Climate Change Quarterly: Summer 2014

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Climate Projections

Chen, Xianyao and Ka-Kit Tung. 2014. **Varying planetary heat sink led to global-warming slowdown and acceleration.** Science 345 (6199): 897-903. doi:10.1126/science.1254937

Abstract. A vacillating global heat sink at intermediate ocean depths is associated with different climate regimes of surface warming under anthropogenic forcing: The latter part of the 20th century saw rapid global warming as more heat stayed near the surface. In the 21st century, surface warming slowed as more heat moved into deeper oceans. In situ and reanalyzed data are used to trace the pathways of ocean heat uptake. In addition to the shallow La Niña–like patterns in the Pacific that were the previous focus, we found that the slowdown is mainly caused by heat transported to deeper layers in the Atlantic and the Southern oceans, initiated by a recurrent salinity anomaly in the subpolar North Atlantic. Cooling periods associated with the latter deeper heat-sequestration mechanism historically lasted 20 to 35 years.

Lee, Jaechoul, Shanghong Li, and Robert Lund. 2014. **Trends in extreme U.S. temperatures.** Journal of Climate, 27, 4209–4225. doi: http://dx.doi.org/10.1175/JCLI-D-13-00283.1

Abstract. This paper develops trend estimation techniques for monthly maximum and minimum temperature time series observed in the 48 conterminous United States over the last century. While most scientists concur that this region has warmed on aggregate, there is no a priori reason to believe that temporal trends in extremes and averages will exhibit the same patterns. Indeed, under minor regularity conditions, the sample partial sum and maximum of stationary time series are asymptotically independent (statistically). Previous authors have suggested that minimum temperatures are warming faster than maximum temperatures in the United States; such an aspect can be investigated via the methods discussed in this study. Here, statistical models with extreme value and changepoint features are used to estimate trends and their standard errors. A spatial smoothing is then done to extract general structure. The results show that monthly maximum temperatures are not often greatly changing—perhaps surprisingly, there are many stations that show some cooling. In contrast, the minimum

temperatures show significant warming. Overall, the southeastern United States shows the least warming (even some cooling), and the western United States, northern Midwest, and New England have experienced the most warming.

Lovejoy, S. 2014. **Return periods of global climate fluctuations and the pause.** Geophysical Research Letters 41(13): 4704–4710. doi:10.1002/2014GL060478.

Abstract. An approach complementary to General Circulation Models (GCMs), using the anthropogenic CO_2 radiative forcing as a linear surrogate for all anthropogenic forcings [Lovejoy, 2014], was recently developed for quantifying human impacts. Using preindustrial multiproxy series and scaling arguments, the probabilities of natural fluctuations at time lags up to 125 years were determined. The hypothesis that the industrial epoch warming was a giant natural fluctuation was rejected with 99.9% confidence. In this paper, this method is extended to the determination of event return times. Over the period 1880–2013, the largest 32 year event is expected to be 0.47 K, effectively explaining the postwar cooling (amplitude 0.42–0.47 K). Similarly, the "pause" since 1998 (0.28–0.37 K) has a return period of 20–50 years (not so unusual). It is nearly cancelled by the pre-pause warming event (1992–1998, return period 30–40 years); the pause is no more than natural variability.

Key Points

- The "pause" has a return period of 20–50 years (not unusual)
- Pre-pause (92–98) warming cancels the pause cooling
- The largest expected cooling event = 0.47 K: almost exactly the postwar cooling

Pulwarty,Roger S. and Mannava V.K. Sivakumar. 2014. **Information systems in a changing climate: Early warnings and drought risk management.** Weather and Climate Extremes 3: 14-21.

Abstract. Drought is among the most damaging, and least understood, of all "natural" hazards. Although some droughts last a single season and affect only small areas, the instrumental and paleoclimate records show that droughts have sometimes continued for decades and have impacted millions of square kilometers in North America, West Africa, and East Asia. To cross the spectrum of potential drivers and impacts, drought information systems have multiple sub-systems which include an integrated risk assessment, communication and decision support system of which early warning is a central component and output. An early warning system is much more than a forecast – it is a linked risk information (including people's perception of risk) and communication system that actively engages communities involved in preparedness. There are numerous drought systems warning systems being implemented at different scales of governance. We draw on the lessons of over 21 drought early warning systems around the world, in both developing and developed countries and at regional, national and community levels. The successes illustrate that effective early warning depends upon a multi-sectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process from monitoring to response and evaluation. However, the links between the community-based approach and the national and global EWSs are relatively weak. Using the rich experience of information systems across the globe, this paper identifies pathways for knowledge management and action at the relevant scales for decision-making in response to a changing climate.

Qu, Michael, Joe Wan, and Xianjun Hao. 2014. **Analysis of diurnal air temperature range change in the continental United States.** Weather and Climate Extremes 4: 86-95.

Abstract. Diurnal temperature range (DTR) is an important indicator for climate change. In this paper, diurnal air temperature range variations of the continental United States over the past one hundred years were investigated to discover the temporal trend and spatial patterns. While the annual mean DTR of the United States has steadily decreased during the past decades, it is found that the decreased amplitude has spatial and seasonal patterns. Seasonal and spatial variations of DTR were analyzed for the four regions, northeastern, northwestern, southeastern, and southwestern. Fall and summer witnessed a significant decrease in DTR in all regions. Spring and winter, on the other hand, have experienced much smaller decreases. Temporal trend and spatial patterns of daily maximum and minimum temperatures were also investigated to gain insight of DTR change.

Screen, James A. and Ian Simmonds. 2014. **Amplified mid-latitude planetary waves favour particular regional weather extremes.** Nature Climate Change 4: 704–709. doi:10.1038/nclimate2271

Abstract. There has been an ostensibly large number of extreme weather events in the Northern Hemisphere mid-latitudes during the past decade. An open question that is critically important for scientists and policy makers is whether any such increase in weather extremes is natural or anthropogenic in origin. One mechanism proposed to explain the increased frequency of extreme weather events is the amplification of mid-latitude atmospheric planetary waves. Disproportionately large warming in the northern polar regions compared with mid-latitudes—and associated weakening of the north–south temperature gradient—may favour larger amplitude planetary waves, although observational evidence for this remains inconclusive. A better understanding of the role of planetary waves in causing mid-latitude weather extremes is essential for assessing the potential environmental and socio-economic impacts of future planetary wave changes. Here we show that months of extreme weather over mid-latitudes are commonly

accompanied by significantly amplified quasi-stationary mid-tropospheric planetary waves. Conversely, months of near-average weather over mid-latitudes are often accompanied by significantly attenuated waves. Depending on geographical region, certain types of extreme weather (for example, hot, cold, wet, dry) are more strongly related to wave amplitude changes than others. The findings suggest that amplification of quasi-stationary waves preferentially increases the probabilities of heat waves in western North America and central Asia, cold outbreaks in eastern North America, droughts in central North America, Europe and central Asia, and wet spells in western Asia.

Weaver, Scott J., Arun Kumar, and Mingyue Chen. 2014. **Recent increases in extreme temperature occurrence over land.** Geophysical Research Letters 41(13): 4669-4675. doi: 10.1002/2014GL060300

Abstract. Recently observed global and U.S. temperature increases are probed from the perspective of several hundred climate realizations afforded by the availability of reforecast climate model runs from the NCEP Climate Forecast System Version 2. The large number of seasonal realizations with the observed time-varying CO_2 affords a unique opportunity to explore the role of greenhouse gas changes on 3 month seasonal mean temperature increases, and specifically, whether they are the result of a shift in the mean temperature distribution or an increase in its variability. It is found that significant positive shifts in the temperature probability density function (PDF) occur primarily as the result of the time-varying CO_2 included in the historical model runs, although a contribution from natural climate variability modes cannot be categorically excluded. The temperature PDF comparison further indicates that the increasing global and U.S. temperatures over the last 30 years are predominantly the result of shifts in the mean temperature distribution and not increasing temperature variability. As such, the likelihood of increases in the occurrence of warm temperature extremes will likely continue to increase worldwide, leading to significant impacts on many socioeconomic sectors such as agriculture and public health.

