Climate Change Quarterly: Summer 2013

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Climate Projections

Bumbaco, Karin A., Kathie D. Dello, Nicholas A. Bond. 2013. **History of Pacific Northwest Heat Waves: Synoptic Pattern and Trends.** Journal of Applied Meteorology and Climatology*.* 52: 1618–1631. doi: http://dx.doi.org/10.1175/JAMC-D-12-094.1

Abstract. A historical record of Pacific Northwest (defined here as west of the Cascade Mountains in Washington and Oregon) heat waves is identified using the U.S. Historical Climate Network, version 2, daily data (1901–2009). Both daytime and nighttime events are examined, defining a heat wave as three consecutive days above the 99th percentile for the maximum and minimum temperature anomalies separately. Although the synoptic characteristics of the daytime and nighttime heat events are similar, they do indicate some differences between the two types of events. Most notable is a stronger influence of downslope warming over the Cascade Mountains for the daytime events versus a more important role of precipitable water content for the nighttime events, presumably through its impact on downward longwave radiative fluxes. Current research suggests that the frequency and duration of heat waves are expected to increase in much of the United States, and analysis of the heat events reveals that a significant, increasing trend in the frequency of the nighttime events is already occurring in the Pacific Northwest. A heat wave occurred in 2009 that set all-time-record maximum temperatures in many locations and ranked as the second strongest daytime event and the longest nighttime event in the record.

Chen, J.*,* F. P. Brissette*,* D. Chaumont*,* and M. Braun. 2013. **Finding appropriate bias correction methods in downscaling precipitation for hydrologic impact studies over North America*.*** Water Resources Research 49: 4187–4205. doi*:*10.1002/wrcr.20331.

Abstract. This work compares the performance of six bias correction methods for hydrological modeling over 10 North American river basins. Four regional climate model (RCM) simulations driven by reanalysis data taken from the North American Regional Climate Change Assessment Program intercomparison project are used to evaluate the sensitivity of bias correction methods to climate models. The hydrological impacts of bias correction methods are assessed through the comparison of streamflows simulated by a lumped empirical hydrology model (HSAMI) using raw RCM-simulated and bias-corrected precipitation time series. The results show that RCMs are biased in the simulation of precipitation, which results in biased simulated streamflows. All six bias correction methods are capable of improving the RCM-simulated precipitation in the representation of watershed streamflows to a certain degree. However, the performance of hydrological modeling depends on the choice of a bias correction method and the location of a watershed. Moreover, distribution-based methods are consistently better than mean-based methods. A low coherence between the temporal sequences of observed and RCM-simulated (driven by reanalysis data) precipitation was observed over 5 of the 10 watersheds studied. All bias corrections methods fail over these basins due to their inability to specifically correct the temporal structure of daily precipitation occurrence, which is critical for hydrology modeling. In this study, this failure occurred on basins that were distant from the RCM model boundaries and where topography exerted little control over precipitation. These results indicate that bias correction performance is location dependent and that a careful validation should always be performed, especially on studies over new regions.

Cook, Benjamin I., Richard Seager, Ron L. Miller, and Joseph A. Mason. 2013. **Intensification of North American Megadroughts through Surface and Dust Aerosol Forcing.** Journal of Climate 26: 4414–4430. doi: http://dx.doi.org/10.1175/JCLI-D-12-00022.1

Abstract. Tree-ring-based reconstructions of the Palmer drought severity index (PDSI) indicate that, during the Medieval Climate Anomaly (MCA), the central plains of North America experienced recurrent periods of drought spanning decades or longer. These megadroughts had exceptional persistence compared to more recent events, but the causes remain uncertain. The authors conducted a suite of general circulation model experiments to test the impact of sea surface temperature (SST) and land surface forcing on the MCA megadroughts over the central plains. The land surface forcing is represented as a set of dune mobilization boundary conditions, derived from available geomorphological evidence and modeled as increased bare soil area and a dust aerosol source (32°–44°N, 105°–95°W). In the experiments, cold tropical Pacific SST forcing suppresses precipitation over the central plains but cannot reproduce the overall drying or persistence seen in the PDSI reconstruction. Droughts in the scenario with dust aerosols, however, are amplified and have significantly longer persistence than in other model experiments, more closely matching the reconstructed PDSI. This additional drying occurs because the dust increases the shortwave planetary albedo, reducing energy inputs to the surface and boundary layer. The energy deficit increases atmospheric stability, inhibiting convection and reducing cloud cover and precipitation over the central plains. Results from this study provide the first model-based evidence that dust aerosol forcing and land surface changes could have contributed to the intensity and persistence of the central plains megadroughts, although

uncertainties remain in the formulation of the boundary conditions and the future importance of these feedbacks.

Gregory, J. M., N. J. White, J. A. Church, M. F. P. Bierkens, J. E. Box, M. R. van den Broeke, J. G. Cogley, X. Fettweis, E. Hanna, P. Huybrechts, L. F. Konikow, P. W. Leclercq, B. Marzeion, J. Oerlemans, M. E. Tamisiea, Y. Wada, L. M. Wake, and R. S. W. van de Wal 2013. **Twentieth-Century Global-Mean Sea Level Rise: Is the Whole Greater than the Sum of the Parts?** Journal of Climate 26: 4476–4499. doi: http://dx.doi.org/10.1175/JCLI-D-12-00319.1

Abstract. Confidence in projections of global-mean sea level rise (GMSLR) depends on an ability to account for GMSLR during the twentieth century. There are contributions from ocean thermal expansion, mass loss from glaciers and ice sheets, groundwater extraction, and reservoir impoundment. Progress has been made toward solving the "enigma" of twentieth-century GMSLR, which is that the observed GMSLR has previously been found to exceed the sum of estimated contributions, especially for the earlier decades. The authors propose the following: thermal expansion simulated by climate models may previously have been underestimated because of their not including volcanic forcing in their control state; the rate of glacier mass loss was larger than previously estimated and was not smaller in the first half than in the second half of the century; the Greenland ice sheet could have made a positive contribution throughout the century; and groundwater depletion and reservoir impoundment, which are of opposite sign, may have been approximately equal in magnitude. It is possible to reconstruct the time series of GMSLR from the quantified contributions, apart from a constant residual term, which is small enough to be explained as a long-term contribution from the Antarctic ice sheet. The reconstructions account for the observation that the rate of GMSLR was not much larger during the last 50 years than during the twentieth century as a whole, despite the increasing anthropogenic forcing. Semiempirical methods for projecting GMSLR depend on the existence of a relationship between global climate change and the rate of GMSLR, but the implication of the authors' closure of the budget is that such a relationship is weak or absent during the twentieth century.

Huntingford, Chris, Philip D. Jones, Valerie N. Livina, Timothy M. Lenton and Peter M. Cox. 2013. **No increase in global temperature variability despite changing regional patterns.** Nature 500: 327–330. doi:10.1038/nature12310

Abstract. Evidence from Greenland ice cores shows that year-to-year temperature variability was probably higher in some past cold periods, but there is considerable interest in determining whether global warming is increasing climate variability at present. This interest is motivated by an understanding that increased variability and resulting extreme weather conditions may be more difficult for society to adapt to than altered mean conditions. So far, however, in spite of suggestions of increased variability, there is considerable uncertainty as to whether it is occurring. Here we show that although fluctuations in annual temperature have indeed shown substantial geographical variation over the past few decades, the time-evolving standard deviation of globally averaged temperature anomalies has been stable. A feature of the changes has been a tendency for many regions of low variability to experience increases, which might contribute to the perception of increased climate volatility. The normalization of temperature anomalies creates the impression of larger relative overall increases, but our use of absolute values, which we argue is a more appropriate approach, reveals little change. Regionally, greater year-to-year changes recently occurred in much of North America and Europe. Many climate models predict that total variability will ultimately decrease under high greenhouse gas concentrations, possibly associated with reductions in sea-ice cover. Our findings contradict the view that a warming world will automatically be one of more overall climatic variation.

Muschinski, T. and J. I. Katz. 2013. **Trends in hourly rainfall statistics in the United States under a warming climate.** Nature Climate Change 3: 577–580. doi:10.1038/nclimate1828

Abstract. It is now widely accepted that the mean world climate has warmed since the beginning of climatologically significant anthropogenic emission of greenhouse gases. Warming may be accompanied by changes in the rate of extreme weather events such as severe storms and drought. Here we use hourly precipitation data from 13 stations in the 48 contiguous United States to determine trends in the frequency of such events, taking the normalized variance and a renormalized fourth moment of the precipitation measurements, averaged over decades, as objective measures of the frequency and severity of extreme weather. Using data mostly from the period 1940–1999 but also two longer data series, periods that include the rapid warming that seems to have begun at approximately 1970, we find a significant increase of $6.5 \pm 1.3\%(1\sigma)$ per decade in the normalized variance at a site on the Olympic Peninsula at which it is low. We place statistical limits on any trend at the remaining 12 sites, where the normalized variance and its uncertainty are larger. At most sites these limits are consistent with the same rate of linear increase as at the Olympic Peninsula site, but exclude the same rate of percentage increase.

Smith. Tiffany T., Benjamin F. Zaitchik, and Julia M. Gohlke. 2013. **Heat waves in the United States: definitions, patterns and trends.** Climatic Change 118(3-4): 811-825.

Abstract. High temperatures and heat waves are related but not synonymous concepts. Heat waves, generally understood to be acute periods of extreme warmth, are relevant to a wide range of stakeholders because of the impacts that these events have on human health and activities and on natural environments. Perhaps because of the diversity of communities engaged in heat wave monitoring and research, there is no single, standard definition of a heat wave. Experts differ in which threshold values (absolute versus relative), duration and ancillary variables to incorporate into heat wave definitions. While there is value in this diversity of perspectives, the lack of a unified index can cause confusion when discussing patterns, trends, and impacts. Here, we use data from the North American Land Data Assimilation System to examine patterns and trends in 15 previously published heat wave indices for the period 1979–2011 across the Continental United States. Over this period the Southeast region saw the highest number of heat wave days for the majority of indices considered. Positive trends (increases in number of heat wave days per year) were greatest in the Southeast and Great Plains regions, where more than 12 % of the land area experienced significant increases in the number of heat wave days per year for the majority of heat wave indices. Significant negative trends were relatively rare, but were found in portions of the Southwest, Northwest, and Great Plains.

Carbon and Carbon Storage

Devine, Warren D.; Footen, Paul W.; Harrison, Robert B.; Terry, Thomas A.; Harrington, Constance A.; Holub, Scott M.; Gould, Peter J. 2013. **Estimating tree biomass, carbon, and nitrogen in two vegetation control treatments in an 11-year-old Douglas-fir plantation on a highly productive site.** Res. Pap. PNW-RP-591. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.

Abstract. We sampled trees grown with and without competing vegetation control in an 11-year-old Douglas-fir (Pseudotsuga menziesii var. menziesii (Mirb.) Franco) plantation on a highly productive site in southwestern Washington to create diameter-based allometric equations for estimating individual-tree bole, branch, foliar,and total aboveground biomass. We used these equations to estimate per-hectare aboveground biomass, nitrogen (N), and carbon (C) content, and compared these results to (1) estimates based on biomass equations published in other studies, and (2) estimates made using the mean-tree method rather than allometric equations. Component and total-tree biomass equations were not influenced by the presence of vegetation control, although per-hectare biomass, C, and N estimates were greater where vegetation control was applied. Our biomass estimates differed from estimates using previously published biomass equations by as much as 23 percent. When using the mean-tree biomass estimation approach, we found that incorporating a previously published biomass equation improved accuracy of the mean-tree diameter calculation.

