

PROJECT SUMMARY/ABSTRACT

Experimental field studies are needed to understand the consequences of global climate change for local community structure and ecosystem processes. We propose to manipulate temperature in a novel regression design using open-top environmental chambers at two field sites situated at the northern and southern extremes of temperate hardwood forest in eastern North America.

(Massachusetts, North Carolina). The proposed field manipulations will reveal the effects of temperature increases on the populations, communities and ecosystem services of assemblages of ground-foraging ants. Ants are a model taxon for studying effects of global climate change because they comprise the dominant fraction of biomass in terrestrial communities, and they provide essential ecosystem services such as soil turnover and seed dispersal. The experiment is designed to test three predictions: 1. Projected atmospheric warming will lead to declines in ant species' abundances at the warmer, southern extent of their ranges in the US. Conversely, projected atmospheric warming lead to increases in abundance or range extensions of ant species at the cooler, northern extent of their ranges in the US. 2. Warming will change the relative abundance and composition of ant communities, and will reduce ant biodiversity. 3. Warming will potentially diminish ecosystem processes and services provided by ants, particularly with respect to the dispersal of seeds. Ten open-top chambers at each site which will each be exposed to one of ten levels of temperature increase, ranging from no change (ambient conditions) to 5 degrees C (commensurate with best-case IPCC climate model forecasts for the year 2100). After an initial year of pre-intervention measurements, the experiment will run for 3 consecutive years of continuous warming. The response variables measured will include ant activity, population densities and colony sizes of focal species, ant community diversity and species composition, and rates of seed dispersal and predation as mediated by ants. This study will provide an experimental test of hypothesis that species at the northern and southern boundaries of their ranges will respond predictably to climate change. In addition, this research will take a step forward in establishing ants as a model taxon for the study of climatic change.

Our work will address PER's core mission to "deliver improved scientific data and models about the potential response of the Earth's climate and terrestrial biosphere to increased greenhouse gas levels for policy makers to determine safe levels of greenhouse gases in the atmosphere," while focusing on one aspect of greenhouse gas emissions temperature. Our novel regression design, unlike more conventional experimental designs, makes our study more likely than most to "identify safe levels of emissions," and to reveal potential nonlinearities and threshold effects in the relationship between temperature and animal community structure.

FACILITIES AND OTHER RESOURCES (FIELD 9)

NCSU

Lab: Dunn has a lab space for field supplies, lab experiments and data processing at our study site.

Computer: Dunn has computers at NC State (3 PC's, including 2 laptops) that can be dedicated to this project. These are equipped with standard software for data processing, data analysis, and word processing.

Office: NC State will provide office space for Dunn, the NCSU postdoc and Dunn's graduate students.

UTK

General lab equipment includes: Top-loading and analytical balances, several dissecting microscopes, drying ovens (forced air and convection), muffle furnace, -80 C chest freezer, orbital shakers, Wiley mill, Licor Leaf Area Meter, miscellaneous field equipment (tapes, coolers, pole pruners).

Lab equipment for chemical analyses will includes: glass dessicators, 40 sample digest block, pipettes and re-pipetors, vortex, stir- and hotplates, conductivity and pH meters, sonicator, benchtop centrifuge, Beckman ultracentrifuge, water bath, rotary evaporator and N-evaporator, Lachat AE flow-injector auto-analyzer with in-line digest capacity, Molecular Devices microplate spectrophotometer, lyophilizer, Ankom fibre analyzer, and CHN autoanalyzer. The Ecosystem Ecology Laboratory facility ORNL includes a Costech ECS 4010

There is sufficient office space and computer support for this project.

Harvard Forest

The 1200-ha Harvard Forest has operated as Harvard University's main ecological research and educational facility since 1907. The Harvard Forest provides a complete base for research in forest, ecosystem and historical ecology and biosphere-atmosphere interactions. Coincident with LTER I, II, and III, the Forest has overseen phenomenal growth in scientists, educators, students, collaborators, research and education programs, and laboratory, computing, archival, teaching, and housing facilities. Common research space includes a graphics and mapping room, a projection and film analysis room for video microscopy, and twenty-five microcomputers linked by a T1 line to Harvard University.

The Laboratory at Harvard Forest is a multi-investigator, multi-institutional facility adapted for diverse research interests and educational activities. It includes two recently renovated research greenhouses, offices, and physiology and nutrient analysis laboratories with fume hoods, gas chromatograph, Lachat 8500 autoanalyzer, CN analyzer, nano pure water system, precision balances, and drying ovens.

Equipment for experimental manipulations, construction, and maintenance includes a back-hoe, bulldozer, crawler, skidder, tractor, dump truck, flat bed truck, vehicles including pick-ups, a van, SUVs and a sedan, a wood-working shop, maintenance garage and a sawmill. A mobile lift provides access for up to four researchers to 20-m forest canopies

UVM

I have an Olympus dissecting scope for ant identification in my lab. I also maintain a reference collection of ant specimens from New England and the eastern U.S., and a personal library of reprints, monographs, and other resources for identification of U.S. ants.

I have adequate office space for a PhD student associated with this grant.

Do projected temperature increases have the potential to exacerbate the impact of fire ants and affect the abundance and/or geographic distribution of native and non-native ants?

Principal Investigator: Robert R. Dunn, Department of Zoology, North Carolina State University, 919-782-5187, Rob_Dunn@ncsu.edu

Co-PIs: Aaron Ellison, Harvard Forest; Nicholas Gotelli, University of Vermont; Nathan Sanders, University of Tennessee

Significance of the proposed project and overall project goal: Climatic change can have direct effects on the distribution of native species and indirect effects that are mediated through changes in the distribution of invasive species. However, few studies have experimentally assessed the additive and interactive effects of climate change and invasive species on the structure of native communities, at broad biogeographic scales. **The overall goal of this proposed research is to assess the effects of climatic warming and two invasive fire ant species on the distribution and abundance of native ants in the eastern US.**

Study Organisms: We will focus on the ants of eastern North America. Ants are an abundant (up to 40% of animal biomass), ecologically important (~35% of all herbaceous species have their seeds dispersed by ants, and ants modify ecosystem properties) and diverse taxon whose distribution, diversity and abundance are directly limited by temperature (our work shows that temperature can explain >65% of the variation in ant species richness both within the study region and globally).

Sites and Manipulations: We will experimentally increase soil-surface temperature by ~2°C using heat lamps at a northern and southern site in the US. At the southern site (near Raleigh, NC), the South American fire ant *Solenopsis invicta* is currently invading ant communities in which many native species are at their southern range limits. At the northern site (the Plum Island LTER in Massachusetts) the European fire ant *Myrmica rubra* is invading intact ant communities in which many species are near their northern range limits. Two other invasive ants, the Argentine ant *Linepithema humile* and the Giant needle ant, *Pachichondyla chinensis*, also occur in the southeastern US. In both regions, native ant species density and abundance are known to decrease following the arrival of the invasive species.

The experiment will cross temperature increase with the presence of the invasive fire ant species in a three-way 2 × 2 × 3 ANOVA design. The three factors in the design are SITE (northern, southern) INVASIVE SPECIES (present, removed), and WARMING (control, heated, heated control). At each site, we will establish 30 experimental plots (10 × 10 m area, $n=5$ for each treatment), census each plot for species identity and relative abundance, and document pair-wise species interactions in each plot using standardized behavioral assays. In half of the plots, we will remove invasive fire ant nests, and in the other half, we will not. For the WARMING treatment, half of the plots will be heated by hanging an array of five 165 × 15 cm infrared heaters above each plot at 1.5 m height. Controls will be unheated. Disturbance controls will have identical, unlit lamps to control for disturbance and shading effects. Both the INVASIVE SPECIES and WARMING treatments will be applied for three consecutive field seasons in an ecological press experiment. Each year, we will measure the abundance, species identity, nest distribution, and species interactions of ants within each plot. In addition, at the end of the experiment, we will harvest nests of the invasive and native species to estimate reproductive potential of colonies and forecast future changes in assemblage structure.

