Climate Projections

Cappa, Christopher D., Timothy B. Onasch, Paola Massoli, Douglas R. Worsnop, Timothy S. Bates, Eben S. Cross, Paul Davidovits, Jani Hakala, Katherine L. Hayden, B. Tom Jobson, Katheryn R. Kolesar, Daniel A. Lack, Brian M. Lerner, Shao-Meng Li, Daniel Mellon, Ibraheem Nuaaman, Jason S. Olfert, Tuukka Petäjä, Patricia K. Quinn, Chen Song, R. Subramanian, Eric J. Williams, and Rahul A. Zaveri. 2012. Radiative Absorption Enhancements Due to the Mixing State of Atmospheric Black Carbon. Science 337(6098): 1078-1081. DOI: 10.1126/science.1223447

Abstract. Atmospheric black carbon (BC) warms Earth's climate, and its reduction has been targeted for near-term climate change mitigation. Models that include forcing by BC assume internal mixing with non-BC aerosol components that enhance BC absorption, often by a factor of ~2; such model estimates have yet to be clearly validated through atmospheric observations. Here, direct in situ measurements of BC absorption enhancements (E_{abs}) and mixing state are reported for two California regions. The observed E_{abs} is small—6% on average at 532 nm—and increases weakly with photochemical aging. The E_{abs} is less than predicted from observationally constrained theoretical calculations, suggesting that many climate models may overestimate warming by BC. These ambient observations stand in contrast to laboratory measurements that show substantial E_{abs} for BC are possible.

Deser, Clara, Reto Knutti, Susan Solomon and Adam S. Phillips. 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change 2(11): 775-779. doi: 10.1038/nclimate1562

Abstract. As climate models improve, decision-makers' expectations for accurate climate predictions are growing. Natural climate variability, however, poses inherent limits to climate predictability and the related goal of adaptation guidance in many places, as illustrated here for North America. Other locations with low natural variability show a more predictable future in which anthropogenic forcing can be more readily identified, even on small scales. We call for a more focused dialogue between scientists, policymakers and the public to improve communication and avoid raising expectations for accurate regional predictions everywhere.

Sheffield, Justin, Eric F. Wood and Michael L. Roderick. 2012. Little change in global drought over the past 60 years. Nature 491: 435–438. doi: 10.1038/nature11575

Abstract. Drought is expected to increase in frequency and severity in the future as a result of climate change, mainly as a consequence of decreases in regional precipitation but also because of increasing evaporation driven by global warming. Previous assessments of historic changes in drought over the late twentieth and early twenty-first centuries indicate that this may already be happening globally. In particular, calculations of the Palmer Drought Severity Index (PDSI) show a decrease in moisture globally since the 1970s with a commensurate increase in the area in drought that is attributed, in part, to global warming. The simplicity of the PDSI,

which is calculated from a simple water-balance model forced by monthly precipitation and temperature data, makes it an attractive tool in large-scale drought assessments, but may give biased results in the context of climate change. Here we show that the previously reported increase in global drought is overestimated because the PDSI uses a simplified model of potential evaporation that responds only to changes in temperature and thus responds incorrectly to global warming in recent decades. More realistic calculations, based on the underlying physical principles that take into account changes in available energy, humidity and wind speed, suggest that there has been little change in drought over the past 60 years. The results have implications for how we interpret the impact of global warming on the hydrological cycle and its extremes, and may help to explain why palaeoclimate drought reconstructions based on tree-ring data diverge from the PDSI-based drought record in recent years.

Taylor, Christopher M., Richard A. M. de Jeu, Françoise Guichard, Phil P. Harris and Wouter A. Dorigo. 2012. Afternoon rain more likely over drier soils. Nature 489: 423–426. doi: 10.1038/nature11377

Abstract. Land surface properties, such as vegetation cover and soil moisture, influence the partitioning of radiative energy between latent and sensible heat fluxes in daytime hours. During dry periods, soil-water deficit can limit evapotranspiration, leading to warmer and drier conditions in the lower atmosphere. Soil moisture can influence the development of convective storms through such modifications of low-level atmospheric temperature and humidity, which in turn feeds back on soil moisture. Yet there is considerable uncertainty in how soil moisture affects convective storms across the world, owing to a lack of observational evidence and uncertainty in large-scale models. Here we present a global-scale observational analysis of the coupling between soil moisture and precipitation. We show that across all six continents studied, afternoon rain falls preferentially over soils that are relatively dry compared to the surrounding area. The signal emerges most clearly in the observations over semi-arid regions, where surface fluxes are sensitive to soil moisture, and convective events are frequent. Mechanistically, our results are consistent with enhanced afternoon moist convection driven by increased sensible heat flux over drier soils, and/or mesoscale variability in soil moisture. We find no evidence in our analysis of a positive feedback—that is, a preference for rain over wetter soils—at the spatial scale (50–100 kilometres) studied. In contrast, we find that a positive feedback of soil moisture on simulated precipitation does dominate in six state-of-the-art global weather and climate models—a difference that may contribute to excessive simulated droughts in large-scale models.

Carbon and Carbon Storage

Cheng, Lei, Fitzgerald L. Booker, Cong Tu, Kent O. Burkey, Lishi Zhou, H. David Shew, Thomas W. Rufty, and Shuijin Hu. 2012. Arbuscular Mycorrhizal Fungi Increase Organic Carbon Decomposition Under Elevated CO_2. Science 337(6098): 1084-1087. DOI: 10.1126/science.1224304

Abstract. The extent to which terrestrial ecosystems can sequester carbon to mitigate climate change is a matter of debate. The stimulation of arbuscular mycorrhizal fungi (AMF) by elevated atmospheric carbon dioxide (CO_2) has been assumed to be a major mechanism facilitating soil carbon sequestration by increasing carbon inputs to soil and by protecting organic carbon from decomposition via aggregation. We present evidence from four independent microcosm and field experiments demonstrating that CO_2 enhancement of AMF results in considerable soil carbon losses. Our findings challenge the assumption that AMF protect against degradation of organic carbon in soil and raise questions about the current prediction of terrestrial ecosystem carbon balance under future climate-change scenarios.

Colombo, Stephen J., Jiaxin Chen, Michael T. Ter-Mikaelian, Jon McKechnie, Philip C. Elkie, Heather L. MacLean, Linda S. Heath. 2012. Forest protection and forest harvest as strategies for ecological sustainability and climate change mitigation. Forest Ecology and Management 281: 140-151.

Abstract. An important consideration in forest management to mitigate climate change is the balance between forest carbon (C) storage and ecological sustainability. We explore the effects of management strategies on tradeoffs between forest C stocks and ecological sustainability under five scenarios, three of which included management and two scenarios which provide baselines emulating the natural forest. Managed forest scenarios were: (a) Protection (PROT), i.e., management by suppression of natural disturbance and harvest exclusion; (b) Harvest at a higher rate removing all sustainably available wood (HHARV); (c) Harvest at the lower historical average rate of harvest, AHARV. Both harvest scenarios reflected current forest management practices in the study area, including suppression of natural disturbance and a large (>20% of total) forest area reserved from harvest. Scenarios (d) and (e) simulated "natural" forest with unsuppressed fire at higher (NDH) or lower (NDL) levels and no harvest. Ecological sustainability was evaluated using a coarse filter approach where forest age class and tree species composition were indicators of condition. The study area encompassed 3.4 million hectares of forest in northeastern Ontario at the interface between the temperate hardwood and boreal forest zones. Future forest condition for each scenario was modeled using a timber supply model (SFMM), and C stored in forests and wood products were estimated using the FORCARB-ON model. Forest protection (PROT) resulted in greatest forest C stocks, especially in the near term, but was within 95% of its maximum, becoming saturated within 30 years. Harvesting (HHARV and AHARV) resulted in less forest C stock compared to PROT, however, after 100 years of adding C in wood products to that in regenerating forests total C storage was equivalent or greater than forest C with PROT. In contrast, removing management (NDH and NDL) decreased C relative to any of the management regimes, though in NDL the decrease was delayed for 30 years compared to HHARV. Forest sustainability measured by similarity to natural forest age class was superior with HHARV and AHARV compared to PROT, although no management regime produced a fully natural result. PROT in particular largely lacked younger age classes. All management regimes produced species composition that was near or within the range of natural variation. This analysis provides an example of the types of tradeoffs that can be considered in evaluating the contribution of forests to climate change mitigation, either in a commercial forestry context or in an approach based on protected areas.

