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Climate Projections

Cai, Wenju. Simon Borlace, Matthieu Lengaigne, Peter van Rensch, Mat Collins, Gabriel Vecchi, Axel Timmermann, Agus Santoso, Michael J. McPhaden, Lixin Wu, Matthew H. England, Guojian Wang, Eric Guilyardi and Fei-Fei Jin. 2014. **Increasing frequency of extreme El Niño events due to greenhouse warming.** Nature Climate Change 4: 111–116. doi:10.1038/nclimate2100

Abstract. El Niño events are a prominent feature of climate variability with global climatic impacts. The 1997/98 episode, often referred to as 'the climate event of the twentieth century' and the 1982/83 extreme El Niño3, featured a pronounced eastward extension of the west Pacific warm pool and development of atmospheric convection, and hence a huge rainfall increase, in the usually cold and dry equatorial eastern Pacific. Such a massive reorganization of atmospheric convection, which we define as an extreme El Niño, severely disrupted global weather patterns, affecting ecosystems, agriculture, tropical cyclones, drought, bushfires, floods and other extreme weather events worldwide. Potential future changes in such extreme El Niño occurrences could have profound socio-economic consequences. Here we present climate modelling evidence for a doubling in the occurrences in the future in response to greenhouse warming. We estimate the change by aggregating results from climate models in the Coupled Model Intercomparison Project phases 3 (CMIP3) and 5 (CMIP5) multi-model databases, and a perturbed physics ensemble. The increased frequency arises from a projected surface warming over the eastern equatorial Pacific that occurs faster than in the surrounding ocean waters, facilitating more occurrences of atmospheric convection in the eastern equatorial region.

Chang, Edmund K. M., 2013: **CMIP5 Projection of Significant Reduction in Extratropical Cyclone Activity over North America.** Journal of Climate 26: 9903–9922. doi: http://dx.doi.org/10.1175/JCLI-D-13-00209.1

Abstract. Projections of storm-track changes over the continental United States and southern Canada made by 23 models from phase 5 of the Coupled Model Intercomparison Project (CMIP5) have been compared to changes projected by 11 models from phase 3 of CMIP (CMIP3). Overall, under representative concentration pathway 8.5 (RCP8.5) forcing, CMIP5 models project much more significant decreases in North American storm-track activity than CMIP3 models under the Special Report on Emission Scenarios (SRES) A2 scenario, with the largest decrease in summer and the smallest decrease in spring. The decrease is found both in temporal variance and cyclone statistics, with the frequency of strong cyclones projected to decrease by 15.9%, 6.6%, 32.6%, and 16.9% for winter, spring, summer, and fall, respectively. There is a strong consensus among the 23 models regarding the sign of the projected change, with less than 20% of the models projecting changes in the opposite sign in any of the storm-track parameters examined. Nevertheless, there are also significant model-to-model differences in the magnitude of the projected changes.

Projected changes in mean flow baroclinicity have also been examined. Model-to-model differences in the projected storm-track change are found to correlate significantly with model-to-model differences in the projected change in a locally defined mean available potential energy (MAPE) across the ensemble of 34 CMIP5 and CMIP3 models, suggesting that the differences in the projected change in local MAPE can partly account for not only the model-to-model differences but also the differences between CMIP5 and CMIP3 projections. Examination of projected precipitation change suggests that models projecting larger decrease in North American storm-track activity also project a farther northward intrusion of the decrease in subtropical precipitation.

Fischer, E. M., U. Beyerle and R. Knutti. 2013. **Robust spatially aggregated projections of climate extremes.** Nature Climate Change 3: 1033–1038. doi:10.1038/nclimate2051.

Abstract. Many climatic extremes are changing and decision-makers express a strong need for reliable information on further changes over the coming decades as a basis for adaptation strategies. Here, we demonstrate that for extremes stakeholders will have to deal with

large irreducible uncertainties on local to regional scales as a result of internal variability, even if climate models improve rapidly. A multimember initial condition ensemble carried out with an Earth system model shows that trends towards more intense hot and less intense cold extremes may be masked or even reversed locally for the coming three to five decades even if greenhouse gas emissions rapidly increase. Likewise, despite a long-term trend towards more intense precipitation and longer dry spells, multidecadal trends of opposite sign cannot be excluded over many land points. However, extremes may dramatically change at a rate much larger than anticipated from the long-term signal. Despite these large irreducible uncertainties on the local scale, projections are remarkably consistent from an aggregated spatial probability perspective. Models agree that within only three decades about half of the land fraction will see significantly more intense hot extremes. We show that even in the short term the land fraction experiencing more intense precipitation events is larger than expected from internal variability. The proposed perspective yields valuable information for decision-makers and stakeholders at the international level.

Mueller, B., and S. I. Seneviratne . 2014. **Systematic land climate and evapotranspiration biases in CMIP5 simulations.** Geophysical Research Letters 41: 128–134. doi:10.1002/2013GL058055.

Abstract. Land climate is important for human population since it affects inhabited areas. Here we evaluate the realism of simulated evapotranspiration (ET), precipitation, and temperature in the CMIP5 multimodel ensemble on continental areas. For ET, a newly compiled synthesis data set prepared within the Global Energy and Water Cycle Experiment-sponsored LandFlux-EVAL project is used. The results reveal systematic ET biases in the Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations, with an overestimation in most regions, especially in Europe, Africa, China, Australia, Western North America, and part of the Amazon region. The global average overestimation amounts to 0.17 mm/d. This bias is more pronounced than in the previous CMIP3 ensemble (overestimation of 0.09 mm/d). Consistent with the ET overestimation, precipitation is also overestimated relative to existing reference data sets. We suggest that the identified biases in ET can explain respective systematic biases in temperature in many of the considered regions. The biases additionally display a seasonal dependence and are generally of opposite sign (ET underestimation and temperature overestimation) in boreal summer (June–August).

Santoso, Agus, Shayne McGregor, Fei-Fei Jin, Wenju Cai, Matthew H. England, Soon-Il An, Michael J. McPhaden and Eric Guilyardi. 2013. **Late-twentieth-century emergence of the El Niño propagation asymmetry and future projections.** Nature 504: 126–130. doi:10.1038/nature12683

Abstract. The El Niño/Southern Oscillation (ENSO) is the Earth's most prominent source of interannual climate variability, exerting profound worldwide effects. Despite decades of research, its behaviour continues to challenge scientists. In the eastern equatorial Pacific Ocean, the anomalously cool sea surface temperatures (SSTs) found during La Niña events and the warm waters of modest El Niño events both propagate westwards, as in the seasonal cycle. In contrast, SST anomalies propagate eastwards during extreme El Niño events, prominently in the post-1976 period spurring unusual weather events worldwide with costly consequences. The cause of this propagation asymmetry is currently unknown. Here we trace the cause of the asymmetry to the variations in upper ocean currents in the equatorial Pacific, whereby the westward-flowing currents are enhanced during La Niña events but reversed during extreme El Niño events. Our results highlight that propagation asymmetry is favoured when the westward mean equatorial currents weaken, as is projected to be the case under global warming. By analysing past and future climate simulations of an ensemble of models with more realistic propagation, we find a doubling in the occurrences of El Niño events that feature prominent eastward propagation characteristics in a warmer world. Our analysis thus suggests that more frequent emergence of propagation asymmetry will be an indication of the Earth's warming climate.

Steven C. Sherwood, Sandrine Bony and Jean-Louis Dufresne. 2014. **Spread in model climate sensitivity traced to atmospheric convective mixing.** Nature 505: 37–42. doi:10.1038/nature12829

Abstract. Equilibrium climate sensitivity refers to the ultimate change in global mean temperature in response to a change in external forcing. Despite decades of research attempting to narrow uncertainties, equilibrium climate sensitivity estimates from climate models still span roughly 1.5 to 5 degrees Celsius for a doubling of atmospheric carbon dioxide concentration, precluding accurate projections of future climate. The spread arises largely from differences in the feedback from low clouds, for reasons not yet

understood. Here we show that differences in the simulated strength of convective mixing between the lower and middle tropical troposphere explain about half of the variance in climate sensitivity estimated by 43 climate models. The apparent mechanism is that such mixing dehydrates the low-cloud layer at a rate that increases as the climate warms, and this rate of increase depends on the initial mixing strength, linking the mixing to cloud feedback. The mixing inferred from observations appears to be sufficiently strong to imply a climate sensitivity of more than 3 degrees for a doubling of carbon dioxide. This is significantly higher than the currently accepted lower bound of 1.5 degrees, thereby constraining model projections towards relatively severe future warming.