Matsuzaki, Eiji, Paul Sanborn, Arthur L. Fredeen, Cindy H. Shaw, and Chris Hawkins. 2013. **Carbon stocks in managed and unmanaged old-growth western redcedar and western hemlock stands of Canada's inland temperate rainforests.** Forest Ecology and Management 297: 108-119.

Abstract. In the inland temperate rainforests (ITRs) of east-central British Columbia (BC), there is a lack of baseline carbon (C) stocks information for managed and unmanaged stands of old-growth western redcedar and hemlock. To fill the knowledge gap, we estimated C stocks of live trees, snags, coarse woody debris and forest floor (excluding mineral soil) and evaluated impacts of harvesting on these C stocks. We also accounted for heart-rot in stem wood of live cedar and hemlock, and identified uncertainties in live-tree C stocks estimation for more accurate assessment of the C. Forests stands were selected from three previously established silvicultural systems trials that contrasted three levels of harvesting intensity (clear-cut (CC, 0% retention), group retention (GR, 30%), group selection (GS, 70%)), and uncut old-growth (100%). Despite a high incidence of heart-rot, live-tree and total forest (minus mineral soil) C stocks (348 ± 155 and 455 ± 156 Mg C ha^{-1}, respectively) in uncut old-growth ITR stands were within the range of regional averages for old-growth forests in the Pacific Northwest (US) and coastal cedar and hemlocks forests of BC. Intensive harvesting (CC and GR) resulted in significant reductions in total forest C stocks (78% and 64%) relative to uncut old-growth stands. By contrast, total forest C stocks in stands where high-retention harvesting (GS) occurred were reduced by only 13% (not significant) relative to uncut old-growth stands. Analysis of uncertainty identified allometric equations to be the largest contributor to total uncertainty in live-tree C stocks, indicating the need to develop more robust equations to reduce the uncertainty for more accurate evaluation of harvesting impacts in old ITRs. Although heart-rot had no significant effects on forest C stocks in this study, we need a better scientific understanding of their contribution to live-tree C in this ecosystem. Nonetheless, these results underscore the importance of conserving C-rich old ITRs where possible and the potential for high-retention harvesting to maintain C stocks in this forest type.

Veraverbeke, Sander and Simon J. Hook. 2013. **Evaluating spectral indices and spectral mixture analysis for assessing fire severity, combustion completeness and carbon emissions.** International Journal of Wildland Fire 22(5): 707-720. http://dx.doi.org/10.1071/WF12168

Abstract. We used a Landsat Thematic Mapper (TM) image from the 2011 Wallow fire in Arizona, USA, in combination with field data to assess different methods for determining fire severity. These include the normalised burn ratio (NBR), the differenced NBR (dNBR), the relative dNBR (RdNBR) and the burned fraction (BF) estimated by spectral mixture analysis (SMA). The Geo Composite Burn Index (GeoCBI) and vegetation mortality data were used as

ground truth. Of all the remotely sensed measures evaluated the dNBR had the best performance (GeoCBI–dNBR R2 = 0.84), which supports the operational use of the dNBR for post-fire management. Of the other remotely sensed measures, the SMA-derived BF also had moderately high correlations with the GeoCBI (R2 = 0.66). Both approaches demonstrated their usefulness for refining modelled CC values, however, the SMA approach has the advantage of providing transferable quantitative estimates without the need for calibration with field data. The carbon emission estimates that included fire severity were more than 50% lower than the estimate derived from modelling alone. These results suggest that for certain fire types, especially mixed-severity fires, current emission estimates are significantly overestimated, which will affect global carbon emission estimates from wildfires.

Phenology Changes

Mazer, Susan J., Steven E. Travers, Benjamin I. Cook, T. Jonathan Davies, Kjell Bolmgren, Nathan J. B. Kraft, Nicolas Salamin and David W. Inouye. 2013. **Flowering date of taxonomic families predicts phenological sensitivity to temperature: Implications for forecasting the effects of climate change on unstudied taxa.** American Journal of Botany 100(7): 1381-1397.

Abstract. *Premise of the study:* Numerous long-term studies in seasonal habitats have tracked interannual variation in first flowering date (FFD) in relation to climate, documenting the effect of warming on the FFD of many species. Despite these efforts, long-term phenological observations are still lacking for many species. If we could forecast responses based on taxonomic affinity, however, then we could leverage existing data to predict the climate-related phenological shifts of many taxa not yet studied.

Methods: We examined phenological time series of 1226 species occurrences (1031 unique species in 119 families) across seven sites in North America and England to determine whether family membership (or family mean FFD) predicts the sensitivity of FFD to standardized interannual changes in temperature and precipitation during seasonal periods before flowering and whether families differ significantly in the direction of their phenological shifts.

Key results: Patterns observed among species *within* and *across* sites are mirrored among family means *across* sites; early-flowering families advance their FFD in response to warming more than late-flowering families. By contrast, we found no consistent relationships among taxa between mean FFD and sensitivity to precipitation as measured here.

Conclusions: Family membership can be used to identify taxa of high and low sensitivity to temperature within the seasonal, temperate zone plant communities analyzed here. The high sensitivity of early-flowering families

(and the absence of early-flowering families not sensitive to temperature) may reflect plasticity in flowering time, which may be adaptive in environments where early-season conditions are highly variable among years.

Ovaskainen, Otso, Svetlana Skorokhodova, Marina Yakovleva, Alexander Sukhov, Anatoliy Kutenkov, Nadezhda Kutenkova, Anatoliy Shcherbakov, Evegeniy Meyke, and Maria del Mar Delgado. 2013. **Community-level phenological response to climate change.** Proceedings of the National Academy of Sciences 110(33): 13434–13439.

Abstract. Climate change may disrupt interspecies phenological synchrony, with adverse consequences to ecosystem functioning. We present here a 40-y-long time series on 10,425 dates that were systematically collected in a single Russian locality for 97 plant, 78 bird, 10 herptile, 19 insect, and 9 fungal phenological events, as well as for 77 climatic events related to temperature, precipitation, snow, ice, and frost. We show that species are shifting their phenologies at dissimilar rates, partly because they respond to different climatic factors, which in turn are shifting at dissimilar rates. Plants have advanced their spring phenology even faster than average temperature has increased, whereas migratory birds have shown more divergent responses and shifted, on average, less than plants. Phenological events of birds and insects were mainly triggered by climate cues (variation in temperature and snow and ice cover) occurring over the course of short periods, whereas many plants, herptiles, and fungi were affected by long-term climatic averages. Year-to-year variation in plants, herptiles, and insects showed a high degree of synchrony, whereas the phenological timing of fungi did not correlate with any other taxonomic group. In many cases, species that are synchronous in their year-to-year dynamics have also shifted in congruence, suggesting that climate change may have disrupted phenological synchrony less than has been previously assumed. Our results illustrate how a multidimensional change in the physical environment has translated into a community-level change in phenology.

Wolkovich, Elizabeth M., T. Jonathan Davies, Hanno Schaefer, Elsa E. Cleland, Benjamin I. Cook, Steven E. Travers, Charles G. Willis and Charles C. Davis. 2013. **Temperature-dependent shifts in phenology contribute to the success of exotic species with climate change.** American Journal of Botany 100(7): 1407-1421.

Abstract. *Premise of the study:* The study of how phenology may contribute to the assembly of plant communities has a long history in ecology. Climate change has brought renewed interest in this area, with many studies examining how phenology may contribute to the success of exotic species. In particular, there is increasing evidence that exotic species occupy unique

phenological niches and track climate change more closely than native species.

Methods: Here, we use long-term records of species' first flowering dates from five northern hemisphere temperate sites (Chinnor, UK and in the United States, Concord, Massachusetts; Fargo, North Dakota; Konza Prairie, Kansas; and Washington, D.C.) to examine whether invaders have distinct phenologies. Using a broad phylogenetic framework, we tested for differences between exotic and native species in mean annual flowering time, phenological changes in response to temperature and precipitation, and longer-term shifts in first flowering dates during recent pronounced climate change ("flowering time shifts").

Key results: Across North American sites, exotic species have shifted flowering with climate change while native species, on average, have not. In the three mesic systems, exotic species exhibited higher tracking of interannual variation in temperature, such that flowering advances more with warming, than native species. Across the two grassland systems, however, exotic species differed from native species primarily in responses to precipitation and soil moisture, not temperature.

Conclusions: Our findings provide cross-site support for the role of phenology and climate change in explaining species' invasions. Further, they support recent evidence that exotic species may be important drivers of extended growing seasons observed with climate change in North America.

Species Range Changes

Blois, Jessica L., John W. Williams, Matthew C. Fitzpatrick, Stephen T. Jackson, and Simon Ferrier. 2013. **Space can substitute for time in predicting climate-change effects on biodiversity.** Proceedings of the National Academy of Sciences 110(23): 9374–9379

Abstract. "Space-for-time" substitution is widely used in biodiversity modeling to infer past or future trajectories of ecological systems from contemporary spatial patterns. However, the foundational assumption—that drivers of spatial gradients of species composition also drive temporal changes in diversity—rarely is tested. Here, we empirically test the space-for-time assumption by constructing orthogonal datasets of compositional turnover of plant taxa and climatic dissimilarity through time and across space from Late Quaternary pollen records in eastern North America, then modeling climate-driven compositional turnover. Predictions relying on space-for-time substitution were ~72% as accurate as "time-for-time" predictions. However, space-for-time substitution performed poorly during the Holocene when temporal variation in climate was small relative to spatial variation and required subsampling to match the extent of spatial and temporal climatic gradients. Despite this caution, our results generally

support the judicious use of space-for-time substitution in modeling community responses to climate change.

Ettinger, Ailene K. and Janneke HilleRisLambers. 2013. **Climate isn't everything: Competitive interactions and variation by life stage will also affect range shifts in a warming world.** American Journal of Botany 100(7): 1344-1355.

Abstract. *Premise of the study:* The extent to which climate controls species' range limits is a classic biological question that is particularly relevant given anthropogenic climate change. While climate is known to play a role in species distributions, biotic interactions such as competition also affect range limits. Furthermore, climatic and biotic controls of ranges may vary in strength across life stages, implying complex range shift dynamics with climate change.

Methods: We quantified climatic and competitive influences on growth of juvenile and adult trees of three conifer species on Mt. Rainier, Washington, United States. We collected annual growth data of these trees, which we compared to the competitive environment and annual climate (100 years of data) experienced by each individual.

Key results: We found that the relationships between growth and climate and between growth and competition differed by life stage and location. Growth was sensitive to heavy snowpack and cold temperatures at high elevation upper limits (treeline), but growth was poorly explained by climate in low elevation closed-canopy forests. Competitive effects on growth were more important for saplings than adults, but did not become more important at either upper or lower range limits.

Conclusions: In all, our results suggest that range shifts under climate change will differ at leading vs. trailing edges. At treeline, warmer temperatures will lead to increased growth and likely to range expansion. However, climate change will have less dramatic effects in low elevation closed-canopy forest communities, where growth is less strongly limited by climate, especially at young life stages.

Jackson, S. T. 2013. **Natural, potential and actual vegetation in North America.** Journal of Vegetation Science 24: 772–776. doi: 10.1111/jvs.12004

Abstract. The potential natural vegetation (PNV) concept has parallel applications in Europe and North America. Paleoecological studies in parts of North America provide records of vegetation patterns and dynamics under little or no human disturbance. Something resembling PNV emerges at millennial temporal scales and at regional to subcontinental spatial scales. However, at finer spatial and temporal scales, actual vegetation often displays properties of inertia, contingency and hysteresis, most frequently because of climatic variability across multiple timescales and the episodic

nature of disturbance and establishment. Thus, in the absence of human disturbance, the actual vegetation that develops at a site may not resemble a particular PNV ideal, but could instead represent one of any number of potential outcomes constrained by historically contingent processes. PNV may best be viewed as an artificial construct, with utility in some settings. Its utility may diminish and even be detrimental in a rapidly changing environment.