Key Points

- Anthropogenic related increase in land temperature over the last 30 years
- Temperature increases are the result of mean temperature shifts
- Increased occurrence of extreme temperature events

Carbon and Carbon Storage

Carrillo, Y., F. Dijkstra, D. LeCain, J. Morgan, D. Blumenthal, S. Waldron, and E. Pendall. 2014. **Disentangling root responses to climate change in a semiarid grassland.** Oecologia 175:699-711. doi: 10.1007/s00442-014-2912-z

Abstract. Future ecosystem properties of grasslands will be driven largely by belowground biomass responses to climate change, which are challenging to understand due to experimental and technical constraints. We used a multi-faceted approach to explore single and combined impacts of elevated CO_2 and warming on root carbon (C) and nitrogen (N) dynamics in a temperate, semiarid, native grassland at the Prairie Heating and CO_2 Enrichment experiment. To investigate the indirect, moisture mediated effects of elevated CO_2, we included an irrigation treatment. We assessed root standing mass, morphology, residence time and seasonal appearance/disappearance of community-aggregated roots, as well as mass and N losses during decomposition of two dominant grass species (a C_3 and a C_4). In contrast to what is common in mesic grasslands, greater root standing mass under elevated CO_2 resulted from increased production, unmatched by disappearance. Elevated CO_2 plus warming produced roots that were longer, thinner and had greater surface area, which, together with greater standing biomass, could potentially alter root function and dynamics. Decomposition increased under environmental conditions generated by elevated CO_2, but not those generated by warming, likely due to soil desiccation with warming. Elevated CO_2, particularly under warming, slowed N release from C_4—but not C_3—roots, and consequently could indirectly affect N availability through treatment effects on species composition. Elevated CO_2 and warming effects on root morphology and decomposition could offset increased C inputs from greater root biomass, thereby limiting future net C accrual in this semiarid grassland.

Earles, J. Mason, Malcolm P. North, and Matthew D. Hurteau. 2014. **Wildfire and drought dynamics destabilize carbon stores of fire-suppressed forests.** Ecological Applications 24:732–740. http://dx.doi.org/10.1890/13-1860.1

Abstract. Widespread fire suppression and thinning have altered the structure and composition of many forests in the western United States, making them more susceptible to the synergy of large-scale drought and fire events. We examine how these changes affect carbon storage and stability compared to historic fire-adapted conditions. We modeled carbon dynamics under possible drought and fire conditions over a 300-year simulation period in two mixed-conifer conditions common in the western United States: (1) pine-dominated with an active fire regime and (2) fir-dominated, fire suppressed forests. Fir-dominated stands, with higher live- and dead-wood density, had much lower carbon stability as drought and fire frequency increased compared to pine-dominated forest. Carbon instability resulted

from species (i.e., fir's greater susceptibility to drought and fire) and stand (i.e., high density of smaller trees) conditions that develop in the absence of active management. Our modeling suggests restoring historic species composition and active fire regimes can significantly increase carbon stability in fire-suppressed, mixed-conifer forests. Long-term management of forest carbon should consider the relative resilience of stand structure and composition to possible increases in disturbance frequency and intensity under changing climate.

Fernández-Martínez,M., S. Vicca, I. A. Janssens, J. Sardans, S. Luyssaert, M. Campioli, F. S. Chapin III, P. Ciais, Y. Malhi, M. Obersteiner, D. Papale, S. L. Piao, M. Reichstein, F. Rodà & J. Peñuelas. 2014. **Nutrient availability as the key regulator of global forest carbon balance.** Nature Climate Change 4:471–476. doi:10.1038/nclimate2177

Abstract. Forests strongly affect climate through the exchange of large amounts of atmospheric CO_2. The main drivers of spatial variability in net ecosystem production (NEP) on a global scale are, however, poorly known. As increasing nutrient availability increases the production of biomass per unit of photosynthesis and reduces heterotrophic respiration in forests, we expected nutrients to determine carbon sequestration in forests. Our synthesis study of 92 forests in different climate zones revealed that nutrient availability indeed plays a crucial role in determining NEP and ecosystem carbon-use efficiency (CUEe; that is, the ratio of NEP to gross primary production (GPP)). Forests with high GPP exhibited high NEP only in nutrient-rich forests (CUEe = 33 ± 4%; mean ± s.e.m.). In nutrient-poor forests, a much larger proportion of GPP was released through ecosystem respiration, resulting in lower CUEe (6 ± 4%). Our finding that nutrient availability exerts a stronger control on NEP than on carbon input (GPP) conflicts with assumptions of nearly all global coupled carbon cycle–climate models, which assume that carbon inputs through photosynthesis drive biomass production and carbon sequestration. An improved global understanding of nutrient availability would therefore greatly improve carbon cycle modelling and should become a critical focus for future research.

Holdaway, R. J., S. J. McNeill, N. W. H. Mason, and F. E. Carswell. 2014. **Propagating Uncertainty in Plot-based Estimates of Forest Carbon Stock and Carbon Stock Change.** Ecosystems 17:627-640. doi: 10.1007/s10021-014-9749-5

Abstract. Ecosystem science increasingly relies on highly derived metrics to synthesize across large datasets. However, full uncertainty associated with these metrics is seldom quantified. Our objective was to evaluate measurement error and model uncertainty in plot-based estimates of carbon stock and carbon change. We quantified the measurement error associated with live stems, deadwood and plot-level variables in temperate rainforest in New Zealand. We also quantified model uncertainty for height–diameter

allometry, stem volume equations and wood-density estimates. We used Monte Carlo simulation to assess the net effects on carbon stock and carbon change estimated using data from 227 plots from throughout New Zealand. Plot-to-plot variation was the greatest source of uncertainty, amounting to 9.1% of mean aboveground carbon stock estimates (201.11 MgC ha^{-1}). Propagation of the measurement error and model uncertainty resulted in a 1% increase in uncertainty (0.1% of mean stock estimate). Carbon change estimates (mean −0.86 MgC ha^{-1} y^{-1}) were more uncertain, with sampling error equating to 56% of the mean, and when measurement error and model uncertainty were included this uncertainty increased by 35% (22.1% of the mean change estimate). For carbon change, the largest sources of measurement error were missed/double counted stems and fallen coarse woody debris. Overall, our findings show that national-scale plot-based estimates of carbon stock and carbon change in New Zealand are robust to measurement error and model uncertainty. We recommend that calculations of carbon stock and carbon change incorporate both these sources of uncertainty so that management implications and policy decisions can be assessed with the appropriate level of confidence.

Keith, Heather, David Lindenmayer, Brendan Mackey, David Blair, Lauren Carter, Lachlan McBurney, Sachiko Okada, and Tomoko Konishi-Nagano. 2014. **Managing temperate forests for carbon storage: impacts of logging versus forest protection on carbon stocks.** Ecosphere 5:art75. http://dx.doi.org/10.1890/ES14-00051.1

Abstract. Management of native forests offers opportunities to store more carbon in the land sector through two main activities. Emissions to the atmosphere can be avoided by ceasing logging. Removals of carbon dioxide from the atmosphere can be increased by allowing forests to continue growing. However, the relative benefits for carbon storage of managing native forests for wood production versus protection are contested. Additionally, the potential for carbon storage is impacted upon by disturbance events, such as wildfire, that alter the amount and longevity of carbon stocks.

Using a case study of montane ash forests in southeastern Australia, we demonstrated that the total biomass carbon stock in logged forest was 55% of the stock in old growth forest. Total biomass included above- and belowground, living and dead. Biomass carbon stock was calculated spatially as an average across the landscape, accounting for variation in environmental conditions and forest age distribution. Reduction in carbon stock in logged forest was due to 66% of the initial biomass being made into products with short lifetimes (<3 years), and to the lower average age of logged forest (<50 years compared with >100 years in old growth forest). Only 4% of the initial carbon stock in the native forest was converted to sawn timber products with lifetimes of 30–90 years.

Carbon stocks are depleted in a harvested forest system compared with an old growth forest, even when storage in wood products and landfill are

included. We estimated that continued logging under current plans represented a loss of 5.56 Tg C over 5 years in the area logged (824 km2), compared with a potential gain of 5.18–6.05 TgC over 5 years by allowing continued growth across the montane ash forest region (2326 km2). Avoiding emissions by not logging native forests and allowing them to continue growing is therefore an important form of carbon sequestration. The mitigation value of forest management options of protection versus logging should be assessed in terms of the amount, longevity and resilience of the carbon stored in the forest, rather than the annual rate of carbon uptake.