Trenberth, Kevin E., Aiguo Dai, Gerard van der Schrier, Philip D. Jones, Jonathan Barichivich, Keith R. Briffa and Justin Sheffield. 2014. **Global warming and changes in drought.** Nature Climate Change 4: 17–22. doi:10.1038/nclimate2067

Abstract. Several recently published studies have produced apparently conflicting results of how drought is changing under climate change. The reason is thought to lie in the formulation of the Palmer Drought Severity Index (PDSI) and the data sets used to determine the evapotranspiration component. Here, we make an assessment of the issues with the PDSI in which several other sources of discrepancy emerge, not least how precipitation has changed and is analysed. As well as an improvement in the precipitation data available, accurate attribution of the causes of drought requires accounting for natural variability, especially El Niño/Southern Oscillation effects, owing to the predilection for wetter land during La Niña events. Increased heating from global warming may not cause droughts but it is expected that when droughts occur they are likely to set in quicker and be more intense.

Carbon and Carbon Storage

Averill, Colin, Benjamin L. Turner and Adrien C. Finzi. 2014. **Mycorrhiza-mediated competition between plants and decomposers drives soil carbon storage.** Nature 505: 543–545. doi:10.1038/nature12901.

Abstract. Soil contains more carbon than the atmosphere and vegetation combined. Understanding the mechanisms controlling the

accumulation and stability of soil carbon is critical to predicting the Earth's future climate. Recent studies suggest that decomposition of soil organic matter is often limited by nitrogen availability to microbes and that plants, via their fungal symbionts, compete directly with free-living decomposers for nitrogen. Ectomycorrhizal and ericoid mycorrhizal (EEM) fungi produce nitrogen-degrading enzymes, allowing them greater access to organic nitrogen sources than arbuscular mycorrhizal (AM) fungi. This leads to the theoretical prediction that soil carbon storage is greater in ecosystems dominated by EEM fungi than in those dominated by AM fungi. Using global data sets, we show that soil in ecosystems dominated by EEM-associated plants contains 70% more carbon per unit nitrogen than soil in ecosystems dominated by AM-associated plants. The effect of mycorrhizal type on soil carbon is independent of, and of far larger consequence than, the effects of net primary production, temperature, precipitation and soil clay content. Hence the effect of mycorrhizal type on soil carbon content holds at the global scale. This finding links the functional traits of mycorrhizal fungi to carbon storage at ecosystem-to-global scales, suggesting that plant–decomposer competition for nutrients exerts a fundamental control over the terrestrial carbon cycle.

Bennett, J. M., Cunningham, S. C., Connelly, C. A., Clarke, R. H., Thomson, J. R. and Mac Nally, R. 2013. **The interaction between a drying climate and land use affects forest structure and above-ground carbon storage.** Global Ecology and Biogeography 22: 1238–1247. doi: 10.1111/geb.12083

Abstract. *Aim:* Climate change has been linked to negative effects on vegetation, including drought-induced dieback. Large-scale dieback not only leads to considerable carbon emissions but often leads to loss of ecological resources. We investigated whether, and how, the structure, composition and carbon content changed over a period of extended drought (the 'Big Dry') in a much-modified forest ecosystem. We explored whether landscape configuration, management practice or soil type influenced vegetation change. *Location:* The Box-Ironbark forests of south-eastern Australia. *Methods:* In 2010, we remeasured 120 forest transects that had first been measured in 1997 by using identical field methods. Vegetation structure and composition were quantified. We used allometric growth models to estimate the expected increase in above-ground carbon (AGC) storage between 1997 and 2010; these estimates were compared with observed values. *Results:* Forest structure was systematically different between the two periods. Canopy cover, shrub cover and litter decreased between the

1997 and 2010 surveys, whereas total basal area of dead trees, dead trees in all size classes and saplings increased between the two surveys. Climate, fragment size and their interaction were the major predictors of change in most of the measured vegetation characteristics. By comparing measured AGC in 2010 and estimates from growth models, we estimated that 5.6 ± 2.1 SE t C ha^{-1} may have been foregone over the Big Dry. *Main conclusions:* Our findings add to the evidence linking climate change to negative effects on vegetation, including mortality, canopy dieback and reduced carbon sequestration. These effects may be amplified in fragmented vegetation because of greater water and heat stress. If the carbon sequestration deficit of c. 5.6 t C ha^{-1} were to apply across the extant Box-Ironbark forests of Victoria (c. 255,400 ha), then 1.43 Mt of carbon sequestration may not have occurred during the Big Dry.

Gálvez, Fabián B, Andrew T Hudak, John C Byrne, Nicholas L Crookston and Robert F Keefe. 2014. **Using climate-FVS to project landscape-level forest carbon stores for 100 years from field and LiDAR measures of initial conditions.** Carbon Balance and Management 9:1 doi:10.1186/1750-0680-9-1

Abstract. *Background.* Forest resources supply a wide range of environmental services like mitigation of increasing levels of atmospheric carbon dioxide (CO_2). As climate is changing, forest managers have added pressure to obtain forest resources by following stand management alternatives that are biologically sustainable and economically profitable. The goal of this study is to project the effect of typical forest management actions on forest C levels, given a changing climate, in the Moscow Mountain area of north-central Idaho, USA. Harvest and prescribed fire management treatments followed by plantings of one of four regionally important commercial tree species were simulated, using the climate-sensitive version of the Forest Vegetation Simulator, to estimate the biomass of four different planted species and their C sequestration response to three climate change scenarios. *Results.* Results show that anticipated climate change induces a substantial decrease in C sequestration potential regardless of which of the four tree species tested are planted. It was also found that *Pinus monticola* has the highest capacity to sequester C by 2110, followed by *Pinus ponderosa*, then *Pseudotsuga menziesii*, and lastly *Larix occidentalis*. *Conclusions.* Variability in the growth responses to climate change exhibited by the four planted species considered in this study points to the importance to forest managers of considering how well adapted seedlings may be to predicted climate change, before the

seedlings are planted, and particularly if maximizing C sequestration is the management goal.

Larreguy, C., A.L. Carrera, and M.B. Bertiller. 2014. **Effects of long-term grazing disturbance on the belowground storage of organic carbon in the Patagonian Monte, Argentina.** Journal of Environmental Management 134: 47-55.

Abstract. The objective of this study was to analyze the effect of grazing disturbance on the amount and the spatial distribution (vertical and horizontal) of root biomass and soil organic carbon (SOC) in order to evaluate whether grazing alters the belowground storage of organic carbon (C) in arid rangelands of the Patagonian Monte. We selected three representative sites (3 ha each) with low, moderate and high grazing disturbance located far, mid-distance and near the watering point, respectively, in rangelands submitted to sheep grazing for more than 100 years. We assessed the canopy structure and identified the four most frequent plant patch types at each site. We selected four replications of each patch type and extracted a soil sample (0–30 cm depth) underneath the canopy and in the middle of the nearest inter-patch bare soil area in winter and summer. We assessed the root and soil dry mass and the respective organic C concentration in each sample and then we estimated the total belowground organic C storage at each site. Total plant and perennial grass cover were lower with high than low grazing disturbance while the reverse occurred with dwarf shrub cover. High grazing disturbance led to the increase in total root biomass in the whole soil profile of patch areas and in the upper soil of inter-patch areas. SOC was higher in patch than in inter-patch areas at all sites but at both areas was reduced with high grazing disturbance. This was probably the result of the low total plant cover and the low and recalcitrant contribution of above and below-ground plant litter to soils at sites with high grazing disturbance. Accordingly, these changes did not result in variations in the total belowground organic C storage. We concluded that high grazing disturbance did not affect the total belowground organic C storage but led to changes in the spatial patterning of this organic C storage (i.e shifting from soil to roots).

Sharma, Tara, Werner A. Kurz, Graham Stinson, Marlow G. Pellatt, Qinglin Li. 2013. **A 100-year conservation experiment: Impacts on forest carbon stocks and fluxes.** Forest Ecology and Management 310: 242-255.

