and passive dispersers) increased and beta diversity (passive dispersers) decreased with increasing latitude. Vernal pool surface area was correlated with active disperser alpha and passive disperser beta diversity. This suggests that climate-driven habitat size influences alpha and beta diversity patterns depending on dispersal ability. Active dispersers and predators exhibited higher beta

diversity than passive dispersers and prey, respectively. Species composition differed among counties and some of these differences were correlated with pool depth and temperature. These results suggest that seasonal habitats will have diversity patterns strongly associated with local scale characteristics (habitat size and hydroperiod) determined by climate variation along the latitudinal gradient. Understanding these diversity patterns along the gradient will also contribute to management and restoration of these ecosystems with high endemism and diversity.

Pyke, G. H., J. D. Thomson, D. W. Inouye, and T. J. Miller. 2016. **Effects of climate change on phenologies and distributions of bumble bees and the plants they visit.** Ecosphere 7:e01267.

Abstract. Surveys of bumble bees and the plants they visit, carried out in 1974 near the Rocky Mountain Biological Laboratory in Colorado, were repeated in 2007, thus permitting the testing of hypotheses arising from observed climate change over the intervening 33-yr period. As expected, given an increase in average air temperature with climate warming and a declining temperature with increasing elevation, there have been significant shifts toward higher elevation for queens or workers or both, for most bumble bee species, for bumble bee queens when species are combined, and for two focal plant species, with no significant downward shifts. However, contrary to our hypotheses, we failed to observe significant altitudinal changes for some bumble bee species and most plant species, and observed changes in elevation were often less than the upward shift of 317 m required to maintain average temperature. As expected, community flowering phenology shifted toward earlier in the season throughout our study area, but bumble bee phenology generally did not change, resulting in decreased synchrony between bees and plants. However, we were unable to confirm the narrower expectation that phenologies of bumble bee workers and community flowering coincided in 1974 but not in 2007. As expected, because of reduced synchrony between bumble bees and community flowering, bumble bee abundance was reduced in 2007 compared with 1974. Hence, climate change in our study area has apparently resulted primarily in reduced abundance and upward shift in distribution for bumble bees and shift toward earlier seasonality for plant flowering. Quantitative disagreements between climate change expectations and our observations warrant further investigation.

Ziska, L. H., J. S. Pettis, J. Edwards, J. E. Hancock, M. B. Tomecek, A. Clark, J. S. Dukes, I. Loladze, and H. W. Polley. 2016. **Rising atmospheric CO2 is reducing the protein concentration of a floral pollen source essential for North American bees.** Proceedings of the Royal Society of London B: Biological Sciences 283:1828.

Abstract. At present, there is substantive evidence that the nutritional content of agriculturally important food crops will decrease in response to rising levels of atmospheric carbon dioxide, C_a. However, whether C_a-induced declines in nutritional quality are also occurring for pollinator food sources is unknown. Flowering late in the season, goldenrod (*Solidago* spp.) pollen is a widely available autumnal food source commonly acknowledged by apiarists to be essential to native bee (e.g. *Bombus* spp.) and honeybee (*Apis mellifera*) health and winter survival. Using floral collections obtained from the Smithsonian Natural History Museum, we quantified C_a-induced temporal changes in pollen protein concentration of Canada goldenrod (*Solidago canadensis*), the most widespread *Solidago* taxon, from hundreds of samples collected throughout the USA and southern Canada over the period 1842–2014 (i.e. a C_a from approx. 280 to 398 ppm). In addition, we conducted a 2 year *in situ* trial of *S. canadensis* populations grown along a continuous C_a gradient from approximately 280 to 500 ppm. The historical data indicated a strong significant correlation between recent increases in C_a and reductions in pollen protein concentration (r^2 = 0.81). Experimental data confirmed this decrease in pollen protein concentration, and indicated that it would be ongoing as C_a continues to rise in the near term, i.e. to 500 ppm (r^2 = 0.88). While additional data are needed to quantify the subsequent effects of reduced protein concentration for Canada goldenrod on bee health and population stability, these results are the first to indicate that increasing C_a can reduce protein content of a floral pollen source widely used by North American bees.

Soils and Hydrology

Lévesque, M., L. Walthert, and P. Weber. 2016. **Soil nutrients influence growth response of temperate tree species to drought.** Journal of Ecology 104:377-387.

Abstract. Soil properties can buffer forest response to global climate change. However, it is unclear how soil characteristics, water availability and their interactions can affect drought response of trees.

The aim of this study was to assess the influence of soil nutrients and physical soil properties on the growth sensitivity of Fagus sylvatica, Quercus spp., Fraxinus excelsior, Abies alba, Picea abies and Pinus sylvestris to drought in Central Europe.

Yearly growth data from increment cores were obtained from 538 trees and combined with forest inventory and soil data at 52 sites covering a large gradient of water availability and C/N ratios in soil. Linear mixed-effects models were used to assess the species-specific growth responses to climate and soil properties for the period 1957–2006. The growth of the species was further projected across the full range of C/N and water availability observed at 1029 sites where soil and species cover-abundance data were available.

