Climate Change Quarterly: Winter 2016

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

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Climate and Weather

Alkama, R., and A. Cescatti. 2016. **Biophysical climate impacts of recent changes in global forest cover.** Science 351:600-604.

Abstract. Changes in forest cover affect the local climate by modulating the land-atmosphere fluxes of energy and water. The magnitude of this biophysical effect is still debated in the scientific community and currently ignored in climate treaties. Here we present an observation-driven assessment of the climate impacts of recent forest losses and gains, based on Earth observations of global forest cover and land surface temperatures. Our results show that forest losses amplify the diurnal temperature variation and increase the mean and maximum air temperature, with the largest signal in arid zones, followed by temperate, tropical, and boreal zones. In the decade 2003–2012, variations of forest cover generated a mean biophysical warming on land corresponding to about 18% of the global biogeochemical signal due to CO_2 emission from land-use change.

Diamond, M. S., and R. Bennartz. 2015. **Occurrence and trends of eastern and central Pacific El Niño in different reconstructed SST data sets.** Geophysical Research Letters 42:10,375-310,381.

Abstract. Interest in El Niño diversity has increased in the past decade, with much attention given to the hypothesis that there exist distinct eastern Pacific and central Pacific (CP) types. It is well known that classification systems in the literature differ, sometimes dramatically, by methodology. We test to what extent differences may occur due to the use of different sea surface temperature (SST) reconstructions, focusing on the newly released version 4 of the Extended Reconstructed Sea Surface Temperature (ERSST) data set, two earlier versions of the ERSST data set, and an independent data set, Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST). The updated ERSST data set identifies more CP El Niños than the two older versions of ERSST and HadISST. Classification differences occur throughout the entire record rather than being restricted to the early period.

We explore the potential influence of SST data set choice on the study of El Niño diversity impacts using precipitation anomalies in the western United States.

Douville, H., J. Colin, E. Krug, J. Cattiaux, and S. Thao. 2016. **Midlatitude daily summer temperatures reshaped by soil moisture under climate change.** Geophysical Research Letters 43:812-818.

Abstract. Projected changes in daily temperatures are highly model dependent, particularly in the summer midlatitudes where the spread in the response of heat waves represents a major obstacle for the design of adaptation strategies. Understanding the main reasons for such uncertainties is obviously a research priority. Here we use a set of global atmospheric simulations to assess the contribution of the soil moisture feedback to changes in the full distribution of daily maximum summer temperatures projected in the late 21st century. Results show that this feedback (i) accounts for up to one third of the mean increase in daily maximum temperatures, (ii) dominates changes in the shape of the distribution, and (iii) explains about half of the increase in the severity of heat waves over densely populated areas of the northern midlatitudes. A dedicated intercomparison project is therefore needed to assess and constrain land surface feedbacks in the new generation Earth System Models.

Hagos, S. M., L. R. Leung, J.-H. Yoon, J. Lu, and Y. Gao. 2016. **A projection of changes in landfalling atmospheric river frequency and extreme precipitation over western North America from the Large Ensemble CESM simulations.** Geophysical Research Letters 43:1357-1363.

Abstract. Simulations from the Community Earth System Model (CESM) Large Ensemble project are analyzed to investigate the impact of global warming on atmospheric rivers (ARs) making landfall in western North America. The model has notable biases in simulating the subtropical jet position and the relationship between extreme precipitation and moisture transport. After accounting for these biases, the model projects an ensemble mean increase of 35% in the number of landfalling AR days between the last 20 years of the twentieth and 21st centuries under Representative concentration pathway 8.5 (RCP8.5). However, the associated extreme precipitation days increase only by 28% because the moisture transport required to produce extreme precipitation also increases with warming. Internal variability introduces an uncertainty of ±8% and ±7% in the changes in AR days and associated extreme precipitation days compared to only about 1% difference from accountings for model biases. The significantly larger mean changes compared to internal variability, and effects of model biases highlight the robust AR responses to global warming.

McEvoy, D. J., J. L. Huntington, J. F. Mejia, and M. T. Hobbins. 2016. **Improved seasonal drought forecasts using reference evapotranspiration anomalies.** Geophysical Research Letters 43:377-385.

Abstract. A novel contiguous United States (CONUS) wide evaluation of reference evapotranspiration (ET_0; a formulation of evaporative demand) anomalies is performed using the Climate Forecast System version 2 (CFSv2) reforecast data for 1982–2009. This evaluation was motivated by recent research showing ET_0 anomalies can accurately represent drought through exploitation of the complementary relationship between actual evapotranspiration and ET_0. Moderate forecast skill of ET_0 was found up to leads of 5 months and was consistently better than precipitation skill over most of CONUS. Forecasts of ET_0 during drought events revealed high categorical skill for notable warm-season droughts of 1988 and 1999 in the central and northeast CONUS, with precipitation skill being much lower or absent. Increased ET_0 skill was found in several climate regions when CFSv2 forecasts were initialized during moderate-to-strong El Niño–Southern Oscillation events. Our findings suggest that ET_0 anomaly forecasts can improve and complement existing seasonal drought forecasts.

Naudts, K., Y. Chen, M. J. McGrath, J. Ryder, A. Valade, J. Otto, and S. Luyssaert. 2016. **Europe's forest management did not mitigate climate warming.** Science 351:597-600.

Abstract. Afforestation and forest management are considered to be key instruments in mitigating climate change. Here we show that since 1750, in spite of considerable afforestation, wood extraction has led to Europe's forests accumulating a carbon debt of 3.1 petagrams of carbon. We found that afforestation is responsible for an increase of 0.12 watts per square meter in the radiative imbalance at the top of the atmosphere, whereas an increase of 0.12 kelvin in summertime atmospheric boundary layer temperature was mainly caused by species conversion. Thus, two and a half centuries of forest management in Europe have not cooled the climate. The political imperative to mitigate climate change through afforestation and forest management therefore risks failure, unless it is recognized that not all forestry contributes to climate change mitigation.

Prein, A. F., G. J. Holland, R. M. Rasmussen, M. P. Clark, and M. R. Tye. 2016. **Running dry: The U.S. Southwest's drift into a drier climate state.** Geophysical Research Letters 43:1272-1279.

Abstract. Changes in precipitation have far-reaching consequences on human society and ecosystems as has been demonstrated by recent severe droughts in California and the Oklahoma region. Droughts are beside tropical cyclones the most costly weather and climate related extreme events in the U.S. We apply a weather type (WT) analysis to reanalysis data from 1979–2014 that characterize typical weather conditions over the contiguous United States. This enables us to assign precipitation trends within 1980–2010 to changes in WT frequencies and changes in precipitation intensities. We show that in the North Atlantic and Midwest region precipitation intensity changes are the major driver of increasing precipitation trends. In the U.S. Southwest, however, WT frequency changes lead to a significant precipitation decrease of up to −25% related to an increase in anticyclonic conditions in the North East Pacific. This trend is partly counteracted by increasing precipitation intensities.

Carbon and Carbon Storage

Bachelet, D., K. Ferschweiler, T. J. Sheehan, B. M. Sleeter, and Z. Zhu. 2015. **Projected carbon stocks in the conterminous USA with land use and variable fire regimes.** Global Change Biology 21:4548-4560.

Abstract. The dynamic global vegetation model (DGVM) MC2 was run over the conterminous USA at 30 arc sec (~800 m) to simulate the impacts of nine climate futures generated by 3GCMs (CSIRO, MIROC and CGCM3) using 3 emission scenarios (A2, A1B and B1) in the context of the LandCarbon national carbon sequestration assessment. It first simulated potential vegetation dynamics from coast to coast assuming no human impacts and naturally occurring wildfires. A moderate effect of increased atmospheric CO_2 on water use efficiency and growth enhanced carbon sequestration but did not greatly influence woody encroachment. The wildfires maintained prairie-forest ecotones in the Great Plains. With simulated fire suppression, the number and impacts of wildfires was reduced as only catastrophic fires were allowed to escape. This greatly increased the expansion of forests and woodlands across the western USA and some of the ecotones disappeared. However, when fires did occur, their impacts (both extent and biomass consumed) were very large. We also evaluated the relative influence of human land use including forest and crop harvest by running the DGVM with land use (and fire suppression) and simple land management rules. From

2041 through 2060, carbon stocks (live biomass, soil and dead biomass) of US terrestrial ecosystems varied between 155 and 162 Pg C across the three emission scenarios when potential natural vegetation was simulated. With land use, periodic harvest of croplands and timberlands as well as the prevention of woody expansion across the West reduced carbon stocks to a range of 122–126 Pg C, while effective fire suppression reduced fire emissions by about 50%. Despite the simplicity of our approach, the differences between the size of the carbon stocks confirm other reports of the importance of land use on the carbon cycle over climate change.

Butman, D., S. Stackpoole, E. Stets, C. P. McDonald, D. W. Clow, and R. G. Striegl. 2016. **Aquatic carbon cycling in the conterminous United States and implications for terrestrial carbon accounting.** Proceedings of the National Academy of Sciences 113:58-63.

Abstract. Inland water ecosystems dynamically process, transport, and sequester carbon. However, the transport of carbon through aquatic environments has not been quantitatively integrated in the context of terrestrial ecosystems. Here, we present the first integrated assessment, to our knowledge, of freshwater carbon fluxes for the conterminous United States, where 106 (range: 71–149) teragrams of carbon per year ($TgC\cdot y^{-1}$) is exported downstream or emitted to the atmosphere and sedimentation stores 21 (range: 9–65) $TgC\cdot y^{-1}$ in lakes and reservoirs. We show that there is significant regional variation in aquatic carbon flux, but verify that emission across stream and river surfaces represents the dominant flux at 69 (range: 36–110) $TgC\cdot y^{-1}$ or 65% of the total aquatic carbon flux for the conterminous United States. Comparing our results with the output of a suite of terrestrial biosphere models (TBMs), we suggest that within the current modeling framework, calculations of net ecosystem production (NEP) defined as terrestrial only may be overestimated by as much as 27%. However, the internal production and mineralization of carbon in freshwaters remain to be quantified and would reduce the effect of including aquatic carbon fluxes within calculations of terrestrial NEP. Reconciliation of carbon mass–flux interactions between terrestrial and aquatic carbon sources and sinks will require significant additional research and modeling capacity.

Gray, A. N., T. R. Whittier, and M. E. Harmon. 2016. **Carbon stocks and accumulation rates in Pacific Northwest forests: role of stand age, plant community, and productivity.** Ecosphere 7:e01224.