Abstract. Forest conservation is an important climate change mitigation strategy. National parks in Canada's Rocky and Purcell Mountains offer a rare opportunity to evaluate the impacts of a century of conservation on forest carbon (C) stocks and fluxes. We studied forest ecosystem C dynamics of three national parks in the Rocky and Purcell Mountains of British Columbia – Yoho, Kootenay, and Glacier National Parks – over the period 1970–2008 using the CBM-CFS3 inventory-based forest C budget model. We hypothesized that parks and protected areas would contain higher forest C density and have lower CO_2 uptake rates compared to their surrounding reference areas because of the exclusion of timber harvesting and resulting predominance of older, slower growing forest stands. Results for Glacier National Park relative to its reference area were consistent with our hypothesis. Forests in Kootenay National Park were substantially younger than those in its reference area despite the exclusion of harvesting because natural disturbances affected large areas within the park over the past century. Site productivity in Kootenay National Park was also generally higher in the park than in its reference area. Consequently, Kootenay National Park had both higher C density and higher CO_2 uptake than its reference area. Yoho National Park forests were similar in age to reference area forests and more productive, and therefore had both higher C stocks and greater CO_2 uptake. C density was higher in all 3 parks compared to their surrounding areas, and parks with younger forests than reference areas had higher CO_2 uptake. The results of this study indicate that forest conservation in protected areas such as national parks can preserve existing C stocks where natural disturbances are rare. Where natural disturbances are an important part of the forest ecology, conservation may or may not contribute to climate change mitigation because of the risk of C loss in the event of wildfire or insect-caused tree mortality. Anticipated increases in natural disturbance resulting from global warming may further reduce the climate change mitigation potential of forest conservation in disturbance-prone ecosystems. We show that managing for the ecological integrity of landscapes can also have carbon mitigation co-benefits.

Vesterdal, Lars, Nicholas Clarke, Bjarni D. Sigurdsson, and Per Gundersen. 2013. **Do tree species influence soil carbon stocks in temperate and boreal forests?** Forest Ecology and Management 309: 4-18.

Abstract. Information on tree species effects on soil organic carbon (SOC) stocks is scattered and there have been few attempts to synthesize results for forest floor and mineral soil C pools. We reviewed and synthesized current knowledge of tree species effects on SOC stocks in temperate and boreal forests based on common garden, retrospective paired stand and retrospective single-tree studies. There was evidence of consistent tree species effects on SOC stocks. Effects were clearest for forest floor C stocks (23 of 24 studies) with consistent differences for tree genera common to European and North American temperate and boreal forests. Support for generalization of tree species effects on mineral soil C stocks was more limited, but significant effects were found in 13 of 22 studies that measured mineral soil C.

Proportional differences in forest floor and mineral soil C stocks among tree species suggested that C stocks can be increased by 200–500% in forest floors and by 40–50% in top mineral soil by tree species change. However, these proportional differences within forest floors and mineral soils are not always additive: the C distribution between forest floor and mineral soil rather than total C stock tends to differ among tree species within temperate forests. This suggests that some species may be better engineers for sequestration of C in stable form in the mineral soil, but it is unclear whether the key mechanism is root litter input or macrofauna activity. Tree species effects on SOC in targeted experiments were most consistent with results from large-scale inventories for forest floor C stocks whereas mineral soil C stocks appeared to be stronger influenced by soil type or climate than by tree species at regional or national scales. Although little studied, there are indications that higher tree species diversity could lead to higher SOC stocks but the role of tree species diversity per se vs. species identity effects needs to be disentangled in rigorous experimental designs.

For targeted use of tree species to sequester soil C we must identify the processes related to C input and output, particularly belowground, that control SOC stock differences. We should also study forms and stability of C along with bulk C stocks to assess whether certain broadleaves store C in more stable form. Joint cooperation is needed to support syntheses and process-oriented work on tree species and SOC, e.g. through an international network of common garden experiments.

Zhang, Y., Yu, G., Yang, J., Wimberly, M. C., Zhang, X., Tao, J., Jiang, Y. and Zhu, J. 2014. **Climate-driven global changes in carbon use efficiency.** Global Ecology and Biogeography 23: 144–155. doi: 10.1111/geb.12086

Abstract. *Aim:* Carbon use efficiency [net primary production (NPP)/gross primary production (GPP) ratio] is a parameter related to the allocation of photosynthesized products by plants and is commonly used in many biogeochemical cycling models. But how this parameter changes with climates is still unknown. Faced by an aggravated global warming, there is a heightened necessity in unravelling the dependence of the NPP/GPP ratio on climates. The objective of this study was to examine how ongoing climate change is regulating global patterns of change in the NPP/GPP ratio. The study finding would elucidate whether the global vegetation ecosystem is becoming more or less efficient in terms of carbon storage under climatic fluctuation. *Location:* The global planetary ecosystem. *Methods:* The annual NPP/GPP ratio of the global terrestrial ecosystem was calculated over a 10-year period based on Moderate Resolution Imaging Spectroradiometer data and an ecosystem productivity model. The temporal dynamics of the global NPP/GPP ratio and their dependence on climate were investigated. *Results:* The global NPP/GPP ratio exhibited a decreasing trend from 2000 to 2009 due to decreasing NPP and stable GPP over this period. The temporal dynamics of the NPP/GPP ratio were strongly controlled by temperature and precipitation. Increased temperature lowered the NPP/GPP ratio, and increased precipitation led to a higher NPP/GPP ratio. *Conclusions:* The NPP/GPP ratio exhibits a clear temporal pattern associated with climatic fluctuations at a global scale. The associations of the NPP/GPP ratio with climatic variability challenge the conventional assumption that the NPP/GPP ratio should be consistent independent of environmental conditions. More importantly, the findings of this study have fundamental significance for our understanding of ongoing global climatic change. In regions and time periods experiencing drought or increased temperatures, plant ecosystems would suffer a higher ecosystem respiration cost and their net productivity would shrink.

Greenhouse Gases

Ståhl, Göran; Heikkinen, Juha; Petersson, Hans; Repola, Jaakko; Holm, Sören. 2014. **Sample-Based Estimation of Greenhouse Gas Emissions From Forests—A New Approach to Account for Both Sampling and Model Errors.** Forest Science 60(1): 3-13. http://dx.doi.org/10.5849/forsci.13-005

Abstract. The Good Practice Guidance (GPG) for reporting emissions and removals of greenhouse gases from the land use, land-use change, and forestry (LULUCF) sector of the United Nation's Framework Convention on Climate Change states that uncertainty estimates should always accompany the estimates of net emissions. Two basic procedures are suggested: simple error propagation and Monte-Carlo simulation. In this article, we argue that these methods are not very well-suited for uncertainty assessments in connection with sample-based surveys such as national forest inventories (NFIs), which provide a majority of the data for the LULUCF sector reporting in several countries. We suggest that a more straightforward approach would be to use standard sampling theory for assessing the sampling errors; however, it may be important to also include the error contribution from biomass and other models that are applied and this requires new methods for the variance estimation. In this article, a method for sample-based uncertainty assessment, including both model and sampling errors, is developed and applied using data from the NFIs of Finland and Sweden. The study revealed that the model error contribution to the combined sampling-model mean square error of ratio estimators of mean aboveground biomass on forestland amounted to about 10% in both countries. In estimating 5-year change of the corresponding biomass stocks, using permanent sampling units, the model error contribution was reduced to less than 1%. The smaller impact in the case of change estimation is due to the fact that any tendency of models to either over- or underestimate due to random parameter estimation errors will be the same both at the beginning and the end of a study period. The fairly small model error contributions in our study are due to the large number of sample trees used in the fitting of biomass models in Finland and Sweden; with less sample trees the model error contributions could be expected to be substantial. The proposed framework applies not only to greenhouse gas inventories but also to traditional NFI estimates of, e.g., growing stock in which uncertainties due to model errors typically are neglected in applications.

Species Range Changes

Bell, D. M., Bradford, J. B. and Lauenroth, W. K. 2014. **Early indicators of change: divergent climate envelopes between tree life stages imply range shifts in the western United States.** Global Ecology and Biogeography 23: 168–180. doi: 10.1111/geb.12109

Abstract. *Aim:* To determine if differences in climate envelopes for six coniferous tree species and two life stages (trees and seedlings) suggest a potential for species range contractions, expansions or shifts in response to climate change and if these patterns differ between subalpine (i.e. cool-climate) and montane (i.e. warm-climate) species. *Location:* The dry domain of the western United States. *Methods:* Using data from the Forest Inventory and Analysis National Program, we quantified the relationship between probability of occurrence and climate for adults and seedlings of each species with a Bayesian logistic regression. Assuming that distributional differences between life stages highlight shifting regeneration patterns relative to adult trees, we assessed differences between seedlings and adult trees based on predicted probabilities of occurrence and climate envelope boundaries. *Results:* Differences between occurrence probabilities for seedlings and adults were greatest for montane, as opposed to subalpine, species and along range margins, especially in the southern and western portions of the study area. Climate envelope boundaries of seedlings differed from adult trees most frequently in montane species and often suggested range contractions or range shifts, as opposed to range expansion. *Main conclusions.* Our results indicated that climate-induced contractions and shifts in seedling distribution in response to recent change are already under way and are particularly severe in montane tree species. While adult trees may persist for hundreds of years without significant regeneration, tree species ranges will eventually contract where tree regeneration fails.