Dore, S., Montes-Helu, M., Hart, S. C., Hungate, B. A., Koch, G. W., Moon, J. B., Finkral, A. J. and Kolb, T. E. 2012. Recovery of ponderosa pine ecosystem carbon and water fluxes from thinning and stand-replacing fire. Global Change Biology 18: 3171–3185. doi: 10.1111/j.1365-2486.2012.02775.x

Abstract. Carbon uptake by forests is a major sink in the global carbon cycle, helping buffer the rising concentration of CO_2 in the atmosphere, yet the potential for future carbon uptake by forests is uncertain. Climate warming and drought can reduce forest carbon uptake by reducing photosynthesis, increasing respiration, and by increasing the frequency and intensity of wildfires, leading to large releases of stored carbon. Five years of eddy covariance measurements in a ponderosa pine (*Pinus ponderosa*)-dominated ecosystem in northern Arizona showed that an intense wildfire that converted forest into sparse grassland shifted site carbon balance from sink to source for at least 15 years after burning. In contrast, recovery of carbon sink strength after thinning, a management practice used to reduce the likelihood of intense wildfires, was rapid. Comparisons between an undisturbed-control site and an experimentally thinned site showed that thinning reduced carbon sink strength only for the first two posttreatment years. In the third and fourth posttreatment years, annual carbon sink strength of the thinned site was higher than the undisturbed site because thinning reduced aridity and drought limitation to carbon uptake. As a result, annual maximum gross primary production occurred when temperature was 3 °C higher at the thinned site compared with the undisturbed site. The severe fire consistently reduced annual evapotranspiration (range of 12–30%), whereas effects of thinning were smaller and transient, and could not be detected in the fourth year after thinning. Our results show large and persistent effects of intense fire and minor and short-lived effects of thinning on southwestern ponderosa pine ecosystem carbon and water exchanges.

Earles, J. Mason, Sonia Yeh and Kenneth E. Skog. 2012. Timing of carbon emissions from global forest clearance. Nature Climate Change 2(9): 682–685. doi: 10.1038/nclimate1535

Abstract. Land-use change, primarily from conventional agricultural expansion and deforestation, contributes to approximately 17% of global greenhouse-gas emissions. The fate of cleared wood and subsequent carbon storage as wood products, however, has not been consistently estimated, and is largely ignored or oversimplified by most models estimating greenhouse-gas emissions from global land-use conversion. Here, we estimate the fate of cleared wood and timing of atmospheric carbon emissions for 169 countries. We show that 30 years after forest clearance the percentage of carbon stored in wood products and landfills ranges from about 0% to 62% globally. For 90 countries, less than 5% of carbon remains after 30 years, whereas 34 countries have more than 25% in storage. Higher storage rates result primarily from a greater percentage of long-lived products such as wood panels and lumber, and tend to occur in countries with predominantly temperate forests. Alternatively, lower storage rates are associated with a greater fraction of non-merchantable wood and more wood used for energy and paper production, which tend to occur in countries with predominantly tropical forests. Hence, the country and fate of cleared wood can considerably affect the timing of greenhouse-gas emissions from forest clearance.

Finkral, Alex J., Alexander M. Evans, Christopher D. Sorensen, David L.R. Affleck. 2012. Estimating consumption and remaining carbon in burned slash piles. Canadian Journal of Forest Research 42(9): 1744-1749. doi: 10.1139/x2012-112.

Abstract. Fuel reduction treatments to reduce fire risk have become commonplace in the fire adapted forests of western North America. These treatments generate significant woody debris, or slash, and burning this material in piles is a common and inexpensive approach to reducing fuel loads. Although slash pile burning is a common practice, there is little information on consumption or even a common methodology for estimating consumption. As considerations of carbon storage and emissions from forests increase, better means of quantifying burn piles are necessary. This study uses two methods, sector sampling and a form of line intersect sampling, for estimating both the percent consumption and conversion to charcoal in slash piles of ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) in northern Arizona, USA. On average, burning released between 92% and 94% of the carbon in each slash pile to the atmosphere and converted between 0.05 and 0.34 Mg C·ha^{-1} to charcoal across the treatment area. These results demonstrate that burning slash piles converts significant quantities of carbon stored in wood to atmospheric carbon and charcoal, both of which should be considered as forest carbon accounting is further refined. Sector sampling and line intersect strategies produced similar estimates of consumption; however, the line intersect protocol was more easily and rapidly implemented.

Kirwan, Matthew L. and Simon M. Mudd. 2012. Response of salt-marsh carbon accumulation to climate change. Nature 489:550–553. doi:10.1038/nature11440

Abstract. About half of annual marine carbon burial takes place in shallow water ecosystems where geomorphic and ecological stability is driven by interactions between the flow of water, vegetation growth and sediment transport. Although the sensitivity of terrestrial and deep marine carbon pools to climate change has been studied for decades, there is little understanding of how coastal carbon accumulation rates will change and potentially feed back on climate. Here we develop a numerical model of salt marsh evolution, informed by recent measurements of productivity and decomposition, and demonstrate that competition between mineral sediment deposition and organic-matter accumulation determines the net impact of climate change on carbon accumulation in intertidal wetlands. We find that the direct impact of warming on soil carbon accumulation rates is more subtle than the impact of warming-driven sea level rise, although the impact of warming increases with increasing rates of sea level rise. Our simulations suggest that the net impact of climate change will be to increase carbon burial rates in the first half of the twenty-first century, but that carbon–climate feedbacks are likely to diminish over time.

Scott, R.L., P. Serrano-Ortiz, F. Domingo, E.P. Hamerlynck, A.S. Kowalski. 2012. Commonalities of carbon dioxide exchange in semiarid regions with monsoon and Mediterranean climates. Journal of Arid Environments 84: 71-79.

Abstract. Comparing biosphere–atmosphere carbon exchange across monsoon (warm-season rainfall) and Mediterranean (cool-season rainfall) regimes can yield information about the interaction between energy and water limitation. Using data collected from eddy covariance towers over grass and shrub ecosystems in Arizona, USA and Almeria, Spain, we used net ecosystem carbon dioxide exchange (NEE), gross ecosystem production (GEP), and other meteorological variables to examine the effects of the different precipitation seasonality. Considerable crossover behavior occurred between the two rainfall regimes. As expected in these usually water-limited ecosystems, precipitation magnitude and timing were the dominant drivers of carbon exchange, but temperature and/or light also played an important role in regulating GEP and NEE at all sites. If significant rainfall occurred in the winter at the Arizona sites, their behavior was characteristically Mediterranean whereby the carbon flux responses were delayed till springtime. Likewise, the Spanish Mediterranean sites showed immediate pulse-like responses to rainfall events in non-winter periods. The observed site differences were likely due to differences in vegetation, soils, and climatology. Together, these results support a more unified conceptual model for which processes governing carbon cycling in semiarid ecosystems need not differ between warm-season and cool-season rainfall regimes.

Sedjo, Roger and Xiaohui Tian. 2012. Does Wood Bioenergy Increase Carbon Stocks in Forests? Journal of Forestry 110(6): 304-311. http://dx.doi.org/10.5849/jof.11-073.

Abstract. Wood bioenergy is touted as carbon neutral because biological regrowth recaptures the carbon released in energy production. However, some argue that using wood as an energy feedstock will result in decreased forest stocks and thereby a net reduction of carbon sequestered by forests. Such arguments fail to recognize that increased demand for wood bioenergy could increase stocks of wood, a renewable resource. We address the carbon neutrality question using a dynamic optimization forest management model to examine the effect of increasing or decreasing wood bioenergy demand on an existing forest, both in the amount of carbon lost by harvests and in that captured by forest management adjustments that change forest stocks under various wood demand and land supply scenarios. The results suggest for a managed regulated forest using foresight, an anticipated substantial increase in future wood biomass demand will not reduce forest and forest carbon stocks, but rather will increase the forest and forest carbon, thus being somewhat self-regulating.

Winford, Eric M. and James C. Gaither Jr. 2012. Carbon outcomes from fuels treatment and bioenergy production in a Sierra Nevada forest. Forest Ecology and Management 282: 1-9.

Abstract. In temperate conifer forests of the Western USA, there is active debate whether fuels reduction treatments and bioenergy production result in decreased carbon emissions and increased carbon sequestration compared to a no-action alternative. To address this debate over net carbon stocks, we performed a carbon life-cycle analysis on data from a fuels reduction treatment in a temperate, dry conifer forest in the northern Sierra Nevada of California, USA. The analysis tracks the net ecosystem carbon balance over 50 years for two scenarios (1) fuels reduction treatment combined with bioenergy production, and (2) a baseline scenario of no action. The study includes above and belowground carbon stocks, removals from harvesting, emissions from harvesting and transporting the removed biomass, and disturbance by wildfire. We evaluate a range of fire rotations, from an historic short rotation to a modern long rotation. In this study, when the fire rotation is 31 years or less, fuels treatment and bioenergy result in a net increase in carbon stocks after

50 years compared to a baseline of no action. When fire rotations exceed 31 years the carbon balance shifts and the baseline scenario holds more carbon after 50 years than the fuels treatment. Over the 50-year period, future wildfire is the greatest source of emissions unless fire rotations are greater than 200 years, when emissions from the combustion of biomass for energy are greater. Emissions from mechanical treatments and transportation of the woody biomass are each less than 1% of total emissions. The results of this case study suggest that there is no single answer to whether fuels reduction treatments with bioenergy production create net carbon benefit. Managers will need to evaluate fuels treatments on a case-by-case or regional basis to determine net carbon outcomes. The life cycle approach presented here is a useful methodology for such determinations.