Leroux, Shawn J., Maxim Larrivée, Véronique Boucher-Lalonde, Amy Hurford, Juan Zuloaga, Jeremy T. Kerr, and Frithjof Lutscher. 2013. **Mechanistic models for the spatial spread of species under climate change.** Ecological Applications 23:815–828. http://dx.doi.org/10.1890/12-1407.1

Abstract. Global climate change is a major threat to biodiversity. The most common methods for predicting the response of biodiversity to changing climate do not explicitly incorporate fundamental evolutionary and ecological processes that determine species responses to changing climate, such as reproduction, dispersal, and adaptation. We provide an overview of an emerging mechanistic spatial theory of species range shifts under climate change. This theoretical framework explicitly defines the ecological processes that contribute to species range shifts via biologically meaningful dispersal, reproductive, and climate envelope parameters. We present methods for estimating the parameters of the model with widely available species occurrence and abundance data and then apply these methods to empirical data for 12 North American butterfly species to illustrate the potential use of the theory for global change biology. The model predicts species persistence in light of current climate change and habitat loss. On average, we estimate that the climate envelopes of our study species are shifting north at a rate of 3.25 ± 1.36 km/yr (mean ± SD) and that our study species produce 3.46 ± 1.39 (mean ± SD) viable offspring per individual per year. Based on our parameter estimates, we are able to predict the relative risk of our 12 study species for lagging behind changing climate. This theoretical framework improves predictions of global change outcomes by facilitating the development and testing of hypotheses, providing mechanistic predictions of current and future range dynamics, and encouraging the adaptive integration of theory and data. The theory is ripe for future developments such as the incorporation of biotic interactions and evolution of adaptations to novel climatic conditions, and it has the potential to be a catalyst for the development of more effective conservation strategies to mitigate losses of biodiversity from global climate change.

Mahlstein, Irina, John S. Daniel and Susan Solomon. 2013. **Pace of shifts in climate regions increases with global temperature.** Nature Climate Change 3: 739–743. doi:10.1038/nclimate1876

Abstract. Human-induced climate change causes significant changes in local climates, which in turn lead to changes in regional climate zones. Large shifts in the world distribution of Köppen–Geiger climate classifications by the end of this century have been projected. However, only a few studies have analysed the pace of these shifts in climate zones, and none has analysed whether the pace itself changes with increasing global mean temperature. In this study, pace refers to the rate at which climate zones change as a function of amount of global warming. Here we show that present climate projections suggest that the pace of shifting climate zones increases approximately linearly with increasing global temperature. Using the RCP8.5 emissions pathway, the pace nearly doubles by the end of this century and about 20% of all land area undergoes a change in its original climate. This implies that species will have increasingly less time to adapt to Köppen zone changes in the future, which is expected to increase the risk of extinction.

Ordonez, Alejandro. 2013. **Realized climatic niche of North American plant taxa lagged behind climate during the end of the Pleistocene.** American Journal of Botany 100(7): 1255-1265.

Abstract. *Premise of the study:* Predicting species responses to climate change has become a dynamic field in global change research. A crucial question in this debate is whether-or-not species have been and will be able to respond quickly enough to keep up with changing climatic conditions.

Methods: Focusing on fossil pollen records and paleoclimatic simulations, this work assesses the change in realized climatic niches (climatic temporal trajectories) of 20 plant taxa over the last 16000 yr, and whether this tracking has been the same for different climatic niche dimensions.

Key results: Climatic factors showed a consistent trend toward warmer temperatures and higher precipitation. Although the response types varied across taxa, species' realized climatic niches lagged in response to changes in climatic conditions. Temperature niches responded to late Pleistocene (16000–11000 yr ago) climate change, but did so at slower rates than changes in climatic conditions during the same period. In contrast, precipitation niches were relatively stable from 16000 to 11000 yr ago, but still lagged behind changes in climatic conditions. Changes in temperature and precipitation niches eventually stabilized during the Holocene (11000–1000 yr ago).

Conclusions: These results underscore how the climatic niche realized at any one moment represents a subset of the climate conditions in which a taxon can persist, particularly during times of fast climatic change. Variability in the rates of temporal trajectories across evaluated climatic variables showed taxa specific responses to changes in climatic conditions over time and

emphasizes the need to incorporate variation, intensity, and duration of lag effects in assessments of the possible effects of climatic change.

Svenning, Jens-Christian and Brody Sandel. 2013. **Disequilibrium vegetation dynamics under future climate change.** American Journal of Botany 100(7): 1266-1286.

Abstract. *Premise of the study:* Near-future climate changes are likely to elicit major vegetation changes. Disequilibrium dynamics, which occur when vegetation comes out of equilibrium with climate, are potentially a key facet of these. Understanding these dynamics is crucial for making accurate predictions, informing conservation planning, and understanding likely changes in ecosystem function on time scales relevant to society. However, many predictive studies have instead focused on equilibrium end-points with little consideration of the transient trajectories.

Methods: We review what we should expect in terms of disequilibrium vegetation dynamics over the next 50–200 yr, covering a broad range of research fields including paleoecology, macroecology, landscape ecology, vegetation science, plant ecology, invasion biology, global change biology, and ecosystem ecology.

Key results: The expected climate changes are likely to induce marked vegetation disequilibrium with climate at both leading and trailing edges, with leading-edge disequilibrium dynamics due to lags in migration at continental to landscape scales, in local population build-up and succession, in local evolutionary responses, and in ecosystem development, and trailing-edge disequilibrium dynamics involving delayed local extinctions and slow losses of ecosystem structural components. Interactions with habitat loss and invasive pests and pathogens are likely to further contribute to disequilibrium dynamics. Predictive modeling and climate-change experiments are increasingly representing disequilibrium dynamics, but with scope for improvement.

Conclusions: The likely pervasiveness and complexity of vegetation disequilibrium is a major challenge for forecasting ecological dynamics and, combined with the high ecological importance of vegetation, also constitutes a major challenge for future nature conservation.

Vellend Mark, Carissa D. Brown, Heather M. Kharouba, Jenny L. McCune and Isla H. Myers-Smith. 2013. **Historical ecology: Using unconventional data sources to test for effects of global environmental change.** American Journal of Botany 100(7): 1294-1395.

Abstract. Predicting the future ecological impact of global change drivers requires understanding how these same drivers have acted in the past to produce the plant populations and communities we see today. Historical ecological data sources have made contributions of central importance to global change biology, but remain outside the toolkit of most ecologists. Here we review the strengths and weaknesses of four unconventional sources of historical ecological data: land survey records, "legacy" vegetation data, historical maps and photographs, and herbarium specimens. We discuss recent contributions made using these data sources to understanding the impacts of habitat disturbance and climate change on plant populations and communities, and the duration of extinction–colonization time lags in response to landscape change. Historical data frequently support inferences made using conventional ecological studies (e.g., increases in warm-adapted species as temperature rises), but there are cases when the addition of different data sources leads to different conclusions (e.g., temporal vegetation change not as predicted by chronosequence studies). The explicit combination of historical and contemporary data sources is an especially powerful approach for unraveling long-term consequences of multiple drivers of global change. Despite the limitations of historical data, which include spotty and potentially biased spatial and temporal coverage, they often represent the only means of characterizing ecological phenomena in the past and have proven indispensable for characterizing the nature, magnitude, and generality of global change impacts on plant populations and communities.

Forest Vegetation

Alberto, F. J., Aitken, S. N., Alía, R., González-Martínez, S. C., Hänninen, H., Kremer, A., Lefèvre, F., Lenormand, T., Yeaman, S., Whetten, R. and Savolainen, O. 2013. **Potential for evolutionary responses to climate change – evidence from tree populations.** Global Change Biology 19: 1645–1661. doi: 10.1111/gcb.12181

Abstract. Evolutionary responses are required for tree populations to be able to track climate change. Results of 250 years of common garden experiments show that most forest trees have evolved local adaptation, as evidenced by the adaptive differentiation of populations in quantitative traits, reflecting environmental conditions of population origins. On the basis of the patterns of quantitative variation for 19 adaptation-related traits studied in 59 tree species (mostly temperate and boreal species from the Northern hemisphere), we found that genetic differentiation between populations and clinal variation along environmental gradients were very common (respectively, 90% and 78% of cases). Thus, responding to climate change will likely require that the quantitative traits of populations again match their environments. We examine what kind of information is needed for evaluating the potential to respond, and what information is already available. We review the genetic models related to selection responses, and what is known currently about the genetic basis of the traits. We address special problems to be found at the range margins, and highlight the need for more modeling to understand specific issues at southern and northern margins. We need new common garden experiments for less known species. For extensively

studied species, new experiments are needed outside the current ranges. Improving genomic information will allow better prediction of responses. Competitive and other interactions within species and interactions between species deserve more consideration. Despite the long generation times, the strong background in quantitative genetics and growing genomic resources make forest trees useful species for climate change research. The greatest adaptive response is expected when populations are large, have high genetic variability, selection is strong, and there is ecological opportunity for establishment of better adapted genotypes.

Anderson-Teixeira, K. J., Miller, A. D., Mohan, J. E., Hudiburg, T. W., Duval, B. D. and DeLucia, E. H. 2013. **Altered dynamics of forest recovery under a changing climate.** Global Change Biology 19: 2001–2021. doi: 10.1111/gcb.12194

Abstract. Forest regeneration following disturbance is a key ecological process, influencing forest structure and function, species assemblages, and ecosystem–climate interactions. Climate change may alter forest recovery dynamics or even prevent recovery, triggering feedbacks to the climate system, altering regional biodiversity, and affecting the ecosystem services provided by forests. Multiple lines of evidence – including global-scale patterns in forest recovery dynamics; forest responses to experimental manipulation of CO_2, temperature, and precipitation; forest responses to the climate change that has already occurred; ecological theory; and ecosystem and earth system models – all indicate that the dynamics of forest recovery are sensitive to climate. However, synthetic understanding of how atmospheric CO_2 and climate shape trajectories of forest recovery is lacking. Here, we review these separate lines of evidence, which together demonstrate that the dynamics of forest recovery are being impacted by increasing atmospheric CO_2 and changing climate. Rates of forest recovery generally increase with CO_2, temperature, and water availability. Drought reduces growth and live biomass in forests of all ages, having a particularly strong effect on seedling recruitment and survival. Responses of individual trees and whole-forest ecosystems to CO_2 and climate manipulations often vary by age, implying that forests of different ages will respond differently to climate change. Furthermore, species within a community typically exhibit differential responses to CO_2 and climate, and altered community dynamics can have important consequences for ecosystem function. Age- and species-dependent responses provide a mechanism by which climate change may push some forests past critical thresholds such that they fail to recover to their previous state following disturbance. Altered dynamics of forest recovery will result in positive and negative feedbacks to climate change. Future research on this topic and corresponding improvements to earth system models will be a key to understanding the future of forests and their feedbacks to the climate system.

Dodson, Erich Kyle and Heather Taylor Root. 2013. **Conifer regeneration following stand-replacing wildfire varies along an elevation gradient in a ponderosa pine forest, Oregon, USA.** Forest Ecology and Management 302: 163-170.