Abstract. Forest ecosystems are removing significant amounts of carbon from the atmosphere. Both abiotic resource availability and biotic interactions during forest succession affect C accumulation rates and

maximum C stocks. However, the timing and controls on the peak and decline in C accumulation rates as stands age, trees increase in size, and canopy gaps become prevalent are not well-understood. Our study examines measured change in live and dead woody C pools from 8767 inventory plots on 9.1 million ha of Pacific Northwest National Forest lands to determine how the balance of tree growth, mortality, and dead wood decomposition varied by stand age, plant community type, and site productivity; and to compare the contribution of different tree sizes to C accumulation. Maximum non-mineral soil C for old-growth stands varied significantly by productivity class within plant community types, but on average stands accumulated 75% of maximum stocks by age 127 ± 35 yr. We did not see a decline in net primary production of wood (NPP_w) with age in moderate and low-productivity classes, but found a 33% reduction in high-productivity classes. Mortality increased with stand age such that net change in live tree biomass, and change in total woody C, was not significantly different from zero in old-growth stands over age 400 (0.15 ± 0.64 Mg $C \cdot ha^{-1} \cdot yr^{-1}$ for woody C). However, significant though modest C accumulation was found in forests 200–400 yr old (0.34–0.70 Mg $C \cdot ha^{-1} \cdot yr^{-1}$, depending on age class). Mortality of trees >100 cm diameter exceeded or equaled NPP_w, but trees were growing into the larger sizes at a high-enough rate that a net increase in large tree C was seen across the region. Although large trees accumulated C at a faster rate than small trees on an individual basis, their contribution to C accumulation rates was smaller on an area basis, and their importance relative to small trees declined in older stands compared to younger stands. In contrast to recent syntheses, our results suggest that old-growth and large trees are important C stocks, but they play a minor role in additional C accumulation.

Lin, J., B. Zhu, and W. Cheng. 2015. **Decadally cycling soil carbon is more sensitive to warming than faster-cycling soil carbon.** Global Change Biology 21:4602-4612.

Abstract. The response of soil organic carbon (SOC) pools to globally rising surface temperature crucially determines the feedback between climate change and the global carbon cycle. However, there is a lack of studies investigating the temperature sensitivity of decomposition for decadally cycling SOC which is the main component of total soil carbon stock and the most relevant to global change. We tackled this issue using two decadally ^{13}C-labeled soils and a much improved measuring system in a long-term incubation experiment. Results indicated that the temperature sensitivity of decomposition for decadally cycling SOC (>23 years in one soil and >55 years in the other soil) was significantly greater than that for faster-cycling SOC (<23 or 55 years) or for the entire SOC stock. Moreover, decadally cycling SOC contributed substantially (35–59%) to the total CO_2

loss during the 360-day incubation. Overall, these results indicate that the decomposition of decadally cycling SOC is highly sensitive to temperature change, which will likely make this large SOC stock vulnerable to loss by global warming in the 21st century and beyond.

Ling, P.-Y., G. Baiocchi, and C. Huang. 2015. **Estimating annual influx of carbon to harvested wood products linked to forest management activities using remote sensing.** Climatic Change 134:45-58.

Abstract. We develop a new framework, based on Landsat time series data and forest inventories, to estimate the carbon in roundwood harvested from forest management activities, which will enter the HWP pool and remain stored in end uses and landfills. The approach keeps the distinction between the carbon from different types of roundwood sources, which allows for better integration with the regional HWP carbon lifetime information. We show that existing methods that are based on large scale regional/national values and linear interpolation of data gaps, can provide only very approximate carbon estimates. The model was applied to a US state using county level data, but can also suit different areas as long as sufficient harvest records are available for calibration. The results can be used to study managed forests and evaluate the impact of forest policies on the carbon cycle at a detailed scale. The estimated quantity of carbon in roundwood harvest provides an upper bound on the gross carbon added to HWP in use, prior to deductions from losses. Our results can also be coupled with mill processing efficiency estimate and wood product life cycle analysis to better understand the effect of forest management activities on the carbon cycle.

Owen, J. J., W. J. Parton, and W. L. Silver. 2015. **Long-term impacts of manure amendments on carbon and greenhouse gas dynamics of rangelands.** Global Change Biology 21:4533-4547.

Abstract. Livestock manure is applied to rangelands as an organic fertilizer to stimulate forage production, but the long-term impacts of this practice on soil carbon (C) and greenhouse gas (GHG) dynamics are poorly known. We collected soil samples from manured and nonmanured fields on commercial dairies and found that manure amendments increased soil C stocks by 19.0 ± 7.3 Mg C ha^{-1} and N stocks by 1.94 ± 0.63 Mg N ha^{-1} compared to nonmanured fields (0–20 cm depth). Long-term historical (1700–present) and future (present–2100) impacts of management on soil C and N dynamics, net primary productivity (NPP), and GHG emissions were modeled with DayCent. Modeled total soil C and N stocks increased with the onset of

dairying. Nitrous oxide (N_2O) emissions also increased by ~2 kg N_2O-N ha^{-1} yr^{-1}. These emissions were proportional to total N additions and offset 75–100% of soil C sequestration. All fields were small net methane (CH_4) sinks, averaging −4.7 ± 1.2 kg CH_4-C ha^{-1} yr^{-1}. Overall, manured fields were net GHG sinks between 1954 and 2011 (−0.74 ± 0.73 Mg CO_2 e ha^{-1} yr^{-1}, CO_2e are carbon dioxide equivalents), whereas nonmanured fields varied around zero. Future soil C pools stabilized 40–60 years faster in manured fields than nonmanured fields, at which point manured fields were significantly larger sources than nonmanured fields (1.45 ± 0.52 Mg CO_2e ha^{-1} yr^{-1} and 0.51 ± 0.60 Mg CO_2e ha^{-1} yr^{-1}, respectively). Modeling also revealed a large background loss of soil C from the passive soil pool associated with the shift from perennial to annual grasses, equivalent to 29.4 ± 1.47 Tg CO_2e in California between 1820 and 2011. Manure applications increased NPP and soil C storage, but plant community changes and GHG emissions decreased, and eventually eliminated, the net climate benefit of this practice.

Santín, C., S. H. Doerr, E. S. Kane, C. A. Masiello, M. Ohlson, J. M. de la Rosa, C. M. Preston, and T. Dittmar. 2016. **Towards a global assessment of pyrogenic carbon from vegetation fires.** Global Change Biology 22:76-91.

Abstract. The production of pyrogenic carbon (PyC; a continuum of organic carbon (C) ranging from partially charred biomass and charcoal to soot) is a widely acknowledged C sink, with the latest estimates indicating that ~50% of the PyC produced by vegetation fires potentially sequesters C over centuries. Nevertheless, the quantitative importance of PyC in the global C balance remains contentious, and therefore, PyC is rarely considered in global C cycle and climate studies. Here we examine the robustness of existing evidence and identify the main research gaps in the production, fluxes and fate of PyC from vegetation fires. Much of the previous work on PyC production has focused on selected components of total PyC generated in vegetation fires, likely leading to underestimates. We suggest that global PyC production could be in the range of 116–385 Tg C yr^{-1}, that is ~0.2–0.6% of the annual terrestrial net primary production. According to our estimations, atmospheric emissions of soot/black C might be a smaller fraction of total PyC (<2%) than previously reported. Research on the fate of PyC in the environment has mainly focused on its degradation pathways, and its accumulation and resilience either in situ (surface soils) or in ultimate sinks (marine sediments). Off-site transport, transformation and PyC storage in intermediate pools are often overlooked, which could explain the fate of a substantial fraction of the PyC mobilized annually. We propose new research directions addressing gaps in the global PyC cycle to fully understand the importance of the products of burning in global C cycle dynamics.

Verbruggen, E., J. Jansa, E. C. Hammer, and M. C. Rillig. 2016. **Do arbuscular mycorrhizal fungi stabilize litter-derived carbon in soil?** Journal of Ecology 104:261-269.

Abstract. Fine roots and mycorrhiza often represent the largest input of carbon (C) into soils and are therefore of primary relevance to the soil C balance. Arbuscular mycorrhizal (AM) fungi have previously been found to increase litter decomposition which may lead to reduced soil C stocks, but these studies have focused on immediate decomposition of relatively high amounts of high-quality litter and may therefore not hold in many ecological settings over longer terms.

Here, we assessed the effect of mycorrhizal fungi on the fate of C and nitrogen (N) contained within a realistic amount of highly ^{13}C-/^{15}N-labelled root litter in soil. This litter was either added fresh or after a 3-month incubation period under field conditions to a hyphal in-growth core where mycorrhizal abundance was either reduced or not through rotation. After 3 months of incubation with a plant under glasshouse conditions, the effect of turning cores on residual ^{13}C and ^{15}N inside the cores was measured, as well as ^{13}C incorporation in microbial signature fatty acids and ^{15}N incorporation of plants.

Turning of cores increased the abundance of fungal decomposers and ^{13}C loss from cores, while ^{15}N content of cores and plants was unaffected. Despite the difference in disturbance that turning the cores could have caused, the results suggest that mycorrhizal fungi and field incubation of litter acted to additively increase the proportion of ^{13}C left in cores.

Synthesis. Apart from stimulating litter decomposition as previously shown, mycorrhizas can also stabilize C during litter decomposition and this effect is persistent through time.

Species Range Changes

Bradley, B. A. 2016. **Predicting abundance with presence-only models.** Landscape Ecology 31:19-30.

Abstract. Context. Understanding and predicting the spatial patterns of species abundance is a critical need in macroecology. But, widespread abundance data are rare, and habitat models based on species occurrences are typically poor predictors of abundance.

Objectives. I ask whether presence-only species distribution models based on locations of high species abundance can more effectively predict abundance than models based on occurrences.

Methods. I created climatic suitability models for fifteen problematic, non-native, invasive plants in the continental US using each of three datasets (1) occurrence data derived from herbarium records, (2) occurrence data derived from regional expert knowledge surveys, and (3) locations of high invasive plant abundance derived from regional expert knowledge surveys.

Results. Models based on occurrences from regional surveys were most effective for distinguishing presence from absence. Models based on locations of high abundance were most effective for characterizing both intermediate and high ranks of abundance. Occurrence data from herbarium records were poor predictors of both presence and abundance.

Conclusions. This analysis suggests that climate suitable for abundant populations is predictable with species distribution modeling, but not using distribution data alone. High probability of species occurrence does not equal high probability of species abundance, suggesting environmental factors differentially influence abundance and distribution. This difference highlights the need for a macrosystems approach to regional habitat modeling to consider how local-scale processes (e.g., biotic interactions) affect regional patterns. Moreover, as abundance is critical for understanding species roles and impacts on ecosystems, large-scale surveys of quantitative or qualitative species abundance are strongly needed.

Robillard, C. M., L. E. Coristine, R. N. Soares, and J. T. Kerr. 2015. **Facilitating climate-change-induced range shifts across continental land-use barriers.** Conservation Biology 29:1586-1595.

Abstract. Climate changes impose requirements for many species to shift their ranges to remain within environmentally tolerable areas, but near-continuous regions of intense human land use stretching across continental extents diminish dispersal prospects for many species. We reviewed the impact of habitat loss and fragmentation on species’ abilities to track changing climates and existing plans to facilitate species dispersal in response to climate change through regions of intensive land uses, drawing on examples from North America and elsewhere. We identified an emerging analytical framework that accounts for variation in species' dispersal capacities relative to both the pace of climate change and habitat availability. Habitat loss and fragmentation hinder climate change tracking, particularly for specialists, by impeding both propagule dispersal and population growth. This framework can be used to identify prospective modern-era climatic refugia, where the pace of climate change has been

slower than surrounding areas, that are defined relative to individual species' needs. The framework also underscores the importance of identifying and managing dispersal pathways or corridors through semi-continental land use barriers that can benefit many species simultaneously. These emerging strategies to facilitate range shifts must account for uncertainties around population adaptation to local environmental conditions. Accounting for uncertainties in climate change and dispersal capabilities among species and expanding biological monitoring programs within an adaptive management paradigm are vital strategies that will improve species' capacities to track rapidly shifting climatic conditions across landscapes dominated by intensive human land use.