Phenology Changes

Kauserud, Håvard, Einar Heegaard, Ulf Büntgen, Rune Halvorsen, Simon Egli, Beatrice Senn-Irlet, Irmgard Krisai-Greilhuber, Wolfgang Dämon, Tim Sparks, Jenni Nordén, Klaus Høiland, Paul Kirk, Mikhail Semenov, Lynne Boddy, and Nils C. Stenseth. 2012. Warming-induced shift in European mushroom fruiting phenology. Proceedings of the National Academy of Science 109(36): 14488-14493. doi:10.1073/pnas.1200789109

Abstract. In terrestrial ecosystems, fungi are the major agents of decomposition processes and nutrient cycling and of plant nutrient uptake. Hence, they have a vital impact on ecosystem processes and the terrestrial carbon cycle. Changes in productivity and phenology of fungal fruit bodies can give clues to changes in fungal activity, but understanding these changes in relation to a changing climate is a pending challenge among ecologists. Here we report on phenological changes in fungal fruiting in Europe over the past four decades. Analyses of 746,297 dated and geo-referenced mushroom records of 486 autumnal fruiting species from Austria, Norway, Switzerland, and the United Kingdom revealed a widening of the annual fruiting season in all countries during the period 1970–2007. The mean annual day of fruiting has become later in all countries. However, the interspecific variation in phenological responses was high. Most species moved toward a later ending of their annual fruiting period, a trend that was particularly strong in the United Kingdom, which may reflect regional variation in climate change and its effects. Fruiting of both saprotrophic and mycorrhizal fungi now continues later in the year, but mycorrhizal fungi generally have a more compressed season than saprotrophs. This difference is probably due to the fruiting of mycorrhizal fungi partly depending on cues from the host plant. Extension of the European fungal fruiting season parallels an extended vegetation season in Europe. Changes in fruiting phenology imply changes in mycelia activity, with implications for ecosystem function.

Lane, **Jeffrey E., Loeske E. B. Kruuk**, **Anne Charmantier**, **Jan O. Murie and F. Stephen Dobson. 2012.** Delayed phenology and reduced fitness associated with climate change in a wild hibernator. Nature 489: 554–557. doi:10.1038/nature11335

Abstract. The most commonly reported ecological effects of climate change are shifts in phenologies, in particular of warmer spring temperatures leading to earlier timing of key events. Among animals, however, these reports have been heavily

biased towards avian phenologies, whereas we still know comparatively little about other seasonal adaptations, such as mammalian hibernation. Here we show a significant delay (0.47 days per year, over a 20-year period) in the hibernation emergence date of adult females in a wild population of Columbian ground squirrels in Alberta, Canada. This finding was related to the climatic conditions at our study location: owing to within-individual phenotypic plasticity, females emerged later during years of lower spring temperature and delayed snowmelt. Although there has not been a significant annual trend in spring temperature, the date of snowmelt has become progressively later owing to an increasing prevalence of late-season snowstorms. Importantly, years of later emergence were also associated with decreased individual fitness. There has consequently been a decline in mean fitness (that is, population growth rate) across the past two decades. Our results show that plastic responses to climate change may be driven by climatic trends other than increasing temperature, and may be associated with declines in individual fitness and, hence, population viability.

Rixen, C., Dawes, M. A., Wipf, S. and Hagedorn, F. 2012. Evidence of enhanced freezing damage in treeline plants during six years of CO_2 enrichment and soil warming. Oikos 121: 1532–1543. doi: 10.1111/j.1600-0706.2011.20031.x

Abstract. Climate change and elevated atmospheric CO_2 levels could increase the vulnerability of plants to freezing. We analyzed tissue damage resulting from naturally occurring freezing events in plants from a long–term in situ CO_2 enrichment (+ 200 ppm, 2001–2009) and soil warming (+ 4°C since 2007) experiment at treeline in the Swiss Alps (Stillberg, Davos). Summer freezing events caused damage in several abundant subalpine and alpine plant species in four out of six years between 2005 and 2010. Most freezing damage occurred when temperatures dropped below –1.5°C two to three weeks after snow melt. The tree *Larix decidua* and the dwarf shrubs *Vaccinium myrtillus* and *Empetrum hermaphroditum* showed more freezing damage under experimentally elevated CO_2 and/or temperatures than under control conditions. Soil warming induced a 50% die-back of *E. hermaphroditum* during a single freezing event due to melting of the protective snow cover. Although we could not identify a clear mechanism, we relate greater freezing susceptibility to a combination of advanced plant phenology in spring and changes in plant physiology. The climate record since 1975 at the treeline site indicated a summer warming by 0.58°C/decade and a 3.5 days/decade earlier snow melt, but no significant decrease in freezing events during the vegetation period. Therefore, in a warmer climate with higher CO_2 levels but constant likelihood of extreme weather events, subalpine and alpine plants may be more susceptible to freezing events, which may partially offset expected enhanced growth with global change. Hence, freezing damage should be considered when predicting changes in growth of alpine plants or changes in community composition under future atmospheric and climate conditions.

Species Range Changes

Johnston, Kevin M., Kathryn A. Freund, and Oswald J. Schmitz. 2012. Projected range shifting by montane mammals under climate change: implications for Cascadia's National Parks. Ecosphere 3:art97. http://dx.doi.org/10.1890/ES12-00077.1

Abstract. We examined potential impacts of climate change over the next century on eight mammal species of conservation concern in western Washington State, under four warming scenarios. Using two species distribution models, including a logistic regression-based model and the "maximum entropy" (MaxEnt) model, we predicted the location and extent of the potential current and future range of each species based on a suite of environmental and geographical variables. Both models projected significant losses in range size within the focal area over the next century across all warming scenarios. Projections suggest that future ranges of high elevation species are likely to shrink inward and upward rather than shifting into new areas, and the average range elevation of most species is projected to increase significantly over time. Future projections for higher elevation species largely agreed across species distribution models, global climate model data, and carbon emission scenarios, although projections for lower elevation species were less consistent. The high elevation of the major national parks in this region is likely to aid in their ability to continue to support these species, and they are predicted to continue to act as important protected refuges, even while species' ranges may shrink dramatically elsewhere.

Norberg, Jon, Mark C. Urban, Mark Vellend, Christopher A. Klausmeier and Nicolas Loeuille. 2012. Eco-evolutionary responses of biodiversity to climate change. Nature Climate Change 2 (10): 747–751. doi: 10.1038/nclimate1588

Abstract. Climate change is predicted to alter global species diversity, the distribution of human pathogens and ecosystem services. Forecasting these changes and designing adequate management of future ecosystem services will require predictive models encompassing the most fundamental biotic responses. However, most present models omit important processes such as evolution and competition. Here we develop a spatially explicit eco-evolutionary model of multi-species responses to climate change. We demonstrate that both dispersal and evolution differentially mediate extinction risks and biodiversity alterations through time and across climate gradients. Together, high genetic variance and low dispersal best minimized extinction risks. Surprisingly, high dispersal did not reduce extinctions, because the shifting ranges of some species hastened the decline of others. Evolutionary responses dominated during the later stages of climatic changes and in hot regions. No extinctions occurred without competition, which highlights the importance of including species interactions in global biodiversity models. Most notably, climate change created extinction and evolutionary debts, with changes in species richness and traits occurring long after climate stabilization. Therefore, even if we halt anthropogenic climate change today, transient eco-evolutionary dynamics would ensure centuries of additional alterations in global biodiversity.

Sleeter, Benjamin M., Terry L. Sohl, Michelle A. Bouchard, Ryan R. Reker, Christopher E. Soulard, William Acevedo, Glenn E. Griffith, Rachel R. Sleeter, Roger F. Auch, Kristi L. Sayler, Stephen Prisley, Zhiliang Zhu. 2012. Scenarios of land use and land cover change in the conterminous United States: Utilizing the special report on emission scenarios at ecoregional scales. Global Environmental Change 22(4): 896-914.

Abstract. Global environmental change scenarios have typically provided projections of land use and land cover for a relatively small number of regions or using a relatively coarse resolution spatial grid, and for only a few major sectors. The coarseness of global projections, in both spatial and thematic dimensions, often limits their direct utility at scales useful for environmental management. This paper describes methods to downscale projections of land-use and land-cover change from the Intergovernmental Panel on Climate Change's Special Report on Emission Scenarios to ecological regions of the conterminous United States, using an integrated assessment model, land-use histories, and expert knowledge. Downscaled projections span a wide range of future potential conditions across sixteen land use/land cover sectors and 84 ecological regions, and are logically consistent with both historical measurements and SRES characteristics. Results appear to provide a credible solution for connecting regionalized projections of land use and land cover with existing downscaled climate scenarios, under a common set of scenario-based socioeconomic assumptions.

