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Prepared by Louisa Evers, Science and Climate Change Coordinator, Bureau of Land Management, Oregon-Washington State Office.

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Climate and Weather

Chang, W., M. L. Stein, J. Wang, V. R. Kotamarthi, and E. J. Moyer. 2016. **Changes in spatiotemporal precipitation patterns in changing climate conditions.** Journal of Climate 29:8355-8376. http://10.1175/jcli-d-15-0844.1

Abstract. Climate models robustly imply that some significant change in precipitation patterns will occur. Models consistently project that the intensity of individual precipitation events increases by approximately 6%–7% K^{-1}, following the increase in atmospheric water content, but that total precipitation increases by a lesser amount (1%–2% K^{-1} in the global average in transient runs). Some other aspect of precipitation events must then change to compensate for this difference. The authors develop a new methodology for identifying individual rainstorms and studying their physical characteristics—including starting location, intensity, spatial extent, duration, and trajectory—that allows identifying that compensating mechanism. This technique is applied to precipitation over the contiguous United States from both radar-based data products and high-resolution model runs simulating 80 years of business-as-usual warming. In the model study the dominant compensating mechanism is a reduction of storm size. In summer, rainstorms become more intense but smaller; in winter,

rainstorm shrinkage still dominates, but storms also become less numerous and shorter duration. These results imply that flood impacts from climate change will be less severe than would be expected from changes in precipitation intensity alone. However, these projected changes are smaller than model–observation biases, implying that the best means of incorporating them into impact assessments is via “data-driven simulations” that apply model-projected changes to observational data. The authors therefore develop a simulation algorithm that statistically describes model changes in precipitation characteristics and adjusts data accordingly, and they show that, especially for summertime precipitation, it outperforms simulation approaches that do not include spatial information.

Prein, A. F., R. M. Rasmussen, K. Ikeda, C. Liu, M. P. Clark, and G. J. Holland. 2017. **The future intensification of hourly precipitation extremes.** Nature Climate Change 7:48-52. http://10.1038/nclimate3168

Abstract. Extreme precipitation intensities have increased in all regions of the Contiguous United States (CONUS) and are expected to further increase with warming at scaling rates of about 7% per degree Celsius, suggesting a significant increase of flash flood hazards due to climate change. However, the scaling rates between extreme precipitation and temperature are strongly dependent on the region, temperature, and moisture availability, which inhibits simple extrapolation of the scaling rate from past climate data into the future. Here we study observed and simulated changes in local precipitation extremes over the CONUS by analysing a very high resolution (4 km horizontal grid spacing) current and high-end climate scenario that realistically simulates hourly precipitation extremes. We show that extreme precipitation is increasing with temperature in moist, energy-limited, environments and decreases abruptly in dry, moisture-limited, environments. This novel framework explains the large variability in the observed and modelled scaling rates and helps with understanding the significant frequency and intensity increases in future hourly extreme precipitation events and their interaction with larger scales.

Rhines, A., K. A. McKinnon, M. P. Tingley, and P. Huybers. 2017. **Seasonally resolved distributional trends of North American temperatures show contraction of winter variability.** Journal of Climate 30:1139-1157. http://10.1175/jcli-d-16-0363.1

Abstract. There is considerable interest in determining whether recent changes in the temperature distribution extend beyond simple shifts in the mean. The authors present a framework based on quantile regression, wherein trends are estimated across percentiles. Pointwise trends from surface station observations are mapped into continuous spatial fields using thin-plate spline regression. This procedure allows for resolving spatial dependence of distributional trends, providing uncertainty estimates that account for spatial covariance and varying station density. The method is applied to seasonal near-surface temperatures between 1979 and 2014 to unambiguously assess distributional changes in the densely sampled North American region. Strong seasonal differences are found, with summer trends exhibiting significant warming throughout the domain with little distributional dependence, while the spatial distribution of spring and fall trends show a dipole structure. In contrast, the spread between the 95th and 5th percentile in winter has decreased, with trends of −0.71° and −0.85°C decade^{-1}, respectively, for daily maximum and minimum temperature, a contraction that is statistically significant over 84% of the domain. This decrease in variability is dominated by warming of the coldest days, which has outpaced the median trend by approximately a factor of 4. Identical analyses using ERA-Interim and NCEP-2 yield consistent estimates for winter (though not for other seasons), suggesting that reanalyses can be reliably used for relating winter trends to circulation anomalies. These results are consistent with Arctic-amplified warming being strongest in winter and with the influence of synoptic-scale advection on winter temperatures. Maps for all percentiles, seasons, and datasets are provided via an online tool.

Thackeray, C. W., and C. G. Fletcher. 2016. **Quantifying the uncertainty in historical and future simulations of northern hemisphere spring snow cover.** Journal of Climate 29:8647-8663. http://10.1175/jcli-d-16-0341.1

Abstract. Projections of twenty-first-century Northern Hemisphere (NH) spring snow cover extent (SCE) from two climate model ensembles are analyzed to characterize their uncertainty. Phase 5 of the Coupled Model Intercomparison Project (CMIP5) multimodel ensemble exhibits variability resulting from both model differences and internal climate variability, whereas spread generated from a Canadian Earth System Model–Large Ensemble (CanESM-LE) experiment is solely a result of internal variability. The analysis shows that simulated 1981–2010 spring SCE trends are slightly weaker than observed (using an ensemble of snow products). Spring SCE is projected to decrease by −3.7% ± 1.1% decade^{-1} within the CMIP5 ensemble over the twenty-first century. SCE loss is projected to accelerate for all spring months over the twenty-first century, with the exception of June (because most snow in this month has melted by the latter half of the twenty-first century). For 30-yr spring SCE trends over the twenty-first century, internal variability estimated from CanESM-LE is substantial, but smaller than intermodel spread from CMIP5. Additionally, internal variability in NH extratropical land warming trends can affect SCE trends in the near future (R^2 = 0.45), while variability in winter precipitation can also have a significant (but lesser) impact on SCE trends. On the other hand, a majority of the intermodel spread is driven by differences in simulated warming (dominant in March–May) and snow cover available for melt (dominant in June). The strong temperature–SCE linkage suggests that model uncertainty in projections of SCE could be potentially reduced through improved simulation of spring season warming over land.

van der Wiel, K., S. B. Kapnick, and G. A. Vecchi. 2017. **Shifting patterns of mild weather in response to projected radiative forcing.** Climatic Change 140:649-658. http://10.1007/s10584-016-1885-9

Abstract. Climate change has been shown to impact the mean climate state and climate extremes. Though climate extremes have the potential to disrupt society, extreme conditions are rare by definition. In contrast, mild weather occurs frequently and many human activities are built around it. We provide a global analysis of mild weather based on simple criteria and explore changes in response to radiative forcing. We find a slight global mean decrease in the annual number of mild days projected both in the near future (−4 days per year, 2016–2035) and at the end of this century (−10 days per year, 2081–2100). Projected seasonal and regional redistributions of mild days are substantially greater. These changes are larger than the interannual variability of mild weather caused by El Niño–Southern Oscillation. Finally, we show an observed global decrease in the recent past, and that observed regional changes in mild weather resemble projections.

Extreme Weather

Angélil, O., D. Stone, and M. Wehner. 2017. **An independent assessment of anthropogenic attribution statements for recent extreme temperature and rainfall events.** Journal of Climate 30:5-16. http://10.1175/jcli-d-16-0077.1

Abstract. The annual "State of the Climate" report, published in the Bulletin of the American Meteorological Society (BAMS), has included a supplement since 2011 composed of brief analyses of the human influence on recent major extreme weather events. There are now several dozen extreme weather events examined in these supplements, but these studies have all differed in their data sources as well as their approaches to defining the events, analyzing the events, and the consideration of the role of anthropogenic emissions. This study reexamines most of these events using a single analytical approach and a single set of climate model and observational data sources. In response to recent studies recommending the importance of using multiple methods for extreme weather event attribution, results are compared from these analyses to those reported in the BAMS supplements collectively, with the aim of characterizing the degree to which the lack of a common methodological framework may or may not influence overall conclusions. Results are broadly similar to those reported earlier for extreme temperature events but disagree for a number of extreme precipitation events. Based on this, it is advised that the lack of comprehensive uncertainty analysis in recent extreme weather attribution studies is important and should be considered when interpreting results, but as yet it has not introduced a systematic bias across these studies.

Barbero, R., H. J. Fowler, G. Lenderink, and S. Blenkinsop. 2017. **Is the intensification of precipitation extremes with global warming better detected at hourly than daily resolutions?** Geophysical Research Letters 44:974-983. http://10.1002/2016GL071917

Abstract. Although it has been documented that daily precipitation extremes are increasing worldwide, faster increases may be expected for subdaily extremes. Here after a careful quality control procedure, we compared trends in hourly and daily precipitation extremes using a large network of stations across the United States (U.S.) within the 1950–2011 period. A greater number of significant increasing trends in annual and seasonal maximum precipitation were detected from daily extremes, with the primary exception of wintertime. Our results also

show that the mean percentage change in annual maximum daily precipitation across the U.S. per global warming degree is ~6.9% $°C^{-1}$ (in agreement with the Clausius-Clapeyron rate) while lower sensitivities were observed for hourly extremes, suggesting that changes in the magnitude of subdaily extremes in response to global warming emerge more slowly than those for daily extremes in the climate record.

Fosu, B. O., S.-Y. S. Wang, and J.-H. Yoon. 2016. **The 2014/15 snowpack drought in Washington state and its climate forcing.** Bulletin of the American Meteorological Society 97:S19-S24. http://10.1175/bams-d-16-0154.1

Abstract. The 2014/15 snowpack drought resulted from exceedingly high temperatures notwithstanding normal precipitation—a drought type that may reoccur due to accelerated anthropogenic warming and aggravated by naturally driven low precipitation.

Wolter, K., J. K. Eischeid, L. Cheng, and M. Hoerling. 2016. **What history tells us about 2015 U.S. daily rainfall extremes.** Bulletin of the American Meteorological Society 97:S9-S13. http://10.1175/bams-d-16-0166.1

Abstract. The United States experienced above-normal daily rainfall extremes in 2015, consistent with national upward trends. However, the most abundant regional extremes were not foreshadowed by co-located long-term seasonal trends.

Drought

Feng, S., M. Trnka, M. Hayes, and Y. Zhang. 2017. **Why do different drought indices show distinct future drought risk outcomes in the U.S. Great Plains?** Journal of Climate 30:265-278. http://10.1175/jcli-d-15-0590.1

Abstract. Vigorous discussions and disagreements about the future changes in drought intensity in the U.S. Great Plains have been taking place recently within the literature. These discussions have involved widely varying estimates based on drought indices and model-based projections of the future. To investigate and understand the causes for such a disparity between these previous estimates, the authors analyzed the soil moisture at the near-surface soil layer and the entire

soil column, as well as the Palmer drought severity index, the Palmer Z index, and the standardized precipitation and evaporation index using the output from the Community Climate System Model, version 4 (CCSM4), and 25 state-of-the-art climate models. These drought indices were computed using potential evapotranspiration estimated by the physically based Penman–Monteith method (PE_{pm}) and the empirically based Thornthwaite method (PE_{th}). The results showed that the short-term drought indices are similar to modeled surface soil moisture and show a small but consistent drying trend in the future. The long-term drought indices and the total column soil moisture, however, are consistent in projecting more intense future drought. When normalized, the drought indices with PE_{th} all show unprecedented future drying, while the drought indices with PE_{pm} show comparable dryness with the modeled soil moisture. Additionally, the drought indices with PE_{pm} are closely related to soil moisture during both the twentieth and twenty-first centuries. Overall, the drought indices with PE_{pm}, as well as the modeled total column soil moisture, suggest a widespread and very significant drying in the Great Plains toward the end of the century. The results suggest that the sharp contrasts about future drought risk in the Great Plains discussed in previous studies are caused by 1) comparing the projected changes in short-term droughts with that of the long-term droughts and/or 2) computing the atmospheric evaporative demand using an empirically based method (e.g., PE_{th}). The analysis here may be applied for drought projections in other regions across the globe.