Serra-Diaz, J. M., J. Franklin, W. W. Dillon, A. D. Syphard, F. W. Davis, and R. K. Meentemeyer. 2016. **California forests show early indications of both range shifts and local persistence under climate change.** Global Ecology and Biogeography 25:164-175.

Abstract. Aim. Forest regeneration data provide an early signal of the persistence and migration of tree species, so we investigated whether species shifts due to climate change exhibit a common signal of response or whether changes vary by species.

Location. California Floristic Province, United States; mediterranean biome.

Methods. We related Forest Inventory and Analysis (FIA) data from 2000−07 for 13 tree species to high-resolution climate and geographical data. Using methods from invasion ecology, we derived indices of species-specific regeneration overlap and central tendency change (range-wide global indicators) based on kernel density estimation of presence and absence of regeneration. We then built regeneration surfaces to identify areas of occurrence of high regeneration (regeneration hotspots, local indicators) in both geographical and climate space for 13 common tree species.

Results. Differences between presence and absence of regeneration in forests varied in magnitude across species, with little evidence that tree regeneration is shifting to higher latitudes and elevations, the expected geographical fingerprint of climate change. We also identified potential topographic mediators of regeneration dynamics. Multiple regeneration hotspots were found for many species, suggesting the influence of non-climatic factors on regeneration. Differences between the presence and absence of regeneration in geographic and climate spaces were not always congruent, suggesting that shifting climate space and range area are not entirely coupled.

Main conclusions. The distributions of regeneration in Californian forests show diverse signals, not always tracking the higher latitudinal–elevation fingerprint of climate change. Local regeneration hotspots are common in our analysis, suggesting spatially varying persistence of forest linked to natural and anthropogenic disturbances. Our results emphasize that projections of tree range shifts in the context of climate change should consider the variation of regeneration drivers within species ranges, beyond the overall climate signal.

Biodiversity

Ladwig, L. M., Z. R. Ratajczak, T. W. Ocheltree, K. A. Hafich, A. C. Churchill, S. J. K. Frey, C. B. Fuss, C. E. Kazanski, J. D. Muñoz, M. D. Petrie, A. B. Reinmann, and J. G. Smith. 2016. **Beyond arctic and alpine: the influence of winter climate on temperate ecosystems.** Ecology 97:372-382.

Abstract. Winter climate is expected to change under future climate scenarios, yet the majority of winter ecology research is focused in cold-climate ecosystems. In many temperate systems, it is unclear how winter climate relates to biotic responses during the growing season. The objective of this study was to examine how winter weather relates to plant and animal communities in a variety of terrestrial ecosystems ranging from warm deserts to alpine tundra. Specifically, we examined the association between winter weather and plant phenology, plant species richness, consumer abundance, and consumer richness in 11 terrestrial ecosystems associated with the U.S. Long-Term Ecological Research (LTER) Network. To varying degrees, winter precipitation and temperature were correlated with all biotic response variables. Bud break was tightly aligned with end of winter temperatures. For half the sites, winter weather was a better predictor of plant species richness than growing season weather. Warmer winters were correlated with lower consumer abundances in both temperate and alpine systems. Our findings suggest winter weather may have a strong influence on biotic activity during the growing season and should be considered in future studies investigating the effects of climate change on both alpine and temperate systems.

Martinuzzi, S., G. I. Gavier-Pizarro, A. E. Lugo, and V. C. Radeloff. 2015. **Future land-use changes and the potential for novelty in ecosystems of the United States.** Ecosystems 18:1332-1342.

Abstract. Rapid global changes due to changing land use, climate, and non-native species are altering environmental conditions, resulting in more novel communities with unprecedented species combinations. Understanding how

future anthropogenic changes may affect novelty in ecosystems is important to advance environmental management and ecological research in the Anthropocene. The main goal of this study was to understand how alternative scenarios of future land-use change may affect novelty in ecosystems throughout the conterminous United States. We used five spatially explicit scenarios of future land-use changes, reflecting different land-use policies and changes in agricultural markets, to quantify and map potential drivers of novelty. Our results showed large areas where future land-use changes may increase novelty in ecosystems. The major land-use changes known to increase novelty, including land abandonment and land-use expansion, were widespread in all scenarios (73 million to 95 million ha), especially in the eastern U.S. and along the West Coast. Our scenarios revealed that, at broad scales, future land-use changes will increase novelty in ecosystems, and that traditional conservation policies may have limited ability to prevent the process. In places such as the eastern U.S., conserving and maintaining historical conditions and associated biological diversity may become increasingly difficult due to future land-use changes and related ecological factors. Successful biodiversity conservation and environmental management in the Anthropocene will require novel conservation approaches to be relevant in areas with high levels of novelty in ecosystems.

Forest Vegetation

Cohen, W. B., Z. Yang, S. V. Stehman, T. A. Schroeder, D. M. Bell, J. G. Masek, C. Huang, and G. W. Meigs. 2016. **Forest disturbance across the conterminous United States from 1985–2012: The emerging dominance of forest decline.** Forest Ecology and Management 360:242-252.

Abstract. Evidence of shifting dominance among major forest disturbance agent classes regionally to globally has been emerging in the literature. For example, climate-related stress and secondary stressors on forests (e.g., insect and disease, fire) have dramatically increased since the turn of the century globally, while harvest rates in the western US and elsewhere have declined. For shifts to be quantified, accurate historical forest disturbance estimates are required as a baseline for examining current trends. We report annual disturbance rates (with uncertainties) in the aggregate and by major change causal agent class for the conterminous US and five geographic subregions between 1985 and 2012. Results are based on human interpretations of Landsat time series from a probability sample of 7200 plots (30 m) distributed throughout the study area. Forest disturbance information was recorded with a Landsat time series visualization and data

collection tool that incorporates ancillary high-resolution data. National rates of disturbance varied between 1.5% and 4.5% of forest area per year, with trends being strongly affected by shifting dominance among specific disturbance agent influences at the regional scale. Throughout the time series, national harvest disturbance rates varied between one and two percent, and were largely a function of harvest in the more heavily forested regions of the US (Mountain West, Northeast, and Southeast). During the first part of the time series, national disturbance rates largely reflected trends in harvest disturbance. Beginning in the mid-90s, forest decline-related disturbances associated with diminishing forest health (e.g., physiological stress leading to tree canopy cover loss, increases in tree mortality above background levels), especially in the Mountain West and Lowland West regions of the US, increased dramatically. Consequently, national disturbance rates greatly increased by 2000, and remained high for much of the decade. Decline-related disturbance rates reached as high as 8% per year in the western regions during the early-2000s. Although low compared to harvest and decline, fire disturbance rates also increased in the early- to mid-2000s. We segmented annual decline-related disturbance rates to distinguish between newly impacted areas and areas undergoing gradual but consistent decline over multiple years. We also translated Landsat reflectance change into tree canopy cover change information for greater relevance to ecosystem modelers and forest managers, who can derive better understanding of forest-climate interactions and better adapt management strategies to changing climate regimes. Similar studies could be carried out for other countries where there are sufficient Landsat data and historic temporal snapshots of high-resolution imagery.

Golladay, S. W., K. L. Martin, J. M. Vose, D. N. Wear, A. P. Covich, R. J. Hobbs, K. D. Klepzig, G. E. Likens, R. J. Naiman, and A. W. Shearer. 2016. **Achievable future conditions as a framework for guiding forest conservation and management.** Forest Ecology and Management 360:80-96.

Abstract. We contend that traditional approaches to forest conservation and management will be inadequate given the predicted scale of social-economic and biophysical changes in the 21st century. New approaches, focused on anticipating and guiding ecological responses to change, are urgently needed to ensure the full value of forest ecosystem services for future generations. These approaches acknowledge that change is inevitable and sometimes irreversible, and that maintenance of ecosystem services depends in part on novel ecosystems, i.e., species combinations with no analog in the past. We propose that ecological responses be evaluated at landscape or regional scales using risk-based approaches to incorporate uncertainty into forest management efforts with subsequent goals for management based on

Achievable Future Conditions (AFC). AFCs defined at a landscape or regional scale incorporate advancements in ecosystem management, including adaptive approaches, resilience, and desired future conditions into the context of the Anthropocene. Inherently forward looking, ACFs encompass mitigation and adaptation options to respond to scenarios of projected future biophysical, social-economic, and policy conditions which distribute risk and provide diversity of response to uncertainty. The engagement of science-management-public partnerships is critical to our risk-based approach for defining AFCs. Robust monitoring programs of forest management actions are also crucial to address uncertainty regarding species distributions and ecosystem processes. Development of regional indicators of response will also be essential to evaluate outcomes of management strategies. Our conceptual framework provides a starting point to move toward AFCs for forest management, illustrated with examples from fire and water management in the Southeastern United States. Our model is adaptive, incorporating evaluation and modification as new information becomes available and as social–ecological dynamics change. It expands on established principles of ecosystem management and best management practices (BMPs) and incorporates scenarios of future conditions. It also highlights the potential limits of existing institutional structures for defining AFCs and achieving them. In an uncertain future of rapid change and abrupt, unforeseen transitions, adjustments in management approaches will be necessary and some actions will fail. However, it is increasingly evident that the greatest risk is posed by continuing to implement strategies inconsistent with current understanding of our novel future.

Laflower, D. M., M. D. Hurteau, G. W. Koch, M. P. North, and B. A. Hungate. 2016. **Climate-driven changes in forest succession and the influence of management on forest carbon dynamics in the Puget Lowlands of Washington State, USA.** Forest Ecology and Management 362:194-204.

Abstract. Projecting the response of forests to changing climate requires understanding how biotic and abiotic controls on tree growth will change over time. As temperature and interannual precipitation variability increase, the overall forest response is likely to be influenced by species-specific responses to changing climate. Management actions that alter composition and density may help buffer forests against the effects of changing climate, but may require tradeoffs in ecosystem services. We sought to quantify how projected changes in climate and different management regimes would alter the composition and productivity of Puget Lowland forests in Washington State, USA. We modeled forest responses to four treatments (control, burn-only, thin-only, thin-and-burn) under five different climate scenarios: baseline climate (historical) and projections from two climate models

(CCSM4 and CNRM-CM5), driven by moderate (RCP 4.5) and high (RCP 8.5) emission scenarios. We also simulated the effects of intensive management to restore Oregon white oak woodlands (Quercus garryana) for the western gray squirrel (Sciurus griseus) and quantified the effects of these treatments on the probability of oak occurrence and carbon sequestration. At the landscape scale we found little difference in carbon dynamics between baseline and moderate emission scenarios. However, by late-century under the high emission scenario, climate change reduced forest productivity and decreased species richness across a large proportion of the study area. Regardless of the climate scenario, we found that thinning and burning treatments increased the carbon sequestration rate because of decreased resource competition. However, increased productivity with management was not sufficient to prevent an overall decline in productivity under the high emission scenario. We also found that intensive oak restoration treatments were effective at increasing the probability of oak presence and that the limited extent of the treatments resulted in small declines in total ecosystem carbon across the landscape as compared to the thin-and-burn treatment. Our research suggests that carbon dynamics in this system under the moderate emission scenario may be fairly consistent with the carbon dynamics under historical climate, but that the high emission scenario may alter the successional trajectory of these forests.