The main expected outcome of this project will be an understanding of how climatic warming and invasive species interact to affect the structure and composition of the fauna in intact ecosystems. We predict that increasing temperatures will lead to increases in the local distribution and abundance of invasive ant species at both the northern and southern sites because these species are limited by temperature. Consequently, we expect to see declines in the abundance and local distribution of native species. We will incorporate our results into a set of general models that forecast potential ranges of many key ant species under predicted scenarios of climatic change. This project will deliver improved data to help scientists and policy makers determine safe levels of greenhouse gases for the Earth system.

Approximate Budget: The annual budget for this four-year project is not expected to exceed \$300,000.

Selected Recent Publications of PI's Related to Climate and Climate Change:

- Albrecht M, Gotelli NJ (2001) Spatial and temporal niche partitioning in grassland ants. *Oecologia* 126: 134-141.
- Dunn RR, Sanders NJ and McCain C (2007) When do empirical patterns of diversity differ from null models and why? *Global Ecology and Biogeography*. doi: 10.1111/j.1466-8238.2006.00284.x.
- Dunn RR, Parker CR and Sanders NJ (In press) Disentangling the roles of competition and the environment as drivers of phenological patterns of ant diversity. *Biological Journal of the Linnean Society*.
- Dunn RR, Colwell RK, Nilsson C (2006) The River Domain: Why are there so many species half way up the river? *Ecography* 29:251-259
- Dunn RR, Parker C, Geraghty M, Sanders NJ. (In press) Reproductive phenologies in a diverse temperature ant fauna. *Ecological Entomology*
- Ellison AM, Gotelli NJ (2002) Nitrogen availability alters the expression of carnivory in the northern pitcher plant *Sarracenia purpurea*. *Proceedings of the National Academy of Sciences, USA* 99: 4409-4412.
- Ellison AM et al. (2005) Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment* 3:479-486
- Fitzpatrick MC, Weltzin JF, Sanders NJ, Dunn RR (2007) The biogeography of prediction error: Why doesn't the introduced range of the fire ant predict its native range or vice versa? *Global Ecology and Biogeography* 15: 24-33
- Gotelli NJ, Ellison AM (2006) Food-web models predict species abundance in response to habitat change. *PLoS Biology* 44: e324.
- Gotelli NJ, Ellison AM (2006) Forecasting extinction risk with non-stationary matrix models. *Ecological Applications* 16: 51-61.
- Gotelli NJ, Ellison AM (2002) Assembly rules for New England ant assemblages. *Oikos* 99: 591-599.
- Gotelli NJ, Ellison AM (2002) Nitrogen deposition and extinction risk in the northern pitcher plant, *Sarracenia purpurea*. *Ecology* 83: 2758-2765.
- Gotelli NJ, Ellison AM (2002) Biogeography at a regional scale: determinants of ant species density in New England bogs and forests. *Ecology* 83: 1604-1609.
- Gotelli NJ, Arnett AE (2000) Biogeographic effects of red fire ant invasion. *Ecology Letters* 3: 257-261.
- Ratchford JS, Wittman SE, Jules ES, Ellison AM, Gotelli NJ, Sanders NJ (2005) The effects of fire, local environment, and time on ant assemblages in fens and forests. *Diversity and Distributions* 11: 487-497
- Sanders NJ, Lessard J-P, Dunn RR, Fitzpatrick MC (In press) Temperature, but not productivity or geometry, predicts elevational diversity gradients in ants across spatial grains. *Global Ecology and Biogeography*
- Sanders NJ, Gordon DM (2004) The interactive effects of climate, life history, and interspecific neighbors on mortality in a population of seed harvester ants. *Ecological Entomology* 29: 632-637
- Sanders NJ, Belote RT, Weltzin JF (2004) Multi-trophic effects of elevated CO₂ on understory plant and arthropod communities. *Environmental Entomology* 33: 1609-1616
- Sanders NJ, Gotelli NJ, Heller NE, Gordon DM (2003) Community disassembly by an invasive ant species. *Proceedings of the National Academy of Sciences* 100: 2474-2477
- Sanders NJ, Moss J, Wagner D (2003) Patterns of ant species richness along elevational gradients in an arid ecosystem. *Global Ecology and Biogeography* 12: 93-102
- Sanders NJ (2002) Elevational gradients in ant distributions: area, species richness, and Rapoport's rule. *Ecography* 25: 25-32
- Sanders NJ, Barton KE, Gordon DM (2001) Long-term dynamics of the distribution of the invasive Argentine ant, *Linepithema humile*, and native ant taxa in Northern California. *Oecologia* 127: 123-130
- Sodhi NS, Lee TM, Koh LP, Dunn RR (In press) A century of avifaunal losses from a small tropical rainforest fragment. *Animal Conservation*

PROJECT SUMMARY/ABSTRACT

Experimental field studies are needed to understand the consequences of global climatic change for local community structure and associated ecosystem processes. We propose to use large open-top environmental chambers to simultaneously manipulate air and soil temperatures using a statistically powerful and cost-efficient response-surface (regression) design at two field sites situated in northern and southern temperate mixed hardwood forests in eastern North America (Massachusetts, North Carolina). The proposed field manipulations will reveal the effects of temperature increases on the populations, communities, and associated ecosystem services of assemblages of ground-foraging ants. Ants are a model taxon for studying effects of global climatic change because they comprise the dominant fraction of animal biomass in many terrestrial communities and because they provide essential ecosystem services, including soil turnover, decomposition, and seed dispersal. The experiment is designed to test three predictions: **1.** Projected atmospheric warming will lead to declines in ant species' abundances at the warmer, southern extent of their ranges in the US. Conversely, projected atmospheric warming will lead to increases in abundance or range extensions of ant species at the cooler, northern extent of their ranges in the US. **2.** Warming will change the relative abundance and composition of ant communities, and will lead to the loss of ant biodiversity. **3.** Warming will potentially diminish ecosystem processes and services provided by ants, particularly with respect to the dispersal of seeds. Ten open-top chambers at each site which will each be exposed to one of ten levels of air temperature increases, ranging from no change (ambient conditions) to 5 °C (commensurate with best-case IPCC climate model forecasts for the year 2100); soil temperatures will be increased simultaneously from 0 to ~ 2 °C. After an initial year of pre-intervention measurements, the experiment will run for 3 consecutive years of continuous warming. The response variables measured will include ant activity, population densities and colony sizes of focal species, ant community diversity and species composition, and rates of seed dispersal and predation as mediated by ants. This study will provide an experimental test of the hypothesis that species at the northern and southern boundaries of their ranges will respond predictably to climatic change. In addition, this research will further establish ants as a model taxon for the study of climatic change.

Our work will address PER's core mission to "deliver improved scientific data and models about the potential response of the Earth's climate and terrestrial biosphere to increased greenhouse gas levels for policy makers to determine safe levels of greenhouse gases in the atmosphere," while focusing on one aspect of greenhouse gas emissions: temperature. Our response-surface experimental design with many levels of temperature, unlike more conventional ANOVA designs that examine only 2 or 3 "extreme" cases, makes our study more likely to "identify safe levels of emissions," and to reveal potential nonlinearities and threshold effects in the relationship between temperature, animal community structure and associated ecosystem function.

PROJECT NARRATIVE

PI-Primary Institution

Robert R. Dunn
Department of Zoology
North Carolina State University
Raleigh, NC 27695-7617
(919) 513-7569
Rob_Dunn@ncsu.edu

Funding opportunity announcement number: DE-ps02-07er07-11
DOE/Office of Science Program Office: Jeff Amthor
DOE/Office of Science Program Office Technical contact: Jeff Amthor

Subcontracting/Collaborating institutions - PIs

Aaron M. Ellison
Harvard University
Harvard Forest
324 North Main Street
Petersham, MA 01366
(978) 724-3302
aellison@fas.harvard.edu

Nicholas J. Gotelli
Department of Biology
University of Vermont
Burlington, VT 05401
(802)-656-0450
Nicholas.Gotelli@uvm.edu

Nathan J. Sanders
Department of Ecology and Evolutionary Biology
569 Dabney Hall
University of Tennessee
Knoxville, TN 37996
(865) 974-5231
nsanders@utk.edu

1. THEORETICAL BACKGROUND

1a. Introduction

Recent estimates of the magnitude of species' range shifts, extinctions, and changes in ecosystem processes resulting from climatic change are alarming (Erasmus et al. 2002, Peterson et al. 2002, Midgley et al. 2003, Parmesan and Yohe 2003, Root et al. 2003a, Williams et al. 2003, Thomas et al. 2004a, Thomas et al. 2004b). Estimates of extinction rates and population losses attributable to climatic change are often based on studies of modeled biogeographic distributions, which rely on simple relationships between present-day distributions of species and climate variables to estimate distributions of species under future climate (Thuiller et al. 2005b, Midgley et al. 2006). Hundreds of papers using distribution models - based almost exclusively on relationships between plants and climate - have been published. The predictions of these models undergird conservation plans, are used to forecast the magnitude of future extinctions, and to leverage efforts to produce policies aimed at mitigating the effects of climatic change. Remarkably few experimental manipulations of the effects of climatic change, and in particular temperature change, have been conducted on animal populations and communities or on ecological processes dependent on their dynamics (Petchey et al. 1999). Although modeling and observational approaches to climatic change have been useful in discerning broad-brush relationships between climate and populations, communities, and ecosystem processes, experimental manipulations are required to determine the mechanisms by which biota respond to climatic change and to validate the assumptions underlying distribution models.