Boucher-Lalonde, Véronique, Jeremy T. Kerr and David J. Currie. 2014. **Does climate limit species richness by limiting individual species' ranges?** Proceedings of the Royal Society B 281: 20132695. doi: 10.1098/rspb.2013.2695.

Abstract. Broad-scale geographical variation in species richness is strongly correlated with climate, yet the mechanisms underlying this correlation are still unclear. We test two broad classes of hypotheses to explain this pattern. Bottom-up hypotheses propose that the

environment determines individual species' ranges. Ranges then sum up to yield species richness patterns. Top-down hypotheses propose that the environment limits the number of species that occur in a region, but not which ones. We test these two classes of hypotheses using a natural experiment: seasonal changes in environmental variables and seasonal range shifts of 625 migratory birds in the Americas. We show that richness seasonally tracks the environment. By contrast, individual species' geographical distributions do not. Rather, species occupy different sets of environmental conditions in two seasons. Our results are inconsistent with extant bottom-up hypotheses. Instead, a top-down mechanism appears to constrain the number of species that can occur in a given region.

Gibson, Jacob, Gretchen Moisen, Tracey Frescino, Thomas C. Edwards Jr. 2014. **Using Publicly Available Forest Inventory Data in Climate-Based Models of Tree Species Distribution: Examining Effects of True Versus Altered Location Coordinates.** Ecosystems 17(1): 43-53.

Abstract. Species distribution models (SDMs) were built with US Forest Inventory and Analysis (FIA) publicly available plot coordinates, which are altered for plot security purposes, and compared with SDMs built with true plot coordinates. Six species endemic to the western US, including four junipers (*Juniperus deppeana* var. *deppeana*, *J. monosperma*, *J. occidentalis*, *J. osteosperma*) and two piñons (*Pinus edulis*, *P. monophylla*), were analyzed. The presence–absence models based on current climatic variables were generated over a series of species-specific modeling extents using Random Forests and applied to forecast climatic conditions. The distributions of predictor variables sampled with public coordinates were compared to those sampled with true coordinates using t tests with a Bonferroni adjustment for multiple comparisons. Public- and true-based models were compared using metrics of classification accuracy. The modeled current and forecast distributions were compared in terms of their overall areal agreement and their geographic mean centroids. Comparison of the underlying distributions of predictor variables sampled with true versus public coordinates did not indicate a significant difference for any species at any extent. Both the public- and true-based models had comparable classification accuracies across extent for each species, with the exception of one species, *J. occidentalis*. True-based models produced geographic distributions with smaller areas under current and future scenarios. The greatest areal difference occurred in the species with the lowest modeled accuracies (*J. occidentalis*), and had a forecast

distribution which diverged severely. The other species had forecast distributions with similar magnitudes of modeled distribution shifts.

Halbritter, Aud H., Jake M. Alexander, Peter J. Edwards and Regula Billeter. 2013. **How comparable are species distributions along elevational and latitudinal climate gradients?** Global Ecology and Biogeography 22(11/12): 1228-1237.

Abstract. *Aim:* Because climatic factors, especially temperature, show similar trends with elevation and latitude, it is often assumed that elevational gradients can be used as a proxy for understanding ecological processes along latitudinal gradients. We investigated the validity of this assumption for herbaceous plants, testing the hypotheses that (1) species reach the same climate limits, and (2) exhibit similar distribution patterns along both types of gradient. *Location:* Swiss Alps and Scandinavia. *Methods:* We recorded the occurrence of 155 ruderal plant species along an elevational gradient in the Swiss Alps and a latitudinal gradient, both reaching beyond the distribution limit of most species. Principal components analysis was used to summarize climatic variation in temperature and precipitation across these gradients and assessed the relationship across species between climatic limits along the two gradients. We used logistic regressions to compare how the probability of occurrence of individual species changed with climate along the two gradients. *Results:* We found no correlation of species principal components analysis (PCA) values (climate limit) along an elevational and latitudinal precipitation gradient (PCI) but a positive correlation along a temperature gradient (PC2). Species reached a colder climate limit (on average 244 growing degree days lower) and decreased in occurrence more gradually along the elevational compared to the latitudinal gradient. *Main conclusions:* We suggest that the differences in distribution patterns and limits along similar climatic gradients are mainly due to the much shorter dispersal distances along elevational than latitudinal gradients, although other explanations are also possible. We can therefore expect plants in mountains and lowland regions to respond differently to rapid climate change, and so caution must be exercised when using elevation as a proxy for latitude in studies of species distribution. Nonetheless, comparative studies along such gradients can yield important insights into the factors that limit species distributions.

Kopp, C. W. and Cleland, E. E. 2014. **Shifts in plant species elevational range limits and abundances observed over nearly five decades in a western North America mountain range.** Journal of Vegetation Science 25: 135–146. doi: 10.1111/jvs.12072

Abstract. *Question.* Have there been shifts in abundance and distribution of alpine and sub-alpine plant species along an elevational gradient in an arid North American mountain range during the last half-century? *Location.* Elevational gradient in the White Mountains, California, USA (37°30′ N, 118°10′ W). *Methods.* We conducted a 49-yr re-survey of plant species distribution and abundance in areas originally surveyed in 1961. Species abundance data were collected along line transects between elevations of 2900 and 4000 m. We evaluated the degree of plant community shift over time across elevations; specifically, we expected species ranges to shift upward such that species peak abundances would be observed higher in elevation in 2010 than in 1961. To address this expectation we conducted a permutational multivariate linear model analysis with elevation, soil type and year as factors. We further performed single-species analyses to evaluate how focal species contributed to the multivariate community-level shifts between 2010 and 1961, and how these varied across elevations and soil types. Growing season climate data (June 1 through October 31) collected between 1961 and 2010 were analysed to quantify the change in annual mean temperature and precipitation at this site. *Results.* We found that *Artemisia rothrockii* increased in abundance at the upper reaches of its distribution between the 2010 and 1961 surveys. Additionally, we recorded significant declines in abundances in the lower elevation ranges of three alpine cushion plants: *Trifolium andersonii*, *Phlox condensata* and *Eriogonum ovalifolium*. These shifts coincided with a 0.98 °C increase in mean growing season temperatures and a 53 mm decrease in mean annual precipitation between 1961 and 2010. *Conclusions.* These results suggest that rising temperatures and decreasing precipitation are negatively impacting alpine plant species while promoting expansion of sub-alpine species, possibly signalling the transition of this alpine plant community to sagebrush steppe.

Mathys, Amanda, Nicholas C. Coops, and Richard H. Waring. 2014. **Soil water availability effects on the distribution of 20 tree species in western North America.** Forest Ecology and Management 313: 144-152.

Abstract. The distribution of tree species is largely shaped by regional variation in climate and soils. Current models make very simple assumptions about soil water availability with limited inclusion into the predicted distribution of species. Recently, methods have been developed that integrate observations from satellites on maximum leaf area index. These remote sensing estimates, when combined with physiology can provide more detailed maps of available soil water holding capacity (ASWC) and soil fertility. By allowing soil properties as well as climate to vary across western North America, our process-based decision tree models predicted the occurrence of 20 tree species with an average accuracy of 84% ($\kappa = 0.79$), based on their recorded presence and absence on 43,404 field plots. Changes in productivity and distributions were assessed with varying soil water inputs. ASWC was increased and decreased by 50% from the originally mapped values to evaluate the effects on predicted species distributions. Soil water availability helped explain the variation in the distribution of 75% of the tree species. We found that 30% of the species were very to extremely sensitive to changes in ASWC, while 45% were somewhat sensitive. We conclude that knowledge of soil properties generally improves overall accuracy of species distribution models. Our sensitivity analysis identified the most sensitive species to changes in water availability, and indicated where additional information on soil properties would be most critical to verify.

