Item 3: Front Page

a. Name: **Ross, Noam Martin**

b. Citizenship: **USA**

c. FON and Topic Title: **EPA-F2012-STAR-B2, Air, Climate, and Energy: Global Change**

d. Current College/University, School or Department: **Graduate Group in Ecology, University of California-Davis, Davis, CA**

e. Intended College/University, School or Department: **Graduate Group in Ecology, University of California-Davis, Davis, CA**

f. Title of project: **EARLY WARNING SIGNALS FOR CLIMATE-DRIVEN FOREST DIE-OFFS**

g. Degree Sought: **Ph.D., May 2016**

h. Environmental Discipline: **Ecology**

i. Educational Level (at the time of application): **Continuing Doctoral Student (DS)**

Item 4: Personal Statement

I am driven by a fascination for the abstract and theoretical, and a desire for my work to have positive impacts in the world. A tension between these desires has driven my academic and professional career, and has led me to the goal of conducting research to turn ecological theory into useful tools for ecosystem protection. My dissertation research on catastrophic shifts in ecosystems is a step in creating such tools. Catastrophic shifts have unique and fascinating properties when viewed from a mathematical perspective. They also offer a path to insights about ecosystem processes, which are often slow and hard to observe. Just as importantly, these shifts have the potential to suddenly and drastically impact natural systems and human livelihoods. Therefore, there is a pressing need to find ways to predict and manage these changes. Creating tools to predict, avoid, and manage these shifts will fill in a key gap in applied ecosystem protection.

I took a circuitous route to a research career. I studies ecosystem science as an undergraduate. Eager to find a field that let me see tangible results from my work, though, I entered the private sector as a corporate consultant shortly after graduating college. For four years I worked with clients to develop products with smaller environmental footprints and more sustainable business models. My clients were enthusiastic about finding ways to tackle climate change, and I had the opportunity to help them develop new business strategies addressing this issue.

I had a particular passion for promoting ecosystem stewardship, and worked to find ways to push companies to engage on this topic. I served as an expert contributor to the World Resource Institute's Corporate Ecosystem Services Review, the development of the Business and Biodiversity Offset Program, and reviewer on the Clinton Global Initiative-McKinsey Forestry project. These were all valuable experiences, but generally I found that corporate interest in these topics was lukewarm because companies lacked tools to quantitatively measure their exposure to declining ecosystems and forecast the risks associated with their actions. I concluded that I could make a greater impact by improving knowledge of ecosystems. I decided to become a researcher.

I have the right background and talents pursue my research catastrophic regime shifts. I have strong mathematical skills, which should serve me well in this highly quantitative research area. From early in my undergraduate career I gravitated towards problems that let me take data- intensive, computational approaches to problem solving. For instance, I chose to build a radiative-convective atmospheric model as part of an introductory meteorology course, and one time I re-created a course's ecological modeling software in a new programming language to better understand the underlying numerical methods. In my graduate courses, I focused on analytical and numerical modeling. In the private sector, I found that reducing problems to mathematical principles helped to solve problems. I developed my firm's system for quantitatively comparing environmental performance across industries, and provided oversight over statistical work across my firm. When working Wal-Mart to promote sales of energy efficient light bulbs, I created tools for predicting light bulb demand by applying principles of population dynamics to product turnover.

I have a robust background in scientific research. I took graduate courses in ecology and modeling as an undergraduate, and had a variety of research experiences. With a fellowship from Brown, I conducted fieldwork to study calcium cycling in White Mountain National Forest in New Hampshire. At the Semester of Environmental Science program Ecosystems Center at the

Marine Biological Laboratory, I developed a microcosm study to characterize how the trophic structure of a microplankton system changed when exposed to different forms of nitrogen loading. For my undergraduate thesis, I studied the interaction of microclimate and land use on soil carbon cycling in Mongolia. Even in high school, I spent two summers at the Center for Neural Science at NYU studying the neural pathways that carry color and motion information to the visual cortex. I stayed involved with scientific literature in my business career, keeping up academic literature in the field and attending meetings of the Ecological Society of America.

While I plan to pursue a career in academic research, I wish to take an active role in translating my research into tools for ecosystem management. I have a strong interdisciplinary background that will help me ensure that my work as broader impacts outside academia. In particular, I have proven ability to work with the for-profit sector, which often has little exposure to ecological research. As a consultant, I worked in varied fields such as home construction, biofuel infrastructure, and equities trading markets. For each project I immersed myself in the subject to learn the vocabulary, stakeholders, and financial and technical issues in the field, and each time I was able to develop a fluency that allowed me to build trust with clients and help solve problems. I developed experience in translating scientific information into useful tools when I worked with the World Resources Institute on the Corporate Ecosystem Services Review. For that project, I provided the perspective of a corporate manager to make the process more streamlined and usable for non-experts.