Temperature, water and nutrient availability (C/N) were the most important factors for tree growth. Drought and low nutrient availability significantly reduced the growth of beech, ash, fir and spruce along the gradient. In contrast, the growth of pine and oak was little reduced on poor and dry sites, hence showing their competitive advantage over nutrient-demanding species under such conditions. The growth of ash and pine was enhanced at sites with high species abundance, whereas an opposite response was found for spruce. No clear relationships between growth and species abundance were found for beech, oak and fir.

Synthesis. Our results suggest that assessing tree responses to climate change without considering simultaneously soil properties and climate may be misleading since soil nutrients can influence growth response of trees to drought. A detailed analysis of the influence of the soil characteristics on growth responses of trees is necessary to understand the sensitivity of tree species to global climate change.

Murray-Tortarolo, G., P. Friedlingstein, S. Sitch, S. I. Seneviratne, I. Fletcher, B. Mueller, P. Greve, A. Anav, Y. Liu, A. Ahlström, C. Huntingford, S. Levis, P. Levy, M. Lomas, B. Poulter, N. Viovy, S. Zaehle, and N. Zeng. 2016. **The dry season intensity as a key driver of NPP trends.** Geophysical Research Letters 43:2632-2639.

Abstract. We analyze the impacts of changing dry season length and intensity on vegetation productivity and biomass. Our results show a wetness asymmetry in dry ecosystems, with dry seasons becoming drier and wet seasons becoming wetter, likely caused by climate change. The increasingly intense dry seasons were consistently correlated with a decreasing trend in net primary productivity (NPP)

and biomass from different products and could potentially mean a reduction of 10–13% in NPP by 2100. We found that annual NPP in dry ecosystems is particularly sensitive to the intensity of the dry season, whereas an increase in precipitation during the wet season has a smaller effect. We conclude that changes in water availability over the dry season affect vegetation throughout the whole year, driving changes in regional NPP. Moreover, these results suggest that usage of seasonal water fluxes is necessary to improve our understanding of the link between water availability and the land carbon cycle.

Niemeyer, R. J., T. E. Link, M. S. Seyfried, and G. N. Flerchinger. 2016. **Surface water input from snowmelt and rain throughfall in western juniper: Potential impacts of climate change and shifts in semi-arid vegetation.** Hydrological Processes In Press

Abstract. In the western U.S., shifts from snow to rain precipitation regimes and increases in western juniper cover in shrub-dominated landscapes can alter surface water input via changes in snowmelt and throughfall. To better understand how shifts in both precipitation and semi-arid vegetation cover alter above-ground hydrological processes, we assessed: how rain interception differs from and snow and rain surface water input; how western juniper alters snowpack dynamics; and how these above-ground processes differ across western juniper, mountain big sagebrush, and low sagebrush plant communities. We collected continuous surface water input with four large lysimeters, interspace and below-canopy snow depth data, and conducted periodic snow surveys for two consecutive water years (2013 and 2014). The ratio of interspace to below canopy surface water input was greater for snow relative to rain events, averaging 79.4% and 54.8% respectively. The greater surface water input ratio for snow is in part due to increased deposition of redistributed snow under the canopy. We simulated above-ground energy and water fluxes in western juniper, low sagebrush, and mountain big sagebrush for two eight-year periods under current and projected mid-21st century warmer temperatures with the Simultaneous Heat and Water model. Juniper compared to low and mountain sagebrush reduced surface water input by an average of 138 mm or 24% of the total site water budget. Conversely, warming temperatures reduced surface water input by only an average of 14 mm across the three vegetation types. The future (warmer) simulations resulted in earlier snow disappearance and surface water input by 51 and 45 days, respectively, across juniper, low sagebrush, and mountain sagebrush. Information from this study can help land managers in the sagebrush steppe understand

how both shifts in climate and semi-arid vegetation will alter fundamental hydrological processes.

Tucker, C. L., S. Tamang, E. Pendall, and K. Ogle. 2016. **Shallow snowpack inhibits soil respiration in sagebrush steppe through multiple biotic and abiotic mechanisms.** Ecosphere 7:e01297.

Abstract. In sagebrush steppe, snowpack may govern soil respiration through its effect on multiple abiotic and biotic factors. Across the Intermountain West of the United States, snowpack has been declining for decades and is projected to decline further over the next century, making the response of soil respiration to snowpack a potentially important factor in the ecosystem carbon cycle. In this study, we evaluated the direct and indirect roles of the snowpack in driving soil respiration in sagebrush steppe ecosystems by taking advantage of highway snowfences in Wyoming to manipulate snowpack. An important contribution of this study is the use of Bayesian modeling to quantify the effects of soil moisture and temperature on soil respiration across a wide range of conditions from frozen to hot and dry, while simultaneously accounting for biotic factors (e.g., vegetation cover, root density, and microbial biomass and substrate-use diversity) affected by snowpack. Elevated snow depth increased soil temperature (in the winter) and moisture (winter and spring), and was associated with reduced vegetation cover and microbial biomass carbon. Soil respiration showed an exponential increase with temperature, with a temperature sensitivity that decreased with increasing seasonal temperature (Q_{10} = 4.3 [winter], 2.3 [spring], and 1.7 [summer]); frozen soils were associated with unrealistic $Q_{10} \approx$ 7989 due to the liquid-to-ice transition of soil water. Soil respiration was sensitive to soil water content; predicted respiration under very dry conditions was less than 10% of respiration under moist conditions. While higher vegetation cover increased soil respiration, this was not due to increased root density, and may reflect differences in litter inputs. Microbial substrate-use diversity was negatively related to reference respiration (i.e., respiration rate at a reference temperature and optimal soil moisture), although the mechanism remains unclear. This study indicates that soil respiration is inhibited by shallow snowpack through multiple mechanisms; thus, future decreases in snowpack across the sagebrush steppe have the potential to reduce losses of soil C, potentially affecting regional carbon balance.