Forest Vegetation

D'Amato,Anthony W., John B. Bradford, Shawn Fraver, and Brian J. Palik. 2013. **Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems.** Ecological Applications 23:1735–1742. http://dx.doi.org/10.1890/13-0677.1

Abstract. Reducing tree densities through silvicultural thinning has been widely advocated as a strategy for enhancing resistance and resilience to drought, yet few empirical evaluations of this approach exist. We examined detailed dendrochronological data from a long-term (>50 years) replicated thinning experiment to determine if density reductions conferred greater resistance and/or resilience to

droughts, assessed by the magnitude of stand-level growth reductions. Our results suggest that thinning generally enhanced drought resistance and resilience; however, this relationship showed a pronounced reversal over time in stands maintained at lower tree densities. Specifically, lower-density stands exhibited greater resistance and resilience at younger ages (49 years), yet exhibited lower resistance and resilience at older ages (76 years), relative to higher-density stands. We attribute this reversal to significantly greater tree sizes attained within the lower-density stands through stand development, which in turn increased tree-level water demand during the later droughts. Results from response–function analyses indicate that thinning altered growth–climate relationships, such that higher-density stands were more sensitive to growing-season precipitation relative to lower-density stands. These results confirm the potential of density management to moderate drought impacts on growth, and they highlight the importance of accounting for stand structure when predicting climate-change impacts to forests.

Dolanc, Christopher R., Robert D. Westfall, Hugh D. Safford, James H. Thorne, Mark W. Schwartz. 2013. **Growth–climate relationships for six subalpine tree species in a Mediterranean climate.** Canadian Journal of Forest Research 43(12): 1114-1126. DOI: 10.1139/cjfr-2013-0196

Abstract. A better understanding of the growth–climate relationship for subalpine trees is key to improving predictions about their future distributions under climate change. In subalpine regions of Mediterranean mountains, drought is an annual event, yet many sites can have long-lasting snowpack. We analyzed the growth–climate relationship from 1896 to 2006 for the six most abundant subalpine tree species (red fir (*Abies magnifica* A. Murray bis), whitebark pine (*Pinus albicaulis* Engelm.), Sierra/Cascade lodgepole pine (*Pinus contorta* var. *murrayana* (Balf.) Engelm.), Jeffrey pine (*Pinus jeffreyi* Balf.), western white pine (*Pinus monticola* Douglas ex D. Don), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière)) of the central Sierra Nevada, California, USA, a region with deep spring snowpack followed by strong summer drought. Chronologies for the six species exhibited a high degree of synchrony in their response to annual fluctuations in temperature and precipitation. For all six species, cool, wet conditions in the year prior to growth are conducive to good radial growth, as well as warm springs with sufficient moisture during the year of growth. For species more common on protected slopes, such as mountain hemlock, deep spring snowpack can limit growth. Although predictions of future precipitation trends in the

region are uncertain, drought stress appears to already be increasing. If this trend continues, radial growth is likely to be inhibited for most or all species in our study. Trees growing where snowpack is deep may be least likely to suffer reduced growth.

Erickson, C. C., Waring, K. M. 2014. **Old *Pinus ponderosa* growth responses to restoration treatments, climate and drought in a southwestern US landscape.** Applied Vegetation Science 17: 97–108. doi: 10.1111/avsc.12056

Abstract. *Questions:* Do landscape-scale thin and burn restoration treatments have a long-term, landscape-scale impact on old *Pinus ponderosa* growth? Is there a relationship between old *P. ponderosa* growth and climatic factors, in particular, drought, before and after restoration treatments? *Location:* Northwestern Arizona, USA. *Methods:* We looked at old *P. ponderosa* growth across the landscape in both an area 'treated' by thin and burn restoration treatments, and a neighbouring untreated area. We re-visited each old *P. ponderosa* located on permanent 0.1-ha plots installed across the landscape prior to treatment implementation and recorded tree status, diameter, aspect, slope and competition from neighbouring trees. Growth was analysed from shallow increment cores taken from each tree at breast height (1.37 m). Comparisons of growth between the treated and untreated areas were carried out using regional proxy and instrumental Palmer drought severity index values and instrument precipitation data. *Results:* We found significant differences in precipitation and temperature between the treated and untreated areas, indicating a drier, less advantageous climate in the untreated area. Old trees in the treated area responded less negatively in diameter growth to treatments; both treatment and abiotic site factors were important in predicting post-treatment growth. All old trees grew slowly during drought years; however, old trees in the treated area grew better after three recent drought years than old trees in the untreated area. *Conclusions:* Old *P. ponderosa* diameter growth increased following restoration, though not immediately. Old trees in the treated area also grew better in the years after drought than old trees in the untreated area. Restoration, or similar treatments removing small, neighbouring trees may be critical in maintaining old *P. ponderosa* in the landscape, particularly under future climate change and increasing drought frequency in the western USA.

Kerhoulas, L. P., Kolb, T. E., Hurteau, M. D., Koch, G. W. 2013. **Managing climate change adaptation in forests: a case study from the U.S. Southwest.** Journal of Applied Ecology 50: 1311–1320. doi: 10.1111/1365-2664.12139

Abstract. Forest mortality related to climate change is an increasingly common global phenomenon. We provide a case study of the U.S. Southwest to investigate the interactions among forest restoration treatments that alter stand density, tree growth and drought resistance in trees of different size classes. Using cores taken from five positions in large trees (coarse roots, breast height, base of live crown, midcrown branch and treetop) and breast height in small trees, we investigated how radial growth response to thinning and precipitation availability varied in 72 ponderosa pines Pinus ponderosa Dougl. in northern Arizona. Ten years after thinning, growth of small trees did not respond significantly to thinning, whereas growth of large trees increased following moderate and heaving thinning, and this response was similar across within-tree core sample positions. The intensity of thinning treatment did not significantly affect dry-year growth in small trees. In large trees, dry-year growth after thinning was maintained at pre-thinning levels in moderate and heavy thinning treatments but decreased in the light thinning and control treatments. *Synthesis and applications.* Our findings indicate that more aggressive thinning treatments used for forest restoration stimulate growth throughout large residual trees from coarse roots to branches and also improve drought resistance, providing a greater resilience to future climate-related stress. These responses to treatment are more pronounced in large trees than small trees. Forest thinning is therefore recommended in systems that are likely to experience increased temperature and decreased precipitation as a result of climate change.

Raymond Crystal L. and Donald McKenzie. 2013. **Temporal carbon dynamics of forests in Washington, US: Implications for ecological theory and carbon management.** Forest Ecology and Management 310: 796-811.

Abstract. We quantified carbon (C) dynamics of forests in Washington, US using theoretical models of C dynamics as a function of forest age. We fit empirical models to chronosequences of forest inventory data at two scales: a coarse-scale ecosystem classification (ecosections) and forest types (potential vegetation) within ecosections. We hypothesized that analysis at the finer scale of forest types would reduce variability, yielding better fitting models. We fit models for three temporal dynamics: accumulation of live biomass,

accumulation of dead biomass, and net primary productivity (NPP). We compared fitted model parameters among ecosections and among forest types to determine differences in potential C storage and uptake.

Models of live biomass C accumulation and NPP fit the data better at the scale of forest types, suggesting this finer scale is important for reducing variability. Model fit for dead biomass C accumulation depended more on the region than on the scale of analysis. Dead biomass C was highly variable and a relationship with forest age was found only in some forest types of the eastern Cascades and Okanogan Highlands. Indicators of C storage potential differed between forest types and differences were consistent with expectations based on spatial variability in climate. Across the study area, maximum live biomass C varied from 6.5 to 38.6 kg C m^{-2} and the range of ages at which 90% of maximum is reached varied from 57 to 838 years. Maximum NPP varied from 0.37 to 0.94 kg C m^{-2} yr^{-1} and the age of maximum NPP varied from 65 to 543 yrs. Forests with the greatest C storage potential are wet forests of the western Cascades. Forests with the greatest potential NPP are 65–100-year-old mesic western redcedar-western hemlock forests and riparian forests, although limited data suggest maximum NPP of coastal sitka spruce forests may be even greater. The observed relationship between the ages at which maximum NPP and maximum live biomass are reached for a given forest type suggests that there is a trade-off between managing for maximum live biomass (storage) vs. NPP (uptake) in some forest types but an optimal age for C management in others. The empirical models of C dynamics in this study can be used to quantify the effects of age-class distributions on C storage and NPP for large areas composed of different forest types. Also, the models can be used to test the effects of current or future natural and anthropogenic disturbance regimes on C sequestration, providing an alternative to biogeochemical process models and stand-scale methods.