Zhang, Q., M. Shao, X. Jia, and X. Wei. 2017. **Relationship of climatic and forest factors to drought- and heat-induced tree mortality.** PLOS ONE 12:e0169770. http://10.1371/journal.pone.0169770

Abstract. Tree mortality due to warming and drought is a critical aspect of forest ecosystem in responding to climate change. Spatial patterns of tree mortality induced by drought and its influencing factors, however, have yet to be documented at the global scale. We collected observations from 248 sites globally where trees have died due to drought and then assessed the effects of climatic and forest factors on the rate of tree mortality. The global mean annual mortality rate was 5.5%. The rate of tree mortality was significantly and negatively correlated with mean annual precipitation ($P < 0.01$). Tree mortality was lowest in tropical rainforests with mean annual precipitation >2000 mm and was severe in regions with mean annual precipitation <1000 mm. Mortality rates varied amongst species. The global annual rate of mortality was much higher for gymnosperms

(7.1%) than angiosperms (4.8%) but did not differ significantly between evergreen (6.2%) and deciduous (6.1%) species. Stand age and wood density affected the mortality rate. Saplings (4.6%) had a higher mortality rate than mature trees (3.2%), and mortality rates significantly decreased with increasing wood density for all species ($P < 0.01$). We therefore concluded that the tree mortality around the globe varied with climatic and forest factors. The differences between tree species, wood density, stand density, and stand age should be considered when evaluating tree mortality at a large spatial scale during future climatic extremes.

Carbon and Carbon Storage

Chiono, L. A., D. L. Fry, B. M. Collins, A. H. Chatfield, and S. L. Stephens. 2017. **Landscape-scale fuel treatment and wildfire impacts on carbon stocks and fire hazard in California spotted owl habitat.** Ecosphere 8:e01648. http://10.1002/ecs2.1648

Abstract. Forest managers are challenged with meeting numerous demands that often include wildlife habitat and carbon (C) sequestration. We used a probabilistic framework of wildfire occurrence to (1) estimate the potential for fuel treatments to reduce fire risk and hazard across the landscape and within protected California spotted owl (Strix occidentalis occidentalis) habitat and (2) evaluate the consequences of treatments with respect to terrestrial C stocks and burning emissions. Silvicultural and prescribed fire treatments were simulated on 20% of a northern Sierra Nevada landscape in three treatment scenarios that varied in the land area eligible for treatment. Treatment prescriptions varied with topography, vegetation characteristics, and ownership. We then simulated many wildfires in the treated and untreated landscapes. Additional simulations allowed us to consider the influence of wildfire size on estimated emissions. Treatments constrained to the land area outside of spotted owl activity centers reduced the probability of burning and potential fire intensity within owl habitat and across the landscape relative to no-treatment scenarios. Allowing treatment of the activity centers achieved even greater fire hazard reductions within the activity centers. Treatments also reduced estimated wildfire emissions of C by 45–61%. However, emissions from prescribed burning exceeded simulated reductions in wildfire emissions. Consequently, all treatment scenarios resulted in higher C emissions than the no-treatment

scenarios. Further, for wildfires of moderate size (714–2133 ha), the treatment scenarios reduced the C contained in live tree biomass following simulated wildfire. When large wildfires (8070–10,757 ha) were simulated, however, the treatment scenario retained more live tree C than the no-treatment scenario. Our approach, which estimated terrestrial C immediately following wildfire, did not account for long-term C dynamics, such as emissions associated with post-wildfire decay, C sequestration by future forest growth, or longer-term C sequestration in structural wood products. While simulated landscape fuel treatments in the present study reduced the risk of uncharacteristically severe wildfire across the landscape and within protected habitat, the C costs of treatment generally exceeded the C benefits.

Dean, C., J. B. Kirkpatrick, and A. J. Friedland. 2017. **Conventional intensive logging promotes loss of organic carbon from the mineral soil.** Global Change Biology 23:1-11. http://10.1111/gcb.13387

Abstract. There are few data, but diametrically opposed opinions, about the impacts of forest logging on soil organic carbon (SOC). Reviews and research articles conclude either that there is no effect, or show contradictory effects. Given that SOC is a substantial store of potential greenhouse gasses and forest logging and harvesting is routine, resolution is important. We review forest logging SOC studies and provide an overarching conceptual explanation for their findings. The literature can be separated into short-term empirical studies, longer-term empirical studies and long-term modelling. All modelling that includes major aboveground and belowground biomass pools shows a long-term (i.e. ≥300 years) decrease in SOC when a primary forest is logged and then subjected to harvesting cycles. The empirical longer-term studies indicate likewise. With successive harvests the net emission accumulates but is only statistically perceptible after centuries. Short-term SOC flux varies around zero. The long-term drop in SOC in the mineral soil is driven by the biomass drop from the primary forest level but takes time to adjust to the new temporal average biomass. We show agreement between secondary forest SOC stocks derived purely from biomass information and stocks derived from complex forest harvest modelling. Thus, conclusions that conventional harvests do not deplete SOC in the mineral soil have been a function of their short time frames. Forest managers, climate change modellers and environmental policymakers need to assume a long-term net transfer of SOC from the mineral soil to the atmosphere when primary forests are logged and then undergo harvest cycles.

However, from a greenhouse accounting perspective, forest SOC is not the entire story. Forest wood products that ultimately reach landfill, and some portion of which produces some soil-like material there rather than in the forest, could possibly help attenuate the forest SOC emission by adding to a carbon pool in landfill.

Garcia, M., S. Saatchi, A. Casas, A. Koltunov, S. Ustin, C. Ramirez, J. Garcia-Gutierrez, and H. Balzter. 2017. **Quantifying biomass consumption and carbon release from the California Rim fire by integrating airborne LiDAR and Landsat OLI data.** Journal of Geophysical Research: Biogeosciences 122:340-353. http://10.1002/2015JG003315

Abstract. Quantifying biomass consumption and carbon release is critical to understanding the role of fires in the carbon cycle and air quality. We present a methodology to estimate the biomass consumed and the carbon released by the California Rim fire by integrating postfire airborne LiDAR and multitemporal Landsat Operational Land Imager (OLI) imagery. First, a support vector regression (SVR) model was trained to estimate the aboveground biomass (AGB) from LiDAR-derived metrics over the unburned area. The selected model estimated AGB with an R^2 of 0.82 and RMSE of 59.98 Mg/ha. Second, LiDAR-based biomass estimates were extrapolated to the entire area before and after the fire, using Landsat OLI reflectance bands, Normalized Difference Infrared Index, and the elevation derived from LiDAR data. The extrapolation was performed using SVR models that resulted in R^2 of 0.73 and 0.79 and RMSE of 87.18 (Mg/ha) and 75.43 (Mg/ha) for the postfire and prefire images, respectively. After removing bias from the AGB extrapolations using a linear relationship between estimated and observed values, we estimated the biomass consumption from postfire LiDAR and prefire Landsat maps to be 6.58 ± 0.03 Tg (10^{12} g), which translate into 12.06 ± 0.06 Tg CO_2e released to the atmosphere, equivalent to the annual emissions of 2.57 million cars.

Garcia, M., S. Saatchi, A. Ferraz, C. A. Silva, S. Ustin, A. Koltunov, and H. Balzter. 2017. **Impact of data model and point density on aboveground forest biomass estimation from airborne LiDAR.** Carbon Balance and Management 12:4. http://10.1186/s13021-017-0073-1

Abstract. Background. Accurate estimation of aboveground forest biomass (AGB) and its dynamics is of paramount importance in understanding the role of forest in the carbon cycle and the effective

implementation of climate change mitigation policies. LiDAR is currently the most accurate technology for AGB estimation. LiDAR metrics can be derived from the 3D point cloud (echo-based) or from the canopy height model (CHM). Different sensors and survey configurations can affect the metrics derived from the LiDAR data. We evaluate the ability of the metrics derived from the echo-based and CHM data models to estimate AGB in three different biomes, as well as the impact of point density on the metrics derived from them.

Results. Our results show that differences among metrics derived at different point densities were significantly different from zero, with a larger impact on CHM-based than echo-based metrics, particularly when the point density was reduced to 1 point m^{-2}. Both data models-echo-based and CHM-performed similarly well in estimating AGB at the three study sites. For the temperate forest in the Sierra Nevada Mountains, California, USA, R^2 ranged from 0.79 to 0.8 and RMSE (relRMSE) from 69.69 (35.59%) to 70.71 (36.12%) Mg ha^{-1} for the echo-based model and from 0.76 to 0.78 and 73.84 (37.72%) to 128.20 (65.49%) Mg ha^{-1} for the CHM-based model. For the moist tropical forest on Barro Colorado Island, Panama, the models gave R^2 ranging between 0.70 and 0.71 and RMSE between 30.08 (12.36%) and 30.32 (12.46) Mg ha^{-1} [between 0.69–0.70 and 30.42 (12.50%) and 61.30 (25.19%) Mg ha^{-1}] for the echo-based [CHM-based] models. Finally, for the Atlantic forest in the Sierra do Mar, Brazil, R^2 was between 0.58–0.69 and RMSE between 37.73 (8.67%) and 39.77 (9.14%) Mg ha^{-1} for the echo-based model, whereas for the CHM R^2 was between 0.37–0.45 and RMSE between 45.43 (10.44%) and 67.23 (15.45%) Mg ha^{-1}.

Conclusions. Metrics derived from the CHM show a higher dependence on point density than metrics derived from the echo-based data model. Despite the median of the differences between metrics derived at different point densities differing significantly from zero, the mean change was close to zero and smaller than the standard deviation except for very low point densities (1 point m^{-2}). The application of calibrated models to estimate AGB on metrics derived from thinned datasets resulted in less than 5% error when metrics were derived from the echo-based model. For CHM-based metrics, the same level of error was obtained for point densities higher than 5 points m^{-2}. The fact that reducing point density does not introduce significant errors in AGB estimates is important for biomass monitoring and for an effective implementation of climate change mitigation policies such as REDD + due to its implications for the costs of data acquisition. Both data models showed similar capability to estimate AGB when point density was greater than or equal to 5 point m^{-2}.

Hoover, C. M., and J. E. Smith. 2017. **Equivalence of live tree carbon stocks produced by three estimation approaches for forests of the western United States.** Forest Ecology and Management 385:236-253. http://dx.doi.org/10.1016/j.foreco.2016.11.041

Abstract. The focus on forest carbon estimation accompanying the implementation of increased regulatory and reporting requirements is fostering the development of numerous tools and methods to facilitate carbon estimation. One such well-established mechanism is via the Forest Vegetation Simulator (FVS), a growth and yield modeling system used by public and private land managers and researchers, which provides two alternate approaches to quantifying carbon in live trees on forest land – these are known as the Jenkins and Fire and Fuels Extension (FFE) equations. A necessary consideration in developing forest carbon estimates is to address alternate, potentially different, estimates that are likely available from more than one source. A key to using such information is some understanding of where alternate estimates are expected to produce equivalent results. We address this here by focusing on potential equivalence among three commonly employed approaches to estimating individual-tree carbon, which are all applicable to inventory sampling or inventory simulation applications. Specifically, the two approaches available in FVS – Jenkins and FFE – and the third, the component ratio method (CRM) used in the U.S. Forest Service's, Forest Inventory and Analysis national DataBase (FIADB).

A key finding of this study is that the Jenkins, FFE, and CRM methods are not universally equivalent, and that equivalence varies across regions, forest types, and levels of data aggregation. No consistent alignment of approaches was identified. In general, equivalence was identified in a greater proportion of cases when forests were summarized at more aggregate levels such as all softwood type groups or entire variants. Most frequently, the FIA inventory-based CRM and FFE were determined to be equivalent.

Hurteau, M. D. 2017. **Quantifying the carbon balance of forest restoration and wildfire under projected climate in the fire-prone southwestern US.** PLOS ONE 12:e0169275. http://10.1371/journal.pone.0169275

Abstract. Climate projections for the southwestern US suggest a warmer, drier future and have the potential to impact forest carbon

(C) sequestration and post-fire C recovery. Restoring forest structure and surface fire regimes initially decreases total ecosystem carbon (TEC), but can stabilize the remaining C by moderating wildfire behavior. Previous research has demonstrated that fire maintained forests can store more C over time than fire suppressed forests in the presence of wildfire. However, because the climate future is uncertain, I sought to determine the efficacy of forest management to moderate fire behavior and its effect on forest C dynamics under current and projected climate. I used the LANDIS-II model to simulate carbon dynamics under early (2010–2019), mid (2050–2059), and late (2090–2099) century climate projections for a ponderosa pine (Pinus ponderosa) dominated landscape in northern Arizona. I ran 100-year simulations with two different treatments (control, thin and burn) and a 1 in 50 chance of wildfire occurring. I found that control TEC had a consistent decline throughout the simulation period, regardless of climate. Thin and burn TEC increased following treatment implementation and showed more differentiation than the control in response to climate, with late-century climate having the lowest TEC. Treatment efficacy, as measured by mean fire severity, was not impacted by climate. Fire effects were evident in the cumulative net ecosystem exchange (NEE) for the different treatments. Over the simulation period, 32.8–48.9% of the control landscape was either C neutral or a C source to the atmosphere and greater than 90% of the thin and burn landscape was a moderate C sink. These results suggest that in southwestern ponderosa pine, restoring forest structure and surface fire regimes provides a reasonable hedge against the uncertainty of future climate change for maintaining the forest C sink.