A key prediction from models of the effects of climatic change on species distributions is that the geographic boundaries of species will change in response to warming (Gaston 2003). In some cases, observed changes in species' ranges over the last hundred years are commensurate with predictions based on distribution models (Parmesan and Yohe 2003, Root et al. 2003b, Thomas et al. 2004a, Araujo et al. 2005, Thuiller et al. 2005a). However, these correlative studies have been criticized because they rely on untested assumptions or spurious associations, and are often confounded by co-varying factors that interact with temperature, such as the appearance of invasive species (Dukes and Mooney 1999, Smith et al. 2000). Moreover, correlative studies can provide only limited mechanistic insights (Davis et al. 1998a, Davis et al. 1998b, Samways et al. 1999, Lawton 2000, Gaston 2003, Hampe 2004, Parmesan et al. 2005).

In contrast to large-scale correlative studies, experimental manipulations of temperature in the field can largely control for co-varying factors and have the potential to show how abundance at range boundaries will change in response to elevated temperatures (Parmesan et al. 2005). If these experiments are carried out at sites at the northern and southern range margins of different species, mechanistic links among temperature, abundance, and biodiversity can be explored (Parmesan et al. 2005). To date, however, such experimental studies are rare and mostly limited to terrestrial plants (Gaston 2003).

In addition to allowing insights into the effects of climatic change on population processes, temperature manipulations can also address effects on community-level processes. Community-level consequences of climatic warming are potentially dramatic (Araujo and Rahbek 2006). Any increases and decreases in populations due to climate change will translate into shifts in the

relative abundance distribution and the species composition of local assemblages. A growing number of studies have examined how a particular groups of species or guilds might respond to experimental warming (Harte and Shaw 1995, Dunne et al. 2004, Klein et al. 2004, 2005). An important next step is to understand how broader communities respond to experimentally manipulated temperature in the field. Because they are both diverse and may respond at small scales, arthropod communities are an obvious target for community-level studies. Recent reviews have highlighted the paucity of information on how most arthropod groups will respond to predicted climatic change (Coviella and Trumble 1999, Hughes 2003). Because they include multiple trophic levels, arthropod communities also can provide novel insights into how interactions among trophic levels will respond to climatic change. Very few studies have examined how entire terrestrial assemblages, as opposed to particular trophic levels (e.g., just plants or perhaps select herbivores that feed on plants) will respond to warming (Kennedy 1998, Convey et al. 2002, Walther et al. 2002, Convey et al. 2003). The few such community-level studies with animals have focused on arctic or subarctic microarthropods (Coulson et al. 2000, Convey et al. 2002, Sinclair 2002, Uvarov 2003, Dollery et al. 2006). ***Here we propose to manipulate atmospheric temperature at the northern and southern range extents of a variety of ant taxa to assess the potential effects of climatic warming on population abundance and species composition of local assemblages.***

Finally, there is a growing appreciation of the links between biodiversity and ecosystem function. Trophic interactions can affect ecosystem function either by directly modifying fluxes of energy and materials, or by influencing the abundances of species that control those fluxes. However, few studies have explicitly examined how changes in the composition of trophic levels other than primary producers affect ecosystem processes, especially under climatic change scenarios (Hooper et al. 2005). To understand better the consequences of climatic change on ecosystem processes, experiments should examine how climatic change affects not only the abundance and diversity of species, but also the processes they mediate (Chapin et al. 2000).

In this proposed research, we ask three key questions:

- 1. Will projected atmospheric warming lead to declines in the abundance of ant species at the warmer, southern extent of their ranges in the US? Conversely, will projected atmospheric warming lead to increases in abundance of species at the cooler, northern extent of their ranges in the US?**
- 2. Will warming lead to changes in relative abundance and composition and to a loss of diversity of ant communities?**
- 3. Will the effects of warming lead to shifts in ecosystem processes and potentially reduce ecosystem services such as seed dispersal and decomposition that are provided or mediated by ants?**

1b. Why ants?

Addressing these key questions requires (1) a taxon that is sufficiently well-known to study population-level processes, (2) a region in which climate is predicted to change at both the southern and northern limits of species' ranges, (3) a taxon that can be experimentally manipulated at logistically tractable scales, and (4) a taxon in which community-level diversity is high in a small area. The ants of the eastern US fit all of these criteria. More generally, ants

possess numerous traits which make them a strong candidate for development as a focal taxon for climatic change studies:

- Ants are numerically dominant organisms in forest communities.
- Ant taxonomy, especially in the eastern US, is reasonably well resolved (Culver 1974, Fellers 1987a, Kaspari et al. 2000b).
- Ant communities can be sampled accurately using rapid and efficient sampling techniques (Agosti et al. 2000).
- The life histories and natural histories of most dominant ant species are understood (Hölldobler and Wilson 1990, Bourke and Franks 1995).
- Ant communities are ecologically important. For example, ~35% of all herbaceous species have their seeds dispersed by ants (Beattie 1985). Ants also modify ecosystem properties through soil turnover and litter processing and decomposition (Lyford 1963, Folgarait 1998, Terborgh et al. 2001, Holec and Frouz 2005).
- Ant communities contain multiple trophic levels, including herbivores, omnivores, predators and secondary predators (Kaspari et al. 2000a, Kaspari 2004, Tillberg et al. 2006).
- Ants and other social insects are predicted to be more susceptible to disturbance and climatic change than are solitary species (Chapman and Bourke 2001, Koh et al. 2004, Dunn 2005), such as most mammals or all butterflies.
- Both the dynamics of ant populations and the structure of ant communities are strongly shaped by climate and in particular temperature (Bestelmeyer 2000, Kaspari et al. 2000a, Retana and Cerdá 2000, Kaspari and Valone 2002, Sanders and Gordon 2002, Sanders et al. In press) (See 1c below).

The ants of eastern of North America offer the additional advantage that they have been better-studied than ants in many other places, both by the PIs and more generally, allowing relatively specific predictions to be made about the responses of species and communities to temperature manipulations. PIs Dunn and Sanders have amassed a global database on patterns of ant diversity and geographic ranges, with a strong focus on ant assemblages in the eastern US. The dataset includes more than 1200 locations in North America and over three thousand sites globally, each of which was quantitatively sampled for ground-foraging ants. The eastern North American portion of the database includes distribution and abundance data for more than 250 species. Dunn and Sanders are developing models aimed at predicted future distributions of species under various climatic change scenarios.

Forest ant communities of the eastern U.S. are also reasonably diverse (5-30 species ha⁻¹; Kaspari et al. 2000, Gotelli and Arnett 2001, Gotelli and Ellison 2002, Sanders et al. 2007), and include a mix of both widespread species and relatively narrow endemics and species from different trophic levels. PIs Ellison and Gotelli have, over the past 7 years, worked extensively on the determinants of ant community structure at the northern range boundaries of many eastern forest ant species (Gotelli and Arnett 2000, Ellison et al. 2002, Gotelli and Ellison 2002b, Gotelli and Ellison 2002a) while Dunn and Sanders spent four years elucidating the determinants of ant community structure at the southern range boundaries of many species (Dunn et al. 2006, Dunn et al. in press, Lessard et al. in press, Sanders et al. 2007). We will carry out the field

experiments in this proposed research at two well-studied field sites, Harvard Forest in Massachusetts in the north and the Yates Forest in North Carolina in the south. Despite differences of 9°C in mean annual temperatures between sites, at least 11 ant species are shared between these two sites (Table 1). Further, species found at both sites tend to be at or near their northern range limits in Massachusetts and at or near their southern range limits in North Carolina.