Tuttle, S., and G. Salvucci. 2016. **Empirical evidence of contrasting soil moisture–precipitation feedbacks across the United States.** Science 352:825-828.

Abstract. Soil moisture influences fluxes of heat and moisture originating at the land surface, thus altering atmospheric humidity and temperature profiles. However, empirical and modeling studies disagree on how this affects the propensity for precipitation, mainly owing to the difficulty in establishing causality. We use Granger causality to estimate the relationship between soil moisture and occurrence of subsequent precipitation over the contiguous United States using remotely sensed soil moisture and gauge-based precipitation observations. After removing potential confounding effects of daily persistence, and seasonal and interannual variability in precipitation, we find that soil moisture anomalies significantly influence rainfall probabilities over 38% of the area with a median factor of 13%. The feedback is generally positive in the west and negative in the east, suggesting dependence on regional aridity.

Fire

Andrus, R. A., T. T. Veblen, B. J. Harvey, and S. J. Hart. 2016. **Fire severity unaffected by spruce beetle outbreak in spruce-fir forests in southwestern Colorado.** Ecological Applications 26:700-711.

Abstract. Recent large and severe outbreaks of native bark beetles have raised concern among the general public and land managers about potential for amplified fire activity in western North America. To date, the majority of studies examining bark beetle outbreaks and subsequent fire severity in the U.S. Rocky Mountains have focused on outbreaks of mountain pine beetle (MPB; *Dendroctonus ponderosae*) in lodgepole pine (*Pinus contorta*) forests, but few studies, particularly field studies, have addressed the effects of the severity of spruce beetle (*Dendroctonus rufipennis* Kirby) infestation on subsequent fire severity in subalpine Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) forests. In Colorado, the annual area infested by spruce beetle outbreaks is rapidly rising, while MPB outbreaks are subsiding; therefore understanding this relationship is of growing importance. We collected extensive field data in subalpine forests in the eastern San Juan Mountains, southwestern Colorado, USA, to investigate whether a gray-stage (<5 yr from outbreak to time of fire) spruce beetle infestation affected fire severity. Contrary to the

expectation that bark beetle infestation alters subsequent fire severity, correlation and multivariate generalized linear regression analysis revealed no influence of pre-fire spruce beetle severity on nearly all field or remotely sensed measurements of fire severity. Findings were consistent across moderate and extreme burning conditions. In comparison to severity of the pre-fire beetle outbreak, we found that topography, pre-outbreak basal area, and weather conditions exerted a stronger effect on fire severity. Our finding that beetle infestation did not alter fire severity is consistent with previous retrospective studies examining fire activity following other bark beetle outbreaks and reiterates the overriding influence of climate that creates conditions conducive to large, high-severity fires in the subalpine zone of Colorado. Both bark beetle outbreaks and wildfires have increased autonomously due to recent climate variability, but this study does not support the expectation that post-beetle outbreak forests will alter fire severity, a result that has important implications for management and policy decisions.

Coop, J. D., S. A. Parks, S. R. McClernan, and L. M. Holsinger. 2016. **Influences of prior wildfires on vegetation response to subsequent fire in a reburned Southwestern landscape.** Ecological Applications 26:346-354.

Abstract. Large and severe wildfires have raised concerns about the future of forested landscapes in the southwestern United States, especially under repeated burning. In 2011, under extreme weather and drought conditions, the Las Conchas fire burned over several previous burns as well as forests not recently exposed to fire. Our purpose was to examine the influences of prior wildfires on plant community composition and structure, subsequent burn severity, and vegetation response. To assess these relationships, we used satellite-derived measures of burn severity and a nonmetric multidimensional scaling of pre- and post- Las Conchas field samples. Earlier burns were associated with shifts from forested sites to open savannas and meadows, oak scrub, and ruderal communities. These non-forested vegetation types exhibited both resistance to subsequent fire, measured by reduced burn severity, and resilience to reburning, measured by vegetation recovery relative to forests not exposed to recent prior fire. Previous shifts toward non-forested states were strongly reinforced by reburning. Ongoing losses of forests and their ecological values confirm the need for restoration interventions. However, given future wildfire and climate projections, there may also be opportunities presented by transformations toward fire-resistant and resilient vegetation types within portions of the landscape.

