Understanding the Problem of Climate Change and Western Ecosystems: Considerations and Tools for Ecoregional Assessment

A Review of Current Literature

This review briefly highlights the effect of climate and resulting landscape change on Western ecosystems, linkages with fire and invasive species and carbon sequestration. A separate literature review is planned for adaptation strategies. Climate change is predicted to be one of the greatest drivers of ecological change in the coming century (Lawler, 2009). Regional modeling of relationships between native ecosystems and climate can help to identify the distribution of ecosystems at risk from climate change as well as locations where species are most likely to remain viable within their current range (Bradley, 2009). At regional scales, climate change poses a substantial threat to ecosystems (Rehfeldt, 2006). The rate of climate change predicted for global warming poses a greater threat to natural populations than the amount of change. Some argue the lag in response is so large that natural landscapes would be incapable of maintaining the production of goods and services that humans expect (Rehfeltd, 2006; Cole, 2008).

Climate:

There is broad consensus among climate models that show that the Southwest will dry in the 21st century and that the transition to a more arid climate should already be underway. If the models are correct, the levels of aridity of the recent multi-year drought or the Dust Bowl and the 1950s droughts will become the new climatology of the America Southwest within a time frame of years to decades (Seager, 2007; Archer, 2008). Seager shows global precipitation minus evaporation decreasing from a net of zero in 1980 to at least -0.1 mm/day in 2080 (Seager, 2007).

In the Southwest, there will be fewer frost days, warmer temperatures, greater water demand by plants, animals and people; increased frequency of extreme weather, warmer nights and declines in snowpack, coupled with earlier spring snow melt, will reduce water supply, lengthen the dry season, create conditions for drought and insect outbreaks and increase intensity of wildfires. Changes in temperature and precipitation will interact directly to impact vegetation and ecosystem processes in the Southwest. The widespread pinyon pine mortality of 2002-2003 could be a preview of things to come (Weiss, 2005, Archer, 2008). Data show widespread warming trends in winter and spring, decreased frequency of freezing temperatures, lengthening of the freeze-free season and increased minimum temperatures per winter year (Weiss, 2005).

Using five global climate models downscaled to 4 km grids, Garfin projects a warmer future for the Colorado Plateau in which annual temperatures seem likely to increase by 1.5-3.6 degrees C by mid-century and 2.5-5.4 degrees C by the end of the century. Annual precipitation is more equivocal with projections of a decrease of annual precipitation of 6% by the end of the century with decreases in the May-June precipitation relied on by plants for establishment, growth and reproduction. Lack of moisture this time of year could increase the likelihood of massive forest mortality events such as the die-off of Colorado Plateau conifers in the early part of the 21st century (Garfin, 2009).

Landscape Change:

With warming expected through the 21st century, ecological responses may include contraction of the overall boundary of the Sonoran Desert in the south-east and expansion northward, eastward and upward in elevation, as well as changes to distributions of plant species within the Sonoran Desert ecosystem (Garfin, 2009; Archer, 2008). Transition from desert scrub to savanna, woodland, and forest along strong elevation gradients and sky island plants have no where to go (Archer, 2008). However, plant response to climate change suggests that current plant communities will not simply move to new landscape positions, but will be replaced by novel plant assemblages (SRM, 2005).

The recent Southwest drought of 2002-3 was devastating because consistently high temperatures occurred in conjunction with low precipitation. Greater temperatures and higher evapotranspiration portend increased mortality for the dominant woody vegetation and may open the door for establishment of nonnative annual grasses. Saguaro density and growth decline with drought and reduced perennial shrub cover to the range and abundance of this charismatic species likely will potentially decline (Archer, 2008). Bioclimatic models can help match species like saguaro appropriate to the array of climates expected decades in the future (Rehfeldt, 2006).

Downscaled bioclimatic model change forecasts for the western USA by the USFS on 1 km resolution show only Gambel oak and Douglas fir to hold or increase present distributions, while those of larch, Englemann spruce and pinyon pine and Utah juniper would be drastically reduced. The latter two species would be expected to vanish across much of their contemporary distribution. The climate envelope for Saguaro would shift northward by 500 km and rise 600m in altitude. Maps of the forecasted distributions are provided. Climate profiles of subalpine, alpine and tundra vegetation should nearly disappear by the end of the century, while those of montane would change little in area (Rehfeldt, 2006).