Tingley, M. W., Koo, M. S., Moritz, C., Rush, A. C. and Beissinger, S. R. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Global Change Biology 18: 3279–3290. doi: 10.1111/j.1365-2486.2012.02784.x

Abstract. Projected effects of climate change on animal distributions primarily focus on consequences of temperature and largely ignore impacts of altered precipitation. While much evidence supports temperature-driven range shifts, there is substantial heterogeneity in species' responses that remains poorly understood. We resampled breeding ranges of birds across three elevational transects in the Sierra Nevada Mountains, USA, that were extensively surveyed in the early 20th century. Presence–absence comparisons were made at 77 sites and occupancy models were used to separate significant range shifts from artifacts of false absences. Over the past century, rising temperature pushed species upslope while increased precipitation pulled them downslope, resulting in range shifts that were heterogeneous within species and among regions. While 84% of species shifted their elevational distribution, only 51% of upper or lower range boundary shifts were upslope. By comparison, 82% of range shifts were in a direction predicted by changes in either temperature or precipitation. Species were significantly more likely to shift elevational ranges than their ecological counterparts if they had small clutch sizes, defended all-purpose territories, and were year-round residents, results that were in opposition to *a priori* predictions from dispersal-related hypotheses. Our results illustrate the complex interplay between species-specific and region-specific factors that structure patterns of breeding range change over long time periods. Future projections of increasing temperature and highly variable precipitation regimes create a strong potential for heterogeneous responses by species at range margins.

Wang, Tongli, Elizabeth M. Campbell, Gregory A. O'Neill, Sally N. Aitken. 2012. Projecting future distributions of ecosystem climate niches: Uncertainties and management applications. Forest Ecology and Management 279: 128-140.

Abstract. Projecting future distributions of ecosystems or species climate niches has widely been used to assess the potential impacts of climate change. However, variability in such projections for the future periods, particularly the variability arising from uncertain future climates, remains a critical challenge for incorporating these projections into climate change adaptation strategies. We combined the use of a robust statistical modeling technique with a simple consensus approach consolidating projected outcomes for multiple climate change scenarios, and exemplify how the results could guide reforestation planning. Random Forest (RF) was used to model relationships between climate (1961–1990), described by 44 variables, and the geographic distribution of 16 major ecosystem types in British Columbia (BC), Canada. The model predicted current ecosystem distributions with high accuracy (mismatch rate = 4–16% for most ecosystem classes). It was then used to predict the distribution of ecosystem climate niches for the last decade (2001–2009) and project future distributions for 20 climate change scenarios. We found that geographic distributions of the suitable climate habitats for BC ecosystems have already shifted in 23% of BC since the 1970s. Consensus projections for future periods (2020s, 2050s, 2080s) indicated climates suitable for grasslands, dry forests, and moist continental cedar–hemlock forests would substantially expand; climate habitat for coastal rainforests would remain relatively stable; and habitat for boreal, subalpine and alpine ecosystems would decrease substantially. Using these consensus projections and data on the occurrence of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in BC ecosystems, we estimated a twofold increase in seedling demand for this frost-sensitive, commercially important timber species, suggesting managers could begin planning to expand seed inventories and seed orchard capacity to more widely plant this species on logged sites. The results of this work demonstrate the power of RF for building climate envelope models and illustrate the utility of consensus projections for incorporating uncertainty about future climate into management planning. It also emphasizes the immediate need for adapting natural resource management to a changing climate.

Forest Vegetation

DeRose, R. Justin, James N. Long. 2012. Drought-driven disturbance history characterizes a southern Rocky Mountain subalpine forest. Canadian Journal of Forest Research 42(9): 1649-1660. doi: 10.1139/x2012-102.

Abstract. The view that subalpine forest vegetation dynamics in western North America are "driven" by a particular disturbance type (i.e., fire) has shaped our understanding of their disturbance regimes. In the wake of a recent (1990s) landscape-extent spruce beetle (*Dendroctonus rufipennis* Kirby) outbreak in the southern Rocky Mountains, we re-examined the temporal continuity in disturbance types and interactions and the possible role of drought on their occurrence by reconstructing antecedent disturbances for 11 sites across the Markagunt Plateau, southern Utah, USA. Multiple consistent lines of evidence suggested that historic fires were the primary antecedent disturbance, while relatively minor, stand-specific spruce beetle activity occurred later in stand development but prior to the recent

outbreak. Unlike the recent outbreak, antecedent fires were spatially and temporally asynchronous over the period examined (~1600–2000). Reconstructed fire events primarily occurred during periods of prolonged drought. Similarly, historic spruce beetle activity, indicated by species-specific tree-ring release, and timing of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) death dates from the recent outbreak were related to drought conditions. Vegetation dynamics on this landscape were strongly driven by historic fires and the recent spruce beetle outbreak, and drought conditions likely influenced the occurrence of both disturbance types.

Iverson, Louis R., Stephen N. Matthews, Anantha M. Prasad, Matthew P. Peters and Gary Yohe. 2012. Development of risk matrices for evaluating climatic change responses of forested habitats. Climatic Change 114(2): 231-243.

Abstract. We present an approach to assess and compare risk from climate change among multiple species through a risk matrix, in which managers can quickly prioritize for species that need to have strategies developed, evaluated further, or watched. We base the matrix upon earlier work towards the National Climate Assessment for potential damage to infrastructures from climate change. Risk is defined here as the product of the likelihood of an event occurring and the consequences or impact of that event. In the context of species habitats, the likelihood component is related to the potential changes in suitable habitat modeled at various times during this century. Consequences are related to the adaptability of the species to cope with the changes, especially the increasing intensity and/or frequency of disturbance events that are projected. We derived consequence scores from nine biological and 12 disturbance characteristics that were pulled from literature for each species. All data were generated from an atlas of climate change for 134 trees of the eastern United States (www.nrs.fs.fed.us/atlas). We show examples which depict a wide range of risk for tree species of northern Wisconsin, including species that may gain substantial habitat as well as lose substantial habitat, both of which will require the development of strategies to help the ecosystems adapt to such changes.

Nothdurft, Arne, Thilo Wolf, Andre Ringeler, Jürgen Böhner, Joachim Saborowski. 2012. Spatio-temporal prediction of site index based on forest inventories and climate change scenarios. Forest Ecology and Management 279: 97-111.

Abstract. A methodological framework is provided for the quantification of climate change effects on site index. Spatio-temporal predictions of site index are derived for six major tree species in the German state of Baden-Württemberg using simplified universal kriging (UK) based on large data sets from forest inventories and a climate sensitive site-index model. It is shown by a simulation study that, with the underlying large sample size, residual kriging using ordinary least squares (OLS) estimates of the mean function leads to an approximately unbiased spatial predictor. Moreover, the simulated coverage probabilities of resulting prediction intervals are quite close to the required level. B-spline regression techniques are applied to model nonlinear cause-and-effect curves for estimating site indexes at existing inventory plots dependent on retrospective climate covariates. The spatially structured error is modeled by exponential covariance functions. The mean model is then applied to downscaled climate projection data to spatially predict the relative changes of site index under perturbed climate conditions.

Applying climate projections of an existing regional climate model based on IPCC emission scenarios A1B and A2, it is found that site index of all tree species would be decreased in lowland areas, and may increase in mountainous regions. Silver fir and common oak stands would also show increased site indexes in mountainous regions, but further extended to lower elevation levels. Site conditions in the Alpine foothills may remain highly productive for growth of Norway spruce, Baden-Württemberg's most dominant tree species. Whereas site index of common beech and Douglas-fir may decrease to almost the same relative amount and on nearly the same sites as Norway spruce, site index of Scots pine may be less affected by future climate change.

Zald, Harold S. J., Thomas A. Spies, Manuela Huso and Demetrios Gatziolis. 2012. Climatic, landform, microtopographic, and overstory canopy controls of tree invasion in a subalpine meadow landscape, Oregon Cascades, USA. Landscape Ecology 27(8): 1197-1212.

Abstract. Tree invasions have been documented throughout Northern Hemisphere high elevation meadows, as well as globally in many grass and forb-dominated ecosystems. Tree invasions are often associated with large-scale changes in climate or disturbance regimes, but are fundamentally driven by regeneration processes influenced by interactions between climatic, topographic, and biotic factors at multiple spatial scales. The purpose of this research was to quantify spatiotemporal patterns of meadow invasion; and how climate, larger landforms, topography, and overstory trees have interactively influenced tree invasion. We combined airborne Light Detection and Ranging (LiDAR) characterizations of landforms, topography, and overstory vegetation with historical climate, field measurements of snow depth, tree abundance, and tree ages to reconstruct spatial and temporal patterns of tree invasion over five decades in a subalpine meadow complex in the Oregon Cascade Range, USA. Proportion of meadow occupied by trees increased from 8% in 1950 to 35% in 2007. Larger landforms, topography, and tree canopies interactively mediated regional climatic controls of tree invasion by modifying depth and persistence of snow pack, while tree canopies also influenced seed source availability. Landscape context played an important role mediating snow depth and tree invasion; on glacial landforms tree invasion was negatively associated with spring snowfall, but on debris flows tree invasion was not associated with snow fall. The importance of snow, uncertain climate change impacts on snow, and mediation of snow by interacting and context dependent factors in complex mountain terrain poses substantial hurdles for understanding how these ecotones may respond to future climate conditions.