Coppoletta, M., K. E. Merriam, and B. M. Collins. 2016. **Post-fire vegetation and fuel development influences fire severity patterns in reburns.** Ecological Applications 26:686-699.

Abstract. In areas where fire regimes and forest structure have been dramatically altered, there is increasing concern that contemporary fires have the potential to set forests on a positive feedback trajectory with successive reburns, one in which extensive stand-replacing fire could promote more stand-replacing fire. Our study utilized an extensive set of field plots established following four fires that occurred between 2000 and 2010 in the northern Sierra Nevada, California, USA that were subsequently reburned in 2012. The information obtained from these field plots allowed for a unique set of analyses investigating the effect of vegetation, fuels, topography, fire weather, and forest management on reburn severity. We also examined the influence of initial fire severity and time since initial fire on influential predictors of reburn severity. Our results suggest that high- to moderate-severity fire in the initial fires led to an increase in standing snags and shrub vegetation, which in combination with severe fire weather promoted high-severity fire effects in the subsequent reburn. Although fire behavior is largely driven by weather, our study demonstrates that post-fire vegetation composition and structure are also important drivers of reburn severity. In the face of changing climatic regimes and increases in extreme fire weather, these results may provide managers with options to create more fire- resilient ecosystems. In areas where frequent high-severity fire is undesirable, management activities such as thinning, prescribed fire, or managed wildland fire can be used to moderate fire behavior not only prior to initial fires, but also before subsequent reburns.

Donato, D. C., J. B. Fontaine, and J. L. Campbell. 2016. **Burning the legacy? Influence of wildfire reburn on dead wood dynamics in a temperate conifer forest.** Ecosphere 7:e01341.

Abstract. Dynamics of dead wood, a key component of forest structure, are not well described for mixed-severity fire regimes with widely varying fire intervals. A prominent form of such variation is when two stand-replacing fires occur in rapid succession, commonly termed an early-seral “reburn.” These events are thought to strongly influence dead wood abundance in a regenerating forest, but this hypothesis has scarcely been tested. We measured dead wood following two overlapping wildfires in conifer-dominated forests of the

Klamath Mountains, Oregon (USA), to assess whether reburning (15-yr interval, with >90% vegetation mortality) resulted in lower dead wood abundance and altered character relative to once-burned stands, and how any differences may project through succession. Total dead wood mass (standing + down) following the reburn (169 ± 83 Mg/ha [95%CI]) was 45% lower than after a single fire (309 ± 87 Mg/ha). Lower levels in reburn stands were due to, in roughly equal parts, additional combustion and greater time for decay. Although a single fire in mature forest both consumed and created dead wood (by killing large live trees), a reburn only consumed dead wood (few large live trees to kill). Charred biomass (black carbon generation) was higher in reburned stands by a factor of 2 for logs and 8 for snags. Projecting these stands forward (notwithstanding future disturbances) suggests: (1) the near-halving of dead-wood mass in reburn stands will persist for ~50 yr until the recruitment of new material begins, and (2) the reburn signature on dead wood abundance will remain apparent for over a century. These findings demonstrate how a single stochastic variation in disturbance interval can impart lasting influence on dead-wood succession, reinforcing the notion that many temperate forests exist in a state of dead-wood disequilibrium governed by site-specific disturbance history. Accounting for such variation in disturbance impacts is crucial to better understanding forests with complex mixed-severity disturbance regimes and with increasing stochasticity under climatic change.

Hessburg, P. F., T. A. Spies, D. A. Perry, C. N. Skinner, A. H. Taylor, P. M. Brown, S. L. Stephens, A. J. Larson, D. J. Churchill, N. A. Povak, P. H. Singleton, B. McComb, W. J. Zielinski, B. M. Collins, R. B. Salter, J. J. Keane, J. F. Franklin, and G. Riegel. 2016. **Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California.** Forest Ecology and Management 366:221-250.

Abstract. Increasingly, objectives for forests with moderate- or mixed-severity fire regimes are to restore successionally diverse landscapes that are resistant and resilient to current and future stressors. Maintaining native species and characteristic processes requires this successional diversity, but methods to achieve it are poorly explained in the literature. In the Inland Pacific US, large, old, early seral trees were a key historical feature of many young and old forest successional patches, especially where fires frequently occurred. Large, old trees are naturally fire-tolerant, but today are often threatened by dense understory cohorts that create fuel ladders that alter likely post-fire successional pathways. Reducing these

understories can contribute to resistance by creating conditions where canopy trees will survive disturbances and climatic stressors; these survivors are important seed sources, soil protectors, and critical habitat elements. Historical timber harvesting has skewed tree size and age class distributions, created hard edges, and altered native patch sizes. Manipulating these altered forests to promote development of larger patches of older, larger, and more widely-spaced trees with diverse understories will increase landscape resistance to severe fires, and enhance wildlife habitat for underrepresented conditions.