Now, in graduate school, I am a trainee in the UC Davis Integrative Graduate Education and Research Traineeship (IGERT) in rapid environmental change. This program brings together researchers and students in the natural sciences, social sciences, and humanities for collaborative interdisciplinary research on global change. Through IGERT I organized conference at UC of business leaders and ecologists to discuss opportunities for collaborative research and identify ecological questions for which businesses needed answers. I am organizing another conference this year to bring together ecologists with entrepreneurs interested in using ecological science to develop new technologies. I also take advantage of my network in the consulting world to give talks at businesses and publish in the business press.

My graduate career will build on my background, talents, and interests. I hope that my research will produce new insights that will enable better ecosystem management and create tools that will be useful to practitioners and policymakers. I am confident that a research career will be the best and most satisfying path for me and that adding to our knowledge of ecosystems is a good way for me to contribute to society.

Item 5: Proposal Description:

# EARLY WARNING SIGNALS FOR CLIMATE-DRIVEN FOREST DIE-OFFS

**Key Words:** forests, die-offs, drought, bark beetles, regime shifts, mathematical modeling, critical slowing down, remote sensing

**Introduction:** Forest die-offs, where many trees die in a short period of time, are increasing in frequency and size, largely due to global climate change (Allen et al. 2010). Forecasting die-off is challenging because of the many interdependent factors that control forest change (McEwan et al. 2011, McDowell et al. 2011). Methods measuring *critical slowing down* (**CSD)** may enable forecasting of such ecosystem events even where we lack detailed understanding of ecosystem processes. CSD is a property observed in ecosystems approach critical thresholds that trigger regime shifts. Under CSD, ecosystems exhibit wider swings in behavior in response to small perturbations and recover more slowly near critical thresholds than when farther from critical thresholds (Scheffer et al. 2009). It may be interpreted as a loss of ecosystem resilience. However, CSD has not been tested in forest systems, and the information requirements for its use are unknown in general.

I will address the question **"Can climate-driven forest die-offs be forecast by measuring critical slowing down?"** I will compare multiple measures of CSD as predictors of forest die-offs, using both a mathematical model of drought-forest-insect interactions and satellite monitoring data of piñon forests of the southwestern U.S. By doing so, I will establish the feasibility and informational requirements for using CSD as a tool to predict die-offs.

This research helps fulfill EPA mandates to address global climate change under the Clean Air Act. Specifically, by improving the ability to forecast forest die-offs, it will allow managers to better respond and adapt to the risks that these die-offs pose as they increase in frequency under global climate change. These risks include changes in rates of water supply, erosion, fuel and food provision, and loss of cultural resources (Breshears et al. 2010). A better understanding of die-off dynamics will also improve the quality of long-term climate projections, as the release of carbon to the atmosphere from these events can be significant (Breshears and Allen 2002). Uncertainty in climate projections stems largely from a lack of knowledge of such feedbacks (Denman et al. 2007).

**Background:** Forest die-offs are good candidates for the application of CSD-based forecasting because they fit the paradigm of *regime shifts*. Regime shifts occur in ecosystems with two or more stable states and intermediate states. In such systems, small and gradual environmental changes can cross critical thresholds, causing a shift to another state with large, sudden changes in ecosystem structure, function, and services. Return to the previous state may be difficult or impossible after a regime shift. Forest die-offs exhibit these characteristics. For example, after a die-off in the southwestern U.S., solar energy input to the understory supplanted tree transpiration as the controlling factor in landscape water budgets (Royer et al. 2011). In another such event, a severe ponderosa pine die-off led to changes in species composition that has persisted for more than 50 years (Allen and Breshears 1998). The regime shift paradigm is applicable even when other processes, such as slow growth and background mortality, drive change over longer time scales of decades to centuries.

CSD is thought to be broadly applicable as a warning signal of imminent threshold-crossing events, even when detailed models of ecosystem processes are lacking. However, not all models of ecological systems with thresholds exhibit CSD (Hastings and Wysham 2010). Also, CSD can be measured in a variety of ways, but the power of these methods to distinguish warning signals from false positives is dependent on assumptions made about the processes controlling ecosystem dynamics (Boettiger and Hasting, *in review*). Thus, some information about ecosystem processes is necessary to test for CSD, but the amount of information needed is unknown.

There have been few empirical tests of CSD, and those few have examined aquatic systems (Dakos et al. 2008, Hewitt and Thrush 2010, Drake and Griffen 2010, Carpenter et al. 2011), not forests. Those studies focused on simple systems with a single threshold. Forest die-offs are caused by a complex interaction of several processes, with multiple interdependent thresholds, including water stress, heat stress, and insect attack (McDowell et al. 2011). Thus, further study of CSD in is needed in order to determine its efficacy as a forecasting tool in forests, and in complex ecological systems generally.