Abstract. Climate change is expected to increase disturbances such as stand-replacing wildfire in many ecosystems, which have the potential to drive rapid turnover in ecological communities. Ecosystem recovery, and therefore maintenance of critical structures and functions (resilience), is likely to vary across environmental gradients such as moisture availability, but has received little study. We examined conifer regeneration a decade following complete stand-replacing wildfire in dry coniferous forests spanning a 700 m elevation gradient where low elevation sites had relatively high moisture stress due to the combination of high temperature and low precipitation. Conifer regeneration varied strongly across the elevation gradient, with little tree regeneration at warm and dry low elevation sites. Logistic regression models predicted rapid increases in regeneration across the elevation gradient for both seedlings of all conifer species and ponderosa pine seedlings individually. This pattern was especially pronounced for well-established seedlings (⩾38 cm in height). Graminoids dominated lower elevation sites following wildfire, which may have added to moisture stress for seedlings due to competition for water. These results suggest moisture stress can be a critical factor limiting conifer regeneration following stand-replacing wildfire in dry coniferous forests, with predicted increases in temperature and drought in the coming century likely to increase the importance of moisture stress. Strongly moisture limited forested sites may fail to regenerate for extended periods after stand-replacing disturbance, suggesting these sites are high priorities for management intervention where maintaining forests is a priority.

Eilmann, Britta, Sven M.G. de Vries, Jan den Ouden, Godefridus M.J. Mohren, Pascal Sauren, and Ute Sass-Klaassen. 2013. **Origin matters! Difference in drought tolerance and productivity of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) provenances.** Forest Ecology and Management 302: 133-143.

Abstract. Forests of the future should be resistant to exacerbating climatic conditions, especially to increasing drought, but at the same time provide a sufficient amount and quality of timber. In this context coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) is a promising species since it remains productive even under chronic drought. By choosing suitable provenances within the range of Douglas-fir (*P. menziesii* (Mirb.)) for a given site we can further optimise tree fitness under dry conditions or even increase timber yield.

Eighteen coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) var. *menziesii*) provenances were tested for seedling survival, yield, wood quality, and drought tolerance by taking advantage of a Dutch provenance trial, established in 1971 within the framework of the 1966/1967 IUFRO seed

collection program. The site of the Dutch trial is representative for many sites in Central Europe and is characterised by a moderate precipitation and temperature regime. Measurements on height and diameter growth were combined with a dendrochronological study on growth response to drought years.

We found a clear latitudinal trend indicating that Douglas-fir provenances from the northern part of the species-distribution range are generally more productive than provenances from the south. In contrast, drought tolerance increased towards the south. This suggests that it is impossible to identify provenances combining maximum productivity with lowest susceptibility towards drought. However, based on the results from the trial we can give recommendations on suitable provenances that are expected to perform best under future conditions in Central Europe. On sites where severe drought events are unlikely to occur in future, fast growing provenances from the north, like Nimkish, should be planted. These provenances respond plastically to drought years, but the strong reduction of tree growth in the drought year itself indicates that these provenances will be harmed by an increasing frequency of drought events. However, on sites where water availability is likely to decrease, provenances from the Olympic Peninsula like *Forks* and *Matlock* are very promising since they showed still relatively high yield in combination with a high potential to cope with drought.

If summer drought increases in frequency and severity as expected, the latewood/earlywood ratio will be drastically reduced with negative consequences for wood quality and cavitation resistance. However, some provenances, like *Marblemount* or *Matlock*, might compensate for the negative effect of summer drought on latewood/earlywood ratio by the contribution of photosynthesis in winter to whole-year carbon stock.

Keenan, Trevor F., David Y. Hollinger, Gil Bohrer, Danilo Dragoni, J. William Munger, Hans Peter Schmid and Andrew D. Richardson. 2013. **Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise.** Nature 499: 324–327. doi:10.1038/nature12291

Abstract. Terrestrial plants remove CO_2 from the atmosphere through photosynthesis, a process that is accompanied by the loss of water vapour from leaves. The ratio of water loss to carbon gain, or water-use efficiency, is a key characteristic of ecosystem function that is central to the global cycles of water, energy and carbon. Here we analyse direct, long-term measurements of whole-ecosystem carbon and water exchange. We find a substantial increase in water-use efficiency in temperate and boreal forests of the Northern Hemisphere over the past two decades. We systematically assess various competing hypotheses to explain this trend, and find that the observed increase is most consistent with a strong CO_2 fertilization effect. The results suggest a partial closure of stomata—small pores on the leaf surface that regulate gas exchange—to maintain a near-constant concentration of CO_2 inside the leaf even under continually increasing

atmospheric CO_2 levels. The observed increase in forest water-use efficiency is larger than that predicted by existing theory and 13 terrestrial biosphere models. The increase is associated with trends of increasing ecosystem-level photosynthesis and net carbon uptake, and decreasing evapotranspiration. Our findings suggest a shift in the carbon- and water-based economics of terrestrial vegetation, which may require a reassessment of the role of stomatal control in regulating interactions between forests and climate change, and a re-evaluation of coupled vegetation–climate models.

Soulé, P.T. and P.A. Knapp. 2013. **Radial growth rates of two co-occurring coniferous trees in the Northern Rockies during the past century.** Journal of Arid Environments 94: 87-95.

Abstract. We examined radial growth rates of locally co-occurring Douglas-fir (PSME – *Pseudotsuga menziesii* var. *glauca*) and ponderosa pine (PIPO – *Pinus ponderosa* var. *ponderosa*) trees growing within the Northern Rockies to determine if there are differential growth and climatic responses between these species and whether these responses are consistent among topographically and climatologically diverse sites. We developed standardized tree-ring chronologies from seven sites, with each site a matched pair of PSME and PIPO. For each chronology we examined the climate response of radial growth by comparing the standardized ring widths to a suite of climatic variables. We examined temporal changes by comparing 1905–1950 and post-1950 growth rates and climatic conditions. Both conifers experience increased radial growth post-1950. A combination of spring/summer moisture conditions related positively to radial growth and the primary climatic drivers were consistent both between species and within the region. The primary climatic drivers of radial growth remain unchanged during the last century or have trended toward drier conditions unfavorable for growth. We conclude that increases in standardized radial growth rates are unlikely climatically-driven. Other potential vectors of radial growth change, such as atmospheric CO_2 enrichment, have affected these co-occurring species on a largely equal basis and positively.

Worrall, James J., Gerald E. Rehfeldt, Andreas Hamann, Edward H. Hogg, Suzanne B. Marchetti, Michael Michaelian, and Laura K. Gray. 2013. **Recent declines of *Populus tremuloides* in North America linked to climate.** Forest Ecology and Management 299: 35-51.

Abstract. *Populus tremuloides* (trembling aspen) recently experienced extensive crown thinning, branch dieback, and mortality across North America. To investigate the role of climate, we developed a range-wide bioclimate model that characterizes climatic factors controlling distribution of aspen. We also examined indices of moisture stress, insect defoliation and other factors as potential causes of the decline. Historic climate records show that most decline regions experienced exceptionally severe drought preceding the recent episodes. The bioclimate model, driven primarily by

maximum summer temperatures and April–September precipitation, shows that decline tended to occur in marginally suitable habitat, and that climatic suitability decreased markedly in the period leading up to decline in almost all decline regions. Other factors, notably multi-year defoliation by tent caterpillars (*Malacosoma* spp.) and stem damage by fungi and insects, also play a substantial role in decline episodes, and may amplify or prolong the impacts of moisture stress on aspen over large areas. Many severely affected stands have poor regeneration potential, raising concerns that increasing aridity could ultimately lead to widespread loss of aspen forest cover. The analysis indicates that exceptional droughts were a major cause of the decline episodes, especially in the drier regions, and that aspen is sensitive to drought in much of its range. Coupling the bioclimate model with climate projections suggests that we should expect substantial loss of suitable habitat within the current distribution, especially in the USA and Mexico.

Rangeland Vegetation

Cleland, Elsa E., Scott L. Collins, Timothy L. Dickson, Emily C. Farrer, Katherine L. Gross, Laureano A. Gherardi, Lauren M. Hallett, Richard J. Hobbs, Joanna S. Hsu, Laura Turnbull, and Katharine N. Suding. 2013. **Sensitivity of grassland plant community composition to spatial vs. temporal variation in precipitation.** Ecology 94:1687–1696. http://dx.doi.org/10.1890/12-1006.1

Abstract. Climate gradients shape spatial variation in the richness and composition of plant communities. Given future predicted changes in climate means and variability, and likely regional variation in the magnitudes of these changes, it is important to determine how temporal variation in climate influences temporal variation in plant community structure. Here, we evaluated how species richness, turnover, and composition of grassland plant communities responded to interannual variation in precipitation by synthesizing long-term data from grasslands across the United States. We found that mean annual precipitation (MAP) was a positive predictor of species richness across sites, but a positive temporal relationship between annual precipitation and richness was only evident within two sites with low MAP. We also found higher average rates of species turnover in dry sites that in turn had a high proportion of annual species, although interannual rates of species turnover were surprisingly high across all locations. Annual species were less abundant than perennial species at nearly all sites, and our analysis showed that the probability of a species being lost or gained from one year to the next increased with decreasing species abundance. Bray-Curtis dissimilarity from one year to the next, a measure of species composition change that is influenced mainly by abundant species, was insensitive to precipitation at all sites. These results suggest that the richness and turnover patterns we observed were driven primarily by rare species, which comprise the majority of the local species pools at these grassland

sites. These findings are consistent with the idea that short-lived and less abundant species are more sensitive to interannual climate variability than longer-lived and more abundant species. We conclude that, among grassland ecosystems, xeric grasslands are likely to exhibit the greatest responsiveness of community composition (richness and turnover) to predicted future increases in interannual precipitation variability. Over the long term, species composition may shift to reflect spatial patterns of mean precipitation; however, perennial-dominated systems will be buffered against rising interannual variation, while systems that have a large number of rare, annual species will show the greatest temporal variability in species composition in response to rising interannual variability in precipitation.

Kulmatiski, Andrew and Karen H. Beard. 2013. **Woody plant encroachment facilitated by increased precipitation intensity.** Nature Climate Change 3: 833–837. doi:10.1038/nclimate1904

Abstract. Global circulation models and empirical evidence suggest that precipitation events are likely to become more extreme across much of the globe. As most plant roots are in shallow soils, small but pervasive changes in precipitation intensity could be expected to cause large-scale shifts in plant growth, yet experimental tests of the effects of precipitation intensity are lacking. Here we show that, without changing the total amount of precipitation, small experimental increases in precipitation intensity can push soil water deeper into the soil, increase aboveground woody plant growth and decrease aboveground grass growth in a savannah system. These responses seemed to reflect the ability of woody plants to increase their rooting depths and competitively suppress grass growth. In many parts of the world, woody plant abundance has multiplied in the past 50–100 years, causing changes in fire, forage value, biodiversity and carbon cycling. Factors such as fire, grazing and atmospheric CO_2 concentrations have become dominant explanations for this woody encroachment and semi-arid structure in general. Our results suggest that niche partitioning is also an important factor in tree–grass coexistence and that the woody plant encroachment observed over the past century may continue in the future should precipitation intensity increase.

Leger, E. A. 2013. **Annual plants change in size over a century of observations.** Global Change Biology 19: 2229–2239. doi: 10.1111/gcb.12208

Abstract. Studies have documented changes in animal body sizes over the last century, but very little is known about changes in plant sizes, even though reduced plant productivity is potentially responsible for declines in size of other organisms. Here, I ask whether warming trends in the Great Basin have affected plant size by measuring specimens preserved on herbarium sheets collected between 1893 and 2011. I asked how maximum and minimum temperatures, precipitation, and the Pacific Decadal Oscillation

(PDO) in the year of collection affected plant height, leaf size, and flower number, and asked whether changes in climate resulted in decreasing sizes for seven annual forbs. Species had contrasting responses to climate factors, and would not necessarily be expected to respond in parallel to climatic shifts. There were generally positive relationships between plant size and increased minimum and maximum temperatures, which would have been predicted to lead to small increases in plant sizes over the observation period. While one species increased in size and flower number over the observation period, five of the seven species decreased in plant height, four of these decreased in leaf size, and one species also decreased in flower production. One species showed no change. The mechanisms behind these size changes are unknown, and the limited data available on these species (germination timing, area of occupancy, relative abundance) did not explain why some species shrank while others grew or did not change in size over time. These results show that multiple annual forbs are decreasing in size, but that even within the same functional group, species may have contrasting responses to similar environmental stimuli. Changes in plant size could have cascading effects on other members of these communities, and differential responses to directional change may change the composition of plant communities over time.