Petrie, M. D., A. M. Wildeman, J. B. Bradford, R. M. Hubbard, and W. K. Lauenroth. 2016. **A review of precipitation and temperature control on seedling emergence and establishment for ponderosa and lodgepole pine forest regeneration.** Forest Ecology and Management 361:328-338.

Abstract. The persistence of ponderosa pine and lodgepole pine forests in the 21st century depends to a large extent on how seedling emergence and establishment are influenced by driving climate and environmental variables, which largely govern forest regeneration. We surveyed the literature, and identified 96 publications that reported data on dependent variables of seedling emergence and/or establishment and one or more independent variables of air temperature, soil temperature, precipitation and moisture availability. Our review suggests that seedling emergence and establishment for both species is highest at intermediate temperatures (20 to 25 °C), and higher precipitation and higher moisture availability support a higher percentage of seedling emergence and establishment at daily, monthly and annual timescales. We found that ponderosa pine seedlings may be more sensitive to temperature fluctuations whereas lodgepole pine seedlings may be more sensitive to moisture fluctuations. In a changing climate, increasing temperatures and declining moisture availability may hinder forest persistence by limiting seedling processes. Yet, only 23 studies in our review investigated the effects of driving climate and environmental variables directly. Furthermore, 74 studies occurred in a laboratory or greenhouse, which do not often replicate the conditions experienced by tree seedlings in a field setting. It is therefore difficult to provide strong conclusions on how sensitive emergence and establishment in ponderosa and lodgepole pine are to these specific driving variables, or to investigate their potential aggregate effects. Thus, the effects of many driving variables on seedling processes remain largely inconclusive. Our review stresses the need for additional field and laboratory studies to better elucidate the effects of driving climate and environmental variables on seedling emergence and establishment for ponderosa and lodgepole pine.

Shestakova, T. A., E. Gutiérrez, A. V. Kirdyanov, J. J. Camarero, M. Génova, A. A. Knorre, J. C. Linares, V. Resco de Dios, R. Sánchez-Salguero, and J. Voltas. 2016. **Forests synchronize their growth in contrasting Eurasian regions in response to climate warming.** Proceedings of the National Academy of Sciences 113:662-667.

Abstract. Forests play a key role in the carbon balance of terrestrial ecosystems. One of the main uncertainties in global change predictions lies in how the spatiotemporal dynamics of forest productivity will be affected by climate warming. Here we show an increasing influence of climate on the spatial variability of tree growth during the last 120 y, ultimately leading to unprecedented temporal coherence in ring-width records over wide geographical scales (spatial synchrony). Synchrony in growth patterns across cold-constrained (central Siberia) and drought-constrained (Spain) Eurasian conifer forests have peaked in the early 21st century at subcontinental scales (~1,000 km). Such enhanced synchrony is similar to that observed in trees co-occurring within a stand. In boreal forests, the combined effects of recent warming and increasing intensity of climate extremes are enhancing synchrony through an earlier start of wood formation and a stronger impact of year-to-year fluctuations of growing-season temperatures on growth. In Mediterranean forests, the impact of warming on synchrony is related mainly to an advanced onset of growth and the strengthening of drought-induced growth limitations. Spatial patterns of enhanced synchrony represent early warning signals of climate change impacts on forest ecosystems at subcontinental scales.

Worrall, J. J., A. G. Keck, and S. B. Marchetti. 2015. ***Populus tremuloides* stands continue to deteriorate after drought-incited sudden aspen decline.** Canadian Journal of Forest Research 45:1768-1774.

Abstract. Reports of forest damage have increased with the frequency of climatic extremes, but longer term impacts of such events on population dynamics of forest trees are generally unknown. Incited by the turn-of-the-century drought, sudden aspen decline (SAD) damaged 535 000 ha of *Populus tremuloides* Michx. in the Southern Rockies ecoregion of western North America. Although spread of the disease stopped in about 2009, most of the affected stands continued to deteriorate. Remeasurement of plots in southwestern Colorado showed that, since the peak of the epidemic, live basal area in sick plots decreased by an additional 28% to only 38% of that in healthy plots. Sick plots had much more recent damage than healthy plots, with almost three times as much recently dead basal area, over twice the density of recently dead trees, and almost four times as much recent crown loss. The important contributing agents in SAD were still active in sick stands in 2013. Density of small regeneration showed opposite trends, increasing in healthy plots and decreasing in sick plots. Timely regeneration treatments may be needed in some such stands to facilitate recovery. In addition to acute damage from climatic extremes, long-term decline diseases like SAD will likely be a common signature of forest damage from climate change.

Zhang, Y., H. Y. H. Chen, and A. R. Taylor. 2016. **Aboveground biomass of understorey vegetation has a negligible or negative association with overstorey tree species diversity in natural forests.** Global Ecology and Biogeography 25:141-150.

Abstract. Aim. The positive relationships between tree species diversity, aboveground biomass and productivity of overstorey tree layers have been widely reported in tropical, temperate and boreal forest ecosystems. However, no consensus has been arrived at on the association between overstorey tree species diversity and the functions of understorey vegetation, such as the biomass of understorey tree, shrub, herb and bryophyte layers, despite their critical contributions to the diversity and functions of natural forests.

Location. Canadian forest (42°37′ to 68°14′ N; 53°25′ to 134°46′ W; 4 to 2170 m elevation).

Methods. We employed Canada's National Forest Inventory dataset to evaluate the influences of overstorey tree species diversity on the aboveground biomass of each forest stratum by accounting for the effects of climate, site condition and stand age.

Results. We found that aboveground biomass of overstorey trees and total aboveground biomass were positively associated with overstorey tree species richness; however, the aboveground biomass of understorey trees, shrubs, herbs and bryophytes were not associated or were negatively associated with overstorey tree species richness, evenness and life-history trait variations.

Main conclusions. Our results show positive associations between aboveground biomass of the overstorey tree layer and overstorey tree species diversity over a wide range of climate, local site conditions and stand ages in natural forests. However, contrary to previous findings that more tree species result in higher levels of multiple ecosystem functions, including understorey plant functions, our results demonstrate that the aboveground biomass of understorey vegetation has either a negligible or negative association with overstorey tree species diversity. The negative associations between overstorey tree species diversity and understorey biomass possibly resulted from greater resource filtering by overstorey trees in ecosystems with more diverse overstorey tree species.

Rangeland Vegetation

Hoover, D. L., M. C. Duniway, and J. Belnap. 2015. **Pulse-drought atop press-drought: unexpected plant responses and implications for dryland ecosystems.** Oecologia 179:1211-1221.

Abstract. In drylands, climate change is predicted to cause chronic reductions in water availability (press-droughts) through reduced precipitation and increased temperatures as well as increase the frequency and intensity of short-term extreme droughts (pulse-droughts). These changes in precipitation patterns may have profound ecosystem effects, depending on the sensitivities of the dominant plant functional types (PFTs). Here we present the responses of four Colorado Plateau PFTs to an experimentally imposed, 4-year, press-drought during which a natural pulse-drought occurred. Our objectives were to (1) identify the drought sensitivities of the PFTs, (2) assess the additive effects of the press- and pulse-drought, and (3) examine the interactive effects of soils and drought. Our results revealed that the C_3 grasses were the most sensitive PFT to drought, the C_3 shrubs were the most resistant, and the C_4 grasses and shrubs had intermediate drought sensitivities. Although we expected the C_3 grasses would have the greatest response to drought, the higher resistance of C_3 shrubs relative to the C_4 shrubs was contrary to our predictions based on the higher water use efficiency of C_4 photosynthesis. Also, the additive effects of press- and pulse-droughts caused high morality in C_3 grasses,

which has large ecological and economic ramifications for this region. Furthermore, despite predictions based on the inverse texture hypothesis, we observed no interactive effects of soils with the drought treatment on cover or mortality. These results suggest that plant responses to droughts in drylands may differ from expectations and have large ecological effects if press- and pulse-droughts push species beyond physiological and mortality thresholds.

Metz, J., and K. Tielbörger. 2016. **Spatial and temporal aridity gradients provide poor proxies for plant–plant interactions under climate change: a large-scale experiment.** Functional Ecology 30:20-29.

Abstract. Plant–plant interactions may critically modify the impact of climate change on plant communities. However, the magnitude and even direction of potential future interactions remains highly debated, especially for water-limited ecosystems. Predictions range from increasing facilitation to increasing competition with future aridification.

The different methodologies used for assessing plant–plant interactions under changing environmental conditions may affect the outcome but they are not equally represented in the literature. Mechanistic experimental manipulations are rare compared with correlative approaches that infer future patterns from current observations along spatial climatic gradients.

Here, we utilize a unique climatic gradient in combination with a large-scale, long-term experiment to test whether predictions about plant–plant interactions yield similar results when using experimental manipulations, spatial gradients or temporal variation. We assessed shrub–annual interactions in three different sites along a natural rainfall gradient (spatial) during 9 years of varying rainfall (temporal) and 8 years of dry and wet manipulations of ambient rainfall (experimental) that closely mimicked regional climate scenarios.

The results were fundamentally different among all three approaches. Experimental water manipulations hardly altered shrub effects on annual plant communities for the assessed fitness parameters biomass and survival. Along the spatial gradient, shrub effects shifted from clearly negative to mildly facilitative towards drier sites, whereas temporal variation showed the opposite trend: more negative shrub effects in drier years.

Based on our experimental approach, we conclude that shrub–annual interaction will remain similar under climate change. In contrast, the commonly applied space-for-time approach based on spatial gradients would have suggested increasing facilitative effects with climate change. We discuss potential mechanisms governing the differences among the three approaches.

Our study highlights the critical importance of long-term experimental manipulations for evaluating climate change impacts. Correlative approaches, for example along spatial or temporal gradients, may be misleading and overestimate the response of plant–plant interactions to climate change.

Morris, C., K. J. Badik, L. R. Morris, and M. A. Weltz. 2016. **Integrating precipitation, grazing, past effects and interactions in long-term vegetation change.** Journal of Arid Environments 124:111-117.

Abstract. Determining the causes of vegetation change in arid and semi-arid environments can be difficult and may involve multiple factors, including disturbance, inter-annual climatic variation, soils, effects from years past and interactions between these factors. Theoretical models describing vegetation change in these systems have generally focused on a single aspect as the primary driver. The integration of these factors into a single model may be what is required to fully understand the drivers of vegetation change in desert systems. To test the contributions of these various factors, we analyzed a long-term (1979–2011) vegetation dataset using multiple linear regression.