**Study Questions and Hypotheses:** I will address the question **"Can climate-driven forest die-offs be forecast by measuring critical slowing down?"** by answering three sub-questions:

- ***Q1*:** What are the key thresholds triggering forest die-off in a mathematical model of drought-forest-pest interactions?
- ***H1*:** The model will exhibit regime shifts that trigger die-off at threshold values of tree carbohydrate stores, insect population levels will exhibit threshold levels, and length of drought time.
- ***Q2*:** Does the mathematical model exhibit CSD as the key variables approach threshold values, and by which measures are CSD detectable?
- ***H2*:** The model will exhibit CSD as it approaches all of the key thresholds, and using a method that makes simple assumptions of model behavior will better detect CSD than naïve statistical measures.
- ***Q3*:** Is CSD detectable in satellite measures of forest canopy water content in the period leading up to die-off, and by which measures?
- ***H3*:** CSD will be detectable in satellite data using a method that makes simple assumptions of model behavior.

**Study System:** Piñon pine trees in the southwestern U.S. underwent a massive die-off in 2002 and 2003, with mortality exceeding 90% of mature piñon in extensive areas, particularly New Mexico. The die-off was preceded by extended drought starting in 1999, and was accompanied by anomalously high temperatures and an outbreak of *Ips confusus,* the native Piñon bark beetle (Shaw et al. 2005, Breshears et al. 2005). Mortality has been attributed to the interaction of all of these factors (McDowell et al. 2011), making this an ideal system to study the applicability of CSD in systems where complex interactions occur.

The die-off of piñon was also societally important. It resulted in a large release of carbon to the atmosphere, a reduction in erosion control and a loss of cooler microclimates generated by the trees. Firewood and piñon nut production declined, which affected local economies in New Mexico. Piñon deaths impacted cultural services, as well; the species is important both to Native and Anglo cultures (Breshears et al. 2010)

Positive feedback cycles in piñon ecosystem processes make it likely that these processes will exhibit threshold behavior. First, piñon respond to drought by closing their stomata to maintain constant water pressures, slowing or stopping photosynthesis. Lowered photosynthesis reduces the ability of piñon to produce carbohydrates to repair drought damage or repel insect attack. Also, positive feedback cycles occur in bark beetle populations; high beetle densities facilitate successful attacks on trees, which leads to more reproduction (Burkett et al. 2005, Nelson and Lewis 2008). At sufficiently large populations insects can escape predation to produce a major outbreak (Ludwig et al. 1978).

## Methods 1: Finding thresholds across multiple processes

***Q1:*** What are the key thresholds triggering forest die-off in a mathematical model of forest-drought pest interactions?

I will address this question in my study by creating and analyzing a mathematical model of the piñon-drought-bark beetle system. The basic model, currently under development, is illustrated in Figure 1.

The model consists of a system of ordinary differential equations that represent the processes driving three state variables: xylem conductivity, carbohydrate stores, and insect population. The time scale modeled is daily. Faster processes such as stomatal control are assumed to be in equilibrium and represented by static equations. The model is driven by three exogenous variables (soil water potential, air water vapor deficit, and temperature).

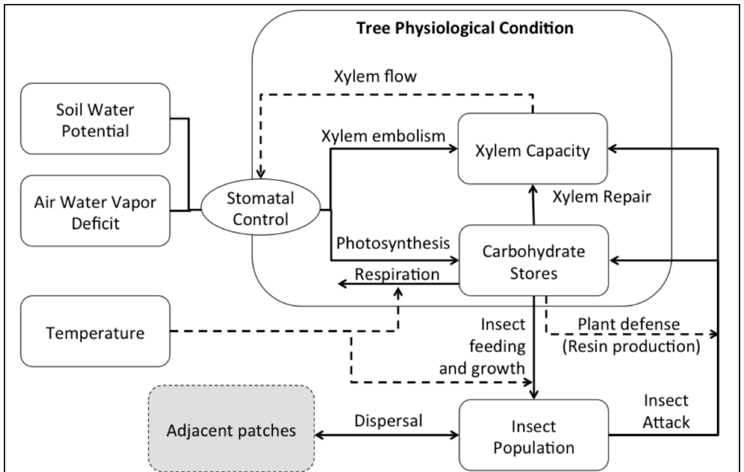


**Figure 1:** Diagram of piñon-drought-bark beetle model

The model is novel in that it combines well-tested models of key processes to explore their interdependent effects on tree die-off. Soil water potential and air vapor deficit affect tree physiological condition through their effect on xylem embolism (Sperry et al. 1998) and photosynthesis, which are modified by the tree via control of stomata opening. The stomatal control function depends both on exogenous variables and the tree's ability to transport water through the xylem (Tardieu and Davies 1993). Tree carbohydrates stores increase with photosynthesis, and are reduced by temperature-dependent respiration (Breshears et al. 2009) xylem repair processes (Zwieniecki and Holbrook 2009). Insect populations can consume tree carbohydrate stores and damage xylem, but attack success depends on insect population density and the trees' ability to use their carbohydrate stores to defend against attack by producing resin (Nelson and Lewis 2008). Successfully attacking insects consume tree resources and grow at a rate dependent on temperature, and can disperse to adjacent areas (Powell et al. 2000).