Newingham, B. A., Vanier, C. H., Charlet, T. N., Ogle, K., Smith, S. D. and Nowak, R. S. 2013. **No cumulative effect of 10 years of elevated [CO_2] on perennial plant biomass components in the Mojave Desert.** Global Change Biology 19: 2168–2181. doi: 10.1111/gcb.12177

Abstract. Elevated atmospheric CO_2 concentrations ([CO_2]) generally increase primary production of terrestrial ecosystems. Production responses to elevated [CO_2] may be particularly large in deserts, but information on their long-term response is unknown. We evaluated the cumulative effects of elevated [CO_2] on primary production at the Nevada Desert FACE (free-air carbon dioxide enrichment) Facility. Aboveground and belowground perennial plant biomass was harvested in an intact Mojave Desert ecosystem at the end of a 10-year elevated [CO_2] experiment. We measured community standing biomass, biomass allocation, canopy cover, leaf area index (LAI), carbon and nitrogen content, and isotopic composition of plant tissues for five to eight dominant species. We provide the first long-term results of elevated [CO_2] on biomass components of a desert ecosystem and offer information on understudied Mojave Desert species. In contrast to initial expectations, 10 years of elevated [CO_2] had no significant effect on standing biomass, biomass allocation, canopy cover, and C : N ratios of above- and belowground components. However, elevated [CO_2] increased short-term responses, including leaf water-use efficiency (WUE) as measured by carbon isotope discrimination and increased plot-level LAI. Standing biomass, biomass allocation, canopy cover, and C : N ratios of above- and belowground pools significantly differed among dominant species, but responses to elevated [CO_2] did not vary among species, photosynthetic

pathway (C_3 vs. C_4), or growth form (drought-deciduous shrub vs. evergreen shrub vs. grass). Thus, even though previous and current results occasionally show increased leaf-level photosynthetic rates, WUE, LAI, and plant growth under elevated [CO_2] during the 10-year experiment, most responses were in wet years and did not lead to sustained increases in community biomass. We presume that the lack of sustained biomass responses to elevated [CO_2] is explained by inter-annual differences in water availability. Therefore, the high frequency of low precipitation years may constrain cumulative biomass responses to elevated [CO_2] in desert environments.

Sankey, Joel B., Cynthia S.A. Wallace, and Sujith Ravi. 2013. **Phenology-based, remote sensing of post-burn disturbance windows in rangelands.** Ecological Indicators 30: 35-44.

Abstract. Wildland fire activity has increased in many parts of the world in recent decades. Ecological disturbance by fire can accelerate ecosystem degradation processes such as erosion due to combustion of vegetation that otherwise provides protective cover to the soil surface. This study employed a novel ecological indicator based on remote sensing of vegetation greenness dynamics (phenology) to estimate variability in the window of time between fire and the reemergence of green vegetation. The indicator was applied as a proxy for short-term, post-fire disturbance windows in rangelands; where a disturbance window is defined as the time required for an ecological or geomorphic process that is altered to return to pre-disturbance levels. We examined variability in the indicator determined for time series of MODIS and AVHRR NDVI remote sensing data for a database of ~100 historical wildland fires, with associated post-fire reseeding treatments, that burned 1990–2003 in cold desert shrub steppe of the Great Basin and Columbia Plateau of the western USA. The indicator-based estimates of disturbance window length were examined relative to the day of the year that fires burned and seeding treatments to consider effects of contemporary variability in fire regime and management activities in this environment. A key finding was that contemporary changes of increased length of the annual fire season could have indirect effects on ecosystem degradation, as early season fires appeared to result in longer time that soils remained relatively bare of the protective cover of vegetation after fires. Also important was that reemergence of vegetation did not occur more quickly after fire in sites treated with post-fire seeding, which is a strategy commonly employed to accelerate post-fire vegetation recovery and stabilize soil. Future work with the indicator could examine other ecological factors that are dynamic in space and time following disturbance – such as nutrient cycling, carbon storage, microbial community composition, or soil hydrology – as a function of disturbance windows, possibly using simulation modeling and historical wildfire information.

Fish and Wildlife

Beer, W. N. and Anderson, J. J. 2013. **Sensitivity of salmonid freshwater life history in western US streams to future climate conditions.** Global Change Biology 19: 2547–2556. doi: 10.1111/gcb.12242

Abstract. We projected effects of mid-21st century climate on the early life growth of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in western United States streams. Air temperature and snowpack trends projected from observed 20th century trends were used to predict future seasonal stream temperatures. Fish growth from winter to summer was projected with temperature-dependent models of egg development and juvenile growth. Based on temperature data from 115 sites, by mid-21st century, the effects of climate change are projected to be mixed. Fish in warm-region streams that are currently cooled by snow melt will grow less, and fish in suboptimally cool streams will grow more. Relative to 20th century conditions, by mid-21st century juvenile salmonids' weights are expected to be lower in the Columbia Basin and California Central Valley, but unchanged or greater in coastal and mountain streams. Because fish weight affects fish survival, the predicted changes in weight could impact population fitness depending on other factors such as density effects, food quality and quantity changes, habitat alterations, etc. The level of year-to-year variability in stream temperatures is high and our analysis suggests that identifying effects of climate change over the natural variability will be difficult except in a few streams.

Beever, Erik A., S. Z. Dobrowski, J. Long, A. R. Mynsberge, and N. B. Piekielek. 2013. **Understanding relationships among abundance, extirpation, and climate at ecoregional scales.** Ecology 94:1563–1571. http://dx.doi.org/10.1890/12-2174.1

Abstract. Recent research on mountain-dwelling species has illustrated changes in species' distributional patterns in response to climate change. Abundance of a species will likely provide an earlier warning indicator of change than will occupancy, yet relationships between abundance and climatic factors have received less attention. We tested whether predictors of counts of American pikas (Ochotona princeps) during surveys from the Great Basin region in 1994–1999 and 2003–2008 differed between the two periods. Additionally, we tested whether various modeled aspects of ecohydrology better predicted relative density than did average annual precipitation, and whether risk of site-wide extirpation predicted subsequent population counts of pikas. We observed several patterns of change in pika abundance at range edges that likely constitute early warnings of distributional shifts. Predictors of pika abundance differed strongly between the survey periods, as did pika extirpation patterns previously reported from this region. Additionally, maximum snowpack and growing-season precipitation resulted in better-supported models than those using average annual precipitation, and constituted two of the top three predictors of pika density in the 2000s surveys (affecting pikas perhaps via vegetation). Unexpectedly, we found that extirpation risk positively predicted subsequent population size. Our results emphasize the need to clarify mechanisms underlying biotic responses to recent climate change at organism-relevant scales, to inform management and conservation strategies for species of concern.

Jones, Russell, Constance Travers, Charles Rodgers, Brian Lazar, Eric English, Joshua Lipton, Jason Vogel, Kenneth Strzepek, and Jeremy Martinich. 2013. **Climate change impacts on freshwater recreational fishing in the United States.** Mitigation and Adaptation Strategies for Global Change 18(6): 731-758.

Abstract. We estimated the biological and economic impacts of climate change on freshwater fisheries in the United States (U.S.). Changes in stream temperatures, flows, and the spatial extent of suitable thermal habitats for fish guilds were modeled for the coterminous U.S. using a range of projected changes in temperature and precipitation caused by increased greenhouse gases (GHGs). Based on modeled shifts in available thermal habitat for fish guilds, we estimated potential economic impacts associated with changes in freshwater recreational fishing using a national-scale economic model of recreational fishing behavior. In general, the spatial distribution of coldwater fisheries is projected to contract, being replaced by warm/cool water and high-thermally tolerant, lower recreational priority (i.e., "rough") fisheries. Changes in thermal habitat suitability become more pronounced under higher emissions scenarios and at later time periods. Under the highest GHG emissions scenario, by year 2100 habitat for coldwater fisheries is projected to decline by roughly 50 % and be largely confined to mountainous areas in the western U.S. and very limited areas of New England and the Appalachians. The economic model projects a decline in coldwater fishing days ranging from 1.25 million in 2030 to 6.42 million by 2100 and that the total present value of national economic losses to freshwater recreational fishing from 2009 to 2100 could range from 81millionto 6.4 billion, depending on the emissions scenario and the choice of discount rate.

Jenouvrier, S. 2013. **Impacts of climate change on avian populations.** Global Change Biology 19: 2036–2057. doi: 10.1111/gcb.12195

Abstract. This review focuses on the impacts of climate change on population dynamics. I introduce the MUP (Measuring, Understanding, and Predicting) approach, which provides a general framework where an enhanced understanding of climate-population processes, along with improved long-term data, are merged into coherent projections of future population responses to climate change. This approach can be applied to any species, but this review illustrates its benefit using birds as examples.

Birds are one of the best-studied groups and a large number of studies have detected climate impacts on vital rates (i.e., life history traits, such as survival, maturation, or breeding, affecting changes in population size and composition) and population abundance. These studies reveal multifaceted effects of climate with direct, indirect, time-lagged, and nonlinear effects. However, few studies integrate these effects into a climate-dependent population model to understand the respective role of climate variables and their components (mean state, variability, extreme) on population dynamics. To quantify how populations cope with climate change impacts, I introduce a new universal variable: the 'population robustness to climate change.' The comparison of such robustness, along with prospective and retrospective analysis may help to identify the major climate threats and characteristics of threatened avian species.

Finally, studies projecting avian population responses to future climate change predicted by IPCC-class climate models are rare. Population projections hinge on selecting a multiclimate model ensemble at the appropriate temporal and spatial scales and integrating both radiative forcing and internal variability in climate with fully specified uncertainties in both demographic and climate processes.

McKellar, Ann E., Peter P. Marra, Susan J. Hannon, Colin E. Studds, and Laurene M. Ratcliffe. 2013. **Winter rainfall predicts phenology in widely separated populations of a migrant songbird.** Oecologia 172(2): 595-605.

Abstract. Climate change is affecting behaviour and phenology in many animals. In migratory birds, weather patterns both at breeding and at non-breeding sites can influence the timing of spring migration and breeding. However, variation in responses to weather across a species range has rarely been studied, particularly among populations that may winter in different locations. We used prior knowledge of migratory connectivity to test the influence of weather from predicted non-breeding sites on bird phenology in two breeding populations of a long-distance migratory bird species separated by 3,000 km. We found that winter rainfall showed similar associations with arrival and egg-laying dates in separate breeding populations on an east–west axis: greater rainfall in Jamaica and eastern Mexico was generally associated with advanced American redstart (*Setophaga ruticilla*) phenology in Ontario and Alberta, respectively. In Ontario, these patterns of response could largely be explained by changes in the behaviour of individual birds, i.e., phenotypic plasticity. By explicitly incorporating migratory connectivity into responses to climate, our data suggest that widely separated breeding populations can show independent and geographically specific associations with changing weather conditions. The tendency of individuals to delay migration and breeding following dry winters could result in population declines due to predicted drying trends in tropical areas and the tight linkage between early arrival/breeding and reproductive success in long-distance migrants.