Vaillant, Nicole M., Alicia L. Reiner, and Erin K. Noonan-Wright. 2013. **Prescribed fire effects on field-derived and simulated forest carbon stocks over time.** Forest Ecology and Management 310: 711-719.

Abstract. To better understand the impact of prescribed fire on carbon stocks, we quantified aboveground and belowground carbon stocks within five pools (live trees and coarse roots, dead trees and coarse roots, live understory vegetation, down woody debris, and litter and duff) and potential carbon emissions from a simulated wildfire

before and up to 8 years after prescribed fire treatments. Total biomass carbon (sum of all the pools) was significantly lower 1 year post-treatment than pre-treatment and returned to 97% of pre-treatment levels by 8 year post-treatment primarily from increases in the tree carbon pool. Prescribed fire reduced predicted wildfire emissions by 45% the first year after treatment and remained reduced through 8 year post-treatment (34%). Net carbon (total biomass minus simulated wildfire emissions) resulted in a source (10.4–15.4 Mg ha^{-1}) when field-derived values were compared to simulated controls for all post-treatment time periods. However, the incidence of potential crown fire in the untreated simulations was at least double for the 2 year and 8 year post-treatment time periods than in the treated plots. We also compared field-derived estimates to simulated values using the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS). In our validation of FFE-FVS to predict carbon stocks, the model performed well for the total biomass carbon (4% difference); however, there was great variability within the individual carbon pools. Live tree carbon had the highest correlation between field-derived and simulated values, and dead tree carbon the lowest correlation and highest percent differences followed by herb and shrub carbon. The lack of trends and variability between the field-derived and simulated carbon pools other than total biomass indicate caution should be used when reporting carbon in the individual pools.

Zhang, Y., Yu, G., Yang, J., Wimberly, M. C., Zhang, X., Tao, J., Jiang, Y. and Zhu, J. 2014. **Climate-driven global changes in carbon use efficiency.** Global Ecology and Biogeography: 23: 144–155. doi: 10.1111/geb.12086

Abstract. *Aim.* Carbon use efficiency [net primary production (NPP)/gross primary production (GPP) ratio] is a parameter related to the allocation of photosynthesized products by plants and is commonly used in many biogeochemical cycling models. But how this parameter changes with climates is still unknown. Faced by an aggravated global warming, there is a heightened necessity in unravelling the dependence of the NPP/GPP ratio on climates. The objective of this study was to examine how ongoing climate change is regulating global patterns of change in the NPP/GPP ratio. The study finding would elucidate whether the global vegetation ecosystem is becoming more or less efficient in terms of carbon storage under climatic fluctuation. *Location.* The global planetary ecosystem. *Methods.* The annual NPP/GPP ratio of the global terrestrial ecosystem was calculated over a 10-year period based on Moderate Resolution Imaging Spectroradiometer data and an ecosystem productivity model. The

temporal dynamics of the global NPP/GPP ratio and their dependence on climate were investigated. *Results.* The global NPP/GPP ratio exhibited a decreasing trend from 2000 to 2009 due to decreasing NPP and stable GPP over this period. The temporal dynamics of the NPP/GPP ratio were strongly controlled by temperature and precipitation. Increased temperature lowered the NPP/GPP ratio, and increased precipitation led to a higher NPP/GPP ratio. *Conclusions.* The NPP/GPP ratio exhibits a clear temporal pattern associated with climatic fluctuations at a global scale. The associations of the NPP/GPP ratio with climatic variability challenge the conventional assumption that the NPP/GPP ratio should be consistent independent of environmental conditions. More importantly, the findings of this study have fundamental significance for our understanding of ongoing global climatic change. In regions and time periods experiencing drought or increased temperatures, plant ecosystems would suffer a higher ecosystem respiration cost and their net productivity would shrink.

Rangeland Vegetation

Nelson, Zachary J., Peter J. Weisberg and Stanley G. Kitchen. 2014. **Influence of climate and environment on post-fire recovery of mountain big sagebrush.** International Journal of Wildland Fire 23(1): 131-142. http://dx.doi.org/10.1071/WF13012

Abstract. In arid and semi-arid landscapes around the world, wildfire plays a key role in maintaining species diversity. Dominant plant associations may depend upon particular fire regime characteristics for their persistence. Mountain shrub communities in high-elevation landscapes of the Intermountain West, USA, are strongly influenced by the post-fire recovery dynamics of the obligate-seeding shrub, mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle). This species is a short-distance disperser with a short-lived seedbank, leading to highly variable post-fire recovery times (15–100 years). We investigated the relative importance of site productivity and seasonal climate in explaining the variance in recovery time for 36 fires, comprising a fire chrono-sequence (from 1971 to 2007) for the Great Basin and Colorado Plateau. *A. t. vaseyana* recovery was positively related to precipitation in the cool season immediately following fire, likely because deep soil-water recharge that persists throughout the growing season enhances first-year seedling survival. Percentage sand fraction positively correlated

with recovery rate yet negatively correlated with live cover in unburnt stands. Our data support the hypothesis that post-fire recovery rate of *A. t. vaseyana* depends on the climatically controlled ephemerality of the regeneration niche, as is likely true for many arid-land shrub species.

Newton, P. C. D., Lieffering, M., Parsons, A. J., Brock, S. C., Theobald, P. W., Hunt, C. L., Luo, D. and Hovenden, M. J. 2014. **Selective grazing modifies previously anticipated responses of plant community composition to elevated CO2 in a temperate grassland.** Global Change Biology: 20: 158–169. doi: 10.1111/gcb.12301

Abstract. Our limited understanding of terrestrial ecosystem responses to elevated CO_2 is a major constraint on predicting the impacts of climate change. A change in botanical composition has been identified as a key factor in the CO_2 response with profound implications for ecosystem services such as plant production and soil carbon storage. In temperate grasslands, there is a strong consensus that elevated CO_2 will result in a greater physiological stimulus to growth in legumes and to a lesser extent forbs, compared with C3 grasses, and the presumption this will lead in turn to a greater proportion of these functional groups in the plant community. However, this view is based on data mainly collected in experiments of three or less years in duration and not in experiments where defoliation has been by grazing animals. Grazing is, however, the most common management of grasslands and known in itself to influence botanical composition. In a long-term Free Air Carbon Dioxide Enrichment (FACE) experiment in a temperate grassland managed with grazing animals (sheep), we found the response to elevated CO_2 in plant community composition in the first 5 years was consistent with the expectation of increased proportions of legumes and forbs. However, in the longer term, these differences diminished so that the proportions of grasses, legumes and forbs were the same under both ambient and elevated CO_2. Analysis of vegetation before and after each grazing event showed there was a sustained disproportionately greater removal (‘apparent selection’) of legumes and forbs by the grazing animals. This bias in removal was greater under elevated CO_2 than ambient CO_2. This is consistent with sustained faster growth rates of legumes and forbs under elevated CO_2 being countered by selective defoliation, and so leading to little difference in community composition.

Scastaa,J. D. and B. S. 2014. **Drought and Ecological Site Interaction on Plant Composition of a Semi-Arid Rangeland.** Arid Land Research and Management 28(2): 197-215. DOI: 10.1080/15324982.2013.824046

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

Twidwell, D., Wonkka, C. L., Taylor, C. A., Zou, C. B., Twidwell, J. J., Rogers, W. E. 2014. **Drought-induced woody plant mortality in an encroached semi-arid savanna depends on topoedaphic factors and land management.** Applied Vegetation Science 17: 42–52. DOI: 10.1111/avsc.12044

Abstract. *Questions:* How do recent patterns of drought-induced woody plant mortality in Texas semi-arid savanna compare to the extended drought of the 1950s? Does the relative composition of the woody plant community shift ubiquitously across the landscape following woody plant mortality and dieback or are shifts dependent on

differences among species, soils, land use and plant demography? *Location:* Texas Agrilife Research Station, Sonora, Texas, USA (30.1° N 100.3° W). *Methods:* Following an exceptional drought from 1951 to 1957, a study was conducted to quantify rates of mortality for various woody plant species. In 2011, we repeated this study within three long-term grazing treatments that were established in 1948. Ten transects were established in each treatment to quantify the frequency and cover of live and dead woody individuals for all woody species. Rates of woody plant dieback were determined for each species and tested for differences among height classes, soil categories, total woody densities and pastoral treatments. *Results:* Flash droughts (defined as rapidly intensifying droughts characterized by moisture deficits and high temperatures) from 2000 to 2011 were the second most severe since 1919 (low PDSI = −4) and were only surpassed by the prolonged drought from 1951 to 1957 (low PDSI = −5.17). Drought-induced shifts from one woody plant community to another did not occur uniformly across the landscape. Instead, high mortality rates of mature *Juniperus ashei* trees in deep soils (67.3%, 33 of 49 trees), combined with the recruitment of *Quercus* species where grazing had been excluded for the last 60 yr, were the only patch types to shift from a *Juniperus–Quercus* woodland to an alternate state. *Conclusions:* Flash droughts since 2000 resulted in significant mortality and dieback, but dieback in cover was 28% higher following the more severe drought of the 1950s. Legacies from long-term land management practices interacted with localized differences in topoedaphic factors to drive patch-level shifts in woody vegetation following drought.