Körner, C. 2017. **A matter of tree longevity.** Science 355:130-131. http://10.1126/science.aal2449

Abstract. There is much scientific and political interest in using the transfer of carbon from the atmosphere to the biosphere, or carbon sequestration, to help mitigate the greenhouse effect (1). Because plants fix carbon dioxide (CO_2) by photosynthesis and store carbon in their body (close to half of plant dry matter is carbon), faster carbon uptake by plants through faster growth is widely held to increase carbon sequestration. Yet, this assumption is supported by neither theory nor evidence. Any gain in carbon storage from faster tree growth will be transitory.

Krofcheck, D. J., M. D. Hurteau, R. M. Scheller, and E. L. Loudermilk. 2017. **Restoring surface fire stabilizes forest carbon under extreme fire weather in the Sierra Nevada.** Ecosphere 8:e01663. http://10.1002/ecs2.1663

Abstract. Climate change in the western United States has increased the frequency of extreme fire weather events and is projected to increase the area burned by wildfire in the coming decades. This changing fire regime, coupled with increased high-severity fire risk from a legacy of fire exclusion, could destabilize forest carbon (C), decrease net ecosystem exchange (NEE), and consequently reduce the ability of forests to regulate climate through C sequestration. While management options for minimizing the risk of high-severity fire exist, little is known about the longer-term carbon consequences of these actions in the context of continued extreme fire weather events. Our goal was to compare the impacts of extreme wildfire events on carbon stocks and fluxes in a watershed in the Sierra National Forest. We ran simulations to model wildfire under contemporary and extreme fire weather conditions, and test how three management scenarios (no-management, thin-only, thin and maintenance burning) influence fire severity, forest C stocks and fluxes, and wildfire C emissions. We found that the effects of treatment on wildfire under contemporary fire weather were minimal, and management conferred neither significant reduction in fire severity nor increases in C stocks. However, under extreme fire weather, the thin and maintenance burning scenario decreased mean fire severity by 25%, showed significantly greater C stability, and unlike the no-management and thin-only management options, the thin and maintenance burning scenario showed no decrease in NEE relative to the contemporary fire weather scenarios. Further, under extreme fire weather conditions, wildfire C emissions were lowest in the thin and maintenance burning scenario, (reduction of 13.7 Mg C/ha over the simulation period) even when taking into account the C costs associated with prescribed burning. Including prescribed burning in thinning operations may be critical to maintaining C stocks and reducing C emissions in the future where extreme fire weather events are more frequent.

Nahlik, A. M., and M. S. Fennessy. 2016. **Carbon storage in US wetlands.** Nature Communications 7:13835. http://10.1038/ncomms13835

Abstract. Wetland soils contain some of the highest stores of soil carbon in the biosphere. However, there is little understanding of the quantity and distribution of carbon stored in our remaining wetlands or of the potential effects of human disturbance on these stocks. Here we use field data from the 2011 National Wetland Condition Assessment to provide unbiased estimates of soil carbon stocks for wetlands at regional and national scales. We find that wetlands in the conterminous United States store a total of 11.52 PgC, much of which is within soils deeper than 30 cm. Freshwater inland wetlands, in part due to their substantial areal extent, hold nearly ten-fold more carbon than tidal saltwater sites—indicating their importance in regional carbon storage. Our data suggest a possible relationship between carbon stocks and anthropogenic disturbance. These data highlight the need to protect wetlands to mitigate the risk of avoidable contributions to climate change.

Schlesinger, W. H. 2017. **An evaluation of abiotic carbon sinks in deserts.** Global Change Biology 23:25-27. http://10.1111/gcb.13336

Abstract. Recent field studies have reported anomalous CO_2 uptake using eddy-covariance techniques in arid and semiarid ecosystems. The rates of CO_2 uptake are incompatible with changes in situ of organic carbon pools. Here, I examine several potential mechanisms of abiotic CO_2 uptake in arid and semiarid soils: atmospheric pressure pumping, carbonate dissolution, and percolation of soil water through the vadose zone. Each mechanism is deemed inadequate to explain the observations of the eddy-covariance systems, which must now be questioned for their accuracy in desert ecosystems.

Species Range Changes

Keith, S. A., and J. W. Bull. 2017. **Animal culture impacts species' capacity to realise climate-driven range shifts.** Ecography 40:296-304. http://10.1111/ecog.02481

Abstract. Ecological predictions of how species will shift their geographical distributions under climate change generally consider individuals as machines that respond optimally to changing environmental conditions. However, animals frequently make active behavioural decisions based on imperfect information about their external environment, potentially mediated by information transmitted through social learning (i.e. culture). Vertical transmission of culture (between generations) might encourage conservative behaviour, constraining the ability of a species to respond, whilst horizontal

transmission (within generations) can encourage innovation and so facilitate dynamic responses to a changing environment. We believe that the time is right to unite recent advances in ecological modelling and behavioural understanding to explicitly incorporate the influence of animal culture into future predictions of species distributions.

Malanson, G. P., L. M. Resler, and D. F. Tomback. 2017. **Ecotone response to climatic variability depends on stress gradient interactions.** Climate Change Responses 4:1. http://10.1186/s40665-017-0029-4

Abstract. Background. Variability added to directional climate change could have consequences for ecotone community responses, or positive and negative variations could balance. The response will depend on interactions among individuals along environmental gradients, further affected by stress gradient effects.

Methods. Two instantiations of the stress gradient hypothesis, simple stress and a size-mediated model, are represented in a spatially explicit agent based simulation of an ecotone derived from observations of *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus albicaulis* in the northern Rocky Mountains. The simple model has two hierarchically competitive species on a single environmental gradient. The environment undergoes progressive climate change and increases in variability. Because the size model includes system memory, it is expected to buffer the effects of extreme events.

Results. The interactions included in both models of the stress gradient hypothesis similarly reduce the effects of increasing climatic variability. With climate amelioration, the spatial pattern at the ecotone shows an advance of both species into what had been a higher stress area, but with less density when variation increases. In the size-mediated model the competitive species advances farther along the stress gradient at the expense of the second species. The memory embedded in the size-mediated model does not appear to buffer extreme events because the interactions between the two species within their shifting ecotone determine the outcomes.

Conclusions. Ecotone responses are determined by the differences in slopes of the species response to the environment near their point of intersection and further changed by whether neighbor interactions are competitive. Interactions are more diverse and more interwoven than previously conceived, and their quantification will be necessary to move beyond simplistic species distribution models.

Roberts, D. R., and A. Hamann. 2016. **Climate refugia and migration requirements in complex landscapes.** Ecography 39:1238-1246. http://10.1111/ecog.01998

Abstract. All of today's species have proven their ability to cope with climate change during the glacial-interglacial cycles of the Quaternary, but future migration requirements may be different regarding speed, direction, geographic barriers, and availability of nearby climate refugia. Here, we contribute a landscape-level climatic analysis of postglacial vs. projected future migration requirements for 24 common western North American tree species. Using a recently developed velocity of climate change algorithm, we quantify required migration velocities for all populations of species to track climate habitat, based on projections from general circulation models for the 2080s and the last glacial maximum, 21 000 yr ago. Specifically, we ask if nearby climate refugia exist for at least some populations within species ranges and whether the current landscape position of species imply qualitatively different migration requirements in the future compared to those during glacial-interglacial cycles. Results showed that velocities to reach the nearest climate refugia in the future still exceed the fastest reconstructed post-glacial migration requirements, but not by orders of magnitude. Regarding landscape positions, we find a low correlation among past and future migration requirements (r = 0.38), suggesting that qualitatively different migration patterns may emerge in the future for some species. Species identified as occupying landscape positions requiring disproportionally faster migration requirements in the future include whitebark pine, pinyon pine, and coast redwood. We discuss uncertainties of our analytical approach as well as implications for human-assisted migration and conservation action to address climate change.

Forest Vegetation

Bradford, J. B., and D. M. Bell. 2017. **A window of opportunity for climate-change adaptation: easing tree mortality by reducing forest basal area.** Frontiers in Ecology and the Environment 15:11-17. http://10.1002/fee.1445

Abstract. Increasing aridity as a result of climate change is expected to exacerbate tree mortality. Reducing forest basal area – the cross-sectional area of tree stems within a given ground area – can decrease tree competition, which may reduce drought-induced tree mortality. However, neither the magnitude of expected mortality increases, nor

the potential effectiveness of basal area reduction, has been quantified in dryland forests such as those of the drought-prone Southwest US. We used thousands of repeatedly measured forest plots to show that unusually warm and dry conditions are related to high tree mortality rates and that mortality is positively related to basal area. Those relationships suggest that while increasing high temperature extremes forecasted by climate models may lead to elevated tree mortality during the 21st century, future tree mortality might be partly ameliorated by reducing stand basal area. This adaptive forest management strategy may provide a window of opportunity for forest managers and policy makers to guide forest transitions to species and/or genotypes more suited to future climates.

Clark, J. A., R. A. Loehman, and R. E. Keane. 2017. **Climate changes and wildfire alter vegetation of Yellowstone National Park, but forest cover persists.** Ecosphere 8:e01636. http://10.1002/ecs2.1636

Abstract. We present landscape simulation results contrasting effects of changing climates on forest vegetation and fire regimes in Yellowstone National Park, USA, by mid-21st century. We simulated potential changes to fire dynamics and forest characteristics under three future climate projections representing a range of potential future conditions using the FireBGCv2 model. Under the future climate scenarios with moderate warming (>2°C) and moderate increases in precipitation (3–5%), model simulations resulted in 1.2–4.2 times more burned area, decreases in forest cover (10–44%), and reductions in basal area (14–60%). In these same scenarios, lodgepole pine (*Pinus contorta*) decreased in basal area (18–41%), while Douglas-fir (*Pseudotsuga menziesii*) basal area increased (21–58%). Conversely, mild warming (<2°C) coupled with greater increases in precipitation (12–13%) suggested an increase in forest cover and basal area by mid-century, with spruce and subalpine fir increasing in abundance. Overall, we found changes in forest tree species compositions were caused by the climate-mediated changes in fire regime (56–315% increase in annual area burned). Simulated changes in forest composition and fire regime under warming climates portray a landscape that shifts from lodgepole pine to Douglas-fir caused by the interaction between the magnitude and seasonality of future climate changes, by climate-induced changes in the frequency and intensity of wildfires, and by tree species response.

Ford, K. R., I. K. Breckheimer, J. F. Franklin, J. A. Freund, S. J. Kroiss, A. J. Larson, E. J. Theobald, and J. HilleRisLambers. 2017. **Competition alters tree growth responses to climate at individual and stand scales.** Canadian Journal of Forest Research 47:53-62. http://10.1139/cjfr-2016-0188

Abstract. Understanding how climate affects tree growth is essential for assessing climate change impacts on forests but can be confounded by effects of competition, which strongly influences tree responses to climate. We characterized the joint influences of tree size, competition, and climate on diameter growth using hierarchical Bayesian methods applied to permanent sample plot data from the montane forests of Mount Rainier National Park, Washington State, USA, which are mostly comprised of *Abies amabilis* Douglas ex Forbes, *Tsuga heterophylla* (Raf.) Sarg., *Pseudotsuga menziesii* (Mirb.) Franco, and *Thuja plicata* Donn ex D. Don. Individual growth was sensitive to climate under low but not high competition, likely because tree ability to increase growth under more favorable climates (generally greater energy availability) was constrained by competition, with important variation among species. Thus, climate change will likely increase individual growth most in uncrowded stands with lower competition. However, crowded stands have more and (or) larger trees, conferring greater capacity for aggregate absolute growth increases. Due to these contrasting effects, our models predicted that climate change will lead to greater stand-scale growth increases in stands with medium compared with low crowding but similar increases in stands with medium and high crowding. Thus, competition will mediate the impacts of climate change on individual- and stand-scale growth in important but complex ways.