While precipitation and livestock density were important variables for explaining vegetation change, the consistency with which past effects and interactions significantly improved the models underscores their importance. Past effects were included in every model except for shrub diversity, and included both precipitation and livestock density effects. A novel approach to addressing the interaction between grazing and precipitation was included by dividing precipitation by stocking density. Grass density had a high positive correlation with this metric, while shrub cover had a small negative correlation. These results support the integration of multiple factors to explain vegetation change.

Munson, S. M., M. C. Duniway, and J. K. Johanson. 2016. **Rangeland monitoring reveals long-term plant responses to precipitation and grazing at the landscape scale.** Rangeland Ecology & Management 69:76-83.

Abstract. Managers of rangeland ecosystems require methods to track the condition of natural resources over large areas and long periods of time as they confront climate change and land use intensification. We demonstrate how rangeland monitoring results can be synthesized using ecological site concepts to understand how climate, site factors, and management actions

affect long-term vegetation dynamics at the landscape-scale. Forty-six years of rangeland monitoring conducted by the Bureau of Land Management (BLM) on the Colorado Plateau reveals variable responses of plant species cover to cool-season precipitation, land type (ecological site groups), and grazing intensity. Dominant C_3 perennial grasses (*Achnatherum hymenoides, Hesperostipa comata*), which are essential to support wildlife and livestock on the Colorado Plateau, had responses to cool-season precipitation that were at least twice as large as the dominant C_4 perennial grass (*Pleuraphis jamesii*) and woody vegetation. However, these C_3 perennial grass responses to precipitation were reduced by nearly one-third on grassland ecological sites with fine- rather than coarse-textured soils, and there were no detectable C_3 perennial grass responses to precipitation on ecological sites dominated by a dense-growing shrub, *Coleogyne ramosissima*. Heavy grazing intensity further reduced the responses of C_3 perennial grasses to cool-season precipitation on ecological sites with coarse-textured soils and surprisingly reduced the responses of shrubs as well. By using ecological site groups to assess rangeland condition, we were able to improve our understanding of the long-term relationships between vegetation change and climate, land use, and site characteristics, which has important implications for developing landscape-scale monitoring strategies.

Riparian Vegetation

McShane, R. R., D. A. Auerbach, J. M. Friedman, G. T. Auble, P. B. Shafroth, M. F. Merigliano, M. L. Scott, and N. L. Poff. 2015. **Distribution of invasive and native riparian woody plants across the western USA in relation to climate, river flow, floodplain geometry and patterns of introduction.** Ecography 38:1254-1265.

Abstract. Management of riparian plant invasions across the landscape requires understanding the combined influence of climate, hydrology, geologic constraints and patterns of introduction. We measured abundance of nine riparian woody taxa at 456 stream gages across the western USA. We constructed conditional inference recursive binary partitioning models to discriminate the influence of eleven environmental variables on plant occurrence and abundance, focusing on the two most abundant non-native taxa, *Tamarix* spp. and *Elaeagnus angustifolia*, and their native competitor *Populus deltoides*. River reaches in this study were distributed along a composite gradient from cooler, wetter higher-elevation reaches with higher stream power and earlier snowmelt flood peaks to warmer, drier lower-elevation reaches with lower power and later peaks. Plant distributions were strongly related to climate, hydrologic and geomorphic factors, and

introduction history. The strongest associations were with temperature and then precipitation. Among hydrologic and geomorphic variables, stream power, peak flow timing and 10-yr flood magnitude had stronger associations than did peak flow predictability, low-flow magnitude, mean annual flow and channel confinement. Nearby intentional planting of *Elaeagnus* was the best predictor of its occurrence, but planting of *Tamarix* was rare. Higher temperatures were associated with greater abundance of *Tamarix* relative to *P. deltoides*, and greater abundance of *P. deltoides* relative to *Elaeagnus*. *Populus deltoides* abundance was more strongly related to peak flow timing than was that of *Elaeagnus* or *Tamarix*. Higher stream power and larger 10-yr floods were associated with greater abundance of *P. deltoides* and *Tamarix* relative to *Elaeagnus*. Therefore, increases in temperature could increase abundance of *Tamarix* and decrease that of *Elaeagnus* relative to *P. deltoides*, changes in peak flow timing caused by climate change or dam operations could increase abundance of both invasive taxa, and dam-induced reductions in flood peaks could increase abundance of *Elaeagnus* relative to *Tamarix* and *P. deltoides*.

Fish and Wildlife

Dugger, K. M., E. D. Forsman, A. B. Franklin, R. J. Davis, G. C. White, C. J. Schwarz, K. P. Burnham, J. D. Nichols, J. E. Hines, C. B. Yackulic, P. F. Doherty, L. Bailey, D. A. Clark, S. H. Ackers, L. S. Andrews, B. Augustine, B. L. Biswell, J. Blakesley, P. C. Carlson, M. J. Clement, L. V. Diller, E. M. Glenn, A. Green, S. A. Gremel, D. R. Herter, J. M. Higley, J. Hobson, R. B. Horn, K. P. Huyvaert, C. McCafferty, T. McDonald, K. McDonnell, G. S. Olson, J. A. Reid, J. Rockweit, V. Ruiz, J. Saenz, and S. G. Sovern. 2015. **The effects of habitat, climate, and Barred Owls on long-term demography of Northern Spotted Owls.** The Condor 118:57-116.

Abstract. Estimates of species' vital rates and an understanding of the factors affecting those parameters over time and space can provide crucial information for management and conservation. We used mark–recapture, reproductive output, and territory occupancy data collected during 1985–2013 to evaluate population processes of Northern Spotted Owls (*Strix occidentalis caurina*) in 11 study areas in Washington, Oregon, and northern California, USA. We estimated apparent survival, fecundity, recruitment, rate of population change, and local extinction and colonization rates, and investigated relationships between these parameters and the amount of suitable habitat, local and regional variation in meteorological conditions, and competition with Barred Owls (*Strix varia*). Data were analyzed for each

area separately and in a meta-analysis of all areas combined, following a strict protocol for data collection, preparation, and analysis. We used mixed effects linear models for analyses of fecundity, Cormack-Jolly-Seber open population models for analyses of apparent annual survival (ϕ), and a reparameterization of the Jolly-Seber capture–recapture model (i.e. reverse Jolly-Seber; RJS) to estimate annual rates of population change (λRJS) and recruitment. We also modeled territory occupancy dynamics of Northern Spotted Owls and Barred Owls in each study area using 2-species occupancy models. Estimated mean annual rates of population change (λ) suggested that Spotted Owl populations declined from 1.2% to 8.4% per year depending on the study area. The weighted mean estimate of λ for all study areas was 0.962 (± 0.019 SE; 95% CI: 0.925–0.999), indicating an estimated range-wide decline of 3.8% per year from 1985 to 2013. Variation in recruitment rates across the range of the Spotted Owl was best explained by an interaction between total winter precipitation and mean minimum winter temperature. Thus, recruitment rates were highest when both total precipitation (29 cm) and minimum winter temperature (−9.5°C) were lowest. Barred Owl presence was associated with increased local extinction rates of Spotted Owl pairs for all 11 study areas. Habitat covariates were related to extinction rates for Spotted Owl pairs in 8 of 11 study areas, and a greater amount of suitable owl habitat was generally associated with decreased extinction rates. We observed negative effects of Barred Owl presence on colonization rates of Spotted Owl pairs in 5 of 11 study areas. The total amount of suitable Spotted Owl habitat was positively associated with colonization rates in 5 areas, and more habitat disturbance was associated with lower colonization rates in 2 areas. We observed strong declines in derived estimates of occupancy in all study areas. Mean fecundity of females was highest for adults (0.309 ± 0.027 SE), intermediate for 2-yr-olds (0.179 ± 0.040 SE), and lowest for 1-yr-olds (0.065 ± 0.022 SE). The presence of Barred Owls and habitat covariates explained little of the temporal variation in fecundity in most study areas. Climate covariates occurred in competitive fecundity models in 8 of 11 study areas, but support for these relationships was generally weak. The fecundity meta-analysis resulted in 6 competitive models, all of which included the additive effects of geographic region and annual time variation. The 2 top-ranked models also weakly supported the additive negative effects of the amount of suitable core area habitat, Barred Owl presence, and the amount of edge habitat on fecundity. We found strong support for a negative effect of Barred Owl presence on apparent survival of Spotted Owls in 10 of 11 study areas, but found few strong effects of habitat on survival at the study area scale. Climate covariates occurred in top or competitive survival models for 10 of 11 study areas, and in most cases the relationships were as predicted; however, there was little consistency among areas regarding the relative importance of specific climate covariates. In contrast, meta-analysis results suggested that Spotted Owl survival was higher across all study areas when the Pacific Decadal Oscillation (PDO) was in a warming phase and the Southern Oscillation Index (SOI) was negative, with a strongly negative SOI indicative of El Niño events. The best model that included the Barred Owl covariate (BO) was ranked 4th and also included the PDO covariate, but the BO effect was strongly negative. Our results indicated that Northern Spotted Owl populations were declining throughout the range of the subspecies and that annual rates of decline were accelerating in many areas. We observed strong evidence that Barred Owls negatively affected Spotted Owl populations, primarily by decreasing apparent survival and increasing local territory extinction rates. However, the amount of suitable owl habitat, local weather, and regional climatic patterns also were related to survival, occupancy (via colonization rate), recruitment, and, to a lesser extent, fecundity, although there was inconsistency in regard to which covariates were important for particular demographic parameters or across study areas. In the study areas where habitat was an important source of variation for Spotted Owl demographics, vital rates were generally positively associated with a greater amount of suitable owl habitat. However, Barred Owl densities may now be high enough across the range of the Northern Spotted Owl that, despite the continued management and conservation of suitable owl habitat on federal lands, the long-term prognosis for the persistence of Northern Spotted Owls may be in question without additional management intervention. Based on our study, the removal of Barred Owls from the Green Diamond Resources (GDR) study area had rapid, positive effects on Northern Spotted Owl survival and the rate of population change, supporting the hypothesis that, along with habitat conservation and management, Barred Owl removal may be able to slow or reverse Northern Spotted Owl population declines on at least a localized scale.

Moriarty, K. M., C. W. Epps, M. G. Betts, D. J. Hance, J. D. Bailey, and W. J. Zielinski. 2015. **Experimental evidence that simplified forest structure interacts with snow cover to influence functional connectivity for Pacific martens.** Landscape Ecology 30:1865-1877.

Abstract. Context. Functional connectivity—the facilitation of individual movements among habitat patches—is essential for species' persistence in fragmented landscapes. Evaluating functional connectivity is critical for predicting range shifts, developing conservation plans, and anticipating effects of disturbance, especially for species affected by climate change.

Objectives. We examined whether simplifying forest structure influenced animal movements and whether an experimental approach to quantifying functional connectivity reflects normal behavior, which is often assumed but remains untested.

Methods. We evaluated functional connectivity for Pacific marten (Martes caurina) across a gradient in forest structural complexity using two novel methods for this species: incentivized food-titration experiments and non-incentivized locations collected via GPS telemetry (24 individuals).