Wang, Xiaoyu, A. J. VandenBygaart, and Brian C. McConkey. 2014. **Land Management History of Canadian Grasslands and the Impact on Soil Carbon Storage.** Rangeland Ecology and Management 67(4): 333-343.

Abstract. Grasslands represent a large potential reservoir in storing carbon (C) in plant biomass and soil organic matter via C sequestration, but the potential greatly depends on how grasslands are managed, especially for livestock and wild animal grazing. Positive and negative grazing effects on soil organic carbon have been reported by various studies globally, but it is not known if Canadian grasslands function as a source or a sink for atmospheric C under current management practices. This article examines the effect of grassland management on carbon storage by compiling historical range management facts and measurements from multiple experiments. Results indicate that grazing on grasslands has contributed to a net C sink in the top 15-cm depth under current utilization regimes with a removal rate of CO_2 at 0.19 ± 0.02 $Mg \cdot C \cdot ha^{-1} \cdot yr^{-1}$ from the atmosphere during recent decades, and net C sequestration was estimated at 5.64 ± 0.97 $Mg \cdot C \cdot ha^{-1}$ on average. Naturalization of 2.3 M ha of previously cultivated grasslands in the 1930s has also led to C sequestration in the Canadian prairies but has likely abated as the pool has saturated. Efforts made by researchers, policymakers, and the public has successfully led to the restoration of the Canadian prairies to a healthier state and to achieve considerable C sequestration in soils since their severe deterioration in the 1930s. In-depth analysis of management, legislation, and agricultural programs is urgently needed to place the focus on maintaining range health and achieving more C storage in soils, particularly when facing the reduced potential for further C sequestration.

Phenology Changes

Reyes-Fox, Melissa, Heidi Steltzer, M. J. Trlica, Gregory S. McMaster, Allan A. Andales, Dan R. LeCain and Jack A. Morgan. 2014. **Elevated CO_2 further lengthens growing season under warming conditions.** Nature 510: 259-262. doi: 10.1038/nature13207

Abstract. Observations of a longer growing season through earlier plant growth in temperate to polar regions have been thought to be a response to climate warming. However, data from experimental warming studies indicate that many species that initiate leaf growth and flowering earlier also reach seed maturation and senesce earlier, shortening their active and reproductive periods. A conceptual model to explain this apparent contradiction, and an analysis of the effect of elevated CO_2—which can delay annual life cycle events—on changing season length, have not been tested. Here we show that experimental warming in a temperate grassland led to a longer growing season through earlier leaf emergence by the first species to leaf, often a grass, and constant or delayed senescence by other species that were the last to senesce, supporting the conceptual model. Elevated CO_2 further extended growing, but not reproductive, season length in the warmed grassland by conserving water, which enabled most species to remain active longer. Our results suggest that a longer growing season, especially in years or biomes where water is a limiting factor, is not due to warming alone, but also to higher atmospheric CO_2 concentrations that extend the active period of plant annual life cycles.

Species Range Changes

Crase, B., Liedloff, A., Vesk, P. A., Fukuda, Y. and Wintle, B. A. 2014. **Incorporating spatial autocorrelation into species distribution models alters forecasts of climate-mediated range shifts.** Global Change Biology 20: 2566–2579. doi: 10.1111/gcb.12598

Abstract. Species distribution models (SDMs) are widely used to forecast changes in the spatial distributions of species and communities in response to climate change. However, spatial autocorrelation (SA) is rarely accounted for in these models, despite its ubiquity in broad-scale ecological data. While spatial autocorrelation in model residuals is known to result in biased parameter estimates and the inflation of type I errors, the influence of unmodeled SA on species' range forecasts is poorly understood. Here we quantify how accounting for SA in SDMs influences the magnitude of range shift forecasts produced by SDMs for multiple climate change scenarios. SDMs were fitted to simulated data with a known autocorrelation structure, and to field observations of three mangrove communities from northern Australia displaying strong spatial autocorrelation. Three modeling approaches were implemented: environment-only models (most frequently

applied in species' range forecasts), and two approaches that incorporate SA; autologistic models and residuals autocovariate (RAC) models. Differences in forecasts among modeling approaches and climate scenarios were quantified. While all model predictions at the current time closely matched that of the actual current distribution of the mangrove communities, under the climate change scenarios environment-only models forecast substantially greater range shifts than models incorporating SA. Furthermore, the magnitude of these differences intensified with increasing increments of climate change across the scenarios. When models do not account for SA, forecasts of species' range shifts indicate more extreme impacts of climate change, compared to models that explicitly account for SA. Therefore, where biological or population processes induce substantial autocorrelation in the distribution of organisms, and this is not modeled, model predictions will be inaccurate. These results have global importance for conservation efforts as inaccurate forecasts lead to ineffective prioritization of conservation activities and potentially to avoidable species extinctions.

Crimmins, Shawn M., Solomon Z. Dobrowski, Alison R. Mynsberge, and Hugh D. Safford. 2014. **Can fire atlas data improve species distribution model projections?** Ecological Applications 24:1057–1069. http://dx.doi.org/10.1890/13-0924.1

Abstract. Correlative species distribution models (SDMs) are widely used in studies of climate change impacts, yet are often criticized for failing to incorporate disturbance processes that can influence species distributions. Here we use two temporally independent data sets of vascular plant distributions, climate data, and fire atlas data to examine the influence of disturbance history on SDM projection accuracy through time in the mountain ranges of California, USA. We used hierarchical partitioning to examine the influence of fire occurrence on the distribution of 144 vascular plant species and built a suite of SDMs to examine how the inclusion of fire-related predictors (fire occurrence and departure from historical fire return intervals) affects SDM projection accuracy. Fire occurrence provided the least explanatory power among predictor variables for predicting species' distributions, but provided improved explanatory power for species whose regeneration is tied closely to fire. A measure of the departure from historic fire return interval had greater explanatory power for calibrating modern SDMs than fire occurrence. This variable did not improve internal model accuracy for most species, although it did provide marginal improvement to models for species adapted to high-frequency fire regimes. Fire occurrence and fire return interval departure were strongly related to the climatic covariates used in SDM development, suggesting that improvements in model accuracy may not be expected due to limited additional explanatory power. Our results suggest that the inclusion of coarse-scale measures of disturbance in SDMs may not be necessary to predict species distributions under climate change, particularly for disturbance processes that are largely mediated by climate.

Harsch, Melanie A., Ying Zhou, Janneke HilleRisLambers, and Mark Kot. 2014. **Keeping Pace with Climate Change: Stage-Structured Moving-Habitat Models.** The American Naturalist 184(1): 25-37.

Abstract. Life cycles can limit the abilities of species to track changing climatic conditions. We combined age or stage structure and a moving-habitat model to explore the effects of life history on the persistence of populations in the presence of climate change. We studied four dissimilar plant species in moving patches and found that (1) population growth rates, (2) elasticities with respect to the survival (stasis and shrinkage) components of the projection matrix, and (3) the evenness of the elasticities with respect to the components of the projection matrix all decreased as we increased the translational speeds of the patches. In addition, the value of long-distance dispersal increased with patch speed for three of the four species. Our analyses confirm that rapid growth, high fecundity, and long-distance dispersal can benefit species in moving patches. Thus, species with long generation times and limited dispersal ability are especially vulnerable to habitat movement. Stage-structured moving-habitat models can easily incorporate spatial complexity and can help us predict the effects of shifting climatic conditions.

Rehfeldt, Gerald E., Barry C. Jaquish, Javier López-Upton, Cuauhtémoc Sáenz-Romero, J. Bradley St Clair, Laura P. Leites, Dennis G. Joyce. 2014. **Comparative genetic responses to climate for the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: Realized climate niches.** Forest Ecology and Management 324: 126-137. doi: 10.1016/j.foreco.2014.02.035

Abstract. The Random Forests classification algorithm was used to predict the occurrence of the realized climate niche for two sub-specific varieties of *Pinus ponderosa* and three varieties of *Pseudotsuga menziesii* from presence-absence data in forest inventory ground plots. Analyses were based on ca. 271,000 observations for *P. ponderosa* and ca. 426,000 observations for *P. menziesii*, with ca. 6% of the observations in each dataset recording the presence of one of the varieties. Classification errors to the respective databases attributable to fitting the models were ca. 5%, most of which were from falsely predicting varietal occurrence. Confusion in classifying varieties was nil. The primary drivers of the niche model were summer precipitation, winter precipitation and summer degree-days >5 C for the varieties of *P. ponderosa* and the summer-winter temperature differential, summer maximum temperatures and summer precipitation for the varieties of *P. menziesii*. Projected impacts of global warming using output from an ensemble of 17 general circulation models were greater for *P. ponderosa* than for *P. menziesii* and for varieties of both species from inland climates than from coastal. Projected impacts imply dire consequences for the varieties of *P. menziesii* occurring in Mexico.