Girardin, M. P., O. Bouriaud, E. H. Hogg, W. Kurz, N. E. Zimmermann, J. M. Metsaranta, R. de Jong, D. C. Frank, J. Esper, U. Büntgen, X. J. Guo, and J. Bhatti. 2016. **No growth stimulation of Canada's boreal forest under half-century of combined warming and CO_2 fertilization.** Proceedings of the National Academy of Sciences 113:E8406-E8414. http://10.1073/pnas.1610156113

Abstract. Considerable evidence exists that current global temperatures are higher than at any time during the past millennium. However, the long-term impacts of rising temperatures and associated shifts in the hydrological cycle on the productivity of ecosystems remain poorly understood for mid to high northern latitudes. Here, we quantify species-specific spatiotemporal variability in terrestrial

aboveground biomass stem growth across Canada's boreal forests from 1950 to the present. We use 873 newly developed tree-ring chronologies from Canada's National Forest Inventory, representing an unprecedented degree of sampling standardization for a large-scale dendrochronological study. We find significant regional- and species-related trends in growth, but the positive and negative trends compensate each other to yield no strong overall trend in forest growth when averaged across the Canadian boreal forest. The spatial patterns of growth trends identified in our analysis were to some extent coherent with trends estimated by remote sensing, but there are wide areas where remote-sensing information did not match the forest growth trends. Quantifications of tree growth variability as a function of climate factors and atmospheric CO_2 concentration reveal strong negative temperature and positive moisture controls on spatial patterns of tree growth rates, emphasizing the ecological sensitivity to regime shifts in the hydrological cycle. An enhanced dependence of forest growth on soil moisture during the late-20th century coincides with a rapid rise in summer temperatures and occurs despite potential compensating effects from increased atmospheric CO_2 concentration.

Mathys, A. S., N. C. Coops, and R. H. Waring. 2017. **An ecoregion assessment of projected tree species vulnerabilities in western North America through the 21st century.** Global Change Biology 23:920-932. http://10.1111/gcb.13440

Abstract. Forest ecosystems across western North America will likely see shifts in both tree species dominance and composition over the rest of this century in response to climate change. Our objective in this study was to identify which ecological regions might expect the greatest changes to occur. We used the process-based growth model 3-PG, to provide estimates of tree species responses to changes in environmental conditions and to evaluate the extent that species are resilient to shifts in climate over the rest of this century. We assessed the vulnerability of 20 tree species in western North America using the Canadian global circulation model under three different emission scenarios. We provided detailed projections of species shifts by including soil maps that account for the spatial variation in soil water availability and soil fertility as well as by utilizing annual climate projections of monthly changes in air temperature, precipitation, solar radiation, vapor pressure deficit and frost at a spatial resolution of one km. Projected suitable areas for tree species were compared to their current ranges based on observations at >40 000 field survey plots. Tree species were classified as vulnerable if environmental conditions projected in the future appear outside that of their current distribution

≥70% of the time. We added a migration constraint that limits species dispersal to <200 m yr^{-1} to provide more realistic projections on species distributions. Based on these combinations of constraints, we predicted the greatest changes in the distribution of dominant tree species to occur within the Northwest Forested Mountains and the highest number of tree species stressed will likely be in the North American Deserts. Projected climatic changes appear especially unfavorable for species in the subalpine zone, where major shifts in composition may lead to the emergence of new forest types.

Rother, M. T., and T. T. Veblen. 2016. **Limited conifer regeneration following wildfires in dry ponderosa pine forests of the Colorado Front Range.** Ecosphere 7:e01594. http://10.1002/ecs2.1594

Abstract. In recent years, increased wildfire activity and climate change have raised concern among scientists and land managers regarding current and future vegetation patterns in post-burn landscapes. We surveyed conifer regeneration 8–15 years after fire in six burn areas in the lower montane zone of the Colorado Front Range. We sampled across a broad range of elevations, aspects, and fire severities and found that densities of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) are generally low, although areas of abundant regeneration do occur. Conifer regeneration was most limited in xeric settings, including more southerly aspects and elevations closer to lower treeline. Additionally, fewer juvenile conifers occurred at greater distances from mature, live trees indicating that seed source as well as topoclimatic setting limits post-fire tree regeneration. Projecting the extent of future forest cover is uncertain due to the possibility of future pulses of tree establishment and unknown depletion rates of existing seedling populations. However, current patterns of post-fire seedling establishment suggest that vegetation composition and structure may differ notably from historic patterns and that lower density stands and even non-forested communities may persist in some areas of these burns long after fire, especially in xeric settings or where no nearby seed source remains.

Song, X., and X. Zeng. 2017. **Evaluating the responses of forest ecosystems to climate change and CO_2 using dynamic global vegetation models.** Ecology and Evolution 7:997-1008. http://10.1002/ece3.2735

Abstract. The climate has important influences on the distribution and structure of forest ecosystems, which may lead to vital feedback to climate change. However, much of the existing work focuses on the changes in carbon fluxes or water cycles due to climate change and/or atmospheric CO_2, and few studies have considered how and to what extent climate change and CO_2 influence the ecosystem structure (e.g., fractional coverage change) and the changes in the responses of ecosystems with different characteristics. In this work, two dynamic global vegetation models (DGVMs): IAP-DGVM coupled with CLM3 and CLM4-CNDV, were used to investigate the response of the forest ecosystem structure to changes in climate (temperature and precipitation) and CO_2 concentration. In the temperature sensitivity tests, warming reduced the global area-averaged ecosystem gross primary production in the two models, which decreased global forest area. Furthermore, the changes in tree fractional coverage (ΔF_{tree}; %) from the two models were sensitive to the regional temperature and ecosystem structure, i.e., the mean annual temperature (MAT; °C) largely determined whether ΔF_{tree} was positive or negative, while the tree fractional coverage (F_{tree}; %) played a decisive role in the amplitude of ΔF_{tree} around the globe, and the dependence was more remarkable in IAP-DGVM. In cases with precipitation change, F_{tree} had a uniformly positive relationship with precipitation, especially in the transition zones of forests (30% < F_{tree} < 60%) for IAP-DGVM and in semiarid and arid regions for CLM4-CNDV. Moreover, ΔF_{tree} had a stronger dependence on F_{tree} than on the mean annual precipitation (MAP; mm/year). It was also demonstrated that both models captured the fertilization effects of the CO_2 concentration.

Welch, K. R., H. D. Safford, and T. P. Young. 2016. **Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone.** Ecosphere 7:e01609. http://10.1002/ecs2.1609

Abstract. Due to fire suppression policies, timber harvest, and other management practices over the last century, many low- to mid-elevation forests in semiarid parts of the western United States have accumulated high fuel loads and dense, multi-layered canopies that are dominated by shade-tolerant and fire-sensitive conifers. To a great extent, the future status of western US forests will depend on tree

species' responses to patterns and trends in fire activity and fire behavior and postfire management decisions. This is especially the case in the North American Mediterranean-climate zone (NAMCZ), which supports the highest precipitation variability in North America and a 4- to 6-month annual drought, and has seen greater-than-average increases in air temperature and fire activity over the last three decades. We established 1490 survey plots in 14 burned areas on 10 National Forests across a range of elevations, forest types, and fire severities in the central and northern NAMCZ to provide insight into factors that promote natural tree regeneration after wildfires and the differences in postfire responses of the most common conifer species. We measured site characteristics, seedling densities, woody shrub, and tree growth. We specified a zero-inflated negative binomial mixed model with random effects to understand the importance of each measured variable in predicting conifer regeneration. Across all fires, 43% of all plots had no conifer regeneration. Ten of the 14 fires had median conifer seedling densities that did not meet Forest Service stocking density thresholds for mixed conifer forests. When regeneration did occur, it was dominated by shade-tolerant but fire-sensitive firs (*Abies* spp.), Douglas-fir (*Pseudotsuga menziesii*) and incense cedar (*Calocedrus decurrens*). Seedling densities of conifer species were lowest in sites that burned at high severity, principally due to the biotic consequences of high severity fire, for example, increased distances to live seed trees and competition with fire-following shrubs. We developed a second model specifically for forest managers and restoration practitioners who work in yellow pine and mixed conifer forests in the central NAMCZ to assess potential natural regeneration in the years immediately following a fire, allowing them to prioritize which areas may need active postfire forest restoration and supplemental planting.

Rangeland Vegetation

Brabec, M. M., M. J. Germino, and B. A. Richardson. 2017. **Climate adaption and post-fire restoration of a foundational perennial in cold desert: insights from intraspecific variation in response to weather.** Journal of Applied Ecology 54:293-302. http://10.1111/1365-2664.12679

Abstract. The loss of foundational but fire-intolerant perennials such as sagebrush due to increases in fire size and frequency in semi-arid regions has motivated efforts to restore them, often with mixed or

even no success. Seeds of sagebrush *Artemisia tridentata* and related species must be moved considerable distances from seed source to planting sites, but such transfers have not been guided by an understanding of local climate adaptation. Initial seedling establishment and its response to weather are a key demographic bottleneck that likely varies among subspecies and populations of sagebrush.

We assessed differences in survival, growth and physiological responses of sagebrush seedlings to weather among eleven seed sources that varied in subspecies, cytotype and climates-of-origin over 18 months following outplanting. Diploid or polyploid populations of mountain, Wyoming and basin big sagebrush (*A. tridentata* ssp. *vaseyana*, *A. tridentata* ssp. *wyomingensis* and *A. tridentata* ssp. *tridentata*, respectively) were planted onto five burned sites that normally support *A.t. wyomingensis* with some *A.t. tridentata*.

A.t. wyomingensis had the most growth and survival, and tetraploid populations had greater survival and height than diploids. Seasonal timing of mortality varied among the subspecies/cytotypes and was more closely related to minimum temperatures than water deficit.

Temperatures required to induce ice formation were up to 6 °C more negative in 4n-*A.t. tridentata* and *A.t. wyomingensis* than in other subspecies/cytotypes, indicating greater freezing avoidance. In contrast, freezing resistance of photosynthesis varied only 1 °C among subspecies/cytotypes, being greatest in *A.t. wyomingensis* and least in the subspecies normally considered most cold-adapted, *A.t. vaseyana*. A large spectrum of reliance on freezing avoidance vs. freezing tolerance was observed and corresponded to differences in post-fire survivorship among subspecies/cytotypes. Differences in water deficit responses among subspecies/cytotypes were not as strong and did not relate to survival patterns.

<u>Synthesis and applications</u>. Low-temperature responses are a key axis defining climate adaptation in young sagebrush seedlings and vary more with cytotype than with subspecies, which contrasts with the traditional emphases on (i) water limitations to explain establishment in these deserts, and (ii) subspecies in selecting restoration seedings. These important and novel insights on climate adaptation are critical for seed selection and parameterizing seed transfer zones, and were made possible by incorporating weather data with survival statistics. The survival/weather statistics used here could be applied to any restoration planting or seeding to help elucidate factors contributing to success and enable adaptive management.

Kimball, S., J. L. Funk, M. J. Spasojevic, K. N. Suding, S. Parker, and M. L. Goulden. 2016. **Can functional traits predict plant community response to global change?** Ecosphere 7:e01602. http://10.1002/ecs2.1602

Abstract. One primary goal at the intersection of community ecology and global change biology is to identify functional traits that are useful for predicting plant community response to global change. We used observations of community composition from a long-term field experiment in two adjacent plant communities (grassland and coastal sage shrub) to investigate how nine key plant functional traits were related to altered water and nitrogen availability following fire. We asked whether the functional responses of species found in more than one community type were context dependent and whether community-weighted mean and functional diversity were significantly altered by water and nitrogen input. Our results suggest varying degrees of context dependency. We found that plants with high leaf nitrogen concentration (specifically nitrogen fixers), shallow roots, and low leaf mass per unit area and plant-level transpiration were similarly negatively influenced by added nitrogen across community types. In contrast, responses to water manipulations exhibited greater context dependency; plants with high water-use efficiency, lower plant-level transpiration rates, and shallower roots were negatively impacted by simulated drought in the shrub-dominated community, but there was no significant relationship between these traits and changes in water inputs in the grassland community. Similarly, we found context dependency in community-wide trait responses to global change. Functional diversity tended to be higher in plots with reduced water as compared to those with added water in grassland, while the opposite trend was observed in coastal sage scrub. Our results indicate that some traits are strong predictors of species and community response to altered water and nitrogen availability, but the magnitude and direction of the response may be modulated by the abiotic and biotic context.