2a. Ants and climate and climatic change

Patterns of ant diversity and distribution, and their population dynamics, appear strongly shaped by temperature (Davidson 1977, Kaspari et al. 2003, Sanders and Gordon 2004, Ratchford et al. 2005). In our focal study sites in the eastern U.S., ant diversity is highest where temperatures are highest both in space and in time (Holway et al. 2002a, Dunn et al. 2006, Dunn et al. in press, Sanders et al. In press), but appears unrelated to rainfall (Sanders et al. In press). In addition, patterns in the activity (Dunn et al. 2006), nest site selection (Banschbach et al. 1997) and distribution of individual species also tend to be correlated with temperature (Fig. 1) and to a lesser extent, precipitation (Holway et al. 2002b, Sanders and Gordon 2004, Fitzpatrick and Weltzin 2005, Fitzpatrick et al. in press, Lessard et al. in press), and productivity (Roura-Pascual et al. 2006). Only a handful of published studies have explicitly manipulated temperature,

Figure 1. The relationship between temperature and species density and abundance of *Aphaenogaster rudis*.

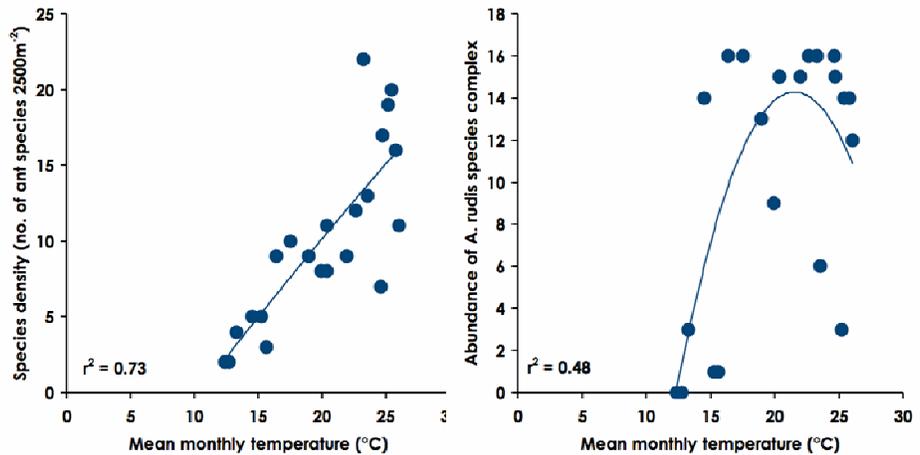


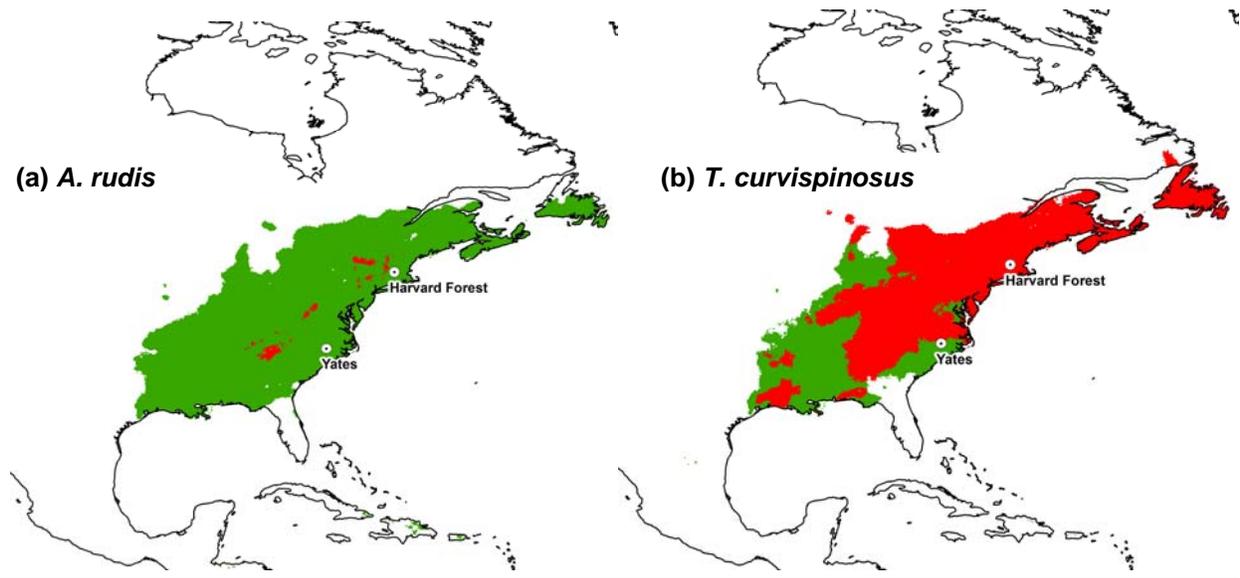
Table 1. Projected effects of a 3 °C increase in mean annual temperature on persistence of 11 ant species that currently occur at both Harvard Forest and Yates Forest.

	Harvard Forest	Yates Forest
Ponerinae		
<i>Ponera pennsylvanica</i>	Persistence	Persistence
Myrmicinae		
<i>Aphaenogaster rudis</i>	Persistence	Extinction
<i>Myrmecina americana</i>	Extinction	Extinction
<i>Temnothorax curvispinosus</i>	Persistence	Persistence
<i>T. longispinosus</i>	Persistence	Extinction
Formicinae		
<i>Formica neogegates</i>	Not modeled	Not modeled
<i>Camponotus pennsylvanicus</i>	Persistence	Extinction
<i>Prenolepis imparis</i>	Extinction	Extinction
<i>Formica subsericea</i>	Persistence	Persistence
<i>Lasius alienus</i>	Persistence	Extinction
<i>L. nearcticus</i>	Persistence	Extinction

generally reducing temperatures by using shade cloths, to examine the effects of temperature on ant communities (Arnan et al., in review; Wittmann et al. in prep.) These studies find shifts in ant composition and interactions with a decrease in temperature (due to shading) of 2 °C or greater. No studies, to our knowledge, have experimentally examined how projected temperature increases will affect ant communities and the functions they provide.

Dunn and Sanders have modeled the potential future distributions of common species found at one or both of our study sites using MaxEnt (Phillips et al. 2006). Assuming a relatively modest 3 °C increase in temperature by the year 2100 and perfect dispersal (species disperse to all potential climatic conditions), the response of the most common ant taxon in the eastern US, (*Aphaenogaster rudis* complex) to changes in temperature and rainfall in the eastern US in the next 100 years will be a dramatic range contraction and extinction at both of our study sites (Table 1, Figure 2). Of the other species found at our field sites, some species are predicted to go extinct at both the northern and southern extent of their ranges, some at just one end of their range, and some to go unchanged (Table 1, Figure 2). At least in a broad sense, these results accord with predictions for tree species (Iverson and Prasad 1998). However, these forecasts are

Figure 2. The effect of projected warming on the range sizes of *Aphaenogaster rudis* (a) and *Temnothorax curvispinosus*. Shown in green are the current ranges and in red, the projected ranges in 2100. Note the extreme contraction in the range of *A. rudis* and that the range of *T. curvispinosus* is projected to contract to just north of Yates Forest.



derived from models with strong but untested assumptions; ‘ground-truthing’ these results with experimental manipulations can reveal mechanisms underlying these changes in distribution and can provide valuable information on the ecosystem functions that will be altered as ant populations and communities change with climatic warming.

2b. Ants and the ecosystem functions they provide

Ants eat plants, eat other animals, modify soil properties and nutrient fluxes, and disperse seeds (Lobry de Bruyn 1990, Folgarait 1998). Thus, changes in ant populations and communities due

to climatic change could lead to cascades of changes in other trophic levels and in ecosystem processes in virtually all terrestrial ecosystems. In our proposed experiments, we will examine on how ants regulate seed dispersal and modify decomposition, and how the effects of ants on these processes may change as the climate changes. Here, we review existing information on these topics.