Invasives

Bellard, C., Thuiller, W., Leroy, B., Genovesi, P., Bakkenes, M. and Courchamp, F. 2013. **Will climate change promote future invasions?** Global Change Biology 19: 3740–3748. doi: 10.1111/gcb.12344

Abstract. Biological invasion is increasingly recognized as one of the greatest threats to biodiversity. Using ensemble forecasts from species distribution models to project future suitable areas of the 100 of the world's worst invasive species defined by the International Union for the Conservation of Nature, we show that both climate and land use changes will likely cause drastic species range shifts. Looking at potential spatial aggregation of invasive species, we identify three

future hotspots of invasion in Europe, northeastern North America, and Oceania. We also emphasize that some regions could lose a significant number of invasive alien species, creating opportunities for ecosystem restoration. From the list of 100, scenarios of potential range distributions show a consistent shrinking for invasive amphibians and birds, while for aquatic and terrestrial invertebrates distributions are projected to substantially increase in most cases. Given the harmful impacts these invasive species currently have on ecosystems, these species will likely dramatically influence the future of biodiversity.

Ibáñez, Inés, Jeffrey M. Diez, Luke P. Miller, Julian D. Olden, Cascade J. B. Sorte, Dana M. Blumenthal, Bethany A. Bradley, Carla M. D'Antonio, Jeffrey S. Dukes, Regan I. Early, Edwin D. Grosholz, and Joshua J. Lawler. 2014. **Integrated assessment of biological invasions.** Ecological Applications 24:25–37. http://dx.doi.org/10.1890/13-0776.1

Abstract. As the main witnesses of the ecological and economic impacts of invasions on ecosystems around the world, ecologists seek to provide the relevant science that informs managers about the potential for invasion of specific organisms in their region(s) of interest. Yet, the assorted literature that could inform such forecasts is rarely integrated to do so, and further, the diverse nature of the data available complicates synthesis and quantitative prediction. Here we present a set of analytical tools for synthesizing different levels of distributional and/or demographic data to produce meaningful assessments of invasion potential that can guide management at multiple phases of ongoing invasions, from dispersal to colonization to proliferation. We illustrate the utility of data-synthesis and data-model assimilation approaches with case studies of three well-known invasive species—a vine, a marine mussel, and a freshwater crayfish—under current and projected future climatic conditions. Results from the integrated assessments reflect the complexity of the invasion process and show that the most relevant climatic variables can have contrasting effects or operate at different intensities across habitat types. As a consequence, for two of the study species climate trends will increase the likelihood of invasion in some habitats and decrease it in others. Our results identified and quantified both bottlenecks and windows of opportunity for invasion, mainly related to the role of human uses of the landscape or to disruption of the flow of resources. The approach we describe has a high potential to enhance model realism, explanatory insight, and predictive capability, generating information that can inform management decisions and optimize

phase-specific prevention and control efforts for a wide range of biological invasions.

Fish and Wildlife

Porzig, Elizabeth L., Nathaniel E. Seavy, Thomas Gardali, Geoffrey R. Geupel, Marcel Holyoak, and John M. Eadie. 2014. **Habitat suitability through time: using time series and habitat models to understand changes in bird density.** Ecosphere 5:art12. http://dx.doi.org/10.1890/ES13-00166.1

Abstract. Confronted with a rapidly changing world and limited resources for conservation, ecologists are increasingly challenged with predicting the impact of climate and land-use change on wildlife. A common approach is to use habitat-suitability models (HSMs) to explain aspects of species' occurrence, such as presence, abundance, and distribution, utilizing physical habitat characteristics. Although HSMs are useful, they are limited because they are typically created using spatial rather than temporal data, which omits temporal dynamics. We explored the value of combining spatial and temporal approaches by comparing HSMs with autoregressive population models. We investigated a 28-year period of bird community dynamics at a field site in northern California during which time the plant community has been transitioning from scrub to conifer forest. We used the two model frameworks to quantify the contribution of vegetation change, weather, and population processes (autoregressive models only) to variation in density of seven bird species over the first 23 years. Model predictive ability was then tested using the subsequent five years of population density data. HSMs explained 58% to 90% of the deviance in species' density. However, models that included density dependence in addition to vegetation covariates provided a better fit to the data for three of the seven species, Song Sparrow (*Melospiza melodia*), White-crowned Sparrow (*Zonotrichia leucophrys*), and Wrentit (*Chamaea fasciata*). These three species have more localized dispersal compared to the other four species, suggesting that dispersal tendency may be an important life-history trait to consider when predicting the impact of climate and land-use change on population levels. Our results suggest that HSMs can effectively explain and predict variation in species' densities through time, however for species with localized dispersal, it may be especially informative to include population processes.

Vindenes, Yngvild, Eric Edeline, Jan Ohlberger, Øystein Langangen, Ian J. Winfield, Nils C. Stenseth, and L. Asbjørn Vøllestad. 2014. **Effects of Climate Change on Trait-Based Dynamics of a Top Predator in Freshwater Ecosystems.** The American Naturalist 183(2): 243-256. DOI: 10.1086/674610.

Abstract. Predicted universal responses of ectotherms to climate warming include increased maximum population growth rate and changes in body size through the temperature-size rule. However, the mechanisms that would underlie these predicted responses are not clear. Many studies have focused on proximate mechanisms of physiological processes affecting individual growth. One can also consider ultimate mechanisms involving adaptive explanations by evaluating temperature effects on different vital rates across the life history and using the information in a population dynamical model. Here, we combine long-term data for a top predator in freshwater ecosystems (pike; *Esox lucius*) with a stochastic integral projection model to analyze concurrent effects of temperature on vital rates, body size, and population dynamics. As predicted, the net effect of warming on population growth rate (fitness) is positive, but the thermal sensitivity of this rate is highly size- and vital rate–dependent. These results are not sensitive to increasing variability in temperature. Somatic growth follows the temperature-size rule, and our results support an adaptive explanation for this response. The stable length structure of the population shifts with warming toward an increased proportion of medium-sized but a reduced proportion of small and large individuals. This study highlights how demographic approaches can help reveal complex underlying mechanisms for population responses to warming.

Invertebrates

Creeden, Eric P., Jeffrey A. Hicke, and Polly C. Buotte. 2014. **Climate, weather, and recent mountain pine beetle outbreaks in the western United States.** Forest Ecology and Management 311: 239-251.

Abstract. Recent outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) have impacted large areas of western North America. Climate and weather conditions influence beetle population dynamics, and managers and policymakers are concerned about the potential effects of climate change on outbreaks. Here we studied five locations with extensive outbreaks in lodgepole pine (*Pinus contorta*) forests

across the western United States. Using observations and modeling, we quantified means and changes relative to prior years of three climate or weather factors associated with outbreaks: (1) year-round temperatures that affect adaptive seasonality; (2) low temperatures that induce mortality of overwintering beetles; and (3) drought stress of host trees. Climate variable means varied among locations, indicating the beetle's tolerance to different climate during outbreaks. Analyses of climate or weather factors as outbreaks progressed revealed that year-round temperatures during outbreaks were typically higher than in prior years, and outbreak years lacked very low winter temperatures that often occurred in prior years. Drought was present at each location during some time of an outbreak, and increases in beetle-caused tree mortality at lower beetle population levels (as indicated by killed trees) were usually coincident with drought. Furthermore, drought was not required to maintain large outbreaks; in several locations, relief from drought during periods of high tree mortality did not cause subsequent declines in tree mortality. We did not find strong evidence that maladaptive seasonality, cold-induced mortality, or drought stress was responsible for decreases in tree mortality, suggesting the role of host depletion. Large variability in the relationships between climate or weather variables and outbreaks suggests that different climate and weather factors may have been limiting outbreaks at different times and that these factors did not influence beetle-caused tree mortality similarly among locations. Our results increase understanding of the climate and weather factors that influence beetle outbreaks and their variability in space and time and will lead to more accurate predictions of future patterns of outbreaks that consider future climate.