Schlaepfer, D. R., J. B. Bradford, W. K. Lauenroth, S. M. Munson, B. Tietjen, S. A. Hall, S. D. Wilson, M. C. Duniway, G. Jia, D. A. Pyke, A. Lkhagva, and K. Jamiyansharav. 2017. **Climate change reduces extent of temperate drylands and intensifies drought in deep soils.** Nature Communications 8:14196. http://10.1038/ncomms14196

Abstract. Drylands cover 40% of the global terrestrial surface and provide important ecosystem services. While drylands as a whole are

expected to increase in extent and aridity in coming decades, temperature and precipitation forecasts vary by latitude and geographic region suggesting different trajectories for tropical, subtropical, and temperate drylands. Uncertainty in the future of tropical and subtropical drylands is well constrained, whereas soil moisture and ecological droughts, which drive vegetation productivity and composition, remain poorly understood in temperate drylands. Here we show that, over the twenty first century, temperate drylands may contract by a third, primarily converting to subtropical drylands, and that deep soil layers could be increasingly dry during the growing season. These changes imply major shifts in vegetation and ecosystem service delivery. Our results illustrate the importance of appropriate drought measures and, as a global study that focuses on temperate drylands, highlight a distinct fate for these highly populated areas.

Wertin, T. M., J. Belnap, and S. C. Reed. 2017. **Experimental warming in a dryland community reduced plant photosynthesis and soil CO_2 efflux although the relationship between the fluxes remained unchanged.** Functional Ecology 31:297-305. http://10.1111/1365-2435.12708

Abstract. Drylands represent our planet's largest terrestrial biome and, due to their extensive area, maintain large stocks of carbon (C). Accordingly, understanding how dryland C cycling will respond to climate change is imperative for accurately forecasting global C cycling and future climate. However, it remains difficult to predict how increased temperature will affect dryland C cycling, as substantial uncertainties surround the potential responses of the two main C fluxes: plant photosynthesis and soil CO_2 efflux. In addition to a need for an improved understanding of climate effects on individual dryland C fluxes, there is also notable uncertainty regarding how climate change may influence the relationship between these fluxes.

To address this important knowledge gap, we measured a growing season's in situ photosynthesis, plant biomass accumulation and soil CO_2 efflux of mature *Achnatherum hymenoides* (a common and ecologically important C_3 bunchgrass growing throughout western North America) exposed to ambient or elevated temperature (+2 °C above ambient, warmed via infrared lamps) for 3 years.

The 2 °C increase in temperature caused a significant reduction in photosynthesis, plant growth and soil CO_2 efflux. Of important note, photosynthesis and soil respiration appeared tightly coupled and the relationship between these fluxes was not altered by the elevated

temperature treatment, suggesting C fixation's strong control of both above-ground and below-ground dryland C cycling. Leaf water use efficiency was substantially increased in the elevated temperature treatment compared to the control treatment.

Taken together, our results suggest notable declines in photosynthesis with relatively subtle warming, reveal strong coupling between above- and below-ground C fluxes in this dryland and highlight temperature's strong effect on fundamental components of dryland C and water cycles.

Fish and Wildlife

Bateman, B. L., A. M. Pidgeon, V. C. Radeloff, C. H. Flather, J. VanDerWal, H. R. Akçakaya, W. E. Thogmartin, T. P. Albright, S. J. Vavrus, and P. J. Heglund. 2016. **Potential breeding distributions of U.S. birds predicted with both short-term variability and long-term average climate data.** Ecological Applications 26:2720-2731. http://10.1002/eap.1416

Abstract. Climate conditions, such as temperature or precipitation, averaged over several decades strongly affect species distributions, as evidenced by experimental results and a plethora of models demonstrating statistical relations between species occurrences and long-term climate averages. However, long-term averages can conceal climate changes that have occurred in recent decades and may not capture actual species occurrence well because the distributions of species, especially at the edges of their range, are typically dynamic and may respond strongly to short-term climate variability. Our goal here was to test whether bird occurrence models can be predicted by either covariates based on short-term climate variability or on long-term climate averages. We parameterized species distribution models (SDMs) based on either short-term variability or long-term average climate covariates for 320 bird species in the conterminous USA and tested whether any life-history trait-based guilds were particularly sensitive to short-term conditions. Models including short-term climate variability performed well based on their cross-validated area-under-the-curve AUC score (0.85), as did models based on long-term climate averages (0.84). Similarly, both models performed well compared to independent presence/absence data from the North American Breeding Bird Survey (independent AUC of 0.89 and 0.90, respectively). However, models based on short-term variability covariates more accurately classified true absences for most species (73% of true

absences classified within the lowest quarter of environmental suitability vs. 68%). In addition, they have the advantage that they can reveal the dynamic relationship between species and their environment because they capture the spatial fluctuations of species potential breeding distributions. With this information, we can identify which species and guilds are sensitive to climate variability, identify sites of high conservation value where climate variability is low, and assess how species' potential distributions may have already shifted due recent climate change. However, long-term climate averages require less data and processing time and may be more readily available for some areas of interest. Where data on short-term climate variability are not available, long-term climate information is a sufficient predictor of species distributions in many cases. However, short-term climate variability data may provide information not captured with long-term climate data for use in SDMs.

Benjamin, J. R., J. M. Heltzel, J. B. Dunham, M. Heck, and N. Banish. 2016. **Thermal regimes, nonnative trout, and their influences on native bull trout in the upper Klamath River basin, Oregon.** Transactions of the American Fisheries Society 145:1318-1330. http://10.1080/00028487.2016.1219677

Abstract. The occurrence of fish species may be strongly influenced by a stream's thermal regime (magnitude, frequency, variation, and timing). For instance, magnitude and frequency provide information about sublethal temperatures, variability in temperature can affect behavioral thermoregulation and bioenergetics, and timing of thermal events may cue life history events, such as spawning and migration. We explored the relationship between thermal regimes and the occurrences of native Bull Trout *Salvelinus confluentus* and nonnative Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta* across 87 sites in the upper Klamath River basin, Oregon. Our objectives were to associate descriptors of the thermal regime with trout occurrence, predict the probability of Bull Trout occurrence, and estimate upper thermal tolerances of the trout species. We found that each species was associated with a different suite of thermal regime descriptors. Bull Trout were present at sites that were cooler, had fewer high-temperature events, had less variability, and took longer to warm. Brook Trout were also observed at cooler sites with fewer high-temperature events, but the sites were more variable and Brook Trout occurrence was not associated with a timing descriptor. In contrast, Brown Trout were present at sites that were warmer and reached higher temperatures faster, but they were not associated with frequency or variability descriptors. Among the descriptors considered,

magnitude (specifically June degree-days) was the most important in predicting the probability of Bull Trout occurrence, and model predictions were strengthened by including Brook Trout occurrence. Last, all three trout species exhibited contrasting patterns of tolerating longer exposures to lower temperatures. Tolerance limits for Bull Trout were lower than those for Brook Trout and Brown Trout, with contrasts especially evident for thermal maxima. Our results confirm the value of exploring a suite of thermal regime descriptors for understanding the distribution and occurrence of fishes. Moreover, these descriptors and their relationships to fish should be considered with future changes in land use, water use, or climate.

Böhm, M., D. Cook, H. Ma, A. D. Davidson, A. García, B. Tapley, P. Pearce-Kelly, and J. Carr. 2016. **Hot and bothered: Using trait-based approaches to assess climate change vulnerability in reptiles.** Biological Conservation 204, Part A:32-41. http://dx.doi.org/10.1016/j.biocon.2016.06.002

Abstract. One-fifth of the world's reptiles are currently estimated as threatened with extinction, primarily due to the immediate threats of habitat loss and overexploitation. Climate change presents an emerging slow-acting threat. However, few IUCN Red List assessments for reptiles explicitly consider the potential role of climate change as a threat. Thus, climate change vulnerability assessments can complement existing Red List assessments and highlight further, emerging priorities for conservation action.

Here we present the first trait-based global climate change vulnerability assessment for reptiles to estimate the climate change vulnerability of a random representative sample of 1498 species of reptiles. We collected species-specific traits relating to three dimensions of climate change, sensitivity, low adaptability, and exposure, which we combined to assess overall vulnerability.

We found 80.5% of species highly sensitive to climate change, primarily due to habitat specialisation, while 48% had low adaptability and 58% had high exposure. Overall, 22% of species assessed were highly vulnerable to climate change. Hotspots of climate change vulnerability did not always overlap with hotspots of threatened species richness, with most of the vulnerable species found in northwestern South America, southwestern USA, Sri Lanka, the Himalayan Arc, Central Asia and southern India. Most families were found to be significantly more vulnerable to climate change than expected by chance.

Our findings build on previous work on reptile extinction risk to provide an overview of the risk posed to reptiles by climate change. Despite significant data gaps for a number of traits, we recommend that these findings are integrated into reassessments of species' extinction risk, to monitor both immediate and slow-acting threats to reptiles.

Gsell, A. S., U. Scharfenberger, D. Özkundakci, A. Walters, L.-A. Hansson, A. B. G. Janssen, P. Nõges, P. C. Reid, D. E. Schindler, E. Van Donk, V. Dakos, and R. Adrian. 2016. **Evaluating early-warning indicators of critical transitions in natural aquatic ecosystems.** Proceedings of the National Academy of Sciences 113:E8089-E8095. http://10.1073/pnas.1608242113

Abstract. Ecosystems can show sudden and persistent changes in state despite only incremental changes in drivers. Such critical transitions are difficult to predict, because the state of the system often shows little change before the transition. Early-warning indicators (EWIs) are hypothesized to signal the loss of system resilience and have been shown to precede critical transitions in theoretical models, paleo-climate time series, and in laboratory as well as whole lake experiments. The generalizability of EWIs for detecting critical transitions in empirical time series of natural aquatic ecosystems remains largely untested, however. Here we assessed four commonly used EWIs on long-term datasets of five freshwater ecosystems that have experienced sudden, persistent transitions and for which the relevant ecological mechanisms and drivers are well understood. These case studies were categorized by three mechanisms that can generate critical transitions between alternative states: competition, trophic cascade, and intraguild predation. Although EWIs could be detected in most of the case studies, agreement among the four indicators was low. In some cases, EWIs were detected considerably ahead of the transition. Nonetheless, our results show that at present, EWIs do not provide reliable and consistent signals of impending critical transitions despite using some of the best routinely monitored freshwater ecosystems. Our analysis strongly suggests that a priori knowledge of the underlying mechanisms driving ecosystem transitions is necessary to identify relevant state variables for successfully monitoring EWIs.

Michel, M. J., H. Chien, C. E. Beachum, M. G. Bennett, and J. H. Knouft. 2017. **Climate change, hydrology, and fish morphology: predictions using phenotype-environment associations.** Climatic Change 140:563-576. http://10.1007/s10584-016-1856-1

Abstract. Phenotype-environment associations (PEAs) describe relationships between the mean phenotypes of a set of populations and the environmental values of the areas in which they inhabit. We show how these PEAs can be used to determine the ability of populations to adapt to future environmental changes, using relationships between fish body shape and stream flow rates as an example. First, we establish that fish in high-flow habitats have more streamlined body shapes than those in low-flow habitats. Then, using future estimates of flow rates obtained from landscape hydrologic models, we predict body shapes of stream fish in the year 2055. Lastly, we use simulations based on a quantitative population genetics model to determine each fish population's ability to alter its phenotype to the predicted body shape in 2055. While some fish populations were predicted to be able to reach the predicted body shape, others were identified as vulnerable to changing flow rates and may need human assistance to persist into the mid-century. The simulations introduced here combine correlative and mechanistic methods to predict future adaptation to environmental change and are applicable to a wide range of taxa.

Muñoz, D. J., K. Miller Hesed, E. H. Campbell Grant, and D. A. W. Miller. 2016. **Evaluating within-population variability in behavior and demography for the adaptive potential of a dispersal-limited species to climate change.** Ecology and Evolution 6:8740-8755. http://10.1002/ece3.2573

Abstract. Multiple pathways exist for species to respond to changing climates. However, responses of dispersal-limited species will be more strongly tied to ability to adapt within existing populations as rates of environmental change will likely exceed movement rates. Here, we assess adaptive capacity in *Plethodon cinereus*, a dispersal-limited woodland salamander. We quantify plasticity in behavior and variation in demography to observed variation in environmental variables over a 5-year period. We found strong evidence that temperature and rainfall influence P. cinereus surface presence, indicating changes in climate are likely to affect seasonal activity patterns. We also found that warmer summer temperatures reduced individual growth rates into the autumn, which is likely to have negative demographic consequences.