Rehfeldt, Gerald E., Barry C. Jaquish, Cuauhtémoc Sáenz-Romero, Dennis G. Joyce, Laura P. Leites, J. Bradley St Clair, and Javier López-Upton. 2014. **Comparative genetic responses to climate in the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: Reforestation.** Forest Ecology and Management 324: 147-157. doi: 10.1016/j.foreco.2014.02.040

Abstract. Impacts of climate change on the climatic niche of the sub-specific varieties of *Pinus ponderosa* and *Pseudotsuga menziesii* and on the adaptedness of their populations are considered from the viewpoint of reforestation. In using climate projections from an ensemble of 17 general circulation models targeting the decade surrounding 2060, our analyses suggest that a portion of the lands occupied today primarily by coastal varieties of each species contain genotypes that should remain suitable for the future climate. A much larger portion, particularly for varieties occupying inland sites, should require either introduction of better suited species or conversion to better adapted genotypes. Regeneration strategies are considered with the goal of matching growth potential of contemporary populations to the future climate where that potential can be realized. For some lands, natural reproduction should be suitable, but most lands will require forest renewal to maintain forest health, growth, and productivity. Projected impacts also illustrate the urgent need for conservation programs for *P. menziesii* in Mexico.

Rehfeldt, Gerald E., Laura P. Leites, J. Bradley St Clair, Barry C. Jaquish, Cuauhtémoc Sáenz-Romero, Javier López-Upton, and Dennis G. Joyce. 2014. **Comparative genetic responses to climate in the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: Clines in growth potential.** Forest Ecology and Management 324: 138-146. doi: 10.1016/j.foreco.2014.02.041

Abstract. Height growth data were assembled from 10 *Pinus ponderosa* and 17 *Pseudotsuga menziesii* provenance tests. Data from the disparate studies were scaled according to climate similarities of the provenances to provide single datasets for 781 *P. ponderosa* and 1193 *P. menziesii* populations. Mixed effects models were used for two sub-specific varieties of each species to describe clines in growth potential associated with provenance climate while accounting for study effects not eliminated by scaling. Variables related to winter temperatures controlled genetic variation within the varieties of both species. Clines were converted to climatypes by classifying genetic variation, using variation within provenances in relation to the slope of the cline to determine climatype breadth. Climatypes were broader in varieties of *P. ponderosa* than in *P. menziesii* and were broader for varieties inhabiting coastal regions of both species than for varieties from interior regions. Projected impacts of climate change on adaptedness used output from an ensemble of 17 general circulation models. Impacts were dependent on cline steepness and climatype breadth but implied that maintaining adaptedness

of populations to future climates will require a redistribution of genotypes across forested landscapes.

Land Cover

Sohl, Terry L., Kristi L. Sayler, Michelle A. Bouchard, Ryan R. Reker, Aaron M. Friesz, Stacie L. Bennett, Benjamin M. Sleeter, Rachel R. Sleeter, Tamara Wilson, Chris Soulard, Michelle Knuppe, and Travis Van Hofwegen. 2014. **Spatially explicit modeling of 1992–2100 land cover and forest stand age for the conterminous United States.** Ecological Applications 24:1015–1036. http://dx.doi.org/10.1890/13-1245.1

Abstract. Information on future land-use and land-cover (LULC) change is needed to analyze the impact of LULC change on ecological processes. The U.S. Geological Survey has produced spatially explicit, thematically detailed LULC projections for the conterminous United States. Four qualitative and quantitative scenarios of LULC change were developed, with characteristics consistent with the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). The four quantified scenarios (A1B, A2, B1, and B2) served as input to the forecasting scenarios of land-use change (FORE-SCE) model. Four spatially explicit data sets consistent with scenario storylines were produced for the conterminous United States, with annual LULC maps from 1992 through 2100. The future projections are characterized by a loss of natural land covers in most scenarios, with corresponding expansion of anthropogenic land uses. Along with the loss of natural land covers, remaining natural land covers experience increased fragmentation under most scenarios, with only the B2 scenario remaining relatively stable in both the proportion of remaining natural land covers and basic fragmentation measures. Forest stand age was also modeled. By 2100, scenarios and ecoregions with heavy forest cutting had relatively lower mean stand ages compared to those with less forest cutting. Stand ages differed substantially between unprotected and protected forest lands, as well as between different forest classes. The modeled data were compared to the National Land Cover Database (NLCD) and other data sources to assess model characteristics. The consistent, spatially explicit, and thematically detailed LULC projections and the associated forest stand-age data layers have been used to analyze LULC impacts on carbon and greenhouse gas fluxes, biodiversity, climate and weather variability, hydrologic change, and other ecological processes.

Forest Vegetation

Bell, David M., John B. Bradford, and William K. Lauenroth. 2014. **Forest stand structure, productivity, and age mediate climatic effects on aspen decline.** Ecology 95:2040–2046. http://dx.doi.org/10.1890/14-0093.1

Abstract. Because forest stand structure, age, and productivity can mediate the impacts of climate on quaking aspen (*Populus tremuloides*) mortality, ignoring stand-scale factors limits inference on the drivers of recent sudden aspen decline. Using the proportion of aspen trees that were dead as an index of recent mortality at 841 forest inventory plots, we examined the relationship of this mortality index to forest structure and climate in the Rocky Mountains and Intermountain Western United States. We found that forest structure explained most of the patterns in mortality indices, but that variation in growing-season vapor pressure deficit and winter precipitation over the last 20 years was important. Mortality index sensitivity to precipitation was highest in forests where aspen exhibited high densities, relative basal areas, quadratic mean diameters, and productivities, whereas sensitivity to vapor pressure deficit was highest in young forest stands. These results indicate that the effects of drought on mortality may be mediated by forest stand development, competition with encroaching conifers, and physiological vulnerabilities of large trees to drought. By examining mortality index responses to both forest structure and climate, we show that forest succession cannot be ignored in studies attempting to understand the causes and consequences of sudden aspen decline.

Clark, J. S., Bell, D. M., Kwit, M. C. and Zhu, K. 2014. **Competition-interaction landscapes for the joint response of forests to climate change.** Global Change Biology 20: 1979–1991. doi: 10.1111/gcb.12425

Abstract. The recent global increase in forest mortality episodes could not have been predicted from current vegetation models that are calibrated to regional climate data. Physiological studies show that mortality results from interactions between climate and competition at the individual scale. Models of forest response to climate do not include interactions because they are hard to estimate and require long-term observations on individual trees obtained at frequent (annual) intervals. Interactions involve multiple tree responses that can only be quantified if these responses are estimated as a joint distribution. A new approach provides estimates of climate–competition interactions in two critical ways, (i) among individuals, as a joint distribution of responses to combinations of inputs, such as resources and climate, and (ii) within individuals, due to allocation requirements that control outputs, such as demographic rates. Application to 20 years of data from climate and competition gradients shows that interactions control forest responses, and their omission from models leads to inaccurate predictions. Species most vulnerable to increasing aridity are not those that show the largest growth

response to precipitation, but rather depend on interactions with the local resource environment. This first assessment of regional species vulnerability that is based on the scale at which climate operates, individual trees competing for carbon and water, supports predictions of potential savannification in the southeastern US.

Dolanc, C. R., Safford, H. D., Dobrowski, S. Z., Thorne, J. H. 2014. **Twentieth century shifts in abundance and composition of vegetation types of the Sierra Nevada, CA, US**. Applied Vegetation Science 17: 442–455. doi: 10.1111/avsc.12079

Abstract. Questions: Has tree density changed consistently across vegetation types? Do changes in component species correspond with changes across vegetation types? Do patterns of changes suggest potential drivers of change?

Location: Northern two-thirds of the Sierra Nevada, CA, USA, ca. 45 000 km^2.

Methods: Using two data sets that cover the span of elevations and land jurisdictions in the study area, we classified 4321 historical plots and 1000 modern plots into nine broad groups of vegetation types that are widely used by land managers and researchers in the region. We compared tree density and composition between historical and modern plots across and within these nine types.