Rangeland Vegetation

Fay, Philip A., Virginia L. Jin, Danielle A. Way, Kenneth N. Potter, Richard A. Gill, Robert B. Jackson and H. Wayne Polley. 2012. Soil-mediated effects of subambient to increased carbon dioxide on grassland productivity. Nature Climate Change 2(10): 742–746. doi: 10.1038/nclimate1573

Abstract. Grasslands are structured by climate and soils, and are increasingly affected by anthropogenic changes, including rising atmospheric CO_2 concentrations. CO_2 enrichment can alter grassland ecosystem function both directly and through indirect, soil-specific effects on moisture, nitrogen availability and plant species composition, potentially leading to threshold change in ecosystem properties. Here we show that the increase in aboveground net primary productivity (ANPP) with CO_2 enrichment depends strongly on soil type. We found that the ANPP–CO_2 response of grassland was 2.5× greater on two soils with higher plant-available soil moisture and where direct CO_2 effects on ANPP were accompanied by indirect CO_2 effects on ANPP mediated through an increase in soil moisture or increased dominance of a productive C_4 grass. Indirect CO_2 effects on ANPP were absent on a third soil that was less responsive to CO_2 (1.6×). Unexpectedly, soil N availability changed little with CO_2 and did not seem to drive responses in ANPP. On the more responsive soils, the more productive grass C_4 was favoured with CO_2 enrichment because of greater photosynthetic efficiency. Our results enhance present models of the controls on ecosystem responses to CO_2 and demonstrate mechanisms by which soils could cause spatial variation in CO_2 effects on ANPP and other ecosystem attributes.

Fernandez-Going, B. M., B. L. Anacker, and S. P. Harrison. 2012. Temporal variability in California grasslands: Soil type and species functional traits mediate response to precipitation. Ecology 93:2104–2114. http://dx.doi.org/10.1890/11-2003.1.

Abstract. Plant communities on infertile soils may be relatively resistant to climatic variation if species in these communities have "stress-tolerant" functional traits that limit their ability to respond to climate. Alternatively, such communities may be more sensitive to climatic variation if their relatively sparse vegetative cover exposes species to more extreme changes in factors such as temperature or wind. We compared temporal variability in species richness and composition over 10 years between grasslands on infertile serpentine and "normal" sedimentary soils. Variability in species richness and species composition tracked mean annual precipitation on both soils, but variability was lower in serpentine grasslands. Communities on serpentine had lower functional diversity and had species with more "stress-tolerant" traits than non-serpentine communities (i.e., shorter stature, lower specific leaf area, and lower leaf area). Within and between soils, variability in species richness and temporal turnover were lower in communities scoring as more stress tolerant on a multivariate index of these traits; however, community variability was unrelated to functional diversity. Within 41 species found commonly on both soils, variability in occurrence and cover were also lower on serpentine soils, even though intraspecific trait differences between soils were minimal; this suggests a direct effect of soil type on species variability in addition to the indirect, trait-mediated effect. Communities with higher biomass had higher annual variability in species occurrence and cover. Our results suggest that infertile soils reduce compositional variability indirectly by selecting for stress-tolerant traits and directly by limiting productivity. We conclude that communities on infertile soils may respond more conservatively to predicted changes in precipitation, including increased variability, than communities on soils of normal fertility.

Finch, Deborah M., ed. 2012. Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 139 p. **http://www.fs.fed.us/rm/pubs/rmrs_gtr285.pdf**

Abstract. Recent research and species distribution modeling predict large changes in the distributions of species and vegetation types in the western interior of the United States in response to climate change. This volume reviews existing climate models that predict species and vegetation changes in the western United States, and it synthesizes knowledge about climate change impacts on the native fauna and flora of grasslands, shrublands and deserts of the interior American West. Species' responses will depend not only on their physiological tolerances but also on their phenology, establishment properties, biotic interactions, and capacity to evolve and migrate. The volume is divided into eight chapters that cover the topics of carbon mitigation and adaptation. Current and likely responses of species and habitats to climate change are examined in relation to taxonomic group and ecoregion and with regard to other disturbances. The volume ends with a review of management decision support needs and tools for assessing vulnerability of natural resources and conserving and restoring ecosystems that are or may be impacted by climate change.

Polley, H. W., Jin, V. L. and Fay, P. A. 2012. Feedback from plant species change amplifies CO_2 enhancement of grassland productivity. Global Change Biology 18: 2813–2823. doi: 10.1111/j.1365-2486.2012.02735.x

Abstract. Dynamic global vegetation models simulate feedbacks of vegetation change on ecosystem processes, but direct, experimental evidence for feedbacks that result from atmospheric CO_2 enrichment is rare. We hypothesized that feedbacks from species change would amplify the initial CO_2 stimulation of aboveground net primary productivity (ANPP) of tallgrass prairie communities. Communities of perennial forb and C_4 grass species were grown for 5 years along a field CO_2 gradient (250–500 μL L^{-1}) in central Texas USA on each of three soil types, including upland and lowland clay soils and a sandy soil. CO_2 enrichment increased community ANPP by 0–117% among years and soils and increased the contribution of the tallgrass species *Sorghastrum nutans* (Indian grass) to community ANPP on each of the three soil types. CO_2-induced changes in ANPP and *Sorghastrum* abundance were linked. The slope of ANPP-CO_2 regressions increased between initial and final years on the two clay soils because of a positive feedback from the increase in *Sorghastrum* fraction. This feedback accounted for 30–60% of the CO_2-mediated increase in ANPP on the upland and lowland clay soils during the final 3 years and 1 year of the experiment, respectively. By contrast, species change had little influence on the ANPP-CO_2 response on the sandy soil, possibly because *Sorghastrum* increased largely at the expense of a functionally similar C_4 grass species. By favoring a mesic C_4 tall grass, CO_2 enrichment approximately doubled the initial enhancement of community ANPP on two clay soils. The CO_2-stimulation of grassland productivity may be significantly underestimated if feedbacks from plant community change are not considered.

Reed, Sasha C., Kirsten K. Coe, Jed P. Sparks, David C. Housman, Tamara J. Zelikova and Jayne Belnap. 2012. Changes to dryland rainfall result in rapid moss mortality and altered soil fertility. Nature Climate Change 2(10): 752–755. doi: 10.1038/nclimate1596

Abstract. Arid and semi-arid ecosystems cover ~40% of Earth's terrestrial surface, but we know little about how climate change will affect these widespread landscapes. Like many drylands, the Colorado Plateau in southwestern United States is predicted to experience elevated temperatures and alterations to the timing and amount of annual precipitation. We used a factorial warming and supplemental rainfall experiment on the Colorado Plateau to show that altered precipitation resulted in pronounced mortality of the widespread moss *Syntrichia caninervis*. Increased frequency of 1.2 mm summer rainfall events reduced moss cover from ~25% of total surface cover to <2% after only one growing season, whereas increased temperature had no effect. Laboratory measurements identified a physiological mechanism behind the mortality: small precipitation events caused a negative moss carbon balance, whereas larger events maintained net carbon uptake. Multiple metrics of nitrogen cycling were notably different with moss mortality and had significant implications for soil fertility. Mosses are important members in many dryland ecosystems and the community changes observed here reveal how subtle modifications to climate can affect ecosystem structure and function on unexpectedly short timescales. Moreover, mortality resulted from increased precipitation through smaller, more frequent events, underscoring the importance of precipitation event size and timing, and highlighting our inadequate understanding of relationships between climate and ecosystem function in drylands.

Fish and Wildlife

Forster, Jack, Andrew G. Hirst and David Atkinson. 2012. Warming-induced reductions in body size are greater in aquatic than terrestrial species. Proceedings of the National Academy of Science 109(47): 19310-19314. doi: 10.1073/pnas.1210460109

Abstract. Most ectothermic organisms mature at smaller body sizes when reared in warmer conditions. This phenotypically plastic response, known as the "temperature-size rule" (TSR), is one of the most taxonomically widespread patterns in biology. However, the TSR remains a longstanding life-history puzzle for which no dominant driver has been found. We propose that oxygen supply plays a central role in explaining the magnitude of ectothermic temperature-size responses. Given the much lower oxygen availability and greater effort required to increase uptake in water vs. air, we predict that the TSR in aquatic organisms, especially larger species with lower surface area–body mass ratios, will be stronger than in terrestrial organisms. We performed a meta-analysis of 1,890 body mass responses to temperature in controlled experiments on 169 terrestrial, freshwater, and marine species. This reveals that the strength of the temperature-size response is greater in aquatic than terrestrial species. In animal species of ~100 mg dry mass, the temperature-size response of aquatic organisms is 10 times greater than in terrestrial organisms ($-5.0\%\ °C^{-1}$ vs. $-0.5\%\ °C^{-1}$). Moreover, although the size response of small (<0.1 mg dry mass) aquatic and terrestrial species is similar, increases in species size cause the response to become increasingly negative in aquatic species, as predicted, but on average less negative in terrestrial species.

These results support oxygen as a major driver of temperature-size responses in aquatic organisms. Further, the environment-dependent differences parallel latitudinal body size clines, and will influence predicted impacts of climate warming on food production, community structure, and food-web dynamics.