Reduced growth rates may delay reproductive maturity and lead to reductions in size-specific fecundity, potentially reducing population-level persistence. To better understand within-population variability in responses, we examined differences between two common color morphs. Previous evidence suggests that the color polymorphism may be linked to physiological differences in heat and moisture tolerance. We found only moderate support for morph-specific differences for the relationship between individual growth and temperature. Measuring environmental sensitivity to climatic variability is the first step in predicting species' responses to climate change. Our results suggest phenological shifts and changes in growth rates are likely responses under scenarios where further warming occurs, and we discuss possible adaptive strategies for resulting selective pressures.

Pacifici, M., P. Visconti, S. H. M. Butchart, J. E. M. Watson, F. M. Cassola, and C. Rondinini. 2017. **Species' traits influenced their response to recent climate change.** Nature Climate Change 7:205-208. http://10.1038/nclimate3223

Abstract. Although it is widely accepted that future climatic change—if unabated—is likely to have major impacts on biodiversity, few studies have attempted to quantify the number of species whose populations have already been impacted by climate change. Using a systematic review of published literature, we identified mammals and birds for which there is evidence that they have already been impacted by climate change. We modelled the relationships between observed responses and intrinsic (for example, body mass) and spatial traits (for example, temperature seasonality within the geographic range). Using this model, we estimated that 47% of terrestrial non-volant threatened mammals (out of 873 species) and 23.4% of threatened birds (out of 1,272 species) may have already been negatively impacted by climate change in at least part of their distribution. Our results suggest that populations of large numbers of threatened species are likely to be already affected by climate change, and that conservation managers, planners and policy makers must take this into account in efforts to safeguard the future of biodiversity.

Sutton, A. O., D. Strickland, and D. R. Norris. 2016. **Food storage in a changing world: implications of climate change for food-caching species.** Climate Change Responses 3:12. http://10.1186/s40665-016-0025-0

Abstract. Food caching is a behavioural strategy used by a wide range of animals to store food for future use. When food is stored, it is susceptible to environmental conditions that can lead to spoilage via microbial proliferation or physical and chemical processes. Given that the nutrition gained from consuming cached food will almost always be less than consuming it immediately upon capture, the degree of degradation will play a central role in determining the ecological threshold at which caching is no longer profitable. Our framework proposes that the degree of susceptibility among caching species is based primarily on the duration of storage, and the perishability of stored food. We first summarize the degree of susceptibility of 203 vertebrate caching species. Thirty-eight percent (38%) of these species are long-term cachers (>10 days) but only 2% are both long-term cachers and store highly perishable food. We then integrate insights from the fields of applied food science and plant biology to outline potential mechanisms by which climate change may influence food-caching species. Four climatic factors (temperature, number of freeze-thaw events, deep-freeze events and humidity) have been shown to affect the degradation of food consumed by humans and are also expected to influence the quality of perishable food cached in the wild. Temperature and moisture are likely important factors influencing seemingly nonperishable seeds. Although we are able to provide broad classifications for caching species at risk of climate change, an improved understanding of how environmental conditions affect the quality and persistence of cached food may allow us to better predict the impact of changing climatic conditions on the fitness of food-caching animals.

Wade, A. A., B. K. Hand, R. P. Kovach, G. Luikart, D. C. Whited, and C. C. Muhlfeld. 2017. **Accounting for adaptive capacity and uncertainty in assessments of species' climate-change vulnerability.** Conservation Biology 31:136-149. http://10.1111/cobi.12764

Abstract. Climate-change vulnerability assessments (CCVAs) are valuable tools for assessing species' vulnerability to climatic changes, yet failure to include measures of adaptive capacity and to account for sources of uncertainty may limit their effectiveness. We took a more comprehensive approach that incorporates exposure, sensitivity, and

capacity to adapt to climate change. We applied our approach to anadromous steelhead trout (*Oncorhynchus mykiss*) and nonanadromous bull trout (*Salvelinus confluentus*), threatened salmonids within the Columbia River Basin (U.S.A.). We quantified exposure on the basis of scenarios of future stream temperature and flow, and we represented sensitivity and capacity to adapt to climate change with metrics of habitat quality, demographic condition, and genetic diversity. Both species were found to be highly vulnerable to climate change at low elevations and in their southernmost habitats. However, vulnerability rankings varied widely depending on the factors (climate, habitat, demographic, and genetic) included in the CCVA and often differed for the 2 species at locations where they were sympatric. Our findings illustrate that CCVA results are highly sensitive to data inputs and that spatial differences can complicate multispecies conservation. Based on our results, we suggest that CCVAs be considered within a broader conceptual and computational framework and be used to refine hypotheses, guide research, and compare plausible scenarios of species' vulnerability to climate change.

Biodiversity

Copeland, S. M., and S. P. Harrison. 2017. **Community traits affect plant–plant interactions across climatic gradients.** Oikos 126:n/a-n/a. http://10.1111/oik.03376

Abstract. Plant abundances and demography often vary along gradients of environmental stress, and neighboring plants can amplify or diminish such variation. We asked to what degree the effects of neighboring plants on a focal species can be explained by the traits and abundances of species in the surrounding community. We studied a common understory herb, *Trientalis latifolia*, across climatic gradients created by topography in the Siskiyou Mountains, southwestern Oregon. We compared *Trientalis* fitness along these gradients with and without neighbor removal, and asked whether the effects of neighboring plants could be predicted by their community-weighted trait values and abundances. Environmental conditions alone did not explain whether neighbors had competitive or facilitative effects on *Trientalis*. However, the environment interacted with neighbor traits and biomass to influence neighbor effects: at cool, higher elevations, high neighbor biomass was associated with stronger facilitative effects, while at warm, lower elevations, high neighbor dissimilarity from *Trientalis* was associated with stronger competitive

effects. We suggest that covariation and interactions among environmental and community characteristics are key to understanding species performance along climatic gradients.

Gruner, D. S., M. E. S. Bracken, S. A. Berger, B. K. Eriksson, L. Gamfeldt, B. Matthiessen, S. Moorthi, U. Sommer, and H. Hillebrand. 2017. **Effects of experimental warming on biodiversity depend on ecosystem type and local species composition.** Oikos 126:8-17. http://10.1111/oik.03688

Abstract. Climatic warming is a primary driver of change in ecosystems worldwide. Here, we synthesize responses of species richness and evenness from 187 experimental warming studies in a quantitative meta-analysis. We asked 1) whether effects of warming on diversity were detectable and consistent across terrestrial, freshwater and marine ecosystems, 2) if effects on diversity correlated with intensity, duration, and experimental unit size of temperature change manipulations, and 3) whether these experimental effects on diversity interacted with ecosystem types. Using multilevel mixed linear models and model averaging, we also tested the relative importance of variables that described uncontrolled environmental variation and attributes of experimental units. Overall, experimental warming reduced richness across ecosystems (mean log-response ratio = –0.091, 95% bootstrapped CI: –0.13, –0.05) representing an 8.9% decline relative to ambient temperature treatments. Richness did not change in response to warming in freshwater systems, but was more strongly negative in terrestrial (–11.8%) and marine (–10.5%) experiments. In contrast, warming impacts on evenness were neutral overall and in aquatic systems, but weakly negative on land (7.6%). Intensity and duration of experimental warming did not explain variation in diversity responses, but negative effects on richness were stronger in smaller experimental units, particularly in marine systems. Model-averaged parameter estimation confirmed these main effects while accounting for variation in latitude, ambient temperature at the sites of manipulations, venue (field versus lab), community trophic type, and whether experiments were open or closed to colonization. These analyses synthesize extensive experimental evidence showing declines in local richness with increased temperature, particularly in terrestrial and marine communities. However, the more variable effects of warming on evenness were better explained by the random effect of site identity, suggesting that effects on species' relative abundances were contingent on local species composition.

Soils and Hydrology

Barth, N. A., G. Villarini, M. A. Nayak, and K. White. 2017. **Mixed populations and annual flood frequency estimates in the western United States: The role of atmospheric rivers.** Water Resources Research 53:257-269. http://10.1002/2016WR019064

Abstract. The Bulletin 17B framework assumes that the annual peak flow data included in a flood frequency analysis are from a homogeneous population. However, flood frequency analysis over the western United States is complicated by annual peak flow records that frequently contain annual flows generated from distinctly different flood generating mechanisms. These flood series contain multiple zero flows and/or potentially influential low floods (PILFs) that substantially deviate from the overall pattern in the data. Moreover, they often also contain extreme flood events representing different hydrometeorologic agents. Among the different flood generating mechanisms, atmospheric rivers (ARs) are responsible for large, regional-scale floods. The spatial and fractional contribution of ARs in annual peak flow data is examined based on 1375 long-term U.S. Geological Survey (USGS) streamgage sites with at least 30 years of data. Six main areas in which flooding is impacted by ARs at varying degrees were found throughout the western United States. The Pacific Northwest and the northern California coast have the highest fraction of AR-generated peaks (~80–100%), while eastern Montana, Wyoming, Utah, Colorado, and New Mexico have nearly no impacts from ARs. The individual regions of the central Columbia River Basin in the Pacific Northwest, the Sierra Nevada, the central and southern California coast, and central Arizona all show a mixture of 30–70% AR-generated flood peaks. Analyses related to the largest flood peaks on record and to the estimated annual exceedance probabilities highlight the strong impact of ARs on flood hydrology in this region, together with marked regional differences.

Pyne, M. I., and N. L. Poff. 2017. **Vulnerability of stream community composition and function to projected thermal warming and hydrologic change across ecoregions in the western United States.** Global Change Biology 23:77-93. http://10.1111/gcb.13437

Abstract. Shifts in biodiversity and ecological processes in stream ecosystems in response to rapid climate change will depend on how

numerically and functionally dominant aquatic insect species respond to changes in stream temperature and hydrology. Across 253 minimally perturbed streams in eight ecoregions in the western USA, we modeled the distribution of 88 individual insect taxa in relation to existing combinations of maximum summer temperature, mean annual streamflow, and their interaction. We used a heat map approach along with downscaled general circulation model (GCM) projections of warming and streamflow change to estimate site-specific extirpation likelihood for each taxon, allowing estimation of whole-community change in streams across these ecoregions. Conservative climate change projections indicate a 30–40% loss of taxa in warmer, drier ecoregions and 10–20% loss in cooler, wetter ecoregions where taxa are relatively buffered from projected warming and hydrologic change. Differential vulnerability of taxa with key functional foraging roles in processing basal resources suggests that climate change has the potential to modify stream trophic structure and function (e.g., alter rates of detrital decomposition and algal consumption), particularly in warmer and drier ecoregions. We show that streamflow change is equally as important as warming in projected risk to stream community composition and that the relative threat posed by these two fundamental drivers varies across ecoregions according to projected gradients of temperature and hydrologic change. Results also suggest that direct human modification of streams through actions such as water abstraction is likely to further exacerbate loss of taxa and ecosystem alteration, especially in drying climates. Management actions to mitigate climate change impacts on stream ecosystems or to proactively adapt to them will require regional calibration, due to geographic variation in insect sensitivity and in exposure to projected thermal warming and hydrologic change.

Slater, L. J., and G. Villarini. 2016. **Recent trends in U.S. flood risk.** Geophysical Research Letters 43:12,428-412,436. http://10.1002/2016GL071199

Abstract. Flooding is projected to become more frequent as warming temperatures amplify the atmosphere's water holding capacity and increase the occurrence of extreme precipitation events. However, there is still little evidence of regional changes in flood risk across the USA. Here we present a novel approach assessing the trends in inundation frequency above the National Weather Service's four flood level categories in 2042 catchments. Results reveal stark regional patterns of changing flood risk that are broadly consistent above the four flood categories. We show that these patterns are dependent on the overall wetness and potential water storage, with fundamental

implications for water resources management, agriculture, insurance, navigation, ecology, and populations living in flood-affected areas. Our findings may assist in a better communication of changing flood patterns to a wider audience compared with the more traditional approach of stating trends in terms of discharge magnitudes and frequencies.