Results: In the modern data set, tree density was significantly higher in eight of nine vegetation types. Total density was significantly higher in modern plots for all west slope types, especially for montane hardwood, where modern forests are 128% denser, and mixed conifer forests, which are 69% denser. Relative density of component species was also very different between data sets in these forests, and suggests a shift in dominance toward shade-tolerant conifers and evergreen oaks. Fire suppression is likely a driving factor in these types but density was also significantly higher in high-elevation types such as sub-alpine forest (+20%), where neither fire suppression nor logging have had major impacts on structure. East slope forest types (eastside *P. jeffreyi* forest and piñon-juniper woodland) were very similar in both modern and historical data sets, with no significant differences in density or composition.

Conclusion: West slope forest types, especially montane hardwood and mixed conifer forest, appear the most altered types of the mountain range. These types are more productive but have also been subject to greater disturbance than high-elevation and east slope forest types. Climate change may also be driving changes across the study area. Species such as *Quercus chrysolepis* and *Calocedrus decurrens*, which have each increased markedly in abundance, appear well positioned to dominate in the near future, especially under continued fire suppression and a warmer climate

Rangeland Vegetation

Germino, M. J., Reinhardt, K. 2014. **Desert shrub responses to experimental modification of precipitation seasonality and soil depth: relationship to the two-layer hypothesis and ecohydrological niche.** Journal of Ecology 102: 989–997. doi: 10.1111/1365-2745.12266

Abstract. 1. Ecohydrological niches are important for understanding plant community responses to climate shifts, particularly in dry lands. According to the two-layer hypothesis, selective use of deep-soil water increases growth or persistence of woody species during warm and dry summer periods and thereby contributes to their coexistence with shallow-rooted herbs in dry ecosystems. The resource-pool hypothesis further suggests that shallow-soil water benefits growth of all plants while deep-soil water primarily enhances physiological maintenance and survival of woody species. Few studies have directly tested these by manipulating deep-soil water availability and observing the long-term outcomes.

2. We predicted that factors promoting infiltration and storage of water in deep soils, specifically greater winter precipitation and soil depth, would enhance *Artemisia tridentata* (big sagebrush) in cold, winter-wet/summer-dry desert. Sagebrush responses to 20 years of winter irrigation were compared to summer- or no irrigation, on plots having relatively deep or shallow soils (2 m vs. 1 m depths).

3. Winter irrigation increased sagebrush cover, and crown and canopy volumes, but not density (individuals/plot) compared to summer or no irrigation, on deep-soil plots. On shallow-soil plots, winter irrigation surprisingly decreased shrub cover and size, and summer irrigation had no effect. Furthermore, multiple regression suggested that the variations in growth were related (i) firstly to water in shallow soils (0–0.2 m) and secondly to deeper soils (> 1 m deep) and (ii) more by springtime than by midsummer soil water. Water-use efficiency increased considerably on shallow soils without irrigation and was lowest with winter irrigation.

4. <u>Synthesis.</u> Sagebrush was more responsive to the seasonal timing of precipitation than to total annual precipitation. Factors that enhanced deep-water storage (deeper soils plus more winter precipitation) led to increases in *Artemisia tridentata* that were consistent with the two-layer hypothesis, and the contribution of shallow water to growth on these plots was consistent with the resource-pool hypothesis. However, shallow-soil water also had negative effects on sagebrush, suggesting an ecohydrological trade-off not considered in these or related theories. The interaction between precipitation timing and soil depth indicates that increased winter precipitation could lead to a mosaic of increases and decreases in *A. tridentata* across landscapes having variable soil depth.

Rudgers, Jennifer A., Stephanie N. Kivlin, Kenneth D. Whitney, Mary V. Price, Nickolas M. Waser, and John Harte. 2014. **Responses of high-altitude graminoids and soil fungi to 20 years of experimental warming.** Ecology 95:1918–1928. http://dx.doi.org/10.1890/13-1454.1

Abstract. High-elevation ecosystems are expected to be particularly sensitive to climate warming because cold temperatures constrain biological processes. Deeper understanding of the consequences of climate change will come from studies that consider not only the direct effects of temperature on individual species, but also the indirect effects of altered species interactions. Here we show that 20 years of experimental warming has changed the species composition of graminoid (grass and sedge) assemblages in a subalpine meadow of the Rocky Mountains, USA, by increasing the frequency of sedges and reducing the frequency of grasses. Because sedges typically have weak interactions with mycorrhizal fungi relative to grasses, lowered abundances of arbuscular mycorrhizal (AM) fungi or other root-inhabiting fungi could underlie warming-induced shifts in plant species composition. However, warming increased root colonization by AM fungi for two grass species, possibly because AM fungi can enhance plant water uptake when soils are dried by experimental warming. Warming had no effect on AM fungal colonization of three other graminoids. Increased AM fungal colonization of the dominant shrub Artemisia tridentata provided further grounds for rejecting the hypothesis that reduced AM fungi caused the shift from grasses to sedges. Non-AM fungi (including dark septate endophytes) also showed general increases with warming. Our results demonstrate that lumping grasses and sedges when characterizing plant community responses can mask significant shifts in the responses of primary producers, and their symbiotic fungi, to climate change.

Schlaepfer, Daniel R., William K. Lauenroth, and John B. Bradford. 2014. **Natural Regeneration Processes in Big Sagebrush (*Artemisia tridentata*).** Rangeland Ecology and Management 67(4): 344-357.

Abstract. Big sagebrush, *Artemisia tridentata* Nuttall (Asteraceae), is the dominant plant species of large portions of semiarid western North America. However, much of historical big sagebrush vegetation has been removed or modified. Thus, regeneration is recognized as an important component for land management. Limited knowledge about key regeneration processes, however, represents an obstacle to identifying successful management practices and to gaining greater insight into the consequences of increasing disturbance frequency and global change. Therefore, our objective is to synthesize knowledge about natural big sagebrush regeneration. We identified and characterized the controls of big sagebrush seed production, germination, and establishment. The largest knowledge gaps and associated research needs include quiescence and dormancy of embryos and seedlings; variation in seed production and germination percentages; wet-thermal time model of germination; responses to frost events (including freezing/thawing

of soils), CO_2 concentration, and nutrients in combination with water availability; suitability of microsite vs. site conditions; competitive ability as well as seedling growth responses; and differences among subspecies and ecoregions. Potential impacts of climate change on big sagebrush regeneration could include that temperature increases may not have a large direct influence on regeneration due to the broad temperature optimum for regeneration, whereas indirect effects could include selection for populations with less stringent seed dormancy. Drier conditions will have direct negative effects on germination and seedling survival and could also lead to lighter seeds, which lowers germination success further. The short seed dispersal distance of big sagebrush may limit its tracking of suitable climate; whereas, the low competitive ability of big sagebrush seedlings may limit successful competition with species that track climate. An improved understanding of the ecology of big sagebrush regeneration should benefit resource management activities and increase the ability of land managers to anticipate global change impacts.

Fish and Wildlife

Caruso, N. M., Sears, M. W., Adams, D. C. and Lips, K. R. 2014. **Widespread rapid reductions in body size of adult salamanders in response to climate change.** Global Change Biology 20: 1751–1759. doi: 10.1111/gcb.12550

Abstract. Reduction in body size is a major response to climate change, yet evidence in globally imperiled amphibians is lacking. Shifts in average population body size could indicate either plasticity in the growth response to changing climates through changes in allocation and energetics, or through selection for decreased size where energy is limiting. We compared historic and contemporary size measurements in 15 *Plethodon* species from 102 populations (9450 individuals) and found that six species exhibited significant reductions in body size over 55 years. Biophysical models, accounting for actual changes in moisture and air temperature over that period, showed a 7.1–7.9% increase in metabolic expenditure at three latitudes but showed no change in annual duration of activity. Reduced size was greatest at southern latitudes in regions experiencing the greatest drying and warming. Our results are consistent with a plastic response of body size to climate change through reductions in body size as mediated through increased metabolism. These rapid reductions in body size over the past few decades have significance for the susceptibility of amphibians to environmental change, and relevance for whether adaptation can keep pace with climate change in the future.