I will obtain model parameters from literature on piñon, *Ips confuses,* and closely related species. Many of the process models combined here have tested parameter sets. Where parameters are unknown (e.g., carbon requirements for xylem repair), I will obtain values by fitting the model to observations of piñon physiological condition during drought (Breshears et al. 2009), and confirming values by deriving minimum energetic requirements for physiological processes. I will identify the thresholds that cause terminal decline in xylem conductivity or carbohydrate stores, or unchecked growth in insect populations. I will also determine how these thresholds depend on external conditions, model parameters, and each other.

I have generated **preliminary results** from a version of the model that contains stomatal control, carbon allocation and xylem embolism implemented in R (R Development Core Team 2008). These results indicate that threshold values of water availability (from the model parameter air vapor deficit) control tree mortality (See Figure 2). These results also successfully reproduce other observed behaviors of trees under drought stress, such as increasing carbohydrate stores in early periods of water stress in plants (McDowell 2011).

## Methods 2: Detecting CSD in Model Outputs

***Q2:*** Does the mathematical model exhibit CSD as it approaches key thresholds, and by what measures is CSD detectable?

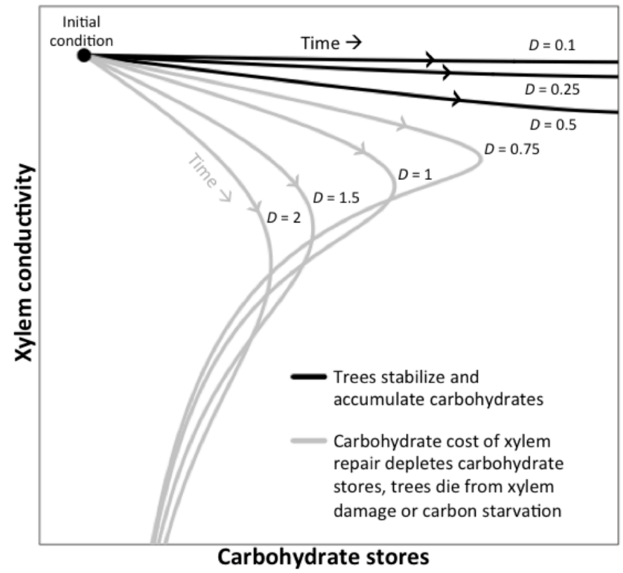


**Figure 2:** Preliminary model results demonstrate thresholds in tree response to drought. Below critical values of air vapor deficit ($D$), trees maintain xylem conductivity and accumulate carbohydrates. Above the threshold, carbohydrate accumulation is insufficient to repair damage to xylem, and trees die.

Having identified key thresholds for die-off, I will determine whether the model system exhibits CSD in the run-up to die-off. I will run the model under both stable and worsening climate conditions in order to determine if CSD is detectable in the model state variables (xylem conductivity, carbohydrate stores, and insect populations) as model conditions approach the threshold values determined above.

In order for CSD occur in an ecosystem, random variation in environmental conditions must be present in order to perturb the system. However, this random variation also generates noise in measured output variables, posing a challenge to detection. Thus in order to assess methods of CSD detection, I must test them under conditions of realistic stochasticity in model inputs and outputs. In both stable and deteriorating test runs, I will introduce random variation into the input variables (soil water potential, air water vapor deficit, and temperature), with variance and autocorrelation that resembles meteorological data from the piñon die-off region in New Mexico.

I will measure CSD in three separate ways to determine their relative efficacy in detecting CSD. The first approach will measure how summary statistics of the model state variables change over time. Statistical properties associated with CSD are rising variance, autocorrelation, and skew of time-series data. These properties have been identified in theoretical models exhibiting CSD have been identified in some aquatic systems near regime shift thresholds (Carpenter and Brock 2006, Dakos et al. 2008, 2011, Drake and Griffen 2010, Carpenter et al. 2011).

For the second approach, I will make the simplifying assumption that output data was generated from a simple system with a single threshold process under the control of a single parameter, causing regime shift as its value passes from positive to negative. Using the model output, I will estimate the value of the hypothetical controlling parameter as the model system approaches die-off using a maximum-likelihood method. This approach is based on the theory that all systems exhibiting CSD have the same essential properties near thresholds, and that little knowledge of specific system properties are required to detect CSD. This approach may have more power to distinguish real warning signals from false alarms, as it makes use of all data rather than reduced statistical summaries. (Boettiger and Hastings, *in review.)*

Finally, in the third approach, I will estimate the model parameters and their distance from threshold values for the full piñon-drought-bark beetle model directly from the model, using a maximum-likelihood method. Estimating the model parameters directly from the data that it generates will demonstrate whether detection is possible under realistic levels of environmental variation. It will also provide a baseline against which to determine how much of the power to detect CSD is lost in the first two approaches.

**Methods 3: Detecting CSD in remote-sensing data**

***Q3:*** Is CSD detectable in satellite measures of forest canopy water content in the period leading up to die-off, and by which measures?