Seed dispersal is one of the most important roles played by ants in the forests of eastern North America. Because ant species differ in the extent to which they disperse seeds, seed dispersal dynamics are likely to change with changes in ant species composition (Beattie 1985, Gove et al. In press). In the temperate forests of eastern North America, species of the *Aphaenogaster rudis* species complex play a disproportionately important role in seed dispersal. At a site adjacent to Yates Forest and in Great Smoky Mountains National Park, *A. rudis* is responsible for > 90% of all seed dispersal by ants (Dunn, Sanders, Zelikova, unpublished data). *A. rudis* plays a similarly disproportionate role further north (Morales and Heithaus 1998, Heithaus et al. 2005).

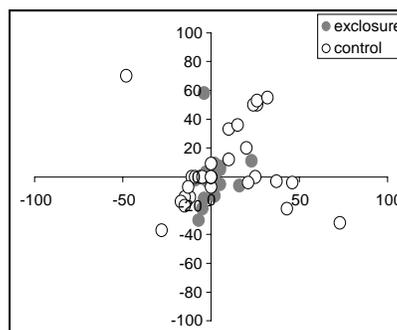
Sanders, Dunn and Zelikova (in preparation) experimentally removed *A. rudis* from forest plots to examine its effects on seed removal and dispersal of *Hexastylis arifolia*, a common understory species. Only limited dispersal occurs in the absence of *A. rudis* (Figure 3). If the range of *A. rudis* contracts as in figure 2, seed dispersal rates and hence the fitness of many rare plant species of the eastern U.S. may also be adversely affected. Furthermore, both the South American fire ant *Solenopsis invicta* and the Argentine ant *Linipithema humile* are predicted to increase in local abundance in and around Yates Forest and both of these invasive species are ineffective at dispersing seeds (Zettler et al. 2001, Carney et al. 2003, Ness and Bronstein 2004, Witt et al. 2004).

There is a growing appreciation that ants modify nutrient dynamics in arid landscapes (Lobry de Bruyn and Conacher 1990, Andersen 1990, Crist and Wiens 1996, Folgarait 1998, Whitford 2000, Wagner et al. 2004, Wagner and Jones 2004, 2006), but their role in ecosystem dynamics of eastern deciduous forests is more poorly understood (Lyford 1963, Stadler et al. 2006b). Ants might limit decomposition rates via their predatory effects on the decomposer community (Gonzalez and Seastedt 2001), but such effects should depend on climatic variation. The effects of ants are often greater in warm, wet environments (like those predicted under climatic change scenarios) than in cool, drier environments (Burghouts et al. 1992, Gonzalez and Seastedt 2001). However, no studies, to our knowledge, have experimentally assessed the extent to which climate mediates the effects of ants and other invertebrates as modulators of decomposition processes.

3. PROPOSED RESEARCH

Our experimental design includes manipulations of temperature in Open-Top Chambers (OTCs) at the northern and southern limits of many ant species in the eastern US. We will use these

Figure 3. Location of seedlings relative to a parent plant of *Hexastylis arifolia* (at 0, 0). In the absence of ants of the keystone seed disperser, *Aphaenogaster rudis*, dispersal distances and plant size (and presumably fitness) are both reduced.



OTCs to understand the consequences of projected warming on ant populations and communities and the ecosystem-level processes that ants mediate. In addition, we will couple these field experiments with warming experiments in the lab to examine the thermal tolerances of ant species in the US and to document how warming might affect colony growth rate and survivorship.

3a. Study sites

At the southern end of our experiment, we will conduct climate manipulations in an experimental forest at Yates Forest on the North Carolina State University (NCSU) properties. Yates Forest is in the North Carolina Piedmont, which is a major transition zone for many ant and plant assemblages. The southeastern boundaries of the majority of hardwood forest ant species are found in the Piedmont (Dunn and Sanders, unpublished). At the northern end of our experiment, we will conduct climate manipulations at the Harvard Forest LTER site (HFR). HFR is in the northern transitional hardwood region, and like the NC Piedmont, both the plants and animals occur at a “tension” zone between more northerly and more southerly flora and fauna (Cogbill et al. 2002). We note that more species (11) are shared between the Yates Forest and the Harvard Forest (1125 km apart) than are shared between the Yates Forest and the more open Longleaf Pine habitat just 100 km south of NCSU. By focusing our experiments on two areas of sharp ecological transitions, we dramatically increase the probability of detecting changes in species abundance due to climatic manipulations, and increase the probability that species not currently found in the study area might disperse into our experimental plots.

3b. Manipulating temperature

Our manipulations are intended to mimic projected increases in temperature over the next 100 years. The Hadley Centre Climate Model projects that by 2030, mean annual temperatures in the Southeast will increase by 1.0 °C; a further 1.3 °C increase is forecast to occur by 2100 (NAST, 2001). The Canadian Centre climate model projects substantially higher mean annual temperature increases of 5.5 °C by 2100. In the Northeast, lower emissions models predict increases of up to 4 °C and higher emissions models predict increases of up to 6 °C (NEAA Climate Report). We seek to bracket most of the range in climate predictions by increasing air temperatures from zero to 5 °C above ambient.

We will employ actively heated open top chambers (OTCs) to heat

Figure 4. OTC as part of the OCCAM experiment at Oak Ridge National Lab. The OTCs for our proposed experiment are modeled after this design with three notable exceptions: (1) our chambers will not have rainout shelters, (2) our chambers will have a 2-cm space at ground level to allow ants access to the plots, (3) our chambers will be 4 times as large: 5 m in diameter. Photo from <http://warming.ornl.gov/OCCAM/photos.html>



air, ground vegetation, and soil to produce a temperature change as similar as possible to that which ants might actually experience under future climate scenarios (Figure 4). Our OTCs will be 4 times larger than OTCs currently in use to study the effects of climatic change on community and ecosystem processes (e.g., Norby 1997; OCCAM experiment at Oak Ridge National Lab: <http://warming.ornl.gov/OCCAM.html>; Smithsonian Environmental Research Center experiments).

At each site, we will establish 10 5-m diameter ($\sim 20 \text{ m}^2$) chambers arranged across the site, approximately 10 m from one another in a 5×2 grid. The perimeter of each chamber will be trenched to 0.75 m depth and lined with polyethylene plastic film and insulating foam to minimize heat loss to surrounding soil. The frames for each chamber will be 3-m tall and constructed from aluminum piping. The frames will be covered with three polyvinyl chloride panels (Livingstone Coatings); the lower panel will serve as a double-walled plenum perforated on the inside with 2.5-cm diameter holes for air flow. The polyvinyl chloride panels of the OTC will be raised ~ 5 cm above the ground to permit ants to move in and out of the OTC. The OTC's will not have a rain shield.

Given the trade-off between the size and cost of experimental units, we sought to maximize the size of our experimental units so as to include within each as many ant colonies and species as possible. We decided on $\sim 20 \text{ m}^2$ for our OTCs because this area represents a sufficiently large size to capture community-level processes. Based on intensive studies by Herbers (1989) in Vermont and New York, we estimate that a 20 m^2 plot is large enough to include 40-60 ant colonies and at least eight species. Such a density of colonies suggests that our OTC manipulations will capture population-level (number of nests, worker activity) and community-level (richness, composition, etc.) responses to the treatments. Given the similarity of our northern study site to those sites studied by Herbers (e.g. Gotelli and Ellison 2002a), it is reasonable to expect a similar density of colonies at Harvard Forest. Because the density and diversity of ants at our southern study site, Yates Forest, are higher than those at Harvard Forest (or Herbers's sites, (Herbers 1989)), we expect even more colonies and species. Further, preliminary data at both sites indicate that the focal species (*Temnothorax curvispinosus*, *Temnothorax curvispinosus* and *Aphaenogaster rudis*) are sufficiently common to occur multiple times within a given 20 m^2 OTC at one or both sites.