Grundel, Ralph, Krystalynn J. Frohnapple, David N. Zaya, Gary A. Glowacki, Chelsea J. Weiskerger, Tamatha A. Patterson, and Noel B. Pavlovic. 2014. **Geographic coincidence of richness, mass, conservation value, and response to climate of U.S. land birds.** Ecological Applications 24:791–811. http://dx.doi.org/10.1890/12-0823.1

Abstract. Distributional patterns across the United States of five avian community breeding-season characteristics—community biomass, richness, constituent species' vulnerability to extirpation, percentage of constituent species' global abundance present in the community (conservation index, CI), and the community's position along the ecological gradient underlying species composition (principal curve ordination score, PC)—were described, their covariation was analyzed, and projected effects of climate change on the characteristics and their covariation were modeled. Higher values of biomass, richness, and CI were generally preferred from a conservation perspective. However, higher values of these characteristics often did not coincide geographically; thus regions of the United States would differ in their value for conservation depending on which characteristic was chosen for setting conservation priorities. For instance, correlation patterns between characteristics differed among Landscape Conservation Cooperatives. Among the five characteristics, community richness and the ecological gradient underlying community composition (PC) had the highest correlations with longitude, with richness declining from east to west across the contiguous United States. The ecological gradient underlying composition exhibited a demarcation near the 100th meridian, separating the contiguous United States grossly into two similar-sized avian ecological provinces. The combined score (CS), a measure of species' threat of decline or extirpation, exhibited the strongest latitudinal pattern, declining from south to north. Over ~75% of the lower United States, projected changes in June temperature and precipitation to year 2080 were associated with decreased averaged values of richness, biomass, and CI, implying decreased conservation value for birds. The two ecological provinces demarcated near the 100th meridian diverged from each other, with projected changes in June temperatures and precipitation from the year 2000 to 2080 suggesting increased ecological dissimilarity between the eastern and western halves of the lower United States with changing climate. Anticipated climate-related changes in the five characteristics by 2080 were more weakly correlated with latitude or longitude then the responses themselves, indicating less distinct geographic patterns of characteristic change than in the characteristics themselves. Climate changes projected for 2080 included geographic shifts in avian biomass, CS, and PC values, a moderate overall decline in CI, and general decline in species richness per site.

Harrigan, R. J., Thomassen, H. A., Buermann, W. and Smith, T. B. 2014. **A continental risk assessment of West Nile virus under climate change.** Global Change Biology 20: 2417–2425. doi: 10.1111/gcb.12534

Abstract. Since first introduced to North America in 1999, West Nile virus (WNV) has spread rapidly across the continent, threatening wildlife populations and posing serious health risks to humans. While WNV incidence has been linked to environmental factors, particularly temperature and rainfall, little is known about how future climate change may affect the spread of the disease. Using available data on WNV infections in vectors and hosts collected from 2003–2011 and using a suite of 10 species distribution models, weighted according to their predictive performance, we modeled the incidence of WNV under current climate conditions at a continental scale. Models were found to accurately predict spatial patterns of WNV that were then used to examine how future climate may affect the spread of the disease. Predictions were accurate for cases of human WNV infection in the following year (2012), with areas reporting infections having significantly higher probability of presence as predicted by our models. Projected geographic distributions of WNV in North America under future climate for 2050 and 2080 show an expansion of suitable climate for the disease, driven by warmer temperatures and lower annual precipitation that will result in the exposure of new and naïve host populations to the virus with potentially serious consequences. Our risk assessment identifies current and future hotspots of West Nile virus where mitigation efforts should be focused and presents an important new approach for monitoring vector-borne disease under climate change.

Khaliq, Imran, Christian Hof, Roland Prinzinger, Katrin Böhning-Gaese, and Markus Pfenninger. 2014. **Global variation in thermal tolerances and vulnerability of endotherms to climate change.** Proceedings of the Royal Society B 281: 20141097.

Abstract. The relationships among species' physiological capacities and the geographical variation of ambient climate are of key importance to understanding the distribution of life on the Earth. Furthermore, predictions of how species will respond to climate change will profit from the explicit consideration of their physiological tolerances. The climatic variability hypothesis, which predicts that climatic tolerances are broader in more variable climates, provides an analytical framework for studying these relationships between physiology and biogeography. However, direct empirical support for the hypothesis is mostly lacking for endotherms, and few studies have tried to integrate physiological data into assessments of species' climatic vulnerability at the global scale. Here, we test the climatic variability hypothesis for endotherms, with a comprehensive dataset on thermal tolerances derived from physiological experiments, and use these data to assess the vulnerability of species to projected climate change. We find the expected relationship between thermal tolerance and ambient

climatic variability in birds, but not in mammals—a contrast possibly resulting from different adaptation strategies to ambient climate via behaviour, morphology or physiology. We show that currently most of the species are experiencing ambient temperatures well within their tolerance limits and that in the future many species may be able to tolerate projected temperature increases across significant proportions of their distributions. However, our findings also underline the high vulnerability of tropical regions to changes in temperature and other threats of anthropogenic global changes. Our study demonstrates that a better understanding of the interplay among species' physiology and the geography of climate change will advance assessments of species' vulnerability to climate change.

Lawrence, David J., Ben Stewart-Koster, Julian D. Olden, Aaron S. Ruesch, Christian E. Torgersen, Joshua J. Lawler, Don P. Butcher, and Julia K. Crown. 2014. **The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon.** Ecological Applications 24:895–912. http://dx.doi.org/10.1890/13-0753.1

Abstract. Predicting how climate change is likely to interact with myriad other stressors that threaten species of conservation concern is an essential challenge in aquatic ecosystems. This study provides a framework to accomplish this task in salmon-bearing streams of the northwestern United States, where land-use-related reductions in riparian shading have caused changes in stream thermal regimes, and additional warming from projected climate change may result in significant losses of coldwater fish habitat over the next century. Predatory, nonnative smallmouth bass have also been introduced into many northwestern streams, and their range is likely to expand as streams warm, presenting an additional challenge to the persistence of threatened Pacific salmon. The goal of this work was to forecast the interactive effects of climate change, riparian management, and nonnative species on stream-rearing salmon and to evaluate the capacity of restoration to mitigate these effects. We intersected downscaled global climate forecasts with a local-scale water temperature model to predict mid- and end-of-century temperatures in streams in the Columbia River basin. We compared one stream that is thermally impaired due to the loss of riparian vegetation and another that is cooler and has a largely intact riparian corridor. Using the forecasted stream temperatures in conjunction with fish–habitat models, we predicted how stream-rearing chinook salmon and bass distributions would change as each stream warmed. In the highly modified stream, end-of-century warming may cause near total loss of chinook salmon-rearing habitat and a complete invasion of the upper watershed by bass. In the less modified stream, bass were thermally restricted from the upstream-most areas. In both systems, temperature increases resulted in higher predicted spatial overlap between stream-rearing chinook salmon and potentially predatory bass in the early summer (two- to fourfold increase) and greater abundance of bass. We found that riparian restoration could prevent the extirpation of chinook salmon from the more altered stream and

could also restrict bass from occupying the upper 31 km of salmon-rearing habitat. The proposed methodology and model predictions are critical for prioritizing climate-change adaptation strategies before salmonids are exposed to both warmer water and greater predation risk by nonnative species

McCain, C. M. and King, S. R. B. 2014. **Body size and activity times mediate mammalian responses to climate change.** Global Change Biology 20: 1760–1769. doi: 10.1111/gcb.12499

Abstract. Model predictions of extinction risks from anthropogenic climate change are dire, but still overly simplistic. To reliably predict at-risk species we need to know which species are currently responding, which are not, and what traits are mediating the responses. For mammals, we have yet to identify overarching physiological, behavioral, or biogeographic traits determining species' responses to climate change, but they must exist. To date, 73 mammal species in North America and eight additional species worldwide have been assessed for responses to climate change, including local extirpations, range contractions and shifts, decreased abundance, phenological shifts, morphological or genetic changes. Only 52% of those species have responded as expected, 7% responded opposite to expectations, and the remaining 41% have not responded. Which mammals are and are not responding to climate change is mediated predominantly by body size and activity times (phylogenetic multivariate logistic regressions, $P < 0.0001$). Large mammals respond more, for example, an elk is 27 times more likely to respond to climate change than a shrew. Obligate diurnal and nocturnal mammals are more than twice as likely to respond as mammals with flexible activity times ($P < 0.0001$). Among the other traits examined, species with higher latitudinal and elevational ranges were more likely to respond to climate change in some analyses, whereas hibernation, heterothermy, burrowing, nesting, and study location did not influence responses. These results indicate that some mammal species can behaviorally escape climate change whereas others cannot, analogous to paleontology's climate sheltering hypothesis. Including body size and activity flexibility traits into future extinction risk forecasts should substantially improve their predictive utility for conservation and management.