Results. Food titration experiments revealed martens selected complex stands, and martens entered and crossed areas with reduced forest cover when motivated by bait, particularly in the winter. However, our telemetry data showed that without such incentive, martens avoided openings and simple stands and selected complex forest stands equally during summer and winter.

Conclusions. Detections at baited stations may not represent typical habitat preferences during winter, and incentivized experiments reflect the capacity of martens to enter non-preferred stand types under high motivation (e.g., hunger, curiosity, dispersal). We hypothesize snow cover facilitates connectivity across openings when such motivation is present; thus, snow cover may benefit dispersing animals and increase population connectivity. Landscapes with joined networks of complex stands are crucial for maintaining functional connectivity for marten, particularly during summer.

Wu, J. 2016. **Detecting and attributing the effects of climate change on the distributions of snake species over the past 50 years.** Environmental Management 57:207-219.

Abstract. It is unclear whether the distributions of snakes have changed in association with climate change over the past years. We detected the distribution changes of snakes over the past 50 years and determined whether the changes could be attributed to recent climate change in China. Long-term records of the distribution of nine snake species in China, grey relationship analysis, fuzzy sets classification techniques, the consistency index, and attributed methods were used. Over the past 50 years, the distributions of snake species have changed in multiple directions, primarily shifting northwards, and most of the changes were related to the thermal index. Driven by climatic factors over the past 50 years, the distribution boundary and distribution centers of some species changed with the fluctuations. The observed and predicted changes in distribution were highly consistent for some snake species. The changes in the northern limits of distributions of nearly half of the species, as well as the southern and eastern limits, and the distribution centers of some snake species can be attributed to climate change.

Zhao, Q., E. Silverman, K. Fleming, and G. S. Boomer. 2016. **Forecasting waterfowl population dynamics under climate change — Does the spatial variation of density dependence and environmental effects matter?** Biological Conservation 194:80-88.

Abstract. Reliable ecological forecasts are essential for conservation decision-making to respond to climate change. It is challenging to forecast the spatial structure of wildlife population dynamics because density dependence and environmental effects vary spatially. We developed models that incorporated density dependence and climatic (precipitation and temperature) effects to explain pond (wetland) dynamics and models that incorporated density dependence and pond effect to explain Mallard (*Anas platyrhynchos*) population dynamics. We trained the models using data from 1974 to 1998 and tested their hindcast performance with data from 1999 to 2010 to examine the scale at which the spatial variation of density dependence and climatic/pond effects should be incorporated to forecast pond and Mallard population dynamics. The pond model that did not allow density dependence and climatic effects to vary spatially (ΔMSE = 0.007–0.018) and the Mallard model that incorporated the spatial variation of density dependence and pond effect at the scale of Bird Conservation Regions (ΔMSE = 0.011–0.012) had the best hindcast performance. Using these models we forecasted the largest decrease (34.7%–43.0%) of Mallard density in the northern Prairie Pothole Region under two climate change scenarios, suggesting that the local Mallard population in this area might be particularly vulnerable to potential future warming. Our results provide insight into the factors that drive the spatial structure of waterfowl population dynamics. Because the spatial variation of density dependence and environmental effects is commonly found in wildlife populations, our framework of modeling and evaluation has wide application for conservation planning in response to climate change.

Soils and Hydrology

Callesen, I., R. Harrison, I. Stupak, J. Hatten, K. Raulund-Rasmussen, J. Boyle, N. Clarke, and D. Zabowski. 2016. **Carbon storage and nutrient mobilization from soil minerals by deep roots and rhizospheres.** Forest Ecology and Management 359:322-331.

Abstract. Roots mobilize nutrients via deep soil penetration and rhizosphere processes inducing weathering of primary minerals. These processes contribute to C transfer to soils and to tree nutrition. Assessments of these characteristics and processes of root systems are important for understanding long-term supplies of nutrient elements essential for forest

growth and resilience. Research and techniques have significantly advanced since Olof Tamm's 1934 "base mineral index" for Swedish forest soils, and the basic nutrient budget estimates for whole-tree harvesting systems of the 1970s. Recent research in areas that include some of the world's most productive and intensively managed forests, including Brazil and the USA, has shown that root systems are often several meters in depth, and often extend deeper than soil is sampled. Large amounts of carbon are also sometimes stored at depth. Other recent studies on potential release of nutrients due to chemical weathering indicate the importance of root access to deep soil layers. Nutrient release profiles clearly indicate depletion in the top layers and a much higher potential in B and C horizons. Reviewing potential sustainability of nutrient supplies for biomass harvesting and other intensive forest management systems will advance understanding of these important ecosystem properties, processes and services relevant for management.

Couradeau, E., U. Karaoz, H. C. Lim, U. Nunes da Rocha, T. Northen, E. Brodie, and F. Garcia-Pichel. 2016. **Bacteria increase arid-land soil surface temperature through the production of sunscreens.** Nature Communications 7:10373.

Abstract. Soil surface temperature, an important driver of terrestrial biogeochemical processes, depends strongly on soil albedo, which can be significantly modified by factors such as plant cover. In sparsely vegetated lands, the soil surface can be colonized by photosynthetic microbes that build biocrust communities. Here we use concurrent physical, biochemical and microbiological analyses to show that mature biocrusts can increase surface soil temperature by as much as 10 °C through the accumulation of large quantities of a secondary metabolite, the microbial sunscreen scytonemin, produced by a group of late-successional cyanobacteria. Scytonemin accumulation decreases soil albedo significantly. Such localized warming has apparent and immediate consequences for the soil microbiome, inducing the replacement of thermosensitive bacterial species with more thermotolerant forms. These results reveal that not only vegetation but also microorganisms are a factor in modifying terrestrial albedo, potentially impacting biosphere feedbacks on past and future climate, and call for a direct assessment of such effects at larger scales.

Dettinger, M., B. Udall, and A. Georgakakos. 2015. **Western water and climate change.** Ecological Applications 25:2069-2093.

Abstract. The western United States is a region long defined by water challenges. Climate change adds to those historical challenges, but does not,

for the most part, introduce entirely new challenges; rather climate change is likely to stress water supplies and resources already in many cases stretched to, or beyond, natural limits. Projections are for continued and, likely, increased warming trends across the region, with a near certainty of continuing changes in seasonality of snowmelt and streamflows, and a strong potential for attendant increases in evaporative demands. Projections of future precipitation are less conclusive, although likely the northernmost West will see precipitation increases while the southernmost West sees declines. However, most of the region lies in a broad area where some climate models project precipitation increases while others project declines, so that only increases in precipitation uncertainties can be projected with any confidence. Changes in annual and seasonal hydrographs are likely to challenge water managers, users, and attempts to protect or restore environmental flows, even where annual volumes change little. Other impacts from climate change (e.g., floods and water-quality changes) are poorly understood and will likely be location dependent.

In this context, four iconic river basins offer glimpses into specific challenges that climate change may bring to the West. The Colorado River is a system in which overuse and growing demands are projected to be even more challenging than climate-change-induced flow reductions. The Rio Grande offers the best example of how climate-change-induced flow declines might sink a major system into permanent drought. The Klamath is currently projected to face the more benign precipitation future, but fisheries and irrigation management may face dire straits due to warming air temperatures, rising irrigation demands, and warming waters in a basin already hobbled by tensions between endangered fisheries and agricultural demands. Finally, California's Bay-Delta system is a remarkably localized and severe weakness at the heart of the region's trillion-dollar economy. It is threatened by the full range of potential climate-change impacts expected across the West, along with major vulnerabilities to increased flooding and rising sea levels.

Hao, G., Q. Zhuang, Q. Zhu, Y. He, Z. Jin, and W. Shen. 2015. **Quantifying microbial ecophysiological effects on the carbon fluxes of forest ecosystems over the conterminous United States.** Climatic Change 133:695-708.

Abstract. There is a pressing need to develop earth system models (ESMs), in which ecosystem processes are adequately represented, to quantify carbon-climate feedbacks. In particular, explicit representation of the effects of microbial activities on soil organic carbon decomposition has been slow in ESM development. Here we revised an existing Q_{10}-based heterotrophic respiration (R_H) algorithm of a large-scale biogeochemical model, the Terrestrial Ecosystem Model (TEM), by incorporating the algorithms of Dual Arrhenius and Michaelis-Menten kinetics and microbial-enzyme interactions. The microbial physiology enabled model (MIC-TEM) was then applied to quantify historical and future carbon dynamics of forest ecosystems in the conterminous United States. Simulations indicate that warming has a weaker positive effect on RH than that traditional Q_{10} model has. Our results demonstrate that MIC-TEM is superior to traditional TEM in reproducing historical carbon dynamics. More importantly, the future trend of soil carbon accumulation simulated with MIC-TEM is more reasonable than TEM did and is generally consistent with soil warming experimental studies. The revised model estimates that regional GPP is 2.48 Pg C year^{-1} (2.02 to 3.03 Pg C year^{-1}) and NEP is 0.10 Pg C year^{-1} (-0.20 to 0.32 Pg C year^{-1}) during 2000–2005. Both models predict that the conterminous United States forest ecosystems are carbon sinks under two future climate scenarios during the 21st century. This study suggests that terrestrial ecosystem models should explicitly consider the microbial ecophysiological effects on soil carbon decomposition to adequately quantify forest ecosystem carbon fluxes at regional scales.

Ivancic, T. J., and S. B. Shaw. 2015. **Examining why trends in very heavy precipitation should not be mistaken for trends in very high river discharge.** Climatic Change 133:681-693.

Abstract. It is firmly established in the hydrologic literature that flooding depends on both antecedent watershed wetness and precipitation. One could phrase this relationship as “heavy precipitation does not necessarily lead to high stream discharge”, but rarely do studies directly affirm this statement. We have observed several non-hydrologists mistake trends in heavy precipitation as a proxy for trends in riverine flooding. If the relationship between heavy precipitation and high discharge was more often explicitly presented, heavy precipitation may less often be misinterpreted as a proxy for discharge. In this paper, we undertake such an analysis for 390 watersheds across the contiguous U.S. We found that 99th percentile precipitation only results in 99th percentage discharge 36 % of the time. However, when conditioned on soil moisture from the Variable Infiltration Capacity model, 62 % of 99th percentile precipitation results in 99th percentile discharge during wet periods and only 13 % during dry periods. When relating trends in heavy precipitation to hydrologic response, precipitation data should, therefore, be segregated based on concurrent soil moisture. Taking this approach for climate predictions, we found that CMIP-5 atmosphere–ocean global circulation model (AOGCM) simulations for a RCP 6.0 forcing project increases in concurrence of greater than median soil wetness and extreme precipitation in the northern United States and a

decrease in the south, suggesting northern regions could see an increase in very high discharges while southern regions could see decreases despite both regions having an increase in extreme precipitation. While the actual outcome is speculative given the uncertainties of the AOGCM's, such an analysis provides a more sophisticated framework from which to evaluate the output as well as historic climate data.