We will control temperature using a modification of the approach advocated by Norby et al. (1997) and employed at Oak Ridge National Lab in the OCCAM experiment. Air will be supplied to each OTC by four combined blower-cooler units (manufactured by Trane). Each of these blower-cooler units provide $2 \text{ m}^3/\text{s}$ of air flow. Ground-water-supplied cooling units will minimize latent cooling (cooling is necessary to maintain ambient temperatures). This approach also minimizes effects on humidity. We will place voltage regulators on resistance heaters to control air temperatures in the OTCs using PID controllers and type-T thermocouples in the middle of each OTC, 20 cm above the ground surface. Soil temperatures should also be elevated using this approach, but only to $\sim 40\%$ of that of air temperatures. Air and soil temperatures, as well as relative humidity, will be monitored in the OTCs. Soil temperatures will be recorded in the organic and mineral soils (approximately 5 and 15 cm below the surface); air temperature and relative humidity will be recorded at 20-cm above the ground surface. All data will be stored using Campbell data loggers and multiplexers and streamed directly to remote servers.

One of the limitations of many temperature manipulations to date has been the use of a single temperature for manipulations – that is, plots are either warmed to the maximum expected level

or maintained at ambient (current) conditions. But these standard experimental designs based on the analysis of variance are not adequate for understanding the effects of gradual global climatic change. Because field manipulations of temperature are expensive, only a few replicates per temperature level would be possible in an ANOVA design. The results of such an experiment might be almost trivial, because we know that if the elevated temperatures are extreme, some response will occur. Moreover, the results of the ANOVA experiment will be entirely dependent on the arbitrary temperature categories that are established (Gotelli and Ellison 2004).

Conceptually, the problem in designing warming experiments is that temperature is a continuous variable yet most studies treat and analyze it (ANOVA) as a categorical variable. The solution is a response-surface (regression) design (Cottingham et al. 2005), in which each replicate is maintained at a different temperature level. The resulting data can be fit with linear or non-linear models to estimate temperature effects, with an error term that is estimated from the deviation of each point from the fitted model. Categorical variables such as site or species can be readily incorporated into an analysis of covariance (ANCOVA), with direct tests for interactions between temperature and categorical factors. Even with no replicates per site ($n = 11$), this design can reveal non-linear, asymptotic, hump-shaped, or threshold effects of elevated temperature on population and community responses (Cottingham et al. 2005). Most importantly, by spanning a large range of temperature increases in the regression design, we will be able to describe the functional form of the temperature response curve that can be integrated into a variety of potential climate-change scenarios.

Table 2. Levels of warming, in °C.

1	Ambient
2	0.5
3	1.0
4	1.5
5	2.0
6	2.5
7	3.0
8	3.5
9	4.0
10	5.0

Thus, our approach is explicitly a response-surface design. At each site, temperatures in the OTCs will be maintained within a range of ambient air temperature + 0°C to ambient + 5°C, with 0.5° steps between chambers, except for the hottest chambers (Table 2).

We chose our temperature manipulations to reflect changes ranging from those projected for the next ten years to those projected for the next hundred years. Temperature manipulations range from ambient (zero change) to 5°C above ambient in each site. Because we will be monitoring ambient temperatures in each chamber, we can analyze effects of both relative and absolute shifts in temperature and calibrate the results to predictions of climate change models for each site.

4. RESPONSE VARIABLES

4a. Activity, abundance, and colony size

Our experiments will examine how projected warming affects the activity, abundance (number of nests), and colony size (number of workers per nest). To track changes in populations we will use three methods. First, we will sample ten substations within each experimental plot once each month using cookie (Pecan Sandies ©) baits which attract the main ants of concern (Agosti 2000). Second, once every two months we will sample 6 points within each plot using pitfall traps. Whereas baits disproportionately sample competitively dominant species, pitfall traps are a more unbiased measure of abundance and do a better job of sampling rare, behaviorally subordinate species. We will also use standard techniques to document interspecific interactions

and foraging behavior at baits (Fellers 1987b, Human and Gordon 1996) to assess how increasing temperature might alter interactions among species (Cerdá et al. 1998). Finally, within each plot, we will place 5 artificial nests for each of the following species *Aphaenogaster* spp. (box nests) (Lubertazzi pers. comm.), *Temnothrax* spp. (drilled dowels) (Foitzik and Heinze 1998), and *Formica* spp. (rocks). Occupation rates of *Aphaenogaster* nest boxes are typically greater than 90% (Lubertazzi, unpublished). Artificial nests will allow us to take snapshots of colony size and reproductive investment through time. Artificial nests can be checked in the field thus allowing the same nest to be sampled repeatedly through time. Sampling nest boxes through time will also give us a sense of changes in colony number through time.

4b. Community composition

Community composition will change as the abundances of species change. For each plot, we will compile the data summarized above to ask how the treatments affect the composition of communities. We will use standard multivariate techniques (PCA, NMDS) to assess the extent to which warming alters community composition. The presence/absence of species from outside the study habitat will be inferred based on extensive ongoing baseline collections in the region.

4c. Seed dispersal

We will use two methods to test whether temperature increases will cause cascading change in the abundance of important seed dispersers (*Aphaenogaster rudis*) and the dispersal and survival of seeds of bloodroot, *Sanguinaria canadensis*. Both methods have been tested successfully in pilot studies by PI Dunn at Yates forest and in Dunn's ongoing work on ants and seeds in Australia (Gove et al. in press, Dunn et al. 2007, Cancela et al. 2007). First, we will examine the rate of removal of seeds by ants. We will place seeds on the ground in each of four sites 1.5 m from the edge of each OTC. We will then observe the ants that remove the seeds, the removal rate of seeds, and the rate of removal overnight of caged (to exclude vertebrates) and uncaged seeds. Seeds will be observed during the first two hours at each site and then checked after 24, 48 and, if necessary, 96 hours. These seed removal trials will assess the rate of seed dispersal and the proportion of seeds that go undispersed. OTCs will be placed in sites lacking bloodroot plants so as to minimize contamination from preexisting bloodroot individuals. We will infer the fitness of those seeds that are taken by ants based on the identity of the ants taking seeds. Judith Canner, a PhD student working with Dunn is in the process of assessing the fitness of *S. canadensis* seeds removed by the ten most common ant species in the area of the Yates Forest study plots. Similar work will be conducted in the Harvard forest plots, where seeds are marked, followed to nests and then their fate tracked over the succeeding year.

4d. Decomposition

Though decomposition is mainly the result of microbial activities and is limited at the local scale by litter quality, soil micro- and macro-arthropods can alter decomposition rates (e.g., Gonzalez and Seastedt 2001, Milton and Kaspari 2007). Here, we will assess the extent to which temperature increase and ant activity affect rates of decomposition. In the 2nd and 3rd year of the experiment (3rd and 4th years of the grant), we will use a standard substrate decomposition design: mass loss of cellulose filter papers (4 g, Whatman #1) in 5 cm square decomposition bags made of two layers of nylon veil (3 mm mesh) on the top and plastic window screen (1.3 mm mesh) on the bottom. This design removes litter quality as an explanation of decomposition in this ecosystem and focuses exclusively on how treatments may alter mass loss (Harmon et al. 1999, Robertson and Paul 2000). Bags will be stitched together on three edges with polyester

thread and stapled on the fourth edge with stainless-steel staples (for easy addition and removal of material). In each chamber, we will place 12 decomposition bags; six of the bags will have two standard mothballs in crystalline form on two of the corners of the bags to deter ants and arthropods and the other six bags will serve as controls. One bag will be removed every two months in each year, brought back to the lab in an individual paper bag. Filter paper will be removed from each bag, dried at 65 °C, weighed, and ashed at 550 °C for 6 h (Binkley 1984).

Ants affect decomposition by affecting microarthropod abundance and composition, which likely responds to ant abundance (ants are omnivorous predators). To examine how temperature and ants interact to shape microarthropod communities, we will extract microarthropods from the decomposition bags just prior to analyzing the filter papers. We will place decomposition bags in modified Tullgren funnels (Santos et al. 1978) to extract microarthropods for 48 hours into water filled containers. We will estimate faunal density and diversity per gram of dried litter, focusing on the collembola, and mites which can make up a large majority of microarthropods in leaf litter samples (Crutsinger and Sanders, in prep; Milton and Kaspari 2007).