I will use remote-sensing images from the 2002-2003 die-off to determine if piñon physiological state fluctuated in ways consistent with CSD prior to mass mortality. Satellite imagery provides a large data resource to test for signs of CSD. The scale of piñon forests and their die-offs is in kilometers, which matches the resolution of long-term data sets from Advanced Very High Resolution Radiometer (AVHRR), which has been used to measure the extent of piñon die-off (Breshears et al. 2005). The temporal scale is appropriate, as well. The stress that period preceded die-off occurred over months to years (Breshears et al. 2009) – the weekly resolution of AVHRR will allow measurement of variation in this period.

Using U.S. Forest Service aerial health surveys (US Forest Service 2003), I will select 1-$km^2$ stands of piñon forest in southwestern U.S. that experienced high mortality in 2002, as well as control sites with low mortality in this period and later years. I will select piñon-dominated sites to avoid confounding effects from other species. I will block my sampling design to capture variation in age, density, and site quality.

I will create a time series of forest health for each site using satellite-measured Normalized Difference Water Index (NDWI). NDWI measures the water content of plant canopies via reflectance in wavelengths of light associated with plant pigments and water, and calibration curves have been developed to relate NDWI to plant water canopy specifically for piñon (Stimson et al. 2005). I will use AVHRR, which has weekly coverage of the study region, to derive NDWI. I will measure CSD via the three methods described in "Methods 2" above.

**Broader Societal Impacts:** My research will fill a key need in the management of forest systems. The method will allow managers to forecast changes in forests due to climate variation, identify risk of regime shifts, and intervene to mitigate or adapt to their effects. This will research provide also test case in applying this approach to new ecosystems.

I will ensure the broader societal impact of work research by collaborating with practitioners, in particular forest managers. UC Davis works with forest managers through its extension program and relationship with the U.S. Forest Service. Several of my collaborators are joint USFS-UC Davis faculty, and I will present my results to USFS managers at their regional meeting. I will also collaborate with World Resources Institute's Global Forest Watch program, which provides training to governments and NGOs worldwide on using remote sensing to manage forests.

A second key audience of my work will be business managers. CSD-based estimates of the risk of ecosystem collapse provide information to enable investment decisions that take environmental risks into account. I have a unique ability to access this audience through the network I developed in my previous career as a corporate consultant. I will make presentations to firms with exposure to forest ecosystems in their supply chains and write about my research in GreenBiz, GOOD, and the Harvard Business Review, where I have previously published. At Davis I organize an annual workshop on ecology-business collaborations. I expect to present my results at this workshop at a session on information technology development.

Remote sensing lends itself to compelling visuals, and I will use my results to create "risk maps" that illustrate the relationship between CSD and risk ecosystem failure for all audiences.

**Summary:** I will test new method for forecasting forest die-offs using both modeling and empirical approaches. This will provide a test case for applying the method to forecast ecosystem regime shifts under uncertain global change, and provide a valuable tool for forest management.

**Works Cited**


Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, and E. H. (Ted) Hogg. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259:660-684. doi: 10.1016/j.foreco.2009.09.001.

Allen, C. D., and D. D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation. Proceedings of the National Academy of Sciences of the United States of America 95:14839-42.

Boettiger, C., and A. Hastings, *in review*. Quantifying limits to the detection of early warning for critical transitions.

Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America 102:15144-8. doi: 10.1073/pnas.0505734102.

Breshears, D. D., L. López-Hoffman, and L. J. Graumlich. 2010. When Ecosystem Services Crash: Preparing for Big, Fast, Patchy Climate Change. Ambio 40:256-263. doi: 10.1007/s13280-010-0106-4.

Breshears, D. D., O. B. Myers, C. W. Meyer, F. J. Barnes, C. B. Zou, C. D. Allen, N. G. McDowell, and W. T. Pockman. 2009. Tree die-off in response to global change-type drought: mortality insights from a decade of plant water potential measurements. Frontiers in Ecology and the Environment 7:185-189. doi: 10.1890/080016.

Breshears, D. D., and C. D. Allen. 2002. The importance of rapid, disturbance-induced losses in carbon management and sequestration. Global Ecology and Biogeography 11:1-5. doi: 10.1046/j.1466-822X.2002.00274.x.

Burkett, V., D. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J. Nielsen, C. D. Allen, and D. Peterson. 2005. Nonlinear dynamics in ecosystem response to climatic change: Case studies and policy implications. Ecological Complexity 2:357-394. doi: 10.1016/j.ecocom.2005.04.010.

Carpenter, S. R., J. J. Cole, M. L. Pace, R. Batt, W. a Brock, T. Cline, J. Coloso, J. R. Hodgson, J. F. Kitchell, D. a Seekell, L. Smith, and B. Weidel. 2011. Early Warnings of Regime Shifts: A Whole-Ecosystem Experiment. Science 1079. doi: 10.1126/science.1203672.

Carpenter, S. R., and W. a Brock. 2006. Rising variance: a leading indicator of ecological transition. Ecology letters 9:311-8. doi: 10.1111/j.1461-0248.2005.00877.x.