Maestre, F. T., M. Delgado-Baquerizo, T. C. Jeffries, D. J. Eldridge, V. Ochoa, B. Gozalo, J. L. Quero, M. García-Gómez, A. Gallardo, W. Ulrich, M. A. Bowker, T. Arredondo, C. Barraza-Zepeda, D. Bran, A. Florentino, J. Gaitán, J. R. Gutiérrez, E. Huber-Sannwald, M. Jankju, R. L. Mau, M. Miriti, K. Naseri, A. Ospina, I. Stavi, D. Wang, N. N. Woods, X. Yuan, E. Zaady, and B. K. Singh. 2015. **Increasing aridity reduces soil microbial diversity and abundance in global drylands.** Proceedings of the National Academy of Sciences 112:15684-15689.

Abstract. Soil bacteria and fungi play key roles in the functioning of terrestrial ecosystems, yet our understanding of their responses to climate change lags significantly behind that of other organisms. This gap in our understanding is particularly true for drylands, which occupy ~41% of Earth´s surface, because no global, systematic assessments of the joint diversity of soil bacteria and fungi have been conducted in these environments to date. Here we present results from a study conducted across 80 dryland sites from all continents, except Antarctica, to assess how changes in aridity affect the composition, abundance, and diversity of soil bacteria and fungi. The diversity and abundance of soil bacteria and fungi was reduced as aridity increased. These results were largely driven by the negative impacts of aridity on soil organic carbon content, which positively affected the abundance and diversity of both bacteria and fungi. Aridity promoted shifts in the composition of soil bacteria, with increases in the relative abundance of *Chloroflexi* and *α-Proteobacteria* and decreases in *Acidobacteria* and *Verrucomicrobia*. Contrary to what has been reported by previous continental and global-scale studies, soil pH was not a major driver of bacterial diversity, and fungal communities were dominated by *Ascomycota*. Our results fill a critical gap in our understanding of soil microbial communities in terrestrial ecosystems. They suggest that changes in aridity, such as those predicted by climate-change models, may reduce microbial abundance and diversity, a response that will likely impact the provision of key ecosystem services by global drylands.

Mariotte, P., B. J. M. Robroek, V. E. J. Jassey, and A. Buttler. 2015. **Subordinate plants mitigate drought effects on soil ecosystem processes by stimulating fungi.** Functional Ecology 29:1578-1586.

Abstract. The subordinate insurance hypothesis suggests that highly diverse communities contain greater numbers of subordinate species than less diverse communities. It has previously been reported that subordinate species can improve grassland productivity during drought, but the underlying mechanisms remain undetermined.

Using a combination of subordinate species removal and summer drought, we show that soil processes play a critical role in community resistance to drought. Interestingly, subordinate species drive soil microbial community structure and largely mitigate the effect of drought on grassland soil functioning. Our results highlight subordinate species in shifting the balance within the phospholipid fatty acid (PLFA) microbial community towards more fungal dominance.

Fungal communities promoted by subordinate species were more resistant to drought and maintained higher rates of litter decomposition and soil respiration. These results emphasize the important role of subordinate species in mitigating drought effects on soil ecosystem functions. Reciprocal effects between fungi and subordinate species explain also how subordinate species better resisted to drought conditions.

Our results point to a delayed plant–soil feedback following environmental perturbation. Additionally, they extend the diversity insurance hypothesis by showing that more diverse communities not only contain species well adapted to perturbations, but also species with higher impacts on soil microbial communities and related ecosystem functions.

Mueller, B., and X. Zhang. 2015. **Causes of drying trends in northern hemispheric land areas in reconstructed soil moisture data.** Climatic Change 134:255-267.

Abstract. The amount of soil moisture affects water availability, the occurrence of droughts and floods, and the frequency and intensity of heat waves in many regions across the globe. Here, we evaluate historical trends in soil moisture estimated by land-surface models (LSMs) with observed atmospheric forcing and trends simulated by global climate models participating in the Coupled Models Inter-comparison Project Phase 5 (CMIP5). We classify northern hemispheric land into wet and dry regions and analyze soil moisture changes in these regions. We find a significant decrease in soil moisture from 1951 to 2005 in the northern hemispheric land areas, in particular in dry regions, both in LSM and CMIP5 model simulations. Soil moisture trends in wet regions are less consistent among simulations. The increase in the area affected by drought (defined as the area where soil moisture is below its 10th percentile) from 1951 to 2005 is estimated to be 20 % (LSMs) and 30 % (CMIP5 models). A comparison between soil moisture simulated by LSMs and CMIP5 model output under different external forcings suggests that anthropogenic forcing contributed significantly to the observed drying and could explain the increase in the area affected by drought. As increases in atmospheric greenhouse gas concentrations will continue in the near future, dry areas are projected to become drier and larger in extent, which could negatively impact future water supply and food security.

van Groenigen, K. J., J. Xia, C. W. Osenberg, Y. Luo, and B. A. Hungate. 2015. **Application of a two-pool model to soil carbon dynamics under elevated CO_2.** Global Change Biology 21:4293-4297.

Abstract. Elevated atmospheric CO_2 concentrations increase plant productivity and affect soil microbial communities, with possible consequences for the turnover rate of soil carbon (C) pools and feedbacks to the atmosphere. In a previous analysis (Van Groenigen et al., 2014), we used experimental data to inform a one-pool model and showed that elevated CO_2 increases the decomposition rate of soil organic C, negating the storage potential of soil. However, a two-pool soil model can potentially explain patterns of soil C dynamics without invoking effects of CO_2 on decomposition rates. To address this issue, we refit our data to a two-pool soil C model. We found that CO2 enrichment increases decomposition rates of both fast and slow C pools. In addition, elevated CO_2 decreased the carbon use efficiency of soil microbes (CUE), thereby further reducing soil C storage. These findings are consistent with numerous empirical studies and corroborate the results from our previous analysis. To facilitate understanding of C dynamics, we suggest that empirical and theoretical studies incorporate multiple soil C pools with potentially variable decomposition rates.

Ye, S., H.-Y. Li, S. Li, L. R. Leung, Y. Demissie, Q. Ran, and G. Blöschl. 2015. **Vegetation regulation on streamflow intra-annual variability through adaption to climate variations.** Geophysical Research Letters 42:10,307-310,315.

Abstract. This study aims to provide a mechanistic explanation of the empirical patterns of streamflow intra-annual variability revealed by watershed-scale hydrological data across the contiguous United States. A mathematical extension of the Budyko formula with explicit account for the soil moisture storage change is used to show that, in catchments with a

strong seasonal coupling between precipitation and potential evaporation, climate aridity has a dominant control on intra-annual streamflow variability. But in other catchments, additional factors related to soil water storage change also have important controls on how precipitation seasonality propagates to streamflow. More importantly, use of leaf area index as a direct and indirect indicator of the above ground biomass and plant root system, respectively, reveals the vital role of vegetation in regulating soil moisture storage and hence streamflow intra-annual variability under different climate conditions.

Fire

Flannigan, M. D., B. M. Wotton, G. A. Marshall, W. J. de Groot, J. Johnston, N. Jurko, and A. S. Cantin. 2015. **Fuel moisture sensitivity to temperature and precipitation: climate change implications.** Climatic Change 134:59-71.

Abstract. The objective of this paper is to examine the sensitivity of fuel moisture to changes in temperature and precipitation and explore the implications under a future climate. We use the Canadian Forest Fire Weather Index System components to represent the moisture content of fine surface fuels (Fine Fuel Moisture Code, FFMC), upper forest floor (duff) layers (Duff Moisture Code, DMC) and deep organic soils (Drought Code, DC). We obtained weather data from 12 stations across Canada for the fire season during the 1971–2000 period and with these data we created a set of modified weather streams from the original data by varying the daily temperatures by 0 to +5 °C in increments of 1 °C and the daily precipitation from −40 to 40 % in increments of 10 %. The fuel moistures were calculated for all the temperature and precipitation combinations. When temperature increases we find that for every degree of warming, precipitation has to increase by more than 15 % for FFMC, about 10 % for DMC and about 5 % for DC to compensate for the drying caused by warmer temperatures. Also, we find in terms of the number of days equal to or above an FFMC of 91, a critical value for fire spread, that no increase in precipitation amount alone could compensate for a temperature increase of 1 °C. Results from three General Circulation Models (GCMs) and three emission scenarios suggest that this sensitivity to temperature increases will result in a future with drier fuels and a higher frequency of extreme fire weather days.

Liu, Z., M. C. Wimberly, A. Lamsal, T. L. Sohl, and T. J. Hawbaker. 2015. **Climate change and wildfire risk in an expanding wildland-urban interface: a case study from the Colorado Front Range corridor.** Landscape Ecology 30:1943-1957.

Abstract. Context. Wildfire is a particular concern in the wildland–urban interface (WUI) of the western United States where human development occurs close to flammable natural vegetation.

Objectives. (1) Assess the relative influences of WUI expansion versus climate-driven fire regime change on spatial and temporal patterns of burned WUI, and (2) determine whether WUI developed in the future will have higher or lower wildfire risk than existing WUI.

Methods. We projected the spatial pattern of the WUI and its associated wildfire risk from 2005 to 2050 at 90-m spatial resolution and 5-year intervals in Colorado Front Range using CHANGE, a landscape change model that simulates land cover and land use change, natural vegetation dynamics, and wildfire in a unified framework. A total of four scenarios from a factorial design with static versus changing WUI and static versus changing fire regimes were simulated to examine the effects of WUI expansion and climate-driven fire regime change on burned area in the WUI.

Results. Both WUI expansion and fire regime change contributed to the increase of burned WUI, but fire regime change had a stronger influence. The effects of WUI expansion and fire regime change had a combined influence greater than the sum of their individual effects. This interaction was a result of projected WUI expansion into regions of higher wildfire risk than existing WUI.

Conclusions. The human footprint will continue to expand into wildland areas and must be considered along with climate effects when assessing the impacts of changing fire regimes in future landscapes.

Sea Level Rise and Ocean Conditions

Osland, M. J., N. M. Enwright, R. H. Day, C. A. Gabler, C. L. Stagg, and J. B. Grace. 2016. **Beyond just sea-level rise: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change.** Global Change Biology 22:1-11.

Abstract. Due to their position at the land-sea interface, coastal wetlands are vulnerable to many aspects of climate change. However, climate change vulnerability assessments for coastal wetlands generally focus solely on sea-level rise without considering the effects of other facets of climate change.

Across the globe and in all ecosystems, macroclimatic drivers (e.g., temperature and rainfall regimes) greatly influence ecosystem structure and function. Macroclimatic drivers have been the focus of climate change-related threat evaluations for terrestrial ecosystems, but largely ignored for coastal wetlands. In some coastal wetlands, changing macroclimatic conditions are expected to result in foundation plant species replacement, which would affect the supply of certain ecosystem goods and services and could affect ecosystem resilience. As examples, we highlight several ecological transition zones where small changes in macroclimatic conditions would result in comparatively large changes in coastal wetland ecosystem structure and function. Our intent in this communication is not to minimize the importance of sea-level rise. Rather, our overarching aim is to illustrate the need to also consider macroclimatic drivers within vulnerability assessments for coastal wetlands.