4e. Ancillary datasets

There is no dearth of data that could be collected in this experiment. Though we will focus on the response of ant populations and communities and the processes they mediate, we will also collect data on plant community structure in the understory (cover, richness, phenology, height, and estimated aboveground biomass). Within each OTC, we will randomly place three permanent 0.25 m² quadrats. During the peak growing season at each site, we will record species identity, height, and canopy cover. Cover will be estimated based on the pin-drop method. Aboveground net primary production (ANPP) will be determined for each species based on non-destructive allometric equations.

4f. Statistical analyses

The experimental design has 10 temperature levels established at two sites, for a total sample size of N= 20 replicates. The plots will be censused before the start of the experiment and then during 3 years following treatment establishment. The statistical analysis is a repeated measures analysis of covariance, with site (Yates Forest, Harvard Forest) as the factor, temperature (10 levels ranging from ambient to ambient + 5° C) as the continuous covariate, and year (1,2,3) as the repeated measures factor. Data collected the year before the temperature manipulations will be treated as a second covariate, or used to make a scaling adjustment to each observation in a plot. Analyses will be performed for standard univariate measurements of biological variables (ant abundance, activity, colony size, seed density, decomposition rates). Subsamples collected within years or within plots will be pooled and averaged to avoid problems with pseudo-replication (Gotelli and Ellison 2004). For analyses of the abundance of common species, species identity will be introduced as a second discrete factor, and *a-priori* contrasts will be used to test for differential responses of northern versus southern species. All of the ANCOVA analyses will be subject to diagnostic analysis of residuals. When warranted, we will use non-linear regression models (including LOESS and spline smoothing, and logistic regression) to estimate parameters for non-linear or threshold responses in the data (Venables and Ripley 2002).

The analyses will generate two kinds of information. First, the standard null hypothesis tests will reveal whether there is a statistically significant effect of temperature on the response variable. Second, and most important, we will be able to estimate the regression model parameters (and their confidence intervals). These parameters will quantify the strength of the response to

projected temperature increases, and the uncertainty associated with that response. Non-linear models will generate parameters that quantify threshold and asymptotic responses. These model results can then be related to the predictions of climate change models to forecast how communities will shift under different warming scenarios.

4g. Complementary lab experiments

We will maintain field-collected colonies in the lab to focus on how temperature manipulations affect colony survival and production. Lab colonies of seven of the species found at Yates are already maintained. At each site, for at least the 10 most common species, we will examine the effects of temperature manipulation on five aspects of colony life history likely to be influenced by temperature, (1) number of larvae, (2) size of larvae, (3) number of reproductive ants (males and females), and (4) size of reproductives, (5) colony growth rate. We will also monitor mortality. Our expectation is that for most species that the number and size of larvae and the number and size of reproductive individuals will increase with temperature due to acceleration of growth rates. Beyond some critical point, however, higher temperatures can be expected to lead to higher individual and colony mortality (Elmes and Wardlaw 1983, Southerland 1988). The relative temperatures of those critical points should correlate with species responses to the experimental warming in the field.

Ants will be cultured in standard nests in aerated concrete with adequate supplies of water, sugar and protein (dead cockroaches). Temperature regimes will be designed to approximate those in the field plots with five replicates per treatment level in the regression design. Temperatures will be maintained using water jacketed incubators. Humidity and fresh atmosphere will be maintained in these plots using water and soda lime (the latter absorbing CO₂). Into each nest a standardized number of workers (based on the average found in the field for that species) will be placed along with a queen. Natural photoperiods will be maintained throughout the experiments. Colonies will be checked every ten days for the development of brood, the production of alates, and dead ants. Weights of adult ants and larva will be assessed at the end of the experiment. We will also assess thermal tolerances of the key species at our study sites using standard techniques (Holway et al. 2002b). We will test tolerances in increments 2° C from ambient temperatures at each site up to ~60° C. For each temperature we will pace 10 workers of each species in a glass test tube plugged with cotton and then place the tubes in incubator. After one hour, we will tally the number of workers out of ten that survived.

5. Responsibilities of investigators

Robert R. Dunn (NCSU) will be responsible for overall project integration and coordination and construction and operation of the NC field facility. He will also be responsible for supervision of students and the postdoc based at NCSU and for aspects of the monitoring of plots.

Nathan J. Sanders (UT) will be jointly responsible with Dunn for monitoring the NCSU field facility and for training students.

Aaron Ellison (Harvard Forest) will be responsible for coordination, construction and operation of the Harvard Forest facility. He will also be jointly responsible for supervision of students at the Harvard Forest facility and for aspects of the monitoring of the Harvard Forest plots.

Nick Gotelli (University of Vermont) will be jointly responsible with Ellison for monitoring the Harvard Forest. He will be responsible for supervision of the postdoc based at UVM.

PROJECT OBJECTIVES AND INTEGRATION

Our unique design – replicating a warming experiment at the southern and northern range boundaries extent of many key ants species - will likely yield valuable information about the extent to which projected climatic change will affect the abundances of ants and the ecosystem services that they provide.

While this proposal does not explicitly incorporate a modeling component, our existing databases on ant distribution and ongoing work by Dunn and Sanders employing distribution models to understand the effects climate changes on ant distribution will use the data generated here to develop new models and improve existing models for changes in distributions of a range of ant species. Because we are focusing on two study sites, similarities and differences between sites will allow us to understand the extent to which results for single sites might be generalized to entire landscapes. Finally, the proposed work is part of a broader effort by the PIs to understand the relationship between climate and the distribution, abundance, diversity and composition of ants, in the eastern U.S. and in more far-flung areas. The deliverables from this project, and related projects, are currently underway. For example, a manuscript focused on ascertaining the effects of projected climatic change on regional ant biodiversity (See figure 2) is in preparation. Specific deliverables peer-reviewed publications, websites, teacher training, public tours, undergraduate involvement, and publications for general audiences will begin almost immediately. Collectively, our team of collaborators is heavily engaged in outreach. In addition, we have a long series of collaborative projects and publications.

PROJECT TIMETABLE

OBJECTIVES	1/08-1/09	1/09-1/10	1/10-1/11	1/11-1/12
Install OTCs	■			
Turn on OTCs		■	■	■
Pretreatment sampling of plots			■	■
Sample plots			■	■
Measure seed dispersal			■	■
Sorting and ID of samples from Q1 and Q3			■	■
Manuscript preparation	■		■	■

It will take us a full year to construct the chambers and implement the treatments. We will spend 1/1/08-1/1/09 building our infrastructure. We will start experiments in March 2009 and run them for three field seasons (2009, 2010, 2011). Note we will consequently have no electric bills until 3/09. Because the first year will include only set-up, we have budgeted for contractors, but not for postdocs or graduate students. Postdocs and graduate students will both begin in 1/09, once the infrastructure is ready.

PROJECT PEFFORMANCE SITE

The project will be carried out at two sites, Harvard Forest in Massachusetts and Yates Forest in North Carolina.

BIOGRAPHICAL SKETCH APPENDIX
ROBERT R. DUNN

Department of Zoology, North Carolina State
University David Clark Labs,
Raleigh, NC 27695-7617

Web:<http://www4.ncsu.edu/~rrdunn/>
E-mail: Rob_Dunn@ncsu.edu
Phone: (919) 513-7569

Education and Training

Assistant Professor, North Carolina State University (2005-present)
Postdoctoral Fellow, University of Tennessee (2004-2005)
Fulbright Fellow, Curtin University, Australia (2003-2004)
Ph.D., Dept. Ecology and Evolutionary Biology, University of Connecticut (1998-2003)
B.A. with Honors: Biology, Kalamazoo College (1993-1997)

Selected Research and Professional Experience

Fulbright Postdoctoral Fellow, Curtin University of Technology, Perth, WA and Macquarie University, Sydney, Australia. 2005.
Visiting Researcher, Programa de Manejo de Bosques (PROMAB), Riberalta, Bolivia (1998-2001).
Researcher; Black Rock Forest; The effects of forest fragmentation on burying beetle movement, relative abundance and diversity. Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, with James Danoff-Burg, Barnard College, 1998.
Consultant and Researcher; NCRC, Ghana; Effects of bush clearing on the diversity and abundance of soil arthropods, and the role of remnant trees as refuges for diversity in actively farmed areas, 1998.