A downscaled bioclimatic model of *Pinus edulis* (pinyon pine) to 1 km resolution shows most of the current range in Arizona and Utah will become increasingly inhospitable, but pinyon should expand northeastward and upward in Colorado and northernmost New Mexico. One seed juniper differs with potential expansion into lower elevation grasslands in Arizona. Assuming generous expansion rates, the pinyon woodland is only estimated to fill a small percentage of its new potential range during the period (Cole, 2008; Gibson, 2009). A downscaled bioclimateic model of Joshua tree to 1 km resolution shows only a few populations within the current Mohave Desert range are predicted to be sustainable. Several models project significant potential future expansion into new areas beyond the current range, but the species' historical and current rates of dispersal would seem to prevent natural expansion into these new areas, (Cole, 2009).

Downscaled bioclimatic models of sagebrush, saguaro, Ponderosa pine, creosote bush, Joshua tree and other species at 25 km resolution are mapped using three downscaled general circulation models scenario in 2099. Sagebrush is simulated to shift northward with a significant contraction of its current range. Sagebrush is limited by summer moisture stress. Increases in the frequency of fires under future climate scenarios would also facilitate simulated potential range contraction because sagebrush does not sprout following fire events. Joshua tree potential distributions are likewise reduced and fragmented northward and eastward. Saguaro and creosote bush also show significant potential range shifts. Creosote bush may expand into current sagebrush range and saguaro potential range moves east and west (Shafer). Downscaled dynamic vegetation models show a large migration of frost-sensitive vegetation into the Great Basin under all future warming scenarios. Much of the advance is in the form of woody vegetation types, such as xeromorphic subtropical shrubland, a physiognomic depiction of the same kind of vegetation typified by the shrub live oak that migrated 250 miles (400 km) north during the middle-Holocene thermal maximum. As these different kinds of vegetation move into the Great Basin, they displace large areas of sagebrush (Neilson, 2005).

Bioclimatic modeling of invasive species shows that climate change could result in both range expansion and contraction using ten general circulation models downscaled on 4.5 km resolution. Yellow starthistle may expand into the Great Basin. Cheatgrass contracts in the Great Basin but expands slightly in the Wyoming Basin and the Colorado Plateau. Spotted knapweed potential range is likely to shift from Montana toward the Wyoming Basin and Colorado Plateau. Leafy spurge is likely to contract. Retreat of invasive species may create restoration opportunities. Maps of potential future range are shown for 2100 (Bradley, 2009, Bradley et al 2009).

Bioclimatic modeling shows that climate change could result in both range expansion and contraction using ten general circulation models downscaled on 4.5 km resolution (Bradley2). Bradley used ensembles of general circulation models and bioclimatic models to develop landscape risk assessments to sagebrush from climate change, cheatgrass and pinyon-juniper expansion at 4 km resolution. Sagebrush loss of range was predicted and mapped based on land use, climate, distance to cheatgrass and pinyon-juniper. Loss is most pronounced in southern Nevada (Bradley et al 2009).

Downscaled bioclimatic models of 2954 species of birds, mammals, and amphibians in the Western Hemisphere used 30 general circulation models on a 10 and 200m grid. Predictions show projections based on the low greenhouse gas emission simulations resulting in loss of 10% of the vertebrate fauna over North America. Other emission scenarios show higher species loss (Lawler, 2009) and 15-37% worldwide (Thomas, 2004).

Southwestern fish live at the upper limits of aquatic vertebrate temperature tolerance. Many of these native fish are threatened or endangered. With increased temperatures and decreased precipitation, vulnerable Southwestern native species are the Apache trout, Gila trout, Rio Grande cutthroat trout/chub/sucker and Mohave tui chub (Archer, 2008).

Downscaled climate models for the western U.S. fortell decreased snow water equivalent normalized for precipitation, earlier snowpack runoff (Barnet, 2008). Higher temperature reduces the stability of soil aggregates making the surface more erodible. Rainfall events are expected to decrease in occurrence, but increase in intensity increasing soil and water erosion. Decreases in plant cover caused by lower precipitation or disturbance such as fire or grazing will contribute to erosion (Archer, 2008).

Linkages to Invasive Species and Fire:
Greater CO_2 and nitrogen deposition concentrations appear to benefit nonnative grasses and weeds. Increased CO_2 hypothesized to favor C3 plants which include most invasive species (Archer, 2008; SRM, 2005). Nonnative grasses utilize winter rain for growth more so than native and their ranges are constrained by winter temperatures. Therefore the abundance and range of nonnative grasses could increase in future climates in deserts like the Mohave which receive most of its rainfall in winter (Archer, 2008). Decreased water availability will impact riverine and riparian ecosystem function and may favor nonnative invasion of salt cedar and Russian olive (Archer, 2008). Changes in land use and climate may affect the relationship between cheatgrass and sagebrush (Bradley et al 2009).