Ruesch, A. S., Torgersen, C. E., Lawler, J. J., Olden, J. D., Peterson, E. E., Volk, C. J. and Lawrence, D. J. 2012. Projected Climate-Induced Habitat Loss for Salmonids in the John Day River Network, Oregon, U.S.A. Conservation Biology 26: 873–882. doi: 10.1111/j.1523-1739.2012.01897.x.

Abstract. Climate change will likely have profound effects on cold-water species of freshwater fishes. As temperatures rise, cold-water fish distributions may shift and contract in response. Predicting the effects of projected stream warming in stream networks is complicated by the generally poor correlation between water temperature and air temperature. Spatial dependencies in stream networks are complex because the geography of stream processes is governed by dimensions of flow direction and network structure. Therefore, forecasting climate-driven range shifts of stream biota has lagged behind similar terrestrial modeling efforts. We predicted climate-induced changes in summer thermal habitat for 3 cold-water fish species—juvenile Chinook salmon, rainbow trout, and bull trout (*Oncorhynchus tshawytscha*, *O. mykiss*, and *Salvelinus confluentus*, respectively)—in the John Day River basin, northwestern United States. We used a spatially explicit statistical model designed to predict water temperature in stream networks on the basis of flow and spatial connectivity. The spatial distribution of stream temperature extremes during summers from 1993 through 2009 was largely governed by solar radiation and interannual extremes of air temperature. For a moderate climate change scenario, estimated declines by 2100 in the volume of habitat for Chinook salmon, rainbow trout, and bull trout were 69–95%, 51–87%, and 86–100%, respectively. Although some restoration strategies may be able to offset these projected effects, such forecasts point to how and where restoration and management efforts might focus.

Scheele, B. C., D. A. Driscoll, J. Fischer, and D. A. Hunter. 2012. Decline of an endangered amphibian during an extreme climatic event. Ecosphere 3:art101. http://dx.doi.org/10.1890/ES12-00108.1.

Abstract. Climate change is a poorly understood, emerging threat to many amphibian species. One of the ways climate change is likely to affect amphibians is through increased recruitment failure associated with more frequent climatic extremes. To understand the risk posed by this threat, we combined 13 years of annual monitoring and multi-scaled habitat modelling at the site (n = 60), pool (n = 105) and nest (n = 170) levels to investigate the decline of the endangered northern corroboree frog (*Pseudophryne pengilleyi*), during the most severe drought on record in southern Australia. We documented the local extinction of 42% of *P. pengilleyi* breeding sites during the climatic extreme. Using logistic regression we investigated habitat variables associated with extinction sites. We found that locally extinct sites now resemble historically absent sites, with fewer pools, less water, and drying-related tree invasion. Extended periods of limited water availability at extinction sites is likely to have restricted breeding, contributing to localised extinctions. Habitat variables recorded at the pool and nest level did not significantly influence *P. pengilleyi* presence/absence, indicating that site level wetness had an overriding effect. We anticipate that increasing climate variability is likely to disproportionately threaten seasonal pool-breeding amphibian species, exacerbating the global

amphibian biodiversity crisis. However, our work with *P. pengilleyi* suggests there are a range of simple habitat manipulations that could help to ameliorate the impacts.

Invertebrates

Diamond, Sarah E., Lauren M. Nichols, Neil McCoy, Christopher Hirsch, Shannon L. Pelini, Nathan J. Sanders, Aaron M. Ellison, Nicholas J. Gotelli, and Robert R. Dunn. 2012. A physiological trait-based approach to predicting the responses of species to experimental climate warming. Ecology 93:2305–2312. http://dx.doi.org/10.1890/11-2296.1

Abstract. Physiological tolerance of environmental conditions can influence species-level responses to climate change. Here, we used species-specific thermal tolerances to predict the community responses of ant species to experimental forest-floor warming at the northern and southern boundaries of temperate hardwood forests in eastern North America. We then compared the predictive ability of thermal tolerance vs. correlative species distribution models (SDMs) which are popular forecasting tools for modeling the effects of climate change. Thermal tolerances predicted the responses of 19 ant species to experimental climate warming at the southern site, where environmental conditions are relatively close to the ants' upper thermal limits. In contrast, thermal tolerances did not predict the responses of the six species in the northern site, where environmental conditions are relatively far from the ants' upper thermal limits. Correlative SDMs were not predictive at either site. Our results suggest that, in environments close to a species' physiological limits, physiological trait-based measurements can successfully forecast the responses of species to future conditions. Although correlative SDMs may predict large-scale responses, such models may not be accurate for predicting site-level responses.

Preisler, Haiganoush K., Jeffrey A. Hicke, Alan A. Ager, and Jane L Hayes. 2012. Climate and weather influences on spatial temporal patterns of mountain pine beetle populations in Washington and Oregon. Ecology 93:2421–2434. http://dx.doi.org/10.1890/11-1412.1

Abstract. Widespread outbreaks of mountain pine beetle in North America have drawn the attention of scientists, forest managers, and the public. There is strong evidence that climate change has contributed to the extent and severity of recent outbreaks. Scientists are interested in quantifying relationships between bark beetle population dynamics and trends in climate. Process models that simulate climate suitability for mountain pine beetle outbreaks have advanced our understanding of beetle population dynamics; however, there are few studies that have assessed their accuracy across multiple outbreaks or at larger spatial scales. This study used the observed number of trees killed by mountain pine beetles per square kilometer in Oregon and Washington, USA, over the past three decades to quantify and assess the influence of climate and weather variables on beetle activity over longer time periods and larger scales than previously studied. Influences of temperature and precipitation in addition to process model output variables were assessed at annual and climatological time scales. The statistical analysis showed that new attacks are more likely to occur at locations with climatological mean August temperatures >15°C. After controlling for beetle pressure, the variables with the largest effect on the odds of an outbreak exceeding a certain size were minimum winter temperature (positive relationship) and drought conditions in current and previous years. Precipitation levels in the year prior to the outbreak had a positive effect, possibly an indication of the influence of this driver on brood size. Two-year cumulative precipitation had a negative effect, a possible indication of the influence of drought on tree stress. Among the process model variables, cold tolerance was the strongest indicator of an outbreak increasing to epidemic size. A weather suitability index developed from the regression analysis indicated a 2.5× increase in the odds of outbreak at locations with highly suitable weather vs. locations with low suitability. The models were useful for estimating expected amounts of damage (total area with outbreaks) and for quantifying the contribution of climate to total damage. Overall, the results confirm the importance of climate and weather on the spatial expansion of bark beetle outbreaks over time.

Hydrology

Donley, E. E., Naiman, R. J. and Marineau, M. D. 2012. Strategic planning for instream flow restoration: a case study of potential climate change impacts in the central Columbia River basin. Global Change Biology 18: 3071–3086. doi: 10.1111/j.1365-2486.2012.02773.x

Abstract. We provide a case study prioritizing instream flow restoration activities by sub-basin according to the habitat needs of Endangered Species Act (ESA)-listed salmonids relative to climate change in the central Columbia River basin in Washington State (USA). The objective is to employ scenario analysis to inform and improve existing instream flow restoration projects. We assess the sensitivity of late summer (July, August, and September) flows to the following scenario simulations – singly or in combination: climate change, changes in the quantity of water used for irrigation and possible changes to existing water resource policy. Flows for four sub-basins were modeled using the Water Evaluation and Planning system (WEAP) under historical and projected conditions of 2020 and 2040 for each scenario. Results indicate that Yakima will be the most flow-limited sub-basin with average reductions in streamflow of 41% under climate conditions of 2020 and 56% under 2040 conditions; 1.3–2.5 times greater than those of other sub-basins. In addition, irrigation plays a key role in the hydrology of the Yakima sub-basin – with flow reductions ranging from 78% to 90% under severe to extreme (i.e., 20–40%) increases in agricultural water use (2.0–4.4 times the reductions in the other sub-basins). The Yakima and Okanogan sub-basins are the most responsive to simulations of flow-bolstering policy change (providing salmon with first priority water allocation and at biologically relevant flows), as demonstrated by 91–100% target flows attained. The Wenatchee and Methow sub-basins do not exhibit similar responsiveness to simulated policy changes. Considering climate change only, we conclude that flow restoration should be prioritized first in the Yakima and Wenatchee sub-basins, and second in the Okanogan and Methow. Considering both climate change and possible policy changes, we recommend that the Yakima sub-basin receive the highest priority for flow restoration activities to sustain critical instream habitat for ESA-listed salmonids.