Estay, S. A., Lima, M. and Bozinovic, F. 2014. **The role of temperature variability on insect performance and population dynamics in a warming world.** Oikos: 123: 131–140. doi: 10.1111/j.1600-0706.2013.00607.x

Abstract. Despite the amount of research on the consequences of global warming on ecological systems, most studies examine the impact of increases in average temperature. However, there are few studies concerning the role of thermal variability on ecological processes. Based on insect thermal and population ecology, we propose a theoretical framework for organizing the study of the role that thermal mean and variability plays in individual performance, and how it may affect population dynamics. Starting with three predictions of global warming scenarios, we develop null models of the expected changes in individual physiological performance and population

dynamics. Ecological consequences in each scenario may range from simple changes in performance to drastic changes in population fluctuations and geographic ranges. In particular, our null models show that potential changes in the intrinsic population growth rate (Rm) will depend on the interaction of mean temperature and thermal variability, and that the net effect of the interaction could be synergistic or antagonistic. To evaluate these null models, we fit performance curves to compiled data from the literature on measurements of Rm at several constant and fluctuating temperatures. The fitted models showed that several of the qualitative characteristics predicted by the null model may be found in the fitted curves. We expect that this framework will be useful as a guide to study the influence of thermal changes on the dynamics of natural populations.

Menke, Sean B., John Harte, and Robert R. Dunn. 2014. **Changes in ant community composition caused by 20 years of experimental warming vs. 13 years of natural climate shift.** Ecosphere 5:art6. http://dx.doi.org/10.1890/ES13-00234.1

Abstract. Predicting the effects of climate change on community composition is hampered by the lack of integration between long term data sets tracking the effects of natural climate change and the results of experimental climate manipulations. Here we compare the effects of change in climate through time to experimental warming on the composition of high elevation ant communities at the Rocky Mountain Biological Station in Gothic Colorado. We take advantage of a 20-year continuously running warming experiment which has increased soil temperature by 1.5°C and advanced snowmelt by 10 days and compare the effects of this experimental warming to natural changes in climate over the past 13 years across three sites spread along a 420-m elevation gradient representing a roughly 1°C difference in average annual soil temperature and average advanced snowmelt of 2 weeks. We compared ant community data collected at all four sites in 1997 to collections made at the same sites in 2010. From 1997 to 2010 there was a community wide shift in ant composition along the natural climate gradient with ant communities shifting to higher elevations. Ant communities in the experimental warming site also changed, but they shifted orthogonally to those along the gradient. Interestingly, after 20 years of experimental warming, there is little discernible effect on ant communities in experimentally warmed plots compared to control plots. This discrepancy between the climate manipulation and elevation gradient is probably an effect of the spatial

scale of the experimental warming. Ants respond to experimental warming in complex ways due to the physical location of their nests and their foraging area. This is a concern for warming experiments, but one that is hard to address for species that cover even modest areas in their foraging.

Soils and Hydrology

Abella, Scott R., Charles W. Denton, Rory W. Steinke, and David G. Brewer. 2013. **Soil development in vegetation patches of *Pinus ponderosa* forests: Interface with restoration thinning and carbon storage.** Forest Ecology and Management 310: 632-642.

Abstract. Frequent-fire conifer forests in western North America are undergoing restoration and fuel-reduction treatments to reduce chance of severe crown fire and re-balance tree and understory plant biomass. A central decision in these treatments remains where to retain trees within sites during tree thinning. To help inform thinning prescriptions by identifying patterns of soil development, we sampled and classified 48 soil pedons among three vegetation patch types (grassy openings, openings invaded by post-settlement trees <age 130 years, and pre-settlement tree patches) at 8 sites in northern Arizona *Pinus ponderosa* forests. We found that 69% of pedons in openings were classified as Mollisols (a soil order associated with grasslands), whereas 75% of pedons in pre-settlement tree patches were Alfisols (a forest soil order). Soil differences among patches primarily related to soil morphology and development of epipedons, not necessarily reflected in analyses of properties (e.g., horizon thickness, organic C) of horizons. Turnover in soil orders occurs on a scale of meters to tens of meters within sites on this landscape, corresponding with distribution of vegetation patch types. Owing to long time periods required for these soil patterns to develop, results provide additional support for an idea that locations of tree and herbaceous patches were stable for long time periods (centuries to millennia). Results suggest that soil development patterns warrant consideration when choosing spatial locations of 'leave' trees during forest thinning.

Downard, Rebekah and Joanna Endter-Wada. 2013. **Keeping wetlands wet in the western United States: Adaptations to drought in agriculture-dominated human-natural systems.** Journal of Environmental Management 131: 394-406.

Abstract. Water is critical to protecting wetlands in arid regions, especially in agriculture-dominated watersheds. This comparative case study analyzes three federal wildlife refuges in the Bear River Basin of the U.S. West where refuge managers secured water supplies by adapting to their local environmental context and their refuge's relationship to agriculture in being either irrigation-dependent, reservoir-adjacent or diked-delta wetlands. We found that each refuge's position confers different opportunities for securing a water supply and entails unique management challenges linked to agricultural water uses. Acquiring contextually-appropriate water rights portfolios was important for protecting these arid region wetlands and was accomplished through various strategies. Once acquired, water is managed to buffer wetlands against fluctuations caused by a dynamic climate and agricultural demands, especially during droughts. Management plans are responsive to needs of neighboring water users and values of the public at large. Such context-specific adaptations will be critical as the West faces climate change and population growth that threaten wetlands and agricultural systems to which they are linked.

Luce, C. H., J. T. Abatzoglou, and Z. A. Holden. 2013. **The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest USA.** Science 342: 1360-1364. DOI: 10.1126/science.1242335

Abstract. Trends in streamflow timing and volume in the Pacific Northwest United States have been attributed to increased temperatures, because trends in precipitation at lower-elevation stations were negligible. We demonstrate that observed streamflow declines are probably associated with declines in mountain precipitation, revealing previously unexplored differential trends. Lower-troposphere winter (November to March) westerlies are strongly correlated with high-elevation precipitation but weakly correlated with low-elevation precipitation. Decreases in lower-tropospheric winter westerlies across the region from 1950 to 2012 are hypothesized to have reduced orographic precipitation enhancement, yielding differential trends in precipitation across elevations and contributing to the decline in annual streamflow. Climate projections show weakened lower-troposphere zonal flow across the region under enhanced

greenhouse forcing, highlighting an additional stressor that is relevant for climate change impacts on hydrology.

Maestre, F. T., Escolar, C., de Guevara, M. L., Quero, J. L., Lázaro, R., Delgado-Baquerizo, M., Ochoa, V., Berdugo, M., Gozalo, B. and Gallardo, A. 2013. **Changes in biocrust cover drive carbon cycle responses to climate change in drylands.** Global Change Biology 19: 3835–3847. doi: 10.1111/gcb.12306

Abstract. Dryland ecosystems account for ca. 27% of global soil organic carbon (C) reserves, yet it is largely unknown how climate change will impact C cycling and storage in these areas. In drylands, soil C concentrates at the surface, making it particularly sensitive to the activity of organisms inhabiting the soil uppermost levels, such as communities dominated by lichens, mosses, bacteria and fungi (biocrusts). We conducted a full factorial warming and rainfall exclusion experiment at two semiarid sites in Spain to show how an average increase of air temperature of 2–3 °C promoted a drastic reduction in biocrust cover (ca. 44% in 4 years). Warming significantly increased soil CO_2 efflux, and reduced soil net CO_2 uptake, in biocrust-dominated microsites. Losses of biocrust cover with warming through time were paralleled by increases in recalcitrant C sources, such as aromatic compounds, and in the abundance of fungi relative to bacteria. The dramatic reduction in biocrust cover with warming will lessen the capacity of drylands to sequester atmospheric CO_2. This decrease may act synergistically with other warming-induced effects, such as the increase in soil CO_2 efflux and the changes in microbial communities to alter C cycling in drylands, and to reduce soil C stocks in the mid to long term.