Closed-canopy, multi-layered patches that develop in hot, dry summer environments are vulnerable to droughts, and they increase landscape vulnerability to insect outbreaks and severe wildfires. These same patches provide habitat for species such as the northern spotted owl, which has benefited from increased habitat area. Regional and local planning will be critical for gauging risks, evaluating trade-offs, and restoring dynamics that can support these and other species. The goal will be to manage for heterogeneous landscapes that include variably-sized patches of (1) young, middle-aged, and old, closed-canopy forests growing in upper montane, northerly aspect, and valley bottom settings, (2) a similar diversity of open-canopy, fire-tolerant patches growing on ridgetops, southerly aspects, and lower montane settings, and (3) significant montane chaparral and grassland areas. Tools to achieve this goal include managed wildfire, prescribed burning, and variable density thinning at small to large scales. Specifics on “how much and where?” will vary according to physiographic, topographic and historical templates, and regulatory requirements, and be determined by means of a socio-ecological process.

O'Leary III, D. S., T. D. Bloom, J. C. Smith, C. R. Zemp, and M. J. Medler. 2016. **A new method comparing snowmelt timing with annual area burned.** Fire Ecology 12:41-51.

Abstract. The interactions between climate and wildland fire are complex. To better understand these interactions, we used ArcMap 10.2.2 to examine the relationships between early spring snowmelt and total annual area burned within a defined region of the Rocky Mountains of the western United States. Our research methods used Monitoring Trends in Burn Severity (MTBS) fire perimeter data and weekly snow extent provided by the Rutgers Global Snow Lab analysis of National Oceanic and Atmospheric Administration (NOAA) daily snow maps. Our results indicated a significant correlation between early spring snowmelt and total annual area burned (P = 0.0497),

providing further evidence that snowmelt timing may be a driving factor for wildland fires. This project builds on the findings of previous studies and provides a novel method for making general predictions about the upcoming fire season months in advance, using freely available remotely sensed data in real time. Further research should apply our model to a broader geographic area, and incorporate higher resolution snowmelt timing data.

Waring, R. H., and N. C. Coops. 2016. **Predicting large wildfires across western North America by modeling seasonal variation in soil water balance.** Climatic Change 135:325-339.

Abstract. A lengthening of the fire season, coupled with higher temperatures, increases the probability of fires throughout much of western North America. Although regional variation in the frequency of fires is well established, attempts to predict the occurrence of fire at a spatial resolution <10 km^2 have generally been unsuccessful. We hypothesized that predictions of fires might be improved if depletion of soil water reserves were coupled more directly to maximum leaf area index (LAI_{max}) and stomatal behavior. In an earlier publication, we used LAI_{max} and a process-based forest growth model to derive and map the maximum available soil water storage capacity (ASW_{max}) of forested lands in western North America at l km resolution. To map large fires, we used data products acquired from NASA's Moderate Resolution Imaging Spectroradiometers (MODIS) over the period 2000–2009. To establish general relationships that incorporate the major biophysical processes that control evaporation and transpiration as well as the flammability of live and dead trees, we constructed a decision tree model (DT). We analyzed seasonal variation in the relative availability of soil water (*fASW*) for the years 2001, 2004, and 2007, representing respectively, low, moderate, and high rankings of areas burned. For these selected years, the DT predicted where forest fires >1 km occurred and did not occur at ~100,000 randomly located pixels with an average accuracy of 69%. Extended over the decade, the area predicted burnt varied by as much as 50%. The DT identified four seasonal combinations, most of which included exhaustion of ASW during the summer as critical; two combinations involving antecedent conditions the previous spring or fall accounted for 86% of the predicted fires. The approach introduced in this paper can help identify forested areas where management efforts to reduce fire hazards might prove most beneficial.

Wasko, C., A. Sharma, and S. Westra. 2016. **Reduced spatial extent of extreme storms at higher temperatures.** Geophysical Research Letters 43:4026-4032.

Abstract. Extreme precipitation intensity is expected to increase in proportion to the water-holding capacity of the atmosphere. However, increases beyond this expectation have been observed, implying that changes in storm dynamics may be occurring alongside changes in moisture availability. Such changes imply shifts in the spatial organization of storms, and we test this by analyzing present-day sensitivities between storm spatial organization and near-surface atmospheric temperature. We show that both the total precipitation depth and the peak precipitation intensity increases with temperature, while the storm's spatial extent decreases. This suggests that storm cells intensify at warmer temperatures, with a greater total amount of moisture in the storm, as well as a redistribution of moisture toward the storm center. The results have significant implications for the severity of flooding, as precipitation may become both more intense and spatially concentrated in a warming climate.

Sea Level Rise

Hauer, M. E., J. M. Evans, and D. R. Mishra. 2016. **Millions projected to be at risk from sea-level rise in the continental United States.** Nature Climate Change advance online publication.