Rohr, J. R. and Palmer, B. D. 2013. **Climate Change, Multiple Stressors, and the Decline of Ectotherms.** Conservation Biology 27: 741–751. doi: 10.1111/cobi.12086

Abstract. Climate change is believed to be causing declines of ectothermic vertebrates, but there is little evidence that climatic conditions associated with declines have exceeded critical (i.e., acutely lethal) maxima or minima, and most relevant studies are correlative, anecdotal, or short-term (hours). We conducted an 11-week factorial experiment to examine the effects of temperature (22 °C or 27 °C), moisture (wet or dry), and atrazine (an herbicide; 0, 4, 40, 400 µg/L exposure as embryos and larvae) on the survival, growth, behavior, and foraging rates of postmetamorphic streamside salamanders (Ambystoma barbouri), a species of conservation concern. The tested climatic conditions were between the critical maxima and minima of streamside salamanders; thus, this experiment quantified the long-term effects of climate change within the noncritical range of this species. Despite a suite of behavioral adaptations to warm and dry conditions (e.g., burrowing, refuge use, huddling with conspecifics, and a reduction in activity), streamside salamanders exhibited significant loss of mass and significant mortality in all but the cool and moist conditions, which were closest to the climatic conditions in which they are most active in nature. A temperature of 27 °C represented a greater mortality risk than dry conditions; death occurred rapidly at this temperature and more gradually under cool and dry conditions. Foraging decreased under dry conditions, which suggests there were opportunity costs to water conservation. Exposure to the herbicide atrazine additively decreased water-conserving behaviors, foraging efficiency, mass, and time to death. Hence, the hypothesis that moderate climate change can cause population declines is even more plausible under scenarios with multiple stressors. These results suggest that climate change within the noncritical range of species and pollution may reduce individual performance by altering metabolic demands, hydration, and foraging effort and may facilitate population declines of amphibians and perhaps other ectothermic vertebrates.

Vedder, Oscar, Sandra Bouwhuis, and Ben C. Sheldon. 2013. **Quantitative Assessment of the Importance of Phenotypic Plasticity in Adaptation to Climate Change in Wild Bird Populations.** PLOS Biology: 09 Jul 2013. doi/10.1371/journal.pbio.1001605

Abstract. Predictions about the fate of species or populations under climate change scenarios typically neglect adaptive evolution and phenotypic plasticity, the two major mechanisms by which organisms can adapt to changing local conditions. As a consequence, we have little understanding of the scope for organisms to track changing environments by in situ adaptation. Here, we use a detailed individual-specific long-term population study of great tits (*Parus major*) breeding in Wytham Woods, Oxford, UK to parameterise a mechanistic model and thus directly estimate the rate of

environmental change to which in situ adaptation is possible. Using the effect of changes in early spring temperature on temporal synchrony between birds and a critical food resource, we focus in particular on the contribution of phenotypic plasticity to population persistence. Despite using conservative estimates for evolutionary and reproductive potential, our results suggest little risk of population extinction under projected local temperature change; however, this conclusion relies heavily on the extent to which phenotypic plasticity tracks the changing environment. Extrapolating the model to a broad range of life histories in birds suggests that the importance of phenotypic plasticity for adjustment to projected rates of temperature change increases with slower life histories, owing to lower evolutionary potential. Understanding the determinants and constraints on phenotypic plasticity in natural populations is thus crucial for characterising the risks that rapidly changing environments pose for the persistence of such populations.

Invertebrates

Warren, R. J. and Chick, L. 2013. **Upward ant distribution shift corresponds with minimum, not maximum, temperature tolerance.** Global Change Biology 19: 2082–2088. doi: 10.1111/gcb.12169

Abstract. Rapid climate change may prompt species distribution shifts upward and poleward, but species movement in itself is not sufficient to establish climate causation. Other dynamics, such as disturbance history, may prompt species distribution shifts resembling those expected from rapid climate change. Links between species distributions, regional climate trends and physiological mechanism are needed to convincingly establish climate-induced species shifts. We examine a 38-year shift (1974–2012) in an elevation ecotone between two closely related ant species, Aphaenogaster picea and A. rudis. Even though A. picea and A. rudis are closely related with North American distributions that sometimes overlap, they also exhibit local- and regional-scale differences in temperature requirements so that A. rudis is more southerly and inhabits lower elevations whereas A. picea is more northerly and inhabits high elevations. We find considerable movement by the warm-habitat species upward in elevation between 1974 and 2012 with A. rudis, replacing the cold-habitat species, A. picea, along the southern edge of the Appalachian Mountain chain in north Georgia, USA. Concomitant with the distribution shifts, regional mean and maximum temperatures remain steady (1974–2012), but minimum temperatures increase. We collect individuals from the study sites and subject them to thermal tolerance testing in a controlled setting and find that maximum and minimum temperature acclimatization occurs along the elevation gradient in both species, but A. rudis consistently becomes physiologically incapacitated at minimum and maximum temperatures 2 °C higher than A. picea. These results indicate that rising minimum temperatures allow A. rudis to move

upward in elevation and displace A. picea. Given that Aphaenogaster ants are the dominant woodland seed dispersers in eastern deciduous forests, and that their thermal tolerances drive distinct differences in temperature-cued synchrony with early blooming plants, these climate responses not only impact ant-ant interactions, but might have wide implications for ant-plant interactions.

Disease

Lee, E. Henry, Peter A. Beedlow, Ronald S. Waschmann, Connie A. Burdick, and David C. Shaw. 2013. **Tree-ring analysis of the fungal disease Swiss needle cast in western Oregon coastal forests.** Canadian Journal of Forest Research 43(8): 677-690. doi: 10.1139/cjfr-2013-0062.

Abstract. Swiss needle cast (SNC), an important fungal disease of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), has increased in severity throughout its natural and introduced range over the last half century. The role of climate change and forest management practices in the increase is unclear. We analyzed tree-ring chronologies from six late-successional Douglas-fir stands in the western Oregon Coast Range using time-series intervention analysis (TSIA) to address how climate relates to the impact of SNC on tree growth. Tree-ring chronologies of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), a species not susceptible to the fungus *Phaeocryptopus gaeumannii* (Rhode) Petrak, were used as a climate proxy in the TSIA. We found that growth reductions associated with SNC dated back to the 1590s, the earliest record in our dendritic data. Growth reductions were synchronous across the six sites, indicating that the disease severity was largely influenced by climatic conditions. SNC impact peaked in 1984–1986 at all six study sites, followed by unprecedented disease impacts of 100% in 1996 and 2004 at one site, while decreasing to previous levels at the other five sites. Our SNC index of impact significantly correlated with winter and summer temperatures and summer precipitation. Winter conditions were more strongly associated with disease impact at wetter, cooler sites, whereas summer conditions were more important at less humid, warmer sites. With climate change, SNC impacts are likely to increase in coastal areas where June–July precipitation is much higher than the *P. gaeumannii*-limiting threshold of ~110 mm, and decrease where summer precipitation is at or below the threshold. Warmer winters will increase disease severity at higher elevation, north along the coast from northern Oregon to British Columbia, and at inland sites where current winter temperatures limit fungal growth.

Soils and Hydrology

Davis, J. M., C. V. Baxter, E. J. Rosi-Marshall, J. L. Pierce, and B. T. Crosby. 2013. **Anticipating Stream Ecosystem Responses to Climate Change: Toward Predictions that Incorporate Effects Via Land–Water Linkages**. Ecosystems 16(5): 909-922.

Abstract. Climate change (CC) is projected to increase the frequency and severity of natural disturbances (wildfires, insect outbreaks, and debris flows) and shift distributions of terrestrial ecosystems on a global basis. Although such terrestrial changes may affect stream ecosystems, they have not been incorporated into predictions of stream responses to CC. Here, we introduce a conceptual framework to evaluate to what extent responses of streams to CC will be driven by not only changes in thermal and hydrologic regimes, but also alterations of terrestrial processes. We focused on forested watersheds of western North America because this region is projected to experience CC-induced alteration of terrestrial processes. This provided a backdrop for investigating interactive effects of climate and terrestrial responses on streams. Because stream responses to terrestrial processes have been well-studied in contexts largely independent of CC research, we synthesized this knowledge to demonstrate how CC-induced alterations of terrestrial ecosystems may affect streams. Our synthesis indicated that altered terrestrial processes will change terrestrial–aquatic linkages and autotrophic production, potentially yielding greater sensitivity of streams to CC than would be expected based on shifts in temperature and precipitation regime alone. Despite uncertainties that currently constrain predictions regarding stream responses to these additional pathways of change, this synthesis highlighted broader effects of CC that require additional research. Based on widespread evidence that CC is linked to changing terrestrial processes, we conclude that accurate predictions of CC effects on streams may be coupled to the accuracy of predictions for long-term changes in terrestrial ecosystems.

Dijkstra, F. A., Morgan, J. A., Follett, R. F. and LeCain, D. R. 2013. **Climate change reduces the net sink of CH4 and N2O in a semiarid grassland.** Global Change Biology 19: 1816–1826. doi: 10.1111/gcb.12182

Abstract. Atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O) have increased over the last 150 years because of human activity. Soils are important sources and sinks of both potent greenhouse gases where their production and consumption are largely regulated by biological processes. Climate change could alter these processes thereby affecting both rate and direction of their exchange with the atmosphere. We examined how a rise in atmospheric CO2 and temperature affected CH_4 and N_2O fluxes in a well-drained upland soil (volumetric water content ranging between 6% and 23%) in a semiarid grassland during five growing seasons. We hypothesized that responses of CH_4 and N_2O fluxes to elevated CO_2 and warming would be

driven primarily by treatment effects on soil moisture. Previously we showed that elevated CO_2 increased and warming decreased soil moisture in this grassland. We therefore expected that elevated CO_2 and warming would have opposing effects on CH_4 and N_2O fluxes. Methane was taken up throughout the growing season in all 5 years. A bell-shaped relationship was observed with soil moisture with highest CH_4 uptake at intermediate soil moisture. Both N_2O emission and uptake occurred at our site with some years showing cumulative N_2O emission and other years showing cumulative N_2O uptake. Nitrous oxide exchange switched from net uptake to net emission with increasing soil moisture. In contrast to our hypothesis, both elevated CO_2 and warming reduced the sink of CH_4 and N_2O expressed in CO_2 equivalents (across 5 years by 7% and 11% for elevated CO_2 and warming respectively) suggesting that soil moisture changes were not solely responsible for this reduction. We conclude that in a future climate this semiarid grassland may become a smaller sink for atmospheric CH_4 and N_2O expressed in CO_2-equivalents.

Grant, Gordon E., Christina L Tague, and Craig D Allen. 2013. **Watering the forest for the trees: an emerging priority for managing water in forest landscapes.** Frontiers in Ecology and the Environment 11: 314–321. http://dx.doi.org/10.1890/120209

Abstract. Widespread threats to forests resulting from drought stress are prompting a re-evaluation of priorities for water management on forest lands. In contrast to the widely held view that forest management should emphasize providing water for downstream uses, we argue that maintaining forest health in the context of a changing climate may require focusing on the forests themselves and on strategies to reduce their vulnerability to increasing water stress. Management strategies would need to be tailored to specific landscapes but could include thinning, planting and selecting for drought-tolerant species, irrigating, and making more water available to plants for transpiration. Hydrologic modeling reveals that specific management actions could reduce tree mortality due to drought stress. Adopting water conservation for vegetation as a priority for managing water on forested lands would represent a fundamental change in perspective and potentially involve trade-offs with other downstream uses of water.