Muhlfeld, Clint C., Ryan P. Kovach, Leslie A. Jones, Robert Al-Chokhachy, Matthew C. Boyer, Robb F. Leary, Winsor H. Lowe, Gordon Luikart and Fred W. Allendorf. 2014. **Invasive hybridization in a threatened species is accelerated by climate change.** Nature Climate Change 4: 620–624. doi:10.1038/nclimate2252

Abstract. Climate change will decrease worldwide biodiversity through a number of potential pathways, including invasive hybridization (cross-breeding between invasive and native species). How climate warming influences the spread of hybridization and loss of native genomes poses difficult ecological and evolutionary questions with little empirical information to guide conservation management decisions. Here we combine long-term genetic monitoring data with high-resolution climate and stream temperature predictions to evaluate how recent climate warming has influenced the spatio-temporal spread of human-mediated hybridization between threatened native westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) and non-native rainbow trout (*Oncorhynchus mykiss*), the world's most widely introduced invasive fish. Despite widespread release of millions of rainbow trout over the past century within the Flathead River system, a large relatively pristine watershed in western North America, historical samples revealed that hybridization was prevalent only in one (source) population. During a subsequent 30-year period of accelerated warming, hybridization spread rapidly and was strongly linked to interactions between climatic drivers—precipitation and temperature—and distance to the source population. Specifically, decreases in spring precipitation and increases in summer stream temperature probably promoted upstream expansion of hybridization throughout the system. This study shows that rapid climate warming can exacerbate interactions between native and non-native species through invasive hybridization, which could spell genomic extinction for many species.

Invertebrates

Flower, A., D.G. Gavin, E.K. Heyerdahl, R.A. Parsons, G.M. Cohn. 2014. **Drought-triggered western spruce budworm outbreaks in the interior Pacific Northwest: A multi-century dendrochronological record.** Forest Ecology and Management 324: 16-27. doi: 10.1016/j.foreco.2014.03.042

Abstract. Douglas-fir forests in the interior Pacific Northwest are subject to sporadic outbreaks of the western spruce budworm, a species widely recognized as the most destructive defoliator in western North America. Outbreaks of the western spruce budworm often occur synchronously over broad regions and lead to widespread loss of leaf area and decrease in growth rates in affected stands. In spite of the ecological and economic significance of this defoliator, the mechanisms controlling this species' population dynamics are still not fully understood. We used dendrochronological methods to reconstruct three centuries of western spruce budworm outbreaks at thirteen sites along a transect running from central Oregon to western Montana and compared the outbreak reconstructions with regional drought history. The reconstructions reveal repeated western spruce budworm outbreaks that sometimes persisted more than a decade and were significantly synchronous among sites. Synchrony was higher in the second half of the record, possibly due to changes in forest composition and structure brought about by land use practices. Across stands and regions, there was a moderately strong relationship between initiation of synchronous outbreaks and periods of transitional climate conditions in which

moisture availability was below average prior to outbreak initiation, but above average in the first few years of an outbreak. There was a weak relationship between cessation of outbreaks and one or more years of high moisture availability. Outbreaks tended to occur near the end of droughts. The association between climatic variability and outbreak dynamics observed across this transect indicates that climate is an important driver of western spruce budworm outbreaks. Other factors that we did not test, but that may influence outbreak dynamics include stand structure, forest composition, predation, and phenological synchrony between larvae and host trees. Future changes in western spruce budworm outbreak dynamics will be determined by a combination of changing climate, interactions with other disturbance agents, and changing forest composition and structure. Our results suggest that western spruce budworm outbreaks will likely intensify if drought frequency increases in the future.

Soils and Hydrology

Berghuijs,W. R., R. A. Woods and M. Hrachowitz. 2014. **A precipitation shift from snow towards rain leads to a decrease in streamflow.** Nature Climate Change 4:583–586. doi:10.1038/nclimate2246

Abstract. In a warming climate, precipitation is less likely to occur as snowfall. A shift from a snow- towards a rain-dominated regime is currently assumed not to influence the mean streamflow significantly. Contradicting the current paradigm, we argue that mean streamflow is likely to reduce for catchments that experience significant reductions in the fraction of precipitation falling as snow. With more than one-sixth of the Earth's population depending on meltwater for their water supply and ecosystems that can be sensitive to streamflow alterations, the socio-economic consequences of a reduction in streamflow can be substantial. By applying the Budyko water balance framework to catchments located throughout the contiguous United States we demonstrate that a higher fraction of precipitation falling as snow is associated with higher mean streamflow, compared to catchments with marginal or no snowfall. Furthermore, we show that the fraction of each year's precipitation falling as snowfall has a significant influence on the annual streamflow within individual catchments. This study is limited to introducing these observations; process-based understanding at the catchment scale is not yet provided. Given the importance of streamflow for society, further studies are required to respond to the consequences of a temperature-induced precipitation shift from snow to rain.

Klos, P. Zion, Timothy E. Link, and John T. Abatzoglou. 2014. **Extent of the rain-snow transition zone in the western U.S. under historic and projected climate.** Geophysical Research Letters 41(13): 4560-4568. doi: 10.1002/2014GL060500

Abstract. This study investigates the extent of the rain-snow transition zone across the complex terrain of the western United States for both late 20th century climate and projected changes in climate by the mid-21st century. Observed and projected temperature and precipitation data at 4 km resolution were used with an empirical probabilistic precipitation phase model to estimate and map the likelihood of snow versus rain occurrence. This approach identifies areas most likely to undergo precipitation phase change over the next half century. At broad scales, these projections indicate an average 30% decrease in areal extent of winter wet-day temperatures conducive to snowfall over the western United States. At higher resolution scales, this approach identifies existing and potential experimental sites best suited for research investigating the mechanisms linking precipitation phase change to a broad array of processes, such as shifts in rain-on-snow flood risk, timing of water resource availability, and ecosystem dynamics.

Key Points

- Projections map changes in precipitation phase across the western U.S.
- Approximately 30% reduction by mid-21st century in the wintertime snow-dominated area
- Annual duration of snowfall declining by ~2 months across mountain regions

O'Gorman, Paul A. 2014. **Contrasting responses of mean and extreme snowfall to climate change.** Nature 512: 416-418. doi:10.1038/nature13625

Abstract. Snowfall is an important element of the climate system, and one that is expected to change in a warming climate. Both mean snowfall and the intensity distribution of snowfall are important, with heavy snowfall events having particularly large economic and human impacts. Simulations with climate models indicate that annual mean snowfall declines with warming in most regions but increases in regions with very low surface temperatures. The response of heavy snowfall events to a changing climate, however, is unclear. Here I show that in simulations with climate models under a scenario of high emissions of greenhouse gases, by the late twenty-first century there are smaller fractional changes in the intensities of daily snowfall extremes than in mean snowfall over many Northern Hemisphere land regions. For example, for monthly climatological temperatures just below freezing and surface elevations below 1,000 metres, the 99.99th percentile of daily snowfall decreases by 8% in the multimodel median, compared to a 65% reduction in mean snowfall. Both mean and extreme

snowfall must decrease for a sufficiently large warming, but the climatological temperature above which snowfall extremes decrease with warming in the simulations is as high as −9 °C, compared to −14 °C for mean snowfall. These results are supported by a physically based theory that is consistent with the observed rain–snow transition. According to the theory, snowfall extremes occur near an optimal temperature that is insensitive to climate warming, and this results in smaller fractional changes for higher percentiles of daily snowfall. The simulated changes in snowfall that I find would influence surface snow and its hazards; these changes also suggest that it may be difficult to detect a regional climate-change signal in snowfall extremes.