Abstract. Sea-level rise (SLR) is one of the most apparent climate change stressors facing human society. Although it is known that many people at present inhabit areas vulnerable to SLR, few studies have accounted for ongoing population growth when assessing the potential magnitude of future impacts. Here we address this issue by coupling a small-area population projection with a SLR vulnerability assessment across all United States coastal counties. We find that a 2100 SLR of 0.9m places a land area projected to house 4.2 million people at risk of inundation, whereas 1.8m affects 13.1 million people—approximately three times larger than indicated by current populations. These results suggest that the absence of protective measures could lead to US population movements of a magnitude similar to the twentieth century Great Migration of southern African-Americans. Furthermore, our population projection approach can be readily adapted to assess other hazards or to model future per capita economic impacts.

Socio-Economics

Carlton, J. S., A. S. Mase, C. L. Knutson, M. C. Lemos, T. Haigh, D. P. Todey, and L. S. Prokopy. 2016. **The effects of extreme drought on climate change beliefs, risk perceptions, and adaptation attitudes.** Climatic Change 135:211-226.

Abstract. The role of extreme weather events in shaping people's climate change beliefs and adaptation attitudes has been extensively studied and discussed in academic literature, the popular press, and policy circles. In this manuscript, we contribute to the debate by using data from pre- and post-extreme event surveys to examine the effects of the 2012 Midwestern US drought on agricultural advisors' climate change beliefs, adaptation attitudes, and risk perceptions. We found that neither climate change beliefs nor attitudes toward adaptation changed significantly as a result of the drought. Risk perceptions did change, however, with advisors becoming more concerned about risks from drought and pests and less concerned about risks related to flooding and ponding. Though increased risk perceptions were significantly associated with more favorable adaptation attitudes, the effects were not large enough to cause an overall shift to more favorable attitudes toward adaptation. The results suggest that extreme climate events might not cause significant shifts in climate beliefs, at least not immediately. Additionally, the results caution that policy designs that rely on increasing risk perceptions to motivate action on climate change may be overestimating the effects of extreme events on feeling at risk, at least in the context of buffered systems such as large commercial agriculture in the US.

Fisichelli, N. A., G. W. Schuurman, and C. H. Hoffman. 2016. **Is 'resilience' maladaptive? Towards an accurate lexicon for climate change adaptation.** Environmental Management 57:753-758.

Abstract. Climate change adaptation is a rapidly evolving field in conservation biology and includes a range of strategies from resisting to actively directing change on the landscape. The term 'climate change resilience,' frequently used to characterize adaptation strategies, deserves closer scrutiny because it is ambiguous, often misunderstood, and difficult to apply consistently across disciplines and spatial and temporal scales to support conservation efforts.

Current definitions of resilience encompass all aspects of adaptation from resisting and absorbing change to reorganizing and transforming in response to climate change. However, many stakeholders are unfamiliar with this spectrum of definitions and assume the more common meaning of returning to a previous state after a disturbance. Climate change, however, is unrelenting and intensifying, characterized by both directional shifts in baseline conditions and increasing variability in extreme events. This ongoing change means that scientific understanding and management responses must develop concurrently, iteratively, and collaboratively, in a science-management partnership. Divergent concepts of climate change resilience impede cross-jurisdictional adaptation efforts and complicate use of adaptive management frameworks. Climate change adaptation practitioners require clear terminology to articulate management strategies and the inherent tradeoffs involved in adaptation. Language that distinguishes among strategies that seek to resist change, accommodate change, and direct change (i.e., persistence, autonomous change, and directed change) is prerequisite to clear communication about climate change adaptation goals and management intentions in conservation areas.

Ross, L., K. Arrow, R. Cialdini, N. Diamond-Smith, J. Diamond, J. Dunne, M. Feldman, R. Horn, D. Kennedy, C. Murphy, D. Pirages, K. Smith, R. York, and P. Ehrlich. 2016. **The climate change challenge and barriers to the exercise of foresight intelligence.** BioScience 66:363-370.

Abstract. Despite solid evidence from the scientific community about climate disruption, much of the US public remains unconvinced about the reality of anthropogenic change, and national governments have been slow to undertake major steps to deal with the climate crisis. In order to understand this lack of foresight intelligence regarding climate disruption, we identify some features of climate disruption and human psychology that combine to create barriers to effective action. We also review encouraging, albeit modest, successes in persuading Americans to conserve energy through “psych-wise” initiatives. Although the reductions in energy consumption accomplished by these initiatives and strategies fall far short of what is required to address impending global climate change, we believe that the principles underlying these initiatives suggest ways to achieve more substantial reductions. We conclude by offering some specific steps that could be taken to achieve such reductions and more generally meet the building global challenge.

Wiener, J. D., R. S. Pulwarty, and D. Ware. 2016. **Bite without bark: How the socioeconomic context of the 1950s U.S. drought minimized responses to a multiyear extreme climate event.** Weather and Climate Extremes 11:80-94.