Large wildfire activity increased suddenly and markedly in the mid 1980s with higher large-wildfire frequency, longer wildfire duration, and longer wildfire seasons (Westerling, 2006). Fire has historically been rare in Southwestern arid lands, but invasion of nonnative species after fire, grazing or land use change, contributes fine fuel loads and continuous fuel between shrubs that increase probability of fire. For example, buffelgrass in the Sonoran Desert is constrained by low winter temperatures so it is expected to increase (Archer, 2008). Cheatgrass performs the same function in northern ecoregions (Bradley). Creosote bush, ocotillo, and native bunchgrasses are negatively impacted by wildfires driven by invasive species (Rogstad, 2009).

Sequestration:
Net primary productivity and carbon storage will decrease in arid ecosystems, by reducing biomass and increased soil respiration from higher temperatures. For winter rainfall ecosystems, shifts in wet-dry cycles are known to cause reductions in NPP and soil carbon sequestration (Archer). Grazing lands can sequester between 29-90 million tons of carbon per year or 2-5% of total U.S emissions. Rangelands can also be a source of biomass for fuel (SRM, 2005).

Conclusion:
SRM recommends that development of spatially explicit national soil/vegetation database that describes how climate change interacts with soils vegetation and management should be the highest priority (SRM, 2005). Bradley suggests the HLI will be critically important for sustaining sagebrush ecosystems (Bradley, et al, 2009).

Literature Reviewed:

Archer, S. R., and K. Predick, 2008. Climate Change and Ecosystems of the Southwestern United States, Rangelands, pp. 23-28.

Barnett, T., et al, 2008. Human-induced changes in the hydrology of the western United States, Science, 319, pp 1080-1083.

Bradley, B., 2009. Assessing ecosystem threats from global and regional change: hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography, in press.

Bradley, B., M. Oppenheimer, D. Wilcove, 2009. Climate change and plant invasions; restoration opportunities ahead? Global Change Biology 15, pp 1511-1521.

Cole, K., K. Ironside, S. Arundel, P. Duffy and J. Shaw, 2008. Modeling future plant distributions on the Colorado Plateau, an example using Pinus edulis. The Colorado Plateau III Integration Research and Resources Management for Effective Conservation, pp. 319-330. The University of Arizona Press.

Cole K., K. Ironside, J. Eischeid, G. Garfin, 2009. Title: Past and ongoing shifts in Joshua tree support future modeled range contraction, In Press.

Garfin, G.M., J. Eisheid, M. Lenart, K. Cole, K. Ironside, N. Cobb, 2009. Downscaling Climate Projections to Model Ecological Chang on Topographically diverse Landscapes of the Arid Southwestern Unites States, In Press.

Gibson, J.R, T. Edwards, G. Moisen, N. Zimmermann, 2009. Forecasting Climate-Induced Distribution Shifts in Western North American Conifers, Presented at the 10th Biennial Conference Integrating Science and Management on the Colorado Plateau Research, Flagstaff, AZ.

Lawler, J., et al. 2009. Projected climate induced faunal change in the Western Hemisphere. Ecology 90(3) pp. 588-597.

Neilson, R.P., et al. 2005. Climate Change Implications for Sagebrush Ecosystems, Transactions of the 70th North American Wildlife and Natural Resources Conference.

Rehfeltd, G.E., N. Crookston, M. Warwell and J. Evans, 2006. Empirical Analyses of Plant Climate Relationships for the Western United States, Intl. J. Plant Sci., 167(6):1123-1150.

Rogstad, A., T.M. Bean, A. Olsson and G. Casady, 2009. Fire and Invasive Species Management in Hot Deserts: Resources Strategies, Tactics and Response. Rangelands,31(3) pp 6-13.

Seager, R., et al, 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America, Science, Vol. 316, pp. 1181-1184.

Shafer, S., P. Bartlein and R. Thompson, 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios, Ecosystems, 4: 200-215.

SRM (Society for Range Management), 2005. Rangelands and Global Change, An Issue Paper Created by the Society for Range Management.

Svejcar, T. et al. 2008. Carbon fluxes on North American rangelands, Rangeland Ecology and Management 61(5) 465:474.

Thomas, C., et al. Extinction risk from climate change, Nature, Vol. 427, pp. 145-146.

Weiss, J., J. Overpack, 2005. Is the Sonoran Desert Losing its Cool? Global Change Biology, vol. 11, No.12, pp. 2065-2077.

Westerling, A., G. Hidalgo, D. Cayan, T. Swetman, 2006. Warming and earlier spring increase western U.S. Forest Wildfire Activity. Science 313, pp. 940-943.