Reager, J. T., A. S. Gardner, J. S. Famiglietti, D. N. Wiese, A. Eicker, and M.-H. Lo. 2016. **A decade of sea level rise slowed by climate-driven hydrology.** Science 351:699-703.

Abstract. Climate-driven changes in land water storage and their contributions to sea level rise have been absent from Intergovernmental Panel on Climate Change sea level budgets owing to observational challenges. Recent advances in satellite measurement of time-variable gravity combined with reconciled global glacier loss estimates enable a disaggregation of continental land mass changes and a quantification of this term. We found that between 2002 and 2014, climate variability resulted in an additional 3200 ± 900 gigatons of water being stored on land. This gain partially offset water losses from ice sheets, glaciers, and groundwater pumping, slowing the rate of sea level rise by 0.71 ± 0.20 millimeters per year. These findings highlight the importance of climate-driven changes in hydrology when assigning attribution to decadal changes in sea level.

Somero, G. N., J. M. Beers, F. Chan, T. M. Hill, T. Klinger, and S. Y. Litvin. 2016. **What changes in the carbonate system, oxygen, and temperature portend for the northeastern Pacific Ocean: a physiological perspective.** BioScience 66:14-26.

Abstract. The northeastern Pacific Ocean is undergoing changes in temperature, carbonate chemistry, and dissolved oxygen concentration in concert with global change. Each of these stressors has wide-ranging effects on physiological systems, which may differ among species and life-history stages. Simultaneous exposure to multiple stressors may lead to even stronger impacts on organisms, but interacting effects remain poorly

understood. Here, we examine how single- and multiple-stressor effects on physiology may drive changes in the behavior, biogeography, and ecosystem structure in coastal marine ecosystems, with emphasis on the California Current Large Marine Ecosystem. By analyzing the effects of stressors on physiological processes common to many marine taxa, we may be able to develop broadly applicable understandings of the effects of global change. This mechanistic foundation may contribute to the development of models and other decision-support tools to assist resource managers and policymakers in anticipating and addressing global change–driven alterations in marine populations and ecosystems.

Adaptation

Garden, J. G., T. O'Donnell, and C. P. Catterall. 2015. **Changing habitat areas and static reserves: challenges to species protection under climate change.** Landscape Ecology 30:1959-1973.

Abstract. Context. When climate changes, species' distributions may either shift spatially or expand/contract around continuously-occupied refugia, altering the effectiveness of previously-fixed conservation reserve networks.

Objectives. We characterise the nature of climate-induced changes in species' distributions and the extent of protected habitat, using a topographically diverse, subtropical case-study region.

Methods. Bioclimatic species' distribution models were developed for 13 representative forest-dependent species spanning four vertebrate classes. We used a fine-scale 0.25 km grid with nine environmental and eight climatic predictor variables, selected for biological and land-use realism and statistical independence. Downscaled climate data for future climate regimes were quantified from regional climate data together with the IPCC A1FI predictions for 2040 and 2090.

Results. Range limits and centroids of individual species' modelled habitat areas changed little between present (2000) and future climates. However the total amount of suitable habitat shrank within the initial range limits. Species with the greatest habitat reductions had the smallest proportions of their present habitat areas in refugia (habitat areas suitable under present and future climates), but the largest proportions of their future habitat areas. The absolute areas of species' habitat protected by legislation decreased, whereas the proportions that were protected changed little.

Conclusions. Regional-scale climate change is likely to cause substantial species declines, together with reduced areas of protected suitable habitat. The observed nature of distributional change indicates that long-term

regional species conservation will depend more on identifying, protecting, and restoring habitat refugia than on actions to facilitate larger-scale movements.

Jones, K. R., J. E. M. Watson, H. P. Possingham, and C. J. Klein. 2016. **Incorporating climate change into spatial conservation prioritisation: A review.** Biological Conservation 194:121-130.

Abstract. To ensure the long-term persistence of biodiversity, conservation strategies must account for the entire range of climate change impacts. A variety of spatial prioritisation techniques have been developed to incorporate climate change. Here, we provide the first standardised review of these approaches. Using a systematic search, we analysed peer-reviewed spatial prioritisation publications (n = 46) and found that the most common approaches (n = 41, 89%) utilised forecasts of species distributions and aimed to either protect future species habitats (n = 24, 52%) or identify climate refugia to shelter species from climate change (n = 17, 37%). Other approaches (n = 17, 37%) used well-established conservation planning principles to combat climate change, aimed at broadly increasing either connectivity (n = 11, 24%) or the degree of heterogeneity of abiotic factors captured in the planning process (n = 8, 17%), with some approaches combining multiple goals. We also find a strong terrestrial focus (n = 35, 76%), and heavy geographical bias towards North America (n = 8, 17%) and Australia (n = 11, 24%). While there is an increasing trend of incorporating climate change into spatial prioritisation, we found that serious gaps in current methodologies still exist. Future research must focus on developing methodologies that allow planners to incorporate human responses to climate change and recognise that discrete climate impacts (e.g. extreme events), which are increasing in frequency and severity, must be addressed within the spatial prioritisation framework. By identifying obvious gaps and highlighting future research needs this review will help practitioners better plan for conservation action in the face of multiple threats including climate change.

Lankford-Bingle, A. J., L. K. Svancara, and K. Vierling. 2015. **A new framework for spatio-temporal climate change impact assessment for terrestrial wildlife.** Environmental Management 56:1514-1527.

Abstract. We describe a first step framework for climate change species' impact assessments that produces spatially and temporally heterogeneous models of climate impacts. Case study results are provided for great gray owl (*Strix nebulosa*) in Idaho as an example of framework application. This framework applies species-specific sensitivity weights to spatial and seasonal models of climate exposure to produce spatial and seasonal models of climate impact. We also evaluated three methods of calculating sensitivity by comparing spatial models of combined exposure and sensitivity. We found the methods used to calculated sensitivity showed little difference, except where sensitivity was directional (i.e., more sensitive to an increase in temperature than a decrease). This approach may assist in the development of State Wildlife Action Plans and other wildlife management plans in the face of potential future climate change.

Seidl, R., T. A. Spies, D. L. Peterson, S. L. Stephens, and J. A. Hicke. 2016. **REVIEW: Searching for resilience: addressing the impacts of changing disturbance regimes on forest ecosystem services.** Journal of Applied Ecology 53:120-129.

Abstract. The provisioning of ecosystem services to society is increasingly under pressure from global change. Changing disturbance regimes are of particular concern in this context due to their high potential impact on ecosystem structure, function and composition. Resilience-based stewardship is advocated to address these changes in ecosystem management, but its operational implementation has remained challenging.

We review observed and expected changes in disturbance regimes and their potential impacts on provisioning, regulating, cultural and supporting ecosystem services, concentrating on temperate and boreal forests. Subsequently, we focus on resilience as a powerful concept to quantify and address these changes and their impacts, and present an approach towards its operational application using established methods from disturbance ecology.

We suggest using the range of variability concept – characterizing and bounding the long-term behaviour of ecosystems – to locate and delineate the basins of attraction of a system. System recovery in relation to its range of variability can be used to measure resilience of ecosystems, allowing inferences on both engineering resilience (recovery rate) and monitoring for regime shifts (directionality of recovery trajectory).

It is important to consider the dynamic nature of these properties in ecosystem analysis and management decision-making, as both disturbance processes and mechanisms of resilience will be subject to changes in the future. Furthermore, because ecosystem services are at the interface between natural and human systems, the social dimension of resilience (social adaptive capacity and range of variability) requires consideration in responding to changing disturbance regimes in forests.

Synthesis and applications. Based on examples from temperate and boreal forests we synthesize principles and pathways for fostering resilience to changing disturbance regimes in ecosystem management. We conclude that future work should focus on testing and implementing these pathways in different contexts to make ecosystem services provisioning more robust to changing disturbance regimes and advance our understanding of how to cope with change and uncertainty in ecosystem management.

Sociology and Economics

Blades, J. J., P. Z. Klos, K. B. Kemp, T. E. Hall, J. E. Force, P. Morgan, and W. T. Tinkham. 2016. **Forest managers' response to climate change science: Evaluating the constructs of boundary objects and organizations.** Forest Ecology and Management 360:376-387.

Abstract. Land managers lack locally relevant climate change science and are urgently calling for research to inform management. We conducted four climate change workshops in the U.S. northern Rocky Mountains and applied multiple methods of inquiry to understand whether the boundary organization (workshops) and objects (climate change science products) were perceived as credible and useful. Perceived credibility and usefulness increased overall, and regional-scale hydrologic information was deemed most useful. Regression models found that intention to use climate change science was predicted by usefulness, credibility, and organizational barriers. We discuss the importance of uncertainty, visualization, and best practices for effective climate change deliberation using boundary objects and organizations at the research–management interface.

Knutti, R. and J. Rogelj. 2015. **The legacy of our CO_2 emissions: a clash of scientific facts, politics and ethics.** Climatic Change 133(3): 361-373.

Abstract. Of the carbon dioxide that we emit, a substantial fraction remains in the atmosphere for thousands of years. Combined with the slow response of the climate system, this results in the global temperature increase resulting from CO2 being nearly proportional to the total emitted amount of CO2 since preindustrial times. This has a number of simple but far-reaching consequences that raise important questions for climate change mitigation, policy and ethics. Even if anthropogenic emissions of CO2 were stopped, most of the realized climate change would persist for centuries and thus be irreversible on human timescales, yet standard economic thinking largely discounts these long-term intergenerational effects. Countries and

generations to first order contribute to both past and future climate change in proportion to their total emissions. A global temperature target implies a CO2 “budget” or “quota”, a finite amount of CO2 that society is allowed to emit to stay below the target. Distributing that budget over time and between countries is an ethical challenge that our world has so far failed to address. Despite the simple relationship between CO2 emissions and temperature, the consequences for climate policy and for sharing the responsibility of reducing global CO2 emissions can only be drawn in combination with judgments about equity, fairness, the value of future generations and our attitude towards risk.

Mera, R., N. Massey, D. E. Rupp, P. W. Mote, M. Allen, and P. C. Frumhoff. 2015. **Climate change, climate justice and the application of probabilistic event attribution to summer heat extremes in the California Central Valley.** Climatic Change 133:427-438.

Abstract. Probabilistic event attribution (PEA) is an important tool for assessing the contribution of climate change to extreme weather events. Here, PEA is applied to explore the climate attribution of recent extreme heat events in California’s Central Valley. Heat waves have become progressively more severe due to increasing relative humidity and nighttime temperatures, which increases the health risks of exposed communities, especially Latino farmworkers and other socioeconomically disadvantaged communities. Using a superensemble of simulations with the Hadley Centre Regional Model (HadRM3P), we find that (1) simulations of the hottest summer days during the 2000s were twice as likely to occur using observed levels of greenhouse gases than in a counterfactual world without major human activities, suggesting a strong relationship between heat extremes and the increase in human emissions of greenhouse gases, (2) detrimental impacts of heat on public health-relevant variables, such as the number of days above 40 °C, can be quantified and attributed to human activities using PEA, and (3) PEA can serve as a tool for addressing climate justice concerns of populations within developed nations who are disproportionately exposed to climate risks.