Dakos, V., E. H. van Nes, P. D'Odorico, and M. Scheffer. 2011. Robustness of variance and autocorrelation as indicators of critical slowing down. Ecology. doi: 10.1890/11-0889.1.

Dakos, V., M. Scheffer, E. H. van Nes, V. Brovkin, V. Petoukhov, and H. Held. 2008. Slowing down as an early warning signal for abrupt climate change. Proceedings of the National Academy of Sciences of the United States of America 105:14308-12. doi: 10.1073/pnas.0802430105.

Denman, K. L., G. Brasseur, A. Chidthaisong, P. Ciais, P. M. Cox, R. E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. L. D. S. Dias, S. C. Wofsy, and X. Zhang. 2007. Couplings Between Changes in the Climate System and Biogeochemistry. Page *in* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M.Tignor, and H. L. Miller, editors. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY.

Drake, J. M., and B. D. Griffen. 2010. Early warning signals of extinction in deteriorating environments. Nature 467:1-18. Nature Publishing Group. doi: 10.1038/nature09389.

Hastings, A., and D. B. Wysham. 2010. Regime shifts in ecological systems can occur with no warning. Ecology letters 13:464-472. doi: 10.1111/j.1461-0248.2010.01439.x.

Hewitt, J. E., and S. F. Thrush. 2010. Empirical evidence of an approaching alternate state produced by intrinsic community dynamics, climatic variability and management actions. Marine Ecology Progress Series 413:267-276. doi: 10.3354/meps08626.

Ludwig, D., D. D. Jones, and C. S. Holling. 1978. Qualitative Analysis of Insect Outbreak Systems: The Spruce Budworm and Forest. The Journal of Animal Ecology 47:315. doi: 10.2307/3939.

McDowell, N. 2011. Mechanisms linking drought, hydraulics, carbon metabolism, and vegetation mortality. Plant physiology 155:1051-1059. doi: 10.1104/pp.110.170704.

McDowell, N. G., D. J. Beerling, D. D. Breshears, R. a Fisher, K. F. Raffa, and M. Stitt. 2011. The interdependence of mechanisms underlying climate-driven vegetation mortality. Trends in ecology & evolution 26. doi: 10.1016/j.tree.2011.06.003.

McEwan, R. W., J. M. Dyer, and N. Pederson. 2011. Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. Ecography 34:244-256. doi: 10.1111/j.1600-0587.2010.06390.x.

Nelson, W. A., and M. A. Lewis. 2008. Connecting host physiology to host resistance in the conifer-bark beetle system. Theoretical Ecology 1:163-177. doi: 10.1007/s12080-008-0017-1.

Powell, J. A., B. Kennedy, P. White, B. Bentz, J. Logan, and D. Roberts. 2000. Mathematical elements of attack risk analysis for mountain pine beetles. Journal of theoretical biology 204:601-20. doi: 10.1006/jtbi.2000.1080.

R Development Core Team. 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Royer, P. D., N. S. Cobb, M. J. Clifford, C.-Y. Huang, D. D. Breshears, H. D. Adams, and J. C. Villegas. 2011. Extreme climatic event-triggered overstorey vegetation loss increases understorey solar input regionally: primary and secondary ecological implications. Journal of Ecology 99:714-723. doi: 10.1111/j.1365-2745.2011.01804.x.

Scheffer, M., W. A. Brock, J. Bascompte, V. Brovkin, S. R. Carpenter, V. Dakos, H. Held, E. H. van Nes, M. Rietkerk, and G. Sugihara. 2009. Early-warning signals for critical transitions. Nature 461:53-9. doi: 10.1038/nature08227.

Shaw, J., B. Steed, and L. DeBlander. 2005. Forest Inventory and Analysis (FIA) annual inventory answers the question: what is happening to pinyon-juniper woodlands? Journal of Forestry 103:280-285.

Sperry, J. S., F. R. Adler, G. S. Campbell, and J. P. Comstock. 1998. Limitation of plant water use by rhizosphere and xylem conductance: results from a model. Plant, Cell and Environment 21:347-359. doi: 10.1046/j.1365-3040.1998.00287.x.

Stimson, H., D. D. Breshears, S. Ustin, and S. Kefauver. 2005. Spectral sensing of foliar water conditions in two co-occurring conifer species: and. Remote Sensing of Environment 96:108-118. doi: 10.1016/j.rse.2004.12.007.

Tardieu, F., and W. J. Davies. 1993. Integration of hydraulic and chemical signalling in the control of stomatal conductance and water status of droughted plants. Plant, Cell and Environment 16:341-349. doi: 10.1111/j.1365-3040.1993.tb00880.x.

Zwieniecki, M. a, and N. M. Holbrook. 2009. Confronting Maxwell's demon: biophysics of xylem embolism repair. Trends in plant science 14:530-4. doi: 10.1016/j.tplants.2009.07.002.