Abstract. The drought of the 1950s was among the most widespread, severe and sustained ever experienced in the United States. For several states, the severity of the 1950s drought exceeded that of the 1930s “Dust Bowl”. The 1950s were characterized by low rainfall amounts and by excessively high temperatures. The climatological aspects of the drought subsided in most areas with the spring rains of 1957. A careful review of official reports over this period reveals limited acknowledgment of the drought of the 1950s. The drought was no secret, but it did not receive a great deal of news coverage; later droughts of lower severity and shorter duration, such as 1976–77, 1988, 2002–2004, 2011–2012 and the ongoing drought in California (2011–2015), garnered much greater national focus. In this paper, the question why such a major geophysical variation appears to have elicited little major national policy response, including the apparent lack of significant media concern is addressed. In framing the discussion this study assesses, the evolution of drought during the 1950s to establish its national and regional policy contexts, technological improvements and financial changes prior to and during the event, and on and off-farm responses in terms of the socioeconomic impacts. The study provides an overview of key developments and concerns in agriculture since the early 20th Century sets the context for the 1950s, then moves to the farm itself as a unit of analysis. This approach shows not only how the situation may have appeared to those outside the afflicted areas, but also how decisions were guided by agricultural economics affecting farmers at the time, and the strong influence of broader historical trends in which the 1950s were embedded. The paper provides the relevant agricultural statistics and uncovers the political and public perceptions moving through the drought years. Overproduction was the fundamental, almost paradoxical problem facing American agriculture at the time. The paper concludes with a discussion of how the implications of this event, and the attendant responses, might provide guidance to future assessments of extremes such as severe drought in the context of a changing climate.

Adaptation

Franklin, J., J. M. Serra-Diaz, A. D. Syphard, and H. M. Regan. 2016. **Global change and terrestrial plant community dynamics.** Proceedings of the National Academy of Sciences 113:3725-3734.

Significance. Global terrestrial vegetation plays a critical role in biogeochemical cycles and provides important ecosystem services. Vegetation has been altered by anthropogenic global change drivers including land-use change, altered disturbance regimes, invasive species, and climate change, for decades to centuries, or in some cases millennia. Vegetation responses to land use and disturbance can be more immediate than to climate change and can be long lasting. The effect of global warming on water balance may have a stronger influence than the direct effects of temperature on vegetation. Models deployed at multiple ecological scales, populations, communities, and landscapes will be required to forecast vegetation responses and feedbacks to accelerated global change.

Abstract. Anthropogenic drivers of global change include rising atmospheric concentrations of carbon dioxide and other greenhouse gasses and resulting changes in the climate, as well as nitrogen deposition, biotic invasions, altered disturbance regimes, and land-use change. Predicting the effects of global change on terrestrial plant communities is crucial because of the ecosystem services vegetation provides, from climate regulation to forest products. In this paper, we present a framework for detecting vegetation changes and attributing them to global change drivers that incorporates multiple lines of evidence from spatially extensive monitoring networks, distributed experiments, remotely sensed data, and historical records. Based on a literature review, we summarize observed changes and then describe modeling tools that can forecast the impacts of multiple drivers on plant communities in an era of rapid change. Observed responses to changes in temperature, water, nutrients, land use, and disturbance show strong sensitivity of ecosystem productivity and plant population dynamics to water balance and long-lasting effects of disturbance on plant community dynamics. Persistent effects of land-use change and human-altered fire regimes on vegetation can overshadow or interact with climate change impacts. Models forecasting plant community responses to global change incorporate shifting ecological niches, population dynamics, species interactions, spatially explicit disturbance, ecosystem processes, and plant functional responses. Monitoring, experiments, and models evaluating multiple change

drivers are needed to detect and predict vegetation changes in response to 21st century global change.

Hällfors, M. H., S. Aikio, S. Fronzek, J. J. Hellmann, T. Ryttäri, and R. K. Heikkinen. 2016. **Assessing the need and potential of assisted migration using species distribution models.** Biological Conservation 196:60-68.

Abstract. Assisted migration (AM) has been suggested as a management strategy for aiding species in reaching newly suitable locations as climate changes. Species distribution models (SDMs) can provide important insights for decisions on whether to assist a species in its migration; however, their application includes uncertainties. In this study, we use consensus SDMs to model the future suitable areas for 13 vascular plant species with poor dispersal capacity. Based on the outputs of SDMs under different climate change scenarios and future times, we quantify the predicted changes in suitable area by calculating metrics that describe the need and potential for migration. We find that, by the end of the 21st century, one of the species would benefit from AM under mild climate change, seven under moderate change, and for 12 out of 13 species studied AM appears to be a relevant conservation method under strong climate change. We also test the effect of different modeling attributes on the metrics and find little variation between SDMs constructed using different combinations of modeling methods and variable sets. However, the choice of climate variables had a larger influence on the level of the metrics than did the modeling method. We therefore suggest that the choice of climate variables should receive ample attention when measuring climate change threat using SDMs and that experiments aiming to uncover critical environmental factors for individual species should be extensively conducted. This study illustrates that dispersal assistance may be needed for many species under a wide range of possible future climates.

Moncrieff, G. R., W. J. Bond, and S. I. Higgins. 2016. **Revising the biome concept for understanding and predicting global change impacts.** Journal of Biogeography 43:863-873.