Foreman, **Brady Z., Paul L. Heller and Mark T. Clementz. 2012.** Fluvial response to abrupt global warming at the Palaeocene/Eocene boundary. Nature 491: 92–95. doi: 10.1038/nature11513

Abstract. Climate strongly affects the production of sediment from mountain catchments as well as its transport and deposition within adjacent sedimentary basins. However, identifying climatic influences on basin stratigraphy is complicated by nonlinearities, feedback loops, lag times, buffering and convergence among processes within the sediment routeing system. The Palaeocene/Eocene thermal maximum (PETM) arguably represents the most abrupt and dramatic instance of global warming in the Cenozoic era and has been proposed to be a geologic analogue for anthropogenic climate change. Here we evaluate the fluvial response in western Colorado to the PETM. Concomitant with the carbon isotope excursion marking the PETM we document a basin-wide shift to thick, multistoried, sheets of sandstone characterized by variable channel dimensions, dominance of upper flow regime sedimentary structures, and prevalent crevasse splay deposits. This progradation of coarse-grained lithofacies matches model predictions for rapid increases in sediment flux and discharge, instigated by regional vegetation overturn and enhanced monsoon precipitation. Yet the change in fluvial deposition persisted long after the approximately 200,000-year-long PETM with its increased carbon dioxide levels in the atmosphere, emphasizing the strong role the protracted transmission of catchment responses to distant depositional systems has in constructing large-scale basin stratigraphy. Our results, combined with evidence for increased dissolved loads and terrestrial clay export to world oceans, indicate that the transient hyper-greenhouse climate of the PETM may represent a major geomorphic 'system-clearing event', involving a global mobilization of dissolved and solid sediment loads on Earth's surface.

Posch, Thomas, Oliver Köster, Michaela M. Salcher and Jakob Pernthaler. 2012. Harmful filamentous cyanobacteria favoured by reduced water turnover with lake warming. Nature Climate Change 2(11): 809–813. doi: 10.1038/nclimate1581

Abstract. Anthropogenic-induced changes in nutrient ratios have increased the susceptibility of large temperate lakes to several effects of rising air temperatures and the resulting heating of water bodies. First, warming leads to stronger thermal stratification, thus impeding natural complete water turnover (holomixis), which compensates for oxygen deficits in the deep zones. Second, increased water temperatures and nutrient concentrations can directly favour the growth of harmful algae. Thus, lake-restoration programmes have focused on reducing nutrients to limit toxic algal blooms. Here we present evidence that the ubiquitous harmful cyanobacterium *Planktothrix rubescens* has become the dominant species in a large lake during the past four decades, although the phosphorus content of the ecosystem decreased fivefold. However, the nitrogen input was not diminished concomitantly, favouring this non-N_2-fixing cyanobacterium owing to increased N:P ratios. *P. rubescens* contains gas vesicles that allow for buoyancy to accumulate within the depth of optimal irradiance. As the toxic cyanobacterium has low consumption by predators, water turnover represents the main mechanism of seasonal population control. Thus, unidirectional lake-restoration measures in parallel with recurrent absence of holomixis owing to lake warming may lead to similar undesired effects that have formerly emerged from fertilization.

Saros, Jasmine E., Jeffery R. Stone, Gregory T. Pederson, Krista E. H. Slemmons, Trisha Spanbauer, Anna Schliep, Douglas Cahl, Craig E. Williamson, and Daniel R. Engstrom. 2012. Climate-induced changes in lake ecosystem structure inferred from coupled neo- and paleoecological approaches. Ecology 93:2155–2164. http://dx.doi.org/10.1890/11-2218.1

Abstract. Over the 20th century, surface water temperatures have increased in many lake ecosystems around the world, but long-term trends in the vertical thermal structure of lakes remain unclear, despite the strong control that thermal stratification exerts on the biological response of lakes to climate change. Here we used both neo- and paleoecological approaches to develop a fossil-based inference model for lake mixing depths and thereby refine understanding of lake thermal structure change. We focused on three common planktonic diatom taxa, the distributions of which previous research suggests might be affected by mixing depth. Comparative lake surveys and growth rate experiments revealed that these species respond to lake thermal structure when nitrogen is sufficient, with species optima ranging from shallower to deeper mixing depths. The diatom-based mixing depth model was applied to sedimentary diatom profiles extending back to 1750 AD in two lakes with moderate nitrate concentrations but differing climate settings. Thermal reconstructions were consistent with expected changes, with shallower mixing depths inferred for an alpine lake where treeline has advanced, and deeper mixing depths inferred for a boreal lake where wind strength has increased. The inference model developed here provides a new tool to expand and refine understanding of climate-induced changes in lake ecosystems.

Sea Level

Baustian, J. J., Mendelssohn, I. A. and Hester, M. W. 2012. Vegetation's importance in regulating surface elevation in a coastal salt marsh facing elevated rates of sea level rise. Global Change Biology 18: 3377–3382. doi: 10.1111/j.1365-2486.2012.02792.x

Abstract. Rising sea levels threaten the sustainability of coastal wetlands around the globe, thus understanding how increased inundation alters the elevation change mechanisms in these systems is increasingly important. Typically, the ability of coastal marshes to maintain their position in the intertidal zone depends on the accumulation of both organic and inorganic materials, so one, if not both, of these processes must increase to keep pace with rising seas, assuming all else constant. To determine the importance of vegetation in these processes, we measured elevation change and surface accretion over a 4-year period in recently subsided, unvegetated marshes, resulting from drought-induced marsh dieback, in paired planted and unplanted plots. We compared soil and vegetation responses in these plots with paired reference plots that had neither experienced dieback nor subsidence. All treatments (unvegetated, planted, and reference) were replicated six times. The recently subsided areas were 6–10 cm lower in elevation than the reference marshes at the beginning of the study; thus, mean water levels were 6–10 cm higher in these areas vs. the reference sites. Surface accretion rates were lowest in the unplanted plots at 2.3 mm yr^{-1}, but increased in the presence of vegetation to 16.4 mm yr^{-1} in the reference marsh and 26.1 mm yr^{-1} in the planted plots. The rates of elevation change were also bolstered by the presence of vegetation. The unplanted areas decreased in elevation by 9.4 mm yr^{-1}; whereas the

planted areas increased in elevation by 13.3 mm yr^{-1}, and the reference marshes increased by 3.5 mm yr^{-1}. These results highlight the importance of vegetation in the accretionary processes that maintain marsh surface elevation within the intertidal zone, and provide evidence that coastal wetlands may be able to keep pace with a rising sea in certain situations.

Fire

Honig, Kristen A. and Peter Z. Fulé. 2012. Simulating effects of climate change and ecological restoration on fire behaviour in a south-western USA ponderosa pine forest. International Journal of Wildland Fire 21(6): 731-742. http://dx.doi.org/10.1071/WF11082

Abstract. Global climate change has the potential to affect future wildfire activity, particularly in south-western USA ponderosa pine forests that have been substantially altered by land-use practices and aggressive fire suppression. Using two regional general circulation models for the A1B greenhouse gas emission scenario, Australia's CSIRO:MK3 and Germany's MPIM:ECHAM5, we predicted fire behaviour under the 80th, 90th and 97th percentiles of future fire-weather conditions at a study site on the Kaibab National Forest, Arizona. We then altered the fuel structure by simulating alternative ecological restoration treatments: a full treatment (FULL), a full treatment with a 40.6-cm-diameter restriction on tree removal (16″ CAP) and a full treatment with a 25.4-cm-diameter restriction on tree removal (10″ CAP). Model results show that differences in fire weather (temperature and fuel moistures) expected by the end of the 21st century were not influential enough to alter fire behaviour significantly, but treatments did significantly reduce severe burning. Alteration of fuel structure through the 16″ CAP and FULL ecological restoration treatments caused significant declines in fire behaviour and crown fire activity under all climate scenarios. The 10″ CAP substantially reduced treatment effectiveness.

Luce, Charles; Morgan, Penny; Dwire, Kathleen; Isaak, Daniel; Holden, Zachary; Rieman, Bruce. 2012. Climate change, forests, fire, water, and fish: Building resilient landscapes, streams, and managers. Gen. Tech. Rep. RMRS-GTR-290. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 207 p. **http://www.fs.fed.us/rm/pubs/rmrs_gtr290.pdf**

Abstract. Fire will play an important role in shaping forest and stream ecosystems as the climate changes. Historic observations show increased dryness accompanying more widespread fire and forest die-off. These events punctuate gradual changes to ecosystems and sometimes generate stepwise changes in ecosystems. Climate vulnerability assessments need to account for fire in their calculus. The biophysical template of forest and stream ecosystems determines much of their response to fire. This report describes the framework of how fire and climate change work together to affect forest and fish communities. Learning how to adapt will come from testing, probing, and pushing that framework and then proposing new ideas. The western U.S. defies generalizations, and much learning must necessarily be local in implication. This report serves as a scaffold for that learning. It comprises three primary chapters on physical processes, biological interactions, and management

decisions, accompanied by a special section with separately authored papers addressing interactions of fish populations with wildfire. Any one of these documents could stand on its own. Taken together, they serve as a useful reference with varying levels of detail for land managers and resource specialists. Readers looking for an executive summary are directed to the sections titled "Introduction" and "Next Steps."

Lydersen, Jamie and Malcolm North. 2012. Topographic Variation in Structure of Mixed-Conifer Forests Under an Active-Fire Regime. Ecosystems 15(7): 1134-1146.