Item 6: Background Information

## Education and Experience

Brown University — Providence, RI

*Bachelor of Science in Environmental Science, Magna Cum Laude, 2006*

- Honors thesis: Soil Organic Matter in Northern Mongolia: Permafrost and Land-Use interactions
- Honors: Phi Beta Kappa Society, Sigma Xi Society, Departmental Honors in Environmental Science, Susan Colver Rosenberger Prize for Outstanding Service
- One term at Semester in Environmental Science, Marine Biological Laboratory, Woods Hole, MA

September 2006 – October 2009, GreenOrder — New York, NY

*Analyst (2006-2008), Senior Analyst (2008-2009)*

- Developed environmental product strategies for clients in industrial and commercial sectors
- Managed engagement with construction rental company to identify growth opportunities
- Created and managed firm seminar series and analyst training materials on topics including auditing, statistical analysis, and strategic goal setting; developed firm knowledge management system
- Performed market and competitive analyses for a wide array of clients in retail, real estate and cleantech sectors; prepared and delivered client presentations; managed project workstreams
- Developed company knowledge base on ecosystem service markets; reviewed and critiqued World Resources Institute's Corporate Ecosystem Services Review methodology

May 2006 – August 2006, Wal-Mart, Inc. — Providence, RI

*Contract Researcher/Consultant*

- Responsible for research for design of a program for increasing the market share of energy-efficient lamps
- Developed best practice recommendations for lamp recycling program

Summer 2005, Academy of Natural Sciences — Philadelphia, PA

*National Science Foundation REU Fellow:* Performed research on climate-land use interactions on soil carbon storage in Mongolia

January 2005 – May 2006, Brown Facilities Management — Providence, RI

*Administrative, Research, and Teaching Assistant – Resource Efficiency*

- Developed usage and cost scenarios for facilities energy planning; wrote university vehicle procurement policy
- Teaching assistant for two semesters of ES41: Sustainable Design

Summer 2003, Center for Environmental Studies, Brown University — Providence, RI

*Undergraduate Teaching and Research Fellow:* Conducted research in biogeochemistry at Hubbard Brook Experimental Forest and surrounding region; oversaw field crew

January 2003 – May 2005, Urban Environmental Lab, Brown University — Providence, RI

*Building Systems Coordinator:* Performed maintenance and carpentry for energy efficient, low-impact building and community garden

May - November 2002, Providence Maritime Heritage Foundation — Providence, RI

*Boatswain/Educator*

- Educated elementary, secondary school and adult groups in marine science, history and teambuilding
- Oversaw rig maintenance for 110' tallship, regular ship operations work, watch leading and relief mate duties

**Publications and Presentations:**

Academic:

- Kroetz, Kailin, Kate Fuller, David Kling Noam Ross and James Sanchirico. "Open Access Fisheries," The Encyclopedia of Energy, Natural Resources and Environmental Economics, ed. Peter Berck. Burlington, MA: Elsevier Press.
- Just, Allan and Noam Ross. "The bigger dig: expanded soil pit methods," 9 July 2003, Oral Presentation at Hubbard Brook Ecosystem Study 40th Annual Cooperators' Meeting.

Popular Press:

- "Extinction Debt," (Initial author) Wikipedia. Wikimedia Foundation, Inc., February 23, 2011, http://en.wikipedia.org/wiki/Extinction_debt
- "If Everyone Moves to the City, What Gets Left Behind?" Good.is, January 17, 2011, http://www.good.is/post/if-everyone-moves-to-the-city-what-is-left-behind/
- Ross, Noam, "Why the Ethanol Debate Isn't Helping Anyone," GreenBiz.com, June 3, 2009, http://www.greenbiz.com/blog/2009/06/03/why-ethanol-debate-isnt-helping-anyone
- Shapiro, Andrew and Noam Ross, "Four Lean, Green Strategies for an Uncertain Economy," Harvard Business Review's *Leading Green*, October 29, 2008. http://blogs.harvardbusiness.org/leadinggreen/2008/10/4-lean-green-strategies-for-an.html
- Ross, Noam, "What a Silent Spring Means for Business Risk," GreenBiz.com, March 6, 2007. http://www.greenbiz.com/blog/2007/03/06/what-a-silent-spring-means-business-risk

**Course Work**

<u>Graduate Courses: University of California-Davis</u>

- All courses taken in at as part of program of study for B.Sc. in Environmental Science, awarded May 2006
- GPA 3.95