Turkington, T., K. Breinl, J. Ettema, D. Alkema, and V. Jetten. 2016. **A new flood type classification method for use in climate change impact studies.** Weather and Climate Extremes 14:1-16. http://dx.doi.org/10.1016/j.wace.2016.10.001

Abstract. Flood type classification is an optimal tool to cluster floods with similar meteorological triggering conditions. Under climate change these flood types may change differently as well as new flood types develop. This paper presents a new methodology to classify flood types, particularly for use in climate change impact studies. A weather generator is coupled with a conceptual rainfall-runoff model to create long synthetic records of discharge to efficiently build an inventory with high number of flood events. Significant discharge days are classified into causal types using k-means clustering of temperature and precipitation indicators capturing differences in rainfall amount, antecedent rainfall and snow-cover and day of year. From climate projections of bias-corrected temperature and precipitation, future discharge and associated change in flood types are assessed. The approach is applied to two different Alpine catchments: the Ubaye region, a small catchment in France, dominated by rain-on-snow flood events during spring, and the larger Salzach catchment in Austria, affected more by rainfall summer/autumn flood events. The results show that the approach is able to reproduce the observed flood types in both catchments. Under future climate scenarios, the methodology identifies changes in the distribution of flood types and characteristics of the flood types in both study areas. The developed methodology has potential to be used flood impact assessment and disaster risk management as future changes in flood types will have implications for both the local social and ecological systems in the future.

Fire

Harvey, B. J., D. C. Donato, and M. G. Turner. 2016. **Drivers and trends in landscape patterns of stand-replacing fire in forests of the US Northern Rocky Mountains (1984–2010).** Landscape Ecology 31:2367-2383. http://10.1007/s10980-016-0408-4

Abstract. Context. Resilience in fire-prone forests is strongly affected by landscape burn-severity patterns, in part by governing propagule availability around stand-replacing patches in which all or most vegetation is killed. However, little is known about drivers of landscape patterns of stand-replacing fire, or whether such patterns are changing during an era of increased wildfire activity.

Objectives. (a) Identify key direct/indirect drivers of landscape patterns of stand-replacing fire (e.g., size, shape of patches), (b) test for temporal trends in these patterns, and (c) anticipate thresholds beyond which landscape patterns of burn severity may change fundamentally.

Methods. We applied structural equation modeling to satellite burn-severity maps of fires in the US Northern Rocky Mountains (1984–2010) to test for direct and indirect (via influence on fire size and proportion stand-replacing) effects of climate/weather, vegetation, and topography on landscape patterns of stand-replacing fire. We also tested for temporal trends in landscape patterns.

Results. Landscape patterns of stand-replacing fire were strongly controlled by fire size and proportion stand-replacing, which were, in turn, controlled by climate/weather and vegetation/topography, respectively. From 1984 to 2010, the proportion of stand-replacing fire within burn perimeters increased from 0.22 to 0.27. Trends for other landscape metrics were not significant, but may respond to further increases proportion stand-replacing fire.

Conclusions. Fires from 1984 to 2010 exhibited tremendous heterogeneity in landscape patterns of stand-replacing fire, likely promoting resilience in burned areas. If trends continue on the current trajectory, however, fires may produce larger and simpler shaped patches of stand-replacing fire with more burned area far from seed sources.

McKenzie, D., and J. S. Littell. 2017. Climate change and the eco-hydrology of fire: **Will area burned increase in a warming western USA?** Ecological Applications 27:26-36. http://10.1002/eap.1420

Abstract. Wildfire area is predicted to increase with global warming. Empirical statistical models and process-based simulations agree almost universally. The key relationship for this unanimity, observed at multiple spatial and temporal scales, is between drought and fire. Predictive models often focus on ecosystems in which this relationship appears to be particularly strong, such as mesic and arid forests and shrublands with substantial biomass such as chaparral. We examine the drought–fire relationship, specifically the correlations between water-balance deficit and annual area burned, across the full gradient of deficit in the western USA, from temperate rainforest to desert. In the middle of this gradient, conditional on vegetation (fuels), correlations are strong, but outside this range the equivalence hotter and drier equals more fire either breaks down or is contingent on other factors such as previous-year climate. This suggests that the regional drought–fire dynamic will not be stationary in future climate, nor will other more complex contingencies associated with the variation in fire extent. Predictions of future wildfire area therefore need to consider not only vegetation changes, as some dynamic vegetation models now do, but also potential changes in the drought–fire dynamic that will ensue in a warming climate.

Mietkiewicz, N., and D. Kulakowski. 2016. **Relative importance of climate and mountain pine beetle outbreaks on the occurrence of large wildfires in the western USA.** Ecological Applications 26:2525-2537. http://10.1002/eap.1400

Abstract. Extensive outbreaks of bark beetles have killed trees across millions of hectares of forests and woodlands in western North America. These outbreaks have led to spirited scientific, public, and policy debates about consequential increases in fire risk, especially in the wildland–urban interface (WUI), where homes and communities are at particular risk from wildfires. At the same time, large wildfires have become more frequent across this region. Widespread expectations that outbreaks increase extent, severity, and/or frequency of wildfires are based partly on visible and dramatic changes in foliar moisture content and other fuel properties following outbreaks, as well as associated modeling projections. A competing explanation is that increasing wildfires are driven primarily by climatic extremes, which are becoming more common with climate change.

However, the relative importance of bark beetle outbreaks vs. climate on fire occurrence has not been empirically examined across very large areas and remains poorly understood. The most extensive outbreaks of tree-killing insects across the western United States have been of mountain pine beetle (MPB; *Dendroctonus ponderosae*), which have killed trees over >650,000 km2, mostly in forests dominated by lodgepole pine (*Pinus contorta*). We show that outbreaks of MPB in lodgepole pine forests of the western United States have been less important than climatic variability for the occurrence of large fires over the past 29 years. In lodgepole pine forests in general, as well as those in the WUI, occurrence of large fires was determined primarily by current and antecedent high temperatures and low precipitation but was unaffected by preceding outbreaks. Trends of increasing co-occurrence of wildfires and outbreaks are due to a common climatic driver rather than interactions between these disturbances. Reducing wildfire risk hinges on addressing the underlying climatic drivers rather than treating beetle-affected forests.

Sea Level Rise

Raposa, K. B., K. Wasson, E. Smith, J. A. Crooks, P. Delgado, S. H. Fernald, M. C. Ferner, A. Helms, L. A. Hice, J. W. Mora, B. Puckett, D. Sanger, S. Shull, L. Spurrier, R. Stevens, and S. Lerberg. 2016. **Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices.** Biological Conservation 204, Part B:263-275. http://http://dx.doi.org/10.1016/j.biocon.2016.10.015

Abstract. Tidal marshes and the ecosystem services they provide may be at risk from sea-level rise (SLR). Tidal marsh resilience to SLR can vary due to differences in local rates of SLR, geomorphology, sediment availability and other factors. Understanding differences in resilience is critical to inform coastal management and policy, but comparing resilience across marshes is hindered by a lack of simple, effective analysis tools. Quantitative, multi-metric indices are widely employed to inform management of benthic aquatic ecosystems, but not coastal wetlands. Here, we develop and apply tidal **ma**rsh **r**esilience to **s**ea-level rise (MARS) indices incorporating ten metrics that contribute to overall marsh resilience to SLR. We applied MARS indices to tidal marshes at 16 National Estuarine Research Reserves across the conterminous U.S. This assessment revealed moderate resilience overall, although nearly all marshes had some indication of risk. Pacific

marshes were generally more resilient to SLR than Atlantic ones, with the least resilient marshes found in southern New England. We provide a calculation tool to facilitate application of the MARS indices to additional marshes. MARS index scores can inform the choice of the most appropriate coastal management strategy for a marsh: moderate scores call for actions to enhance resilience while low scores suggest investment may be better directed to adaptation strategies such as creating opportunities for marsh migration rather than attempting to save existing marshes. The MARS indices thus provide a powerful new approach to evaluate tidal marsh resilience and to inform development of adaptation strategies in the face of SLR.

White, E., and D. Kaplan. 2017. Restore or retreat? **Saltwater intrusion and water management in coastal wetlands.** Ecosystem Health and Sustainability 3:e01258. http://10.1002/ehs2.1258

Abstract. Coastal wetlands perform a unique set of physical, chemical, and biological functions, which provide billions of dollars of ecosystem services annually. These wetlands also face myriad environmental and anthropogenic pressures, which threaten their ecological condition and undermine their capacity to provide these services. Coastal wetlands have adapted to a dynamic range of natural disturbances over recent millennia, but face growing pressures from human population growth and coastal development. These anthropogenic pressures are driving saltwater intrusion (SWI) in many coastal systems. The position of coastal wetlands at the terrestrial–marine interface also makes them vulnerable to increasing rates of sea-level rise and changing climate. Critically, anthropogenic and natural stressors to coastal wetlands can act synergistically to create negative, and sometimes catastrophic, consequences for both human and natural systems. This review focused on the drivers and impacts of SWI in coastal wetlands and has two goals: (1) to synthesize understanding of coastal wetland change driven by SWI and (2) to review approaches for improved water management to mitigate SWI in impacted systems. While we frame this review as a choice between restoration and retreat, we acknowledge that choices about coastal wetland management are context-specific and may be confounded by competing management goals. In this setting, the choice between restoration and retreat can be prioritized by identifying where the greatest return in ecosystem services can be achieved relative to restoration dollars invested. We conclude that restoration and proactive water management is feasible in many impacted systems.

Adaptation

Aplet, G. H., and P. S. McKinley. 2017. **A portfolio approach to managing ecological risks of global change.** Ecosystem Health and Sustainability 3:e01261. http://10.1002/ehs2.1261

Abstract. The stressors of global environmental change make it impossible over the long term for natural systems to maintain their historical composition. Conservation's new objective must be to maintain the building blocks of future systems (e.g., species, genes, soil types, and landforms) as they continuously rearrange. Because of the certainty of change, some biologists and managers question continued use of retrospective conservation strategies (e.g., reserves and restoration) informed by the historical range of variability. Prospective strategies that manage toward anticipated conditions have joined the conservation toolbox alongside retrospective conservation. We argue that high uncertainty around the rates and trajectories of climate and ecological change dictate the need to spread ecological risk using prospective and retrospective strategies across conservation networks in a systematic and adaptively managed approach. We term this a portfolio approach drawing comparisons to financial portfolio risk management as a means to maximize conservation benefit and learning. As with a financial portfolio, the portfolio approach requires that management allocations receive minimum temporal commitments to realize longer-term benefits. Our approach requires segregation of the strategies into three landscape zones to avoid counterproductive interactions. The zones will be managed to (1) observe change, (2) resist change, and (3) facilitate change. We offer guidelines for zone allocation based on ecological integrity. All zones should follow principles of conservation design traditionally applied to reserves. Comparable to financial portfolios, zone performance is monitored to facilitate learning and potential reallocation for long-term net minimization of risk to the building blocks of future ecosystems.

Ebi, K. L., L. H. Ziska, and G. W. Yohe. 2016. **The shape of impacts to come: lessons and opportunities for adaptation from uneven increases in global and regional temperatures.** Climatic Change 139:341-349. http://10.1007/s10584-016-1816-9

Abstract. Uneven patterns in the rate of climate change have profound implications for adaptation. Assuming a linear or monotonic increase in global or regional temperatures can lead to inefficient

planning processes that underestimate the magnitude, pattern, and timing of the risks faced by human and natural systems, which could exaggerate future impacts and the costs of managing them. Adaptation planning needs to move beyond imposing linear thinking and analysis onto nonlinear systems. Doing so would improve research into adaptive management processes that learn from and adapt to new knowledge at a pace that reflects non-linearity. Specifically, the pace of adaptation must consider the potential consequences of uneven increases in weather and climate variables as a means to reduce system vulnerability. Projections simulating periods of relative stability with those of rapid change would lead to more complex and more accurate expectations of future risks and associated consequences for human and natural systems. Adaptation planning based on such projections could then consider the implications of non-linear climate change on the extent of any adaptation effort, including quantified (or qualitative) risks and associated costs and benefits. Adaptation planning could be improved by projections that incorporate more nuanced understandings of how development processes could interact with climate change to alter future risks and vulnerabilities. Two examples are highlighted to illustrate the complexity and dynamic nature of non-monotonic climate-development-response scenarios: vector borne diseases and agricultural productivity.