Fire

Bowman, D. M. J. S., Murphy, B. P., Williamson, G. J. and Cochrane, M. A. 2014. **Pyrogeographic models, feedbacks and the future of global fire regimes.** Global Ecology and Biogeography 23: 821–824. doi: 10.1111/geb.12180

Abstract. Conceptual and phenomenological macroecological models of current global fire activity have demonstrated the overwhelming control exerted by primary productivity. Fire activity is very high in savanna regions with intermediate primary productivity, and very low in both densely forested regions with high productivity and arid/cold regions with low productivity. However, predicting future global fire activity using such macroecological models of fire's global ‘niche’ may not be possible because of the feedbacks between fire, climate and vegetation that underpin the fire−productivity relationship. Improving forecasts of global fire activity demands the use of dynamic models to determine how climate, CO_2, vegetation (i.e. canopy closure and plant functional types) and primary productivity constrain fire and evaluation of the strength of feedbacks amongst these variables.

Cansler, C. Alina and Donald McKenzie. 2014. **Climate, fire size, and biophysical setting control fire severity and spatial pattern in the northern Cascade Range, USA.** Ecological Applications 24:1037–1056. http://dx.doi.org/10.1890/13-1077.1

Abstract. Warmer and drier climate over the past few decades has brought larger fire sizes and increased annual area burned in forested ecosystems of western North America, and continued increases in annual area burned are expected due to climate change. As warming continues, fires may also increase in severity and produce larger contiguous patches of severely burned areas. We used remotely sensed burn-severity data from 125 fires in the northern Cascade Range of Washington, USA, to explore relationships between fire size, severity, and the spatial pattern of severity. We examined relationships between climate and the annual area burned and the size of

wildfires over a 25-year period. We tested the hypothesis that increased fire size is commensurate with increased burn severity and increased spatial aggregation of severely burned areas. We also asked how local ecological controls might modulate these relationships by comparing results over the whole study area (the northern Cascade Range) to those from four ecological subsections within it. We found significant positive relationships between climate and fire size, and between fire size and the proportion of high severity and spatial-pattern metrics that quantify the spatial aggregation of high-severity areas within fires, but the strength and significance of these relationships varied among the four subsections. In areas with more contiguous subalpine forests and less complex topography, the proportion and spatial aggregation of severely burned areas were more strongly correlated with fire size. If fire sizes increase in a warming climate, changes in the extent, severity, and spatial pattern of fire regimes are likely to be more pronounced in higher-severity fire regimes with less complex topography and more continuous fuels.

Loudermilk, E. Louise, Alison Stanton, Robert M. Scheller, Thomas E. Dilts, Peter J. Weisberg, Carl Skinner, and Jian Yang. 2014. **Effectiveness of fuel treatments for mitigating wildfire risk and sequestering forest carbon: A case study in the Lake Tahoe Basin.** Forest Ecology and Management 323: 114-125. doi: 10.1016/j.foreco.2014.03.011

Abstract. Fuel-reduction treatments are used extensively to reduce wildfire risk and restore forest diversity and function. In the near future, increasing regulation of carbon (C) emissions may force forest managers to balance the use of fuel treatments for reducing wildfire risk against an alternative goal of C sequestration. The objective of this study was to evaluate how long-term fuel treatments mitigate wildfires and affect forest C. For the Lake Tahoe Basin in the central Sierra Nevada, USA, fuel treatment efficiency was explored with a landscape-scale simulation model, LANDIS-II, using five fuel treatment scenarios and two (contemporary and potential future) fire regimes. Treatment scenarios included applying a combination of light (hand) and moderate (mechanical) forest thinning continuously through time and transitioning from these prescriptions to a more mid-seral thinning prescription, both on a 15 and 30 year rotation interval. In the last scenario, fuel treatments were isolated to around the lake shore (nearby urban settlement) to simulate a low investment alternative were future resources may be limited. Results indicated that the forest will remain a C sink regardless of treatment or fire regime simulated, due to the landscape legacy of historic logging. Achievement of a net C gain required decades with intensive treatment and depended on wildfire activity: Fuel treatments were more effective in a more active fire environment, where the interface between wildfires and treatment areas increased and caused net C gain earlier than as compared to our scenarios with less wildfire activity. Fuel treatments were most effective when continuously applied and strategically placed in high ignition areas. Treatment type and re-application interval were

less influential at the landscape scale, but had notable effects on species dynamics within management units. Treatments created more diverse forest conditions by shifting dominance patterns to a more mixed conifer system, with a higher proportion of fire-tolerant species. We demonstrated that a small amount of wildfire on the landscape resulted in significant changes in the C pool, and that strategically placed fuel treatments substantially reduced wildfire risk, increased fire resiliency of the forest, and is beneficial for long-term C management. Implications for landscape management included consideration for prioritization of treatment areas and creating ideal re-entry schedules that meet logistic, safety, and conservation goals. In forests with a concentrated wildland urban interface, fuel treatments may be vital for ensuring human welfare and enhancing forest integrity in a fire-prone future.

Adaptation

Alagador, D., Cerdeira, J. O., Araújo, M. B. 2014. **Shifting protected areas: scheduling spatial priorities under climate change.** Journal of Applied Ecology 51: 703–713. doi: 10.1111/1365-2664.12230

Abstract. 1. Conservation planning decisions are constrained by three important factors: budgets are limited, important areas for biodiversity compete for space with other uses, and climate- and land-use changes are affecting the distribution of life thus compounding existing threats to biodiversity. Decisions about locating and allocating resources for conservation in such complex and dynamic world are far from trivial, with apparently optimal decisions in the present being potential suboptimal in the future.

2. We propose a methodological framework for the dynamic spatial prioritization of conservation areas that optimizes long-term conservation goals under climate change. This approach involves a sequential scheduling of conservation areas designation, followed by the release of some areas when they stop contributing to the specified long-term conservation goals. The usefulness of the proposed approach is demonstrated with a case study involving ten species in the Iberian Peninsula under severe scenarios of climate change, but the framework could be applied more broadly.

3. Species persistence under climate change is enhanced by the dynamic spatial prioritization strategy that assumes area release. With such strategy, the long-term persistence of species is consistently higher than expected with no release of redundant areas, particularly when the budgets to acquire and manage conservation areas are small. When budgets are small, long-term persistence of species might only be achieved when the release of previously selected areas is considered alongside the selection of new areas.

4. Synthesis and applications. Given that conservation budgets are typically small, conservation strategies involving the release of some underperforming areas might be required to achieve long-term persistence of species. This

should be the case when climate change forces species to move out of current protected areas with other areas becoming important to meet conservation objectives. Implementing such dynamic prioritization approach would require a paradigm shift in conservation planning because conservation areas, once selected, are rarely released. Dynamic selection of areas also involves risks that should be considered in a case-by-case situation.

Mitigation

Bonebrake, T. C., Syphard, A. D., Franklin, J., Anderson, K. E., Akçakaya, H. R., Mizerk, T., Winchell, C. and Regan, H. M. 2014. **Fire Management, Managed Relocation, and Land Conservation Options for Long-Lived Obligate Seeding Plants under Global Changes in Climate, Urbanization, and Fire Regime.** Conservation Biology 28: 1057–1067. doi: 10.1111/cobi.12253

Abstract. Most species face multiple anthropogenic disruptions. Few studies have quantified the cumulative influence of multiple threats on species of conservation concern, and far fewer have quantified the potential relative value of multiple conservation interventions in light of these threats. We linked spatial distribution and population viability models to explore conservation interventions under projected climate change, urbanization, and changes in fire regime on a long-lived obligate seeding plant species sensitive to high fire frequencies, a dominant plant functional type in many fire-prone ecosystems, including the biodiversity hotspots of Mediterranean-type ecosystems. First, we investigated the relative risk of population decline for plant populations in landscapes with and without land protection under an existing habitat conservation plan. Second, we modeled the effectiveness of relocating both seedlings and seeds from a large patch with predicted declines in habitat area to 2 unoccupied recipient patches with increasing habitat area under 2 projected climate change scenarios. Finally, we modeled 8 fire return intervals (FRIs) approximating the outcomes of different management strategies that effectively control fire frequency. Invariably, long-lived obligate seeding populations remained viable only when FRIs were maintained at or above a minimum level. Land conservation and seedling relocation efforts lessened the impact of climate change and land-use change on obligate seeding populations to differing degrees depending on the climate change scenario, but neither of these efforts was as generally effective as frequent translocation of seeds. While none of the modeled strategies fully compensated for the effects of land-use and climate change, an integrative approach managing multiple threats may diminish population declines for species in complex landscapes. Conservation plans designed to mitigate the impacts of a single threat are likely to fail if additional threats are ignored.