Lester, Rebecca E., Peter G. Fairweather, Ian T. Webster, and Rebecca A. Quin. 2013. **Scenarios involving future climate and water extraction: ecosystem states in the estuary of Australia's largest river.** Ecological Applications 23:984–998. http://dx.doi.org/10.1890/12-1331.1

Abstract. Management of natural resources, particularly water, increasingly requires that likely benefits of particular actions (e.g., allocating an environmental flow) are quantified in advance. Therefore, new techniques are required that enable those potential benefits to be objectively compared

among competing options for management (e.g., compared to a "do nothing" scenario). Scenario modeling is one method for developing such an objective comparison. We used existing hydrologic, hydrodynamic, and ecosystem response models for a case study location, the Coorong, an inverse estuary in South Australia, to illustrate the potential for such scenario modeling to inform natural resource management. We modeled a set of 12 scenarios that included different levels of water extraction, potential future climate change, and sea-level change, thereby enabling a comparison of the different drivers of possible future reductions in water availability in the Coorong. We discovered that potential future climate change combined with current extraction levels has the capacity to devastate the ecology of the Coorong, but also that much of the degradation could be averted by reducing upstream extractions of water. The inclusion of possible sea-level change had a surprising effect, whereby higher sea levels increased hydrodynamic connectivity between the Coorong's two lagoons. Increased hydrodynamic connectivity limited the occurrence of extremely low water levels and high salinities due to evapoconcentration that were simulated for dry future climates in the absence of sea-level rise. These findings strongly suggest that future ecological degradation in the Coorong is not a foregone conclusion, and that management decisions regarding water allocations upstream will determine the ecological future of this coastal lagoon.

Meisner, Annelein, Gerlinde B. De Deyn, Wietse de Boer, and Wim H. van der Putten. 2013. **Soil biotic legacy effects of extreme weather events influence plant invasiveness.** Proceedings of the National Academy of Sciences 110(24): 9835–9838.

Abstract. Climate change is expected to increase future abiotic stresses on ecosystems through extreme weather events leading to more extreme drought and rainfall incidences [Jentsch A, et al. (2007) Front Ecol Environ 5(7):365–374]. These fluctuations in precipitation may affect soil biota, soil processes [Evans ST, Wallenstein MD (2012) Biogeochemistry 109:101–116], and the proportion of exotics in invaded plant communities [Jiménez MA, et al. (2011) Ecol Lett 14:1277–1235]. However, little is known about legacy effects in soil on the performance of exotics and natives in invaded plant communities. Here we report that drought and rainfall effects on soil processes and biota affect the performance of exotics and natives in plant communities. We performed two mesocosm experiments. In the first experiment, soil without plants was exposed to drought and/or rainfall, which affected soil N availability. Then the initial soil moisture conditions were restored, and a mixed community of co-occurring natives and exotics was planted and exposed to drought during growth. A single stress before or during growth decreased the biomass of natives, but did not affect exotics. A second drought stress during plant growth resetted the exotic advantage, whereas native biomass was not further reduced. In the second experiment, soil inoculation revealed that drought and/or rainfall influenced soil biotic legacies, which promoted exotics but suppressed natives. Our results demonstrate that extreme weather events can cause legacy effects in soil

biota, promoting exotics and suppressing natives in invaded plant communities, depending on the type, frequency, and timing of extreme events.

Mengistu, S. G., C. G. Quick, and I. F. Creed. 2013. **Nutrient export from catchments on forested landscapes reveals complex nonstationary and stationary climate signals.** Water Resources Research 49: 3863–3880. doi:10.1002/wrcr.20302.

Abstract. Headwater catchment hydrology and biogeochemistry are influenced by climate, including linear trends (nonstationary signals) and climate oscillations (stationary signals). We used an analytical framework to detect nonstationary and stationary signals in yearly time series of nutrient export [dissolved organic carbon (DOC), dissolved organic nitrogen (DON), nitrate (NO_3^--N), and total dissolved phosphorus (TDP)] in forested headwater catchments with differential water loading and water storage potential at the Turkey Lakes Watershed in Ontario, Canada. We tested the hypotheses that (1) climate has nonstationary and stationary effects on nutrient export, the combination of which explains most of the variation in nutrient export; (2) more metabolically active nutrients (e.g., DON, NO_3^--N, and TDP) are more sensitive to these signals; and (3) catchments with relatively low water loading and water storage capacity are more sensitive to these signals. Both nonstationary and stationary signals were identified, and the combination of both explained the majority of the variation in nutrient export data. More variation was explained in more labile nutrients (DON, NO_3^--N, and TDP), which were also more sensitive to climate signals. The catchment with low-water storage potential and low water loading was most sensitive to nonstationary and stationary climatic oscillations, suggesting that these hydrologic features are characteristic of the most effective sentinels of climate change. The observed complex links between climate change, climatic oscillations, and water nutrient fluxes in headwater catchments suggest that climate may have considerable influence on the productivity and biodiversity of surface waters, in addition to other drivers such as atmospheric pollution.

van der Ent, R. J. and H. H. G. Savenije. 2013. **Oceanic sources of continental precipitation and the correlation with sea surface temperature.** Water Resources Research 49: 3993–4004. doi:10.1002/wrcr.20296.

Abstract. Identifying the sources of continental precipitation has received increasing attention in recent years. With the use of various numerical methods, sources of precipitation have been identified from local to global scales. In this paper we identify the oceanic sources based on an atmospheric backtracking analysis of continental precipitation. We find that the strongest source areas are located close to the continents. In general, we define an oceanic area as a significant source when on average more than

20% of the total evaporation, and at least 250 mm/yr of evaporation ends up as continental precipitation. We grouped these identified source areas into 15 regions and performed a forward tracking analysis of oceanic evaporation. We identified the areas on the adjacent continents that receive this oceanic moisture and whether this is nearby or remote. Moreover, we showed how the oceanic sources vary over the year in time and space. Furthermore, we correlated sea surface temperatures (SSTs) in the 15 source regions and the Niño 3.4 region with precipitation on all continents. For South America, we found that the El Niño Southern Oscillation (altering wind patterns) has a larger effect on precipitation than local SSTs. For West Africa, however, we show that SST in the source regions is strongly correlated with precipitation in the rainy season. In Australia, both local SST and the Niño 3.4 region appear to have a big influence on precipitation. As such this research provides new insight in the ocean-atmosphere-land coupling, which can be useful for studying seasonal weather predictions as well as climate change impact.

Fire

Herrera, S., J. Bedia, J. M. Gutiérrez, J. Fernández, and J. M. Moreno. 2013. **On the projection of future fire danger conditions with various instantaneous/mean-daily data sources.** Climatic Change 118 (3-4): 827-840.

Abstract. Fire danger indices are descriptors of fire potential in a large area, and combine a few variables that affect the initiation, spread and control of forest fires. The Canadian Fire Weather Index (FWI) is one of the most widely used fire danger indices in the world, and it is built upon instantaneous values of temperature, relative humidity and wind velocity at noon, together with 24 hourly accumulated precipitation. However, the scarcity of appropriate data has motivated the use of daily mean values as surrogates of the instantaneous ones in several studies that aimed to assess the impact of global warming on fire. In this paper we test the sensitivity of FWI values to both instantaneous and daily mean values, analyzing their effect on mean seasonal fire danger (seasonal severity rating, SSR) and extreme fire danger conditions (90th percentile, FWI90, and FWI>30, FOT30), with a special focus on its influence in climate change impact studies. To this aim, we analyzed reanalysis and regional climate model (RCM) simulations, and compared the resulting instantaneous and daily mean versions both in the present climate and in a future scenario. In particular, we were interested in determining the effect of these datasets on the projected changes obtained for the mean and extreme seasonal fire danger conditions in future climate scenarios, as given by a RCM. Overall, our results warn against the use of daily mean data for the computation of present and future fire danger conditions. Daily mean data lead to systematic negative biases of fire danger calculations. Although the mean seasonal fire danger indices might be

corrected to compensate for this bias, fire danger extremes (FWI90 and specially FOT30) cannot be reliably transformed to accommodate the spatial pattern and magnitude of their respective instantaneous versions, leading to inconsistent results when projected into the future. As a result, we advocate caution when using daily mean data and strongly recommend the application of the standard definition for its calculation as closely as possible. Threshold-dependent indices derived from FWI are not reliably represented by the daily mean version and thus can neither be applied for the estimation of future fire danger season length and severity, nor for the estimation of future extreme events.

McWethy, D. B., Higuera, P. E., Whitlock, C., Veblen, T. T., Bowman, D. M. J. S., Cary, G. J., Haberle, S. G., Keane, R. E., Maxwell, B. D., McGlone, M. S., Perry, G. L. W., Wilmshurst, J. M., Holz, A. and Tepley, A. J. 2013. **A conceptual framework for predicting temperate ecosystem sensitivity to human impacts on fire regimes.** Global Ecology and Biogeography 22: 900–912. doi: 10.1111/geb.12038

Abstract. Aim. The increased incidence of large fires around much of the world in recent decades raises questions about human and non-human drivers of fire and the likelihood of increased fire activity in the future. The purpose of this paper is to outline a conceptual framework for examining where human-set fires and feedbacks are likely to be most pronounced in temperate forests world-wide and to establish and test a methodology for evaluating this framework using palaeoecological records.

Location. Tasmania, north-western USA, southern South America and New Zealand.

Methods. We outline a conceptual framework for predicting the sensitivity of ecosystems to human impacts on fire regimes and then use a circum-Pacific comparison of existing historical reconstructions of fire, climate, human settlement and vegetation to evaluate this approach.

Results. Previous research investigating important controls on fire activity shows that the sensitivity of temperate ecosystems to human-set fires is modulated by the frequency of natural fire occurrence, fuel moisture and fuel type and availability. Palaeoecological data from four temperate regions suggest that the effects of anthropogenic burning are greatest where fire is naturally rare, vegetation is poorly adapted to fire and fuel biomass is abundant and contiguous. Alternatively, where fire activity is naturally high and vegetation is well adapted to fire, evidence of human influence on fire and vegetation is less obvious.

Main conclusions. Palaeofire records suggest that the most dynamic and persistent ecosystem transitions occur where human activities increase landscape flammability through fire–vegetation feedbacks. Rapid forest transitions in biomass-rich ecosystems such as New Zealand and areas of Tasmania and southern South America illustrate how landscapes experiencing few fires can shift past tipping points to become fire-prone

landscapes with new alternative stable state communities. Comparisons of palaeoecological data from different regions with similar biophysical gradients but different human settlement histories can provide new opportunities for understanding ecosystem vulnerability to fire–climate–human interactions.

Pausas, J. G. and Ribeiro, E. 2013. **The global fire–productivity relationship.** Global Ecology and Biogeography 22: 728–736. doi: 10.1111/geb.12043

Abstract. Aim. It has been suggested that on a global scale, fire activity changes along the productivity/aridity gradient following a humped relationship, i.e. the intermediate fire–productivity hypothesis. This relation should be driven by differing relative roles of the main fire drivers (weather and fuel) along the productivity gradient. However, the full intermediate fire–productivity model across all world ecosystems remains to be validated.

Location. The entire globe, excluding Antarctica.

Methods. To test the intermediate fire–productivity hypothesis, we use the world ecoregions as a spatial unit and, for each ecoregion, we compiled remotely sensed fire activity, climate, biomass and productivity information. The regression coefficient between monthly MODIS fire activity and monthly maximum temperature in each ecoregion was considered an indicator of the sensitivity of fire to high temperatures in the ecoregion. We used linear and generalized additive models to test for the linear and humped relationships.

Results. Fire occurs in most ecoregions. Fire activity peaked in tropical grasslands and savannas, and significantly decreased towards the extremes of the productivity gradient. Both the sensitivity of fire to high temperatures and above-ground biomass increased monotonically with productivity. In other words, fire activity in low-productivity ecosystems is not driven by warm periods and is limited by low biomass; in contrast, in high-productivity ecosystems fire is more sensitive to high temperatures, and in these ecosystems, the available biomass for fires is high.

Main conclusion. The results support the intermediate fire–productivity model on a global scale and suggest that climatic warming may affect fire activity differently depending on the productivity of the region. Fire regimes in productive regions are vulnerable to warming (drought-driven fire regime changes), while in low-productivity regions fire activity is more vulnerable to fuel changes (fuel-driven fire regime changes).