| Course Number | Course Name | Grade | Credits |
|---|---|---|---|
| *Fall 2011* | | | |
| **ECL290** | **Forest Pest Outbreaks** | **-** | **2** |
| **ARE204A** | **Microeconomic Analysis I** | **-** | **4** |
| **ECL296** | **Departmental Seminar in Ecology and Evolution** | **-** | **1** |
| *Spring 2011* | | | |
| **ECL290** | **Ecology, Economics, and Society** | **S** | **2** |
| **ECL296** | **Departmental Seminar in Ecology and Evolution** | **S** | **1** |
| **ECL298** | **Forest Biology** | **S** | **3** |
| **EVE100** | **Introduction to Evolution** | **A-** | **4** |
| *Winter 2011* | | | |
| **ECL200B** | **Principles of Ecology** | **A+** | **5** |
| **ECL296** | **Departmental Seminar in Ecology and Evolution** | **S** | **1** |
| **ECL298** | **Computational Methods in Population Biology** | **S** | **1** |
| **PBG250B** | **Interdisciplinary Approaches to Rapid Environmental Change** | **A** | **4** |
| *Fall 2010* | | | |
| **ECL200A** | **Principles of Ecology** | **A** | **5** |
| **ECL296** | **Departmental Seminar in Ecology and Evolution** | **S** | **1** |
| **ECL298** | **Grantwriting** | **S** | **1** |
| **PBG231** | **Mathematical Methods in Population Biology** | **A** | **3** |
| **PBG250A** | **Interdisciplinary Approaches to Rapid Environmental Change** | **A** | **4** |

Undergraduate Courses: Brown University

- All courses taken in at as part of program of study for B.Sc. in Environmental Science, awarded May 2006
- GPA 3.90 (Self-calculated, see footnote)

| Course Number | Course Name | Grade | Sem. Hours |
|---|---|---|---|
| *Spring 2006* | | | |
| **ENVS0268** | **Ecosystem Modeling** | **A** | **4** |
| RISD0085 | Lines in Space: Furniture Design in Metal | S | 4 |
| *Fall 2005* | | | |
| **BIOL0142** | **Experimental Design in Ecology** | **A** | **4** |
| **ENVS0195** | **Independent Thesis Study II** | **A** | **4** |
| *Spring 2005* | | | |
| **ENVS0141** | **Environmental Public Policy and Practice** | **A** | **4** |
| **ENVS0196** | **Independent Thesis Study I** | **A** | **4** |
| **GEOL0133** | **Environmental Remote Sensing** | **A** | **4** |
| HIST0143 | Balkan History from Belgrade to Daytona | AUDIT | 4 |
| *Fall 2004 (All Courses taken at the Semester in Environmental Science at the Marine Biological Laboratory, Woods Hole, MA, as part on Brown-MBL joint program)* | | | |
| **ENVS0146** | **Terrestrial Ecosystems** | **A** | **4** |
| **ENVS0146** | **Aquatic Ecosystems** | **A** | **4** |
| **ENV0146** | **Microbial Methods in Ecology** | **A** | **4** |
| **ENV0149** | **Independent Study in Ecosystems Analysis** (Conducted research on nitrogen and carbon cycling in microplankton food webs) | **A** | **4** |
| *Spring 2004* | | | |
| **APMA0034** | **Applied Math II** | **A** | **4** |
| **BIOL0044** | **Plant Organism** | **B** | **4** |
| **ENVS0192** | **Analysis and Resolution of Environmental Problems** | **A** | **4** |
| **PHP0216** | **Applied Regression Analysis** | **A** | **4** |
| *Fall 2003* | | | |
| **BIOL0043** | **Diversity and Adaptation of Seed Plants** | **A** | **4** |
| **GEOL0022** | **Physical Processes in Geology** | **A** | **4** |
| ENGL0020 | Turning Turk | A | 4 |
| HIST0141 | Modern Russia to the Revolution | B | 4 |
| *Spring 2003* | | | |
| **ENVS0049** | **Environmental Science** | **A** | **4** |
| **APMA0033** | **Applied Math I** | **A** | **4** |
| **BIOL0051** | **Introductory Microbiology** | **B** | **4** |
| ANTH0101 | Origins of Plant and Animal Agriculture | A | 4 |

| | | | |
|---|---|---|---|
| *Spring 2002* | | | |
| **BIOL0042** | **Principles of Ecology** | **A** | **4** |
| **GEOL0135** | **Meteorological Aspects of Climate Change** | **S** | **4** |
| ANTH0109 | Nautical and Underwater Archaeology | A | 4 |
| HIST0197 | Travel Narratives in South Asia | S | 4 |
| JUDS0014 | Intermediate Hebrew II | A | 4 |
| *Fall 2001* | | | |
| **CHEM0033** | **Chemistry: Equilibrium, Rate, and Structure** | **A** | **4** |
| **ENVS0011** | **Environmental Issues** | **A** | **4** |
| ANTH0149 | Shamanism: East and West | A | 4 |
| ARCH0036 | Archaeology of Anatolia | AUDIT | |
| JUDS0013 | Intermediate Hebrew I | A | 4 |
| *Advanced Placement – credits assigned but no grades given* | | | |
| **N/A** | **Mathematics 9** | | **4** |
| **N/A** | **Mathematics 10** | | **4** |
| **N/A** | **Introductory Biology** | | **4** |

*Brown University awards only grades of A,B,C/No Credit (NC), with no plusses or minuses. Grades of "S" denote courses taken on the basis of Satisfactory (S)/No Credit (NC). Brown University does not calculate GPA. Self-calculated GPA assumes A = 4.0, B = 3.0, with all classes assigned equal weight, and no contribution from S/NC or audited courses.*