Abstract. Biomes are globally distributed, structurally and functionally similar vegetation units defined without reference to plant species composition. The boundaries between biomes are presumed to correspond with species turnover and changes in biogeochemical cycling. Determining the controls of biome distributions is thus critical for anticipating global change impacts. Historically, climate and soils have been understood to adequately explain the global distribution of biomes. Convergent evolution and environmental filtering are assumed to be pervasive, ultimately resulting in deterministic patterns of vegetation structure and function in relation to prevailing environmental conditions. Recent studies have highlighted significant problems with this view of biomes. Firstly, systematic structural and functional divergence within biomes has been identified when comparing environmentally similar, yet floristically distinct regions. Secondly, climatic determinism is being further undermined by evidence suggesting multiple stable biome states are possible for some combinations of climatic drivers. We argue that biomes remain useful and necessary constructs for organizing our knowledge of how ecosystems function and for predicting how they might respond to change. However, biome concepts should acknowledge the limits to predictability from environmental conditions alone and the influence of historical processes on modern vegetation patterns. We discuss how direct mapping of plant structure and function, the incorporation of insights into biome evolution and a new generation of vegetation models will lead to improvements in the concept of what biomes are, where they occur, and efforts to predict their distribution.

Wilkin, K., D. Ackerly, and S. Stephens. 2016. **Climate change refugia, fire ecology and management.** Forests 7:77.

Abstract. Early climate change ideas warned of widespread species extinctions. As scientists have probed more deeply into species responses, a more nuanced perspective emerged indicating that some species may persist in microrefugia (refugia), including in mountainous terrain. Refugia are habitats that buffer climate changes and allow species to persist in—and to potentially expand under—changing environmental conditions. While climate and species interactions in refugia have been noted as sources of uncertainty, land management practices and disturbances, such as wildland fire, should also be considered when assessing any given refugium. Our landscape scale study suggests that cold-air pools, an important type of small-scale refugia, have unique fire occurrence, frequency, and severity patterns in frequent-fire mixed conifer forests of California’s Sierra Nevada: cold-air pool refugia have less fire and if it occurs, it is lower severity. Therefore, individuals and small populations are less likely to be extirpated by fire. Active management, such as restoration and fuels treatments for climate change adaptation, may be required to maintain these distinctive and potentially important refugia.

Mitigation

Herrero, M., B. Henderson, P. Havlik, P. K. Thornton, R. T. Conant, P. Smith, S. Wirsenius, A. N. Hristov, P. Gerber, M. Gill, K. Butterbach-Bahl, H. Valin, T. Garnett, and E. Stehfest. 2016. **Greenhouse gas mitigation potentials in the livestock sector.** Nature Climate Change 6:452-461.

Abstract. The livestock sector supports about 1.3 billion producers and retailers, and contributes 40–50% of agricultural GDP. We estimated that between 1995 and 2005, the livestock sector was responsible for greenhouse gas emissions of 5.6–7.5 GtCO2e yr−1. Livestock accounts for up to half of the technical mitigation potential of the agriculture, forestry and land-use sectors, through management options that sustainably intensify livestock production, promote carbon sequestration in rangelands and reduce emissions from manures, and through reductions in the demand for livestock products. The economic potential of these management alternatives is less than 10% of what is technically possible because of adoption constraints, costs and numerous trade-offs. The mitigation potential of reductions in livestock product consumption is large, but their economic potential is unknown at present. More research and investment are needed to increase the affordability and adoption of mitigation practices, to moderate consumption of livestock products where appropriate, and to avoid negative impacts on livelihoods, economic activities and the environment.

Nimmo, D. G., A. Haslem, J. Q. Radford, M. Hall, and A. F. Bennett. 2016. **Riparian tree cover enhances the resistance and stability of woodland bird communities during an extreme climatic event.** Journal of Applied Ecology 53:449-458.

Abstract. Ecosystems world-wide increasingly are subject to multiple interacting disturbances. Biodiversity in anthropogenic landscapes can be enhanced by manipulating landscape patterns, but could such landscape management also assist biota to cope with the effects of extreme climatic events, such as drought?

We surveyed woodland bird communities in 24 ‘whole’ landscapes (each 100 km2) in an agricultural region of south-eastern Australia near the beginning (2002–2003), middle (2006–2007) and after (2011–2012) an extreme drought (the ‘Millennium Drought’). We

quantified the resistance, resilience and stability of the avifauna to the decade of drought and related these measures to properties of the study landscapes: the extent of wooded habitat, configuration of habitat, land-use composition, landscape productivity and geographic context.

Landscape productivity, represented by the extent of riparian tree cover in the landscape, was the strongest driver of the resistance, resilience and stability of avifaunal richness to severe drought. Woodland bird communities in landscapes with larger areas of riparian tree cover retained a larger proportion of their species richness during the Millennium Drought and consequently had greater stability over the drought's duration.

Synthesis and applications. Landscape properties can influence the resistance, resilience and stability of faunal communities to an extreme climatic event. By protecting, restoring and enhancing native vegetation in productive areas of landscapes along stream systems, drainage lines and floodplains, land managers can effectively build climatic refugia and thereby enhance the resistance of biota to climatic extremes. However, a net decline over the entire study period suggests this will not, by itself, arrest decline during periods of extreme drought.