Sea Level Rise

Orlić, Mirko and Zoran Pasarić. 2013. **Semi-empirical versus process-based sea-level projections for the twenty-first century.** Nature Climate Change 3: 735–738. doi:10.1038/nclimate1877

Abstract. Two dynamical methods are presently used to project sea-level changes during the next century. The process-based method relies on coupled atmosphere–ocean models to estimate the effects of thermal expansion and on sea-level models combined with certain empirical relationships to determine the influence of land–ice mass changes. The semi-empirical method uses various physically motivated relationships between temperature and sea level, with parameters determined from the data, to project total sea level. However, semi-empirical projections far exceed process-based projections. Here, we test the robustness of semi-empirical projections to the underlying assumptions about the inertial and equilibrium responses of sea level to temperature forcing and the impacts of groundwater depletion and dam retention during the twentieth century. Our results show that these projections are sensitive to the dynamics considered and the terrestrial-water corrections applied. For B1, which is a moderate climate-change scenario, the lowest semi-empirical projection of sea-level rise over the twenty-first century equals 62±14 cm. The average value is substantially smaller than previously published semi-empirical projections and is therefore closer to the corresponding process-based values. The standard deviation is larger than the uncertainties of process-based estimates.

Adaptation

Furniss, Michael J.; Roby, Ken B.; Cenderelli, Dan; Chatel, John; Clifton, Caty F.; Clingenpeel, Alan; Hays, Polly E.; Higgins, Dale; Hodges, Ken; Howe, Carol; Jungst, Laura; Louie, Joan; Mai, Christine; Martinez, Ralph; Overton, Kerry; Staab, Brian P.; Steinke, Rory; Weinhold, Mark. 2013. **Assessing the vulnerability of watersheds to climate change: results of national forest watershed vulnerability pilot assessments.** Gen. Tech. Rep. PNW-GTR-884. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p. plus appendix.

Abstract. Existing models and predictions project serious changes to worldwide hydrologic processes as a result of global climate change. Projections indicate that significant change may threaten National Forest System watersheds that are an important source of water used to support people, economies, and ecosystems.

Wildland managers are expected to anticipate and respond to these threats, adjusting management priorities and actions. Because watersheds differ

greatly in: (1) the values they support, (2) their exposure to climatic changes, and (3) their sensitivity to climatic changes, understanding these differences will help inform the setting of priorities and selection of management approaches. Drawing distinctions in climate change vulnerability among watersheds on a national forest or grassland allows more efficient and effective allocation of resources and better land and watershed stewardship.

Eleven national forests from throughout the United States, representing each of the nine Forest Service regions, conducted assessments of potential hydrologic change resulting from ongoing and expected climate warming. A pilot assessment approach was developed and implemented. Each national forest identified water resources important in that area, assessed climate change exposure and watershed sensitivity, and evaluated the relative vulnerabilities of watersheds to climate change. The assessments provided management recommendations to anticipate and respond to projected climate-hydrologic changes.

Completed assessments differed in level of detail, but all assessments identified priority areas and management actions to maintain or improve watershed resilience in response to a changing climate. The pilot efforts also identified key principles important to conducting future vulnerability assessments.

Kivlin, Stephanie N., Sarah M. Emery and Jennifer A. Rudgers. 2013.
Fungal symbionts alter plant responses to global change.
American Journal of Botany 100(7): 1445-1457.

Abstract. While direct plant responses to global change have been well characterized, indirect plant responses to global change, via altered species interactions, have received less attention. Here, we examined how plants associated with four classes of fungal symbionts (class I leaf endophytes [EF], arbuscular mycorrhizal fungi [AMF], ectomycorrhizal fungi [ECM], and dark septate endophytes [DSE]) responded to four global change factors (enriched CO2, drought, N deposition, and warming). We performed a meta-analysis of 434 studies spanning 174 publications to search for generalizable trends in responses of plant–fungal symbioses to future environments. Specifically, we addressed the following questions: (1) Can fungal symbionts ameliorate responses of plants to global change? (2) Do fungal symbiont groups differ in the degree to which they modify plant response to global change? (3) Do particular global change factors affect plant–fungal symbioses more than others? In all global change scenarios, except elevated CO2, fungal symbionts significantly altered plant responses to global change. In most cases, fungal symbionts increased plant biomass in response to global change. However, increased N deposition reduced the benefits of symbiosis. Of the global change factors we considered, drought and N deposition resulted in the strongest fungal mediation of plant responses. Our analysis highlighted gaps in current knowledge for responses of particular fungal groups and revealed the importance of considering not only the

nonadditive effects of multiple global change factors, but also the interactive effects of multiple fungal symbioses. Our results show that considering plant–fungal symbioses is critical to predicting ecosystem response to global change.

Javeline, Debra, Jessica J. Hellmann, Rodrigo Castro Cornejo and Gregory Shufeldt. 2013. **Expert Opinion on Climate Change and Threats to Biodiversity.** BioScience 63(8): 666-673.

Abstract. Considerable uncertainty surrounds projections of climate change and its ecological consequences. We surveyed 2329 environmental biologists and found that greater expertise is associated with projections of greater climatic change and more severe consequences. The opinions of scientists with greater expertise converge, and they expect larger temperature increases, higher percentages of species extinctions, and a high percentage of species' ranges will change in response to climate change over the next 100 years. Importantly, even the highest of these estimates is at the lower bounds of many published projections of climate change and threats to biodiversity. These findings suggest that experts are relatively conservative and discerning about the magnitude of climate change and its biodiversity effects, but even their conservative estimates are substantial. We suggest that policymakers consult environmental biologists on emerging and controversial issues such as climate change and use transparent, standardized metrics of expertise when deciding which scientists to consult.

López-Hoffman, Laura, David D. Breshears, Craig D. Allen, and Marc L. Miller. 2013. **Key landscape ecology metrics for assessing climate change adaptation options: rate of change and patchiness of impacts.** Ecosphere 4:art101. http://dx.doi.org/10.1890/ES13-00118.1

Abstract. Under a changing climate, devising strategies to help stakeholders adapt to alterations to ecosystems and their services is of utmost importance. In western North America, diminished snowpack and river flows are causing relatively gradual, homogeneous (system-wide) changes in ecosystems and services. In addition, increased climate variability is also accelerating the incidence of abrupt and patchy disturbances such as fires, floods and droughts. This paper posits that two key variables often considered in landscape ecology—the rate of change and the degree of patchiness of change—can aid in developing climate change adaptation strategies. We use two examples from the "borderland" region of the southwestern United States and northwestern Mexico. In piñon-juniper woodland die-offs that occurred in the southwestern United States during the 2000s, ecosystem services suddenly crashed in some parts of the system while remaining unaffected in other locations. The precise timing and location of die-offs was uncertain. On the other hand, slower, homogeneous change, such as the expected declines in water supply to the Colorado River delta,

will likely impact the entire ecosystem, with ecosystem services everywhere in the delta subject to alteration, and all users likely exposed. The rapidity and spatial heterogeneity of faster, patchy climate change exemplified by tree die-off suggests that decision-makers and local stakeholders would be wise to operate under a Rawlsian "veil of ignorance," and implement adaptation strategies that allow ecosystem service users to equitably share the risk of sudden loss of ecosystem services before actual ecosystem changes occur. On the other hand, in the case of slower, homogeneous, system-wide impacts to ecosystem services as exemplified by the Colorado River delta, adaptation strategies can be implemented after the changes begin, but will require a fundamental rethinking of how ecosystems and services are used and valued. In sum, understanding how the rate of change and degree of patchiness of change will constrain adaptive options is a critical consideration in preparing for climate change.

Mitigation

Warren, R., J. VanDerWal, J. Price, J. A. Welbergen, I. Atkinson, J. Ramirez-Villegas, T. J. Osborn, A. Jarvis, L. P. Shoo, S. E. Williams and J. Lowe. 2013. **Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss.** Nature Climate Change 3: 678–682. doi:10.1038/nclimate1887

Abstract. Climate change is expected to have significant influences on terrestrial biodiversity at all system levels, including species-level reductions in range size and abundance, especially amongst endemic species. However, little is known about how mitigation of greenhouse gas emissions could reduce biodiversity impacts, particularly amongst common and widespread species. Our global analysis of future climatic range change of common and widespread species shows that without mitigation, 57±6% of plants and 34±7% of animals are likely to lose ≥50% of their present climatic range by the 2080s. With mitigation, however, losses are reduced by 60% if emissions peak in 2016 or 40% if emissions peak in 2030. Thus, our analyses indicate that without mitigation, large range contractions can be expected even amongst common and widespread species, amounting to a substantial global reduction in biodiversity and ecosystem services by the end of this century. Prompt and stringent mitigation, on the other hand, could substantially reduce range losses and buy up to four decades for climate change adaptation.

Socioeconomics

Chinowsky, Paul S., Jason C. Price, and James E. Neumann. 2013. **Assessment of climate change adaptation costs for the U.S. road network.** Global Environmental Change 23(4): 764-773.

Abstract. The U.S. road network is one of the nation's most important capital assets and is vital to the functioning of the U.S. economy. Maintaining this asset involves approximately $134 billion of government funds annually from Federal, State, and local agencies. Climate change may represent a risk or an opportunity to this network, as changes in climate stress will affect the resources necessary for both road maintenance and construction projects. This paper develops an approach for estimating climate-related changes in road maintenance and construction costs such that the current level of service provided by roads is maintained over time. We estimate these costs under a baseline scenario in which annual mean global temperature increases by 1.5 °C in 2050 relative to the historical average and a mitigation scenario under which this increase in mean temperature is limited to 1.0 °C. Depending on the nature of the changes in climate that occur in a given area, our analysis suggests that climate change may lead to a reduction in road maintenance and/or construction costs or an increase in costs. Overall, however, our analysis shows that climate change, if unchecked, will increase the annual costs of keeping paved and unpaved roads in service by $785 million in present value terms by 2050. When not discounted, this figure increases to $2.8 billion. Policies to reduce greenhouse gas emissions are estimated to reduce these costs by approximately $280 million in present value terms and by $885 million when not discounted. These costs vary substantially by region and time period, information that should be important for transportation planners at the national, state, and local levels.

Preston, Benjamin L. 2013. **Local path dependence of U.S. socioeconomic exposure to climate extremes and the vulnerability commitment.** Global Environmental Change 23(4): 719-732.

Abstract. Despite improvements in disaster risk management in the United States, a trend toward increasing economic losses from extreme weather events has been observed. This trend has been attributed to growth in socioeconomic exposure to extremes, a process characterized by strong path dependence. To understand the influence of path dependence on past and future losses, an index of potential socioeconomic exposure was developed at the U.S. county level based upon population size and inflation-adjusted wealth proxies. Since 1960, exposure has increased preferentially in the U.S. Southeast (particularly coastal and urban counties) and Southwest relative to the Great Plains and Northeast. Projected changes in exposure from 2009 to 2054 based upon scenarios of future demographic and economic change suggest a long-term commitment to increasing, but spatially heterogeneous, exposure to extremes, independent of climate change. The implications of

this path dependence are examined in the context of several natural hazards. Using methods previously reported in the literature, annualized county-level losses from 1960 to 2008 for five climate-related natural hazards were normalized to 2009 values and then scaled based upon projected changes in exposure and two different estimates of the exposure elasticity of losses. Results indicate that losses from extreme events will grow by a factor of 1.3–1.7 and 1.8–3.9 by 2025 and 2050, respectively, with the exposure elasticity representing a major source of uncertainty. The implications of increasing physical vulnerability to extreme weather events for investments in disaster risk management are ultimately contingent upon the normative values of societal actors.