Hällfors, M. H., S. Aikio, and L. E. Schulman. 2017. **Quantifying the need and potential of assisted migration.** Biological Conservation 205:34-41. http://dx.doi.org/10.1016/j.biocon.2016.11.023

Abstract. Assisted migration is recognized as a possible method for species conservation under climate change. Predicted decrease in range size and emergence of new suitable areas due to climate change are the main reasons for considering assisted migration. The magnitude of such changes can be used to guide decisions on the applicability of this conservation method. However, it has not been formalized how predictions acquired, e.g., with the help of species distribution models or expert assessments, should translate into recommendations or decisions. Climate change threat indices concentrating on predicted loss of habitat are not directly applicable in this context as they do not define whether a species has the potential to expand its range compared to the area that remains suitable. Here we present a conceptual framework for identifying and quantifying situations in which predictions indicate that a species could benefit from assisted migration. We translate predicted changes in suitable area into separate metrics for migration need and migration potential

on the basis of the amount of lost, remnant, and new area. These metrics can be used as part of decision-making frameworks in determining the most suitable conservation method for a specific species. They also hold potential for coarser screening of multiple species to estimate the proportion of species that could benefit from assisted migration within a given time frame and climate change scenario. Furthermore, the approach can be used to highlight time frames during which assisted migration or, alternatively, other conservation actions are the most beneficial for a certain species.

Hevia, V., B. Martín-López, S. Palomo, M. García-Llorente, F. de Bello, and J. A. González. 2017. **Trait-based approaches to analyze links between the drivers of change and ecosystem services: Synthesizing existing evidence and future challenges.** Ecology and Evolution 7:831-844. http://10.1002/ece3.2692

Abstract. Understanding the responses of biodiversity to drivers of change and the effects of biodiversity on ecosystem properties and ecosystem services is a key challenge in the context of global environmental change. We performed a systematic review and meta-analysis of the scientific literature linking direct drivers of change and ecosystem services via functional traits of three taxonomic groups (vegetation, invertebrates, and vertebrates) to: (1) uncover trends and research biases in this field; and (2) synthesize existing empirical evidence. Our results show the existence of important biases in published studies related to ecosystem types, taxonomic groups, direct drivers of change, ecosystem services, geographical range, and the spatial scale of analysis. We found multiple evidence of links between drivers and services mediated by functional traits, particularly between land-use changes and regulating services in vegetation and invertebrates. Seventy-five functional traits were recorded in our sample. However, few of these functional traits were repeatedly found to be associated with both the species responses to direct drivers of change (response traits) and the species effects on the provision of ecosystem services (effect traits). Our results highlight the existence of potential "key functional traits," understood as those that have the capacity to influence the provision of multiple ecosystem services, while responding to specific drivers of change, across a variety of systems and organisms. Identifying "key functional traits" would help to develop robust indicator systems to monitor changes in biodiversity and their effects on ecosystem functioning and ecosystem services supply.

Lenoir, J., T. Hattab, and G. Pierre. 2017. **Climatic microrefugia under anthropogenic climate change: implications for species redistribution.** Ecography 40:253-266. http://10.1111/ecog.02788

Abstract. The role of modern climatic microrefugia is a neglected aspect in the study of biotic responses to anthropogenic climate change. Current projections of species redistribution at continental extent are based on climatic grids of coarse (≥ 1 km) resolutions that fail to capture spatiotemporal dynamics associated with climatic microrefugia. Here, we review recent methods to model the climatic component of potential microrefugia and highlight research gaps in accounting for the buffering capacity due to biophysical processes operating at very fine (< 1 m) resolutions (e.g. canopy cover) and the associated microclimatic stability over time (i.e. decoupling). To overcome this challenge, we propose a spatially hierarchical downscaling framework combining a free-air temperature grid at 1 km resolution, a digital elevation model at 25 m resolution and small-footprint light detection-and-ranging (LiDAR) data at 50 cm resolution with knowledge from the literature to mechanistically model sub-canopy temperatures and account for microclimatic decoupling. We applied this framework on a virtual sub-canopy species and simulated the impact of a warming scenario on its potential distribution. Modelling sub-canopy temperatures at 50 cm resolution and accounting for microclimatic stability over time enlarges the range of temperature conditions towards the cold end of the gradient, mitigates regional temperature changes and decreases extirpation risks. Incorporating these spatiotemporal dynamics into species redistribution models, being correlative, mechanistic or hybrid, will increase the probability of local persistence, which has important consequences in the understanding of the capacity of species to adapt. We finally provide a synthesis on additional ways that the field could move towards effectively considering potential climatic microrefugia for species redistribution.

Woodruff, S. C. 2016. **Planning for an unknowable future: uncertainty in climate change adaptation planning.** Climatic Change 139:445-459. http://10.1007/s10584-016-1822-y

Abstract. Uncertainty in climate projections poses a serious challenge to adaptation planning. Ignoring this uncertainty can cause adaptation plans and strategies to be ineffective and even maladaptive. As such,

there is growing awareness that adaptation planning must adopt approaches that enable discovering, assessing, and addressing uncertainty. In this paper, I examine how uncertainty is managed in adaptation planning. Content analysis of 44 local climate adaptation plans in the U.S. indicates that most plans recognize uncertainty, however, very few employ approaches to address uncertainty. To better understand how uncertainty influences the planning process, I conducted informant interviews in three communities: Boulder, CO; Denver, CO and Salem, MA. These communities capture the variation across plans in content analysis scores, climate threats, and plan author. Interview results suggest that adaptation plans do not fully reflect how uncertainty is managed in the planning process. Rather than focusing on climate projections in the vulnerability assessment, which may reinforce planning for one future, communities in which interviews were conducted emphasized sensitivity and adaptive capacity. Interviewees also emphasized the importance of no-regrets strategies and an iterative adaptation process. Institutional barriers were viewed as a major challenge for adopting uncertainty approaches. For approaches, such as robust strategies and flexible strategies, to be more widely used, we must first breakdown the deeply embedded practice of planning for one future.

Socio-Economics

Bauch, C. T., R. Sigdel, J. Pharaon, and M. Anand. 2016. **Early warning signals of regime shifts in coupled human–environment systems.** Proceedings of the National Academy of Sciences 113:14560-14567. http://10.1073/pnas.1604978113

Abstract. In complex systems, a critical transition is a shift in a system's dynamical regime from its current state to a strongly contrasting state as external conditions move beyond a tipping point. These transitions are often preceded by characteristic early warning signals such as increased system variability. However, early warning signals in complex, coupled human–environment systems (HESs) remain little studied. Here, we compare critical transitions and their early warning signals in a coupled HES model to an equivalent environment model uncoupled from the human system. We parameterize the HES model, using social and ecological data from old-growth forests in Oregon. We find that the coupled HES exhibits a richer variety of dynamics and regime shifts than the uncoupled environment system. Moreover, the early warning signals in the

coupled HES can be ambiguous, heralding either an era of ecosystem conservationism or collapse of both forest ecosystems and conservationism. The presence of human feedback in the coupled HES can also mitigate the early warning signal, making it more difficult to detect the oncoming regime shift. We furthermore show how the coupled HES can be "doomed to criticality": Strategic human interactions cause the system to remain perpetually in the vicinity of a collapse threshold, as humans become complacent when the resource seems protected but respond rapidly when it is under immediate threat. We conclude that the opportunities, benefits, and challenges of modeling regime shifts and early warning signals in coupled HESs merit further research.

Brice, B., C. Fullerton, K. L. Hawkes, M. Mills-Novoa, B. F. O'Neill, and W. M. Pawlowski. 2017. **The impacts of climate change on natural areas recreation: a multi-region snapshot and agency comparison.** Natural Areas Journal 37:86-97. http://10.3375/043.037.0111

Abstract. Recreation is a fundamental component of human culture and the economy. In this paper, we elucidate ways in which recreation should be reconsidered in discussions of climate change. Ecosystems that support outdoor recreation can be significantly altered, extreme climatic conditions can affect plant and animal health, and extreme weather events can limit human outdoor activity. Projections indicate global temperatures will rise and precipitation will shift from historical conditions to less predictable regimes. These projected changes affect recreation and the economies recreation supports. To encourage the inclusion of recreation as a topic in future assessment synthesis reports, a snapshot of climate change impacts on regional recreation in the US is developed, using the National Park Service and Forest Service as case studies. After examining peer-reviewed and agency literature, we suggest that the impact of projected climate change on US recreation needs further scrutiny. Federal land management approaches to identifying, measuring, and managing climate change-induced recreation impacts are developing, but remain fragmented at the local and regional scale. We identify opportunities to address and improve research efforts at the intersection of climate change and outdoor recreation.

Brown, M., and D. Bachelet. 2017. **BLM sagebrush managers give feedback on eight climate web applications.** Weather, Climate, and Society 9:39-52. http://10.1175/wcas-d-16-0034.1

Abstract. Sagebrush ecosystems have endured fragmentation and degradation from multiple disturbances. Climate change poses an additional threat that can exacerbate current stresses. Web-based climate applications can provide information to help land managers prepare for challenges. To develop useful and usable tools for land managers' needs, the collaboration of scientist, web tool developer, and user is needed. Climate scientists and web tool developers at Conservation Biology Institute (CBI) worked with Oregon and Idaho Bureau of Land Management (BLM) sagebrush land managers assessing managers' needs and defining criteria for useful and usable web-based climate applications. During phone interviews, land managers evaluated a series of climate-related web applications and provided insight on how future applications can best meet their needs. They identified climate variables associated with their management activities, such as the seasonality of precipitation and temperature. They provided feedback about website accessibility, terminology, climate model description, spatial and temporal scale appropriateness, graphics effectiveness, and general content credibility and consistency. Managers are interested in changes in climate, but also in climate change impacts, such as vegetation shifts. Managers need seasonal and multiannual weather forecasts for routine activities and 10–20-yr climate projections for planning exercises, but currently an information gap exists between available weather forecasts (≤12 months) and climate projections (30-yr averages). It was also found that scientific jargon contributes to misunderstandings and misinterpretation of climate information, and this study confirmed the need for better climate science education, through enhanced explanation and collaborative efforts that promote understanding and use of existing web applications.

Nordhaus, W. D. 2017. **Revisiting the social cost of carbon.** Proceedings of the National Academy of Sciences 114:1518-1523. http://10.1073/pnas.1609244114

Abstract. The social cost of carbon (SCC) is a central concept for understanding and implementing climate change policies. This term represents the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent. The present study presents updated estimates based on a revised DICE model (Dynamic Integrated model of Climate and the Economy). The study estimates

that the SCC is $31 per ton of CO2 in 2010 US$ for the current period (2015). For the central case, the real SCC grows at 3% per year over the period to 2050. The paper also compares the estimates with those from other sources.

Rosbjerg, D. 2017. **Optimal adaptation to extreme rainfalls in current and future climate.** Water Resources Research 53:535-543. http://10.1002/2016WR019718

Abstract. More intense and frequent rainfalls have increased the number of urban flooding events in recent years, prompting adaptation efforts. Economic optimization is considered an efficient tool to decide on the design level for adaptation. The costs associated with a flooding to the *T*-year level and the annual capital and operational costs of adapting to this level are described with log-linear relations. The total flooding costs are developed as the expected annual damage of flooding above the *T*-year level plus the annual capital and operational costs for ensuring no flooding below the *T*-year level. The value of the return period *T* that corresponds to the minimum of the sum of these costs will then be the optimal adaptation level. The change in climate, however, is expected to continue in the next century, which calls for expansion of the above model. The change can be expressed in terms of a climate factor (the ratio between the future and the current design level) which is assumed to increase in time. This implies increasing costs of flooding in the future for many places in the world. The optimal adaptation level is found for immediate as well as for delayed adaptation. In these cases, the optimum is determined by considering the net present value of the incurred costs during a sufficiently long time-span. Immediate as well as delayed adaptation is considered.

Wall, T. U., A. M. Meadow, and A. Horganic. 2017. **Developing evaluation indicators to improve the process of coproducing usable climate science.** Weather, Climate, and Society 9:95-107. http://10.1175/wcas-d-16-0008.1

Abstract. Resource managers and decision-makers are increasingly tasked with integrating climate change science into their decisions about resource management and policy development. This often requires climate scientists, resource managers, and decision-makers to work collaboratively throughout the research processes, an approach to knowledge development that is often called “coproduction of knowledge.” The goal of this paper is to synthesize the social science theory of coproduction of knowledge, the metrics currently used to

evaluate usable or actionable science in several federal agencies, and insights from experienced climate researchers and program managers to develop a set of 45 indicators supporting an evaluation framework for coproduced usable climate science. Here the proposed indicators and results from two case studies that were used to test the indicators are presented, as well as lessons about the process of evaluating the coproduction of knowledge and collaboratively producing climate knowledge.