Abstract. Management efforts to promote forest resiliency as climate changes have often used historical forest structure and composition to provide general guidance for fuels reduction and forest restoration treatments. However, it has been difficult to identify what stand conditions might be fire and drought resilient because historical data and reconstruction studies are generally limited to accurate estimates only of large, live tree density and composition. Other stand features such as smaller tree densities, dead wood, understory structure, regeneration, and fuel loads have been difficult to quantify, estimate how they may vary across a landscape, or assess how they would be affected by fire under current climate conditions. We sampled old-growth, mixed-conifer forests with at least two low-intensity fires within the last 65 years in 150 plots at 48 sample sites ranging over 400 km of the Sierra Nevada. Recent fire history had the strongest influence on understory conditions with small tree density decreasing and shrub cover increasing with the increased intensity and frequency of fire associated with upper-slope and ridge-top locations. In contrast, stand structures associated with large, overstory trees such as total basal area, canopy cover, and the abundance of large snags and logs increased in topographic locations associated with more mesic, productive sites regardless of fire history. In forests with restored fire regimes, topography, fire and their interaction influence productivity and burn intensity, creating the structural heterogeneity characteristic of frequent-fire forests.

Paleoclimate

Blonder, Benjamin, Vanessa Buzzard, Irena Simova, Lindsey Sloat, Brad Boyle, Rebecca Lipson, Brianna Aguilar-Beaucage, Angelina Andrade, Benjamin Barber, Chris Barnes, Dharma Bushey, Paulina Cartagena, Max Chaney, Karina Contreras, Mandarava Cox, Maya Cueto, Cannon Curtis, Mariah Fisher, Lindsey Furst, Jessica Gallegos, Ruby Hall, Amelia Hauschild, Alex Jerez, Nadja Jones, Aaron Klucas, Anita Kono, Mary Lamb, Jacob David Ruiz Matthai, Colten McIntyre, Joshua McKenna, Nicholas Mosier, Maya Navabi, Alex Ochoa, Liam Pace, Ryland Plassmann, Rachel Richter, Ben Russakoff, Holden St. Aubyn, Ryan Stagg, Marley Sterner, Emily Stewart, Ting Ting Thompson, Jake Thornton, Parker J. Trujillo, Trevor J. Volpe and Brian J. Enquist. 2012. The leaf-area shrinkage effect can bias paleoclimate and ecology research. American Journal of Botany 99(11): 1756-1763

Abstract. *Premise of the Study:* Leaf area is a key trait that links plant form, function, and environment. Measures of leaf area can be biased because leaf area is often estimated from dried or fossilized specimens that have shrunk by an unknown amount. We tested the common assumption that this shrinkage is negligible.

Methods: We measured shrinkage by comparing dry and fresh leaf area in 3401 leaves of 380 temperate and tropical species and used phylogenetic and trait-based approaches to determine predictors of this shrinkage. We also tested the effects of rehydration and simulated fossilization on shrinkage in four species.

Key Results: We found that dried leaves shrink in area by an average of 22% and a maximum of 82%. Shrinkage in dried leaves can be predicted by multiple morphological traits with a standard deviation of 7.8%. We also found that mud burial, a proxy for compression fossilization, caused negligible shrinkage, and that rehydration, a potential treatment of dried herbarium specimens, eliminated shrinkage.

Conclusions: Our findings indicate that the amount of shrinkage is driven by variation in leaf area, leaf thickness, evergreenness, and woodiness and can be reversed by rehydration. The amount of shrinkage may also be a useful trait related to ecologically and physiological differences in drought tolerance and plant life history.

Adaptation

Ash, Andrew, Philip Thornton, Chris Stokes, and Chuluun Togtohyn. 2012. Is Proactive Adaptation to Climate Change Necessary in Grazed Rangelands? Rangeland Ecology and Management 65(6): 563–568.

Abstract. In this article we test the notion that adaptation to climate change in grazed rangelands requires little more effort than current approaches to risk management because the inherent climate variability that characterizes rangelands provides a management environment that is preadapted to climate change. We also examine the alternative hypothesis that rangeland ecosystems and the people they support are highly vulnerable to climate change. Past climate is likely to become an increasingly poor predictor of the future, so there is a risk in relying on adaptation approaches developed solely in response to existing variability. We find incremental, autonomous adaptation will be sufficient to deal with most of the challenges provided by the gradual expression of climate change in the next decade or two. However, projections of greater climate change in the future means that the responses required are qualitatively as well as quantitatively different and are beyond the existing suite of adaptation strategies and coping range. The proactive adaptation responses required go well beyond incremental on-farm or local actions. New policies will be needed to deal with transformational changes associated with land tenure issues and challenges of some displacement and migration of people in vulnerable parts of rangelands. Even where appropriate adaptation actions can be framed, issues of when to act and how much to act in a proactive way remain a challenge for research, management, and policy. Whether incremental or transformational involving system changes, a diversity of adaptation options will be required in different rangeland regions to enhance social and ecological resilience.

Mackey, Brendan, Sandra Berry, Sonia Hugh, Simon Ferrier, Thomas D. Harwood, and Kristen J. Williams. 2012. Ecosystem greenspots: identifying potential drought, fire, and climate-change micro-refuges. Ecological Applications 22:1852–1864. http://dx.doi.org/10.1890/11-1479.1

Abstract. In response to climate change and other threatening processes there is renewed interest in the role of refugia and refuges. In bioregions that experience drought and fire, micro-refuges can play a vital role in ensuring the persistence of species. We develop and apply an approach to identifying potential micro-refuges based on a time series of remotely sensed vegetation greenness (fraction of photosynthetically active radiation intercepted by the sunlit canopy; fPAR). The primary data for this analysis were NASA MODIS 16-day L3 Global 250 m (MOD13Q1) satellite imagery. This method draws upon relevant ecological theory (source–sink habitats, habitat templet) to calculate a micro-refuge index, which is analyzed for each of the major vegetation ecosystems in the case-study region (the Great Eastern Ranges of New South Wales, Australia). Potential ecosystem greenspots were identified, at a range of thresholds, based on an index derived from: the mean and coefficient of variance (COV) of fPAR over the 10-year time series; the minimum mean annual fPAR; and the COV of the 12 values of mean monthly fPAR. These greenspots were mapped and compared with (1) an index of vascular plant species composition, (2) environmental variables, and (3) protected areas. Potential micro-refuges were found within all vegetation ecosystem types. The total area of ecosystem greenspots within the upper 25% threshold was 48 406 ha; around 0.2% of the total area of native vegetation (23.9×10^6 ha) in the study region. The total area affected by fire was 3.4×10^6 ha. The results of the environmental diagnostic analysis suggest deterministic controls on the geographical distribution of potential micro-refuges that may continue to function under climate change. The approach is relevant to other regions of the world where the role of micro-refuges in the persistence of species is recognized, including across the world's arid zones and, in particular, for the Australian, southern African, and South American continents. Micro-refuge networks may play an important role in maintaining beta-diversity at the bio-region scale and contribute to the stability, resilience, and adaptive capacity of ecosystems in the face of ever-growing pressures from human-forced climate change, land use, and other threatening processes.

Pedlar, John H., Daniel W. McKenney, Isabelle Aubin, Tannis Beardmore, Jean Beaulieu, Louis Iverson, Gregory A. O'Neill, Richard S. Winder and Catherine Ste-Marie. 2012. Placing Forestry in the Assisted Migration Debate. BioScience 62(9): 835–842.

Abstract. Assisted migration (AM) is often presented as a strategy to save species that are imminently threatened by rapid climate change. This conception of AM, which has generated considerable controversy, typically proposes the movement of narrowly distributed, threatened species to suitable sites beyond their current range limits. However, existing North American forestry operations present an opportunity to practice AM on a larger scale, across millions of hectares, with a focus on moving populations of widely distributed, nonthreatened tree species within their current range limits. Despite these differences (and many others detailed herein), these two conceptions of AM have not been clearly distinguished in the literature, which has added confusion to recent dialogue and debate. Here, we aim to facilitate clearer communication on this topic by detailing this distinction and encouraging a more nuanced view of AM.

Schwartz, Mark W. 2012. Using niche models with climate projections to inform conservation management decisions. Biological Conservation 155: 149-156.

Abstract. Conservation science strives to inform management decisions. Applying niche models in concert with future climate projections to project species vulnerability to extinction, range size loss, or distribution shifts has emerged as a potentially useful tool for informing resource management decisions. Making climate change niche modeling useful to conservation decisions requires centering studies on the types of decisions that are made regarding the focal taxa of a niche model study. Recent recommendations for climate adaptation strategies suggest four types of decision makers: policy, habitat protection, habitat management, species management. Targeting research to questions relevant for management decisions will increase utility of a niche model study. Constraints to the accuracy and precision of niche models to project potential future distributions are well-recognized. How to incorporate these uncertainties into management decision-making remains a challenge. Refining estimates and making sound management recommendations is critical because species that are generally modeled to be the most vulnerable to climate change (i.e., narrow endemics), are also the most vulnerable to bad decisions based on uncertain models. I review uncertainties of niche models to assert that there is an inherent bias for models to over-estimate climate-driven vulnerability to extirpation. Explicit recognition of this bias leads to a decision framework that accommodates unbalanced uncertainty. Namely, niche models may be more useful for identifying conservation opportunities identifying newly available habitats under changing climate than they are for asserting where current habitat will no longer exist under future climate states.