Publications

**= undergraduate student coauthor
* = graduate student coauthor.

Dunn, R.R., C.R. Parker, M. Gerhaghty, and N.J. Sanders. 2006. Reproductive phenologies in a diverse temperate ant fauna. *Ecological Entomology*. XX: XXX- XXX.
Dunn, R.R., N. Sanders and C. McCain. 2006. When do empirical patterns of diversity differ from null models and why? *Global Ecology and Biogeography*. XX: XXX-XXX.
Dunn, R. R., Gavin, M., Sanchez, M. and J. Solomon. 2006. The pigeon paradox or how the future of conservation depends on pests. *Conservation Biology*. 20: 1814-1816.
Dunn, R.R., C.R. Parker and N. Sanders. 2006. Disentangling the roles of competition and the environment as drivers of phenological patterns of ant diversity. *Biological Journal of the Linnean Society*. XX-XXX.
Matthew C. Fitzpatrick, M.C., Weltzin, J.F., Sanders, N.J. and R.R. Dunn. 2006. The biogeography of prediction error: Why does the introduced range of the fire ant over-predict its native range? *Global Ecology and Biogeography*. XX- XXX (Online early).
Dunn, R. R., Gove, A. & Majer, J. 2006. Seed dispersal mutualisms with ants and patterns of plant diversity in western Australia. (In: eds Vilela, E. F., Santos, I. A., Schoereder, J. H.

- Campos, L. A. O. & Serrão, J. E.). Fronteiras do conhecimento em Insetos Sociais. Editora Universidade Federal de Viçosa, MG. 178 p.
- Dunn, R.R., R.K. Colwell, and C. Nilsson. 2006. The River Domain: Why are there so many species half way up the river? *Ecography*. 29 (2), 251-259.
- Dunn, R.R., and T. S. Romdal. 2005. The effects of local forest conversion on mean geographic range size of Neotropical bird assemblages. *Global Ecology and Biogeography*. 14(4):359-366.
- Dunn, R.R. Where are all the extinct insect species and why don't we know? *Conservation Biology* (*in press*).
- Koh, L.P*, R.R. Dunn (Joint First Author), † N.S. Sodhi, R.K. Colwell, H.C. Proctor, † & V.S. Smith. 2004. Species co-extinctions and the biodiversity crisis. *Science* 305: 1632-1634.

Synergistic activities

My most visible synergistic activity is popular writing. I have published more than forty popular articles in the past 5 years (some below) and am under contract to write a book for Harper Collins/Smithsonian on the history of biological discovery for a broad audience.

- Dunn, R. R. In Press, The Inhabit(ants) of North Carolina. *Carolina Wildlife*.
- Dunn, R. R. In Press, A Little Life in the Smokies. *BBC Wildlife Magazine*.
- Dunn, R. R. In Press, The Edge of the Earth. *Natural History*.
- Dunn, R. R. In Press, What to do with an Urban Turtle. *Natural History*.
- Dunn, R. R. In Press, Guns and Butterflies. *Wildlife Conservation*.
- Dunn, R. R. In Press, Backyard Scientist. *National Wildlife*.
- Dunn, R. R. In Press, In Defense of Roaches. *BBC Wildlife*.
- Dunn, R.R. In Press, A Rat's Nest in Eden. *National Wildlife*.
- Dunn, R. R. December/January, 2006, The Future of Evolution. *Seed Magazine*.
- Dunn, R. R. December, 2006, Dig It! *Natural History*.
- Dunn, R. R. August, 2006, What Humans Can Learn from Social Insects. *Seed Magazine*.
- Dunn, R. R. November, 2006, Primate Behavior. *BBC Wildlife*.
- Dunn, R.R. September, 2005 Jaws of Life. *Natural History*.

NATHAN J. SANDERS
Department of Ecology & Evolutionary Biology
569 Dabney Hall
University of Tennessee
Knoxville, TN 37996

E-mail: nsanders@utk.edu
Web: web.utk.edu/~nsanders
Phone: (865) 974-5231
Fax: (865) 974-3067

Education and Training

Assistant Professor, University of Tennessee (2004-present)
Assistant Professor, Humboldt State University (2001-2003)
Postdoctoral Fellow, University of Tennessee (2001)
2001 PhD, Stanford University
1995 BA, University of Colorado

Selected Research and Professional Experience

Board of Editors, *Ecography* (2006 – present)
Editorial Board Member, *Oecologia* (2006 – present)
Editorial Board Member, *Diversity and Distributions* (2007-present)

Publications

* = graduate student

** = undergraduate student

Sanders NJ, Gotelli NJ, Wittman SE*, Ratchford JS, Ellison AM, Jules ES (In press) Assembly rules for ant communities across spatial scales and habitats. *Journal of Biogeography*

Sanders NJ, Lessard J-P**, Dunn RR, Fitzpatrick MC* (2007) Temperature, but not productivity or geometry, predicts elevational diversity gradients in ants across spatial grains. *Global Ecology and Biogeography*

Hellmann JJ, Sanders NJ (In press) The patterns of and threats against global insect diversity. *Issues in Environmental Science and Technology* [authors contributed equally]

Crutsinger GM*, Collins MD*, Fordyce JA, Gompert Z*, Nice CC, Sanders NJ (2006) Genotypic diversity predicts community structure and governs an ecosystem process. *Science* 313: 966-968

Sanders NJ, Gordon DM (2004) The interactive effects of climate, life history, and interspecific neighbors on mortality in a population of seed harvester ants. *Ecological Entomology* 29: 632-637

Sanders NJ, Belote RT*, Weltzin JF (2004) Multi-trophic effects of elevated CO₂ on understory plant and arthropod communities. *Environmental Entomology* 33: 1609-1616

Sanders NJ, Gotelli NJ, Heller NE*, Gordon DM (2003) Community disassembly by an invasive ant species. *Proceedings of the National Academy of Sciences* 100: 2474-2477 [featured in *Science News* 163: 134]

Sanders NJ, Gordon DM (2003) Resource-dependent interactions and the organization of desert ant communities. *Ecology* 84: 1024-1031

Sanders NJ, Moss J**, Wagner D (2003) Patterns of ant species richness along elevational gradients in an arid ecosystem. *Global Ecology and Biogeography* 12: 93-102

Weltzin JF, Belote RT, Sanders NJ (2003) Biological invaders in a greenhouse world: will elevated CO₂ fuel plant invasions? *Frontiers in Ecology the Environment* 1:146:153

Synergistic activities

I have taught courses in Principles of Ecology and Causes and Consequences of Biodiversity at Humboldt State, Field Ecology at the Rocky Mountain Biological Lab and at Stanford University, Ecological Interactions at Stanford University and Conservation Biology and General Ecology at the University of Tennessee. After graduation from college, I taught high school science. At Stanford, I was a pioneer

member of the I-RITE program at Stanford University (<http://sll.stanford.edu/projects/i-rite/>), a program to integrate teaching and research. My contribution to the program was featured in the Chronicle of Higher Education and at The Boyer Commission on Educating Undergraduates in the Research University: A Second Anniversary Perspective at SUNY-Stony Brook. One outreach program, a bug walk for teenagers from poor neighborhoods, was featured in the March/April 2001 issue of Sierra Magazine. I recently organized a symposium to synthesize the impacts of invasive social insects and another on Niche Theory and Neutral Theory. For the past two summers, I have also engaged public school teachers in my research program.

NICHOLAS J. GOTELLI

Department of Biology, University of
Vermont Marsh Life Science Building
Burlington, VT 05405

Web:
<http://www.uvm.edu/~ngotelli/homepage.html>
E-mail: Nicholas.Gotelli@uvm.edu
Phone: (802) 656-0450

Education and Training

Full Professor, Department of Biology, University of Vermont (2000- present)
Associate Professor, Department of Biology, University of Vermont (1995 – 2000)
Assistant Professor, Department of Biology, University of Vermont (1992-1994)
Assistant Professor, Department of Zoology, University of Oklahoma (1988 – 1992)
Post-doctoral Associate, Dept of Biology, Colorado State University (1987 – 1988)
Lecturer, Dept of Organismic & Evolutionary Biology, Harvard University (1985 – 1987)
Florida State University; Ph.D., December 1985 Advisor: D. Simberloff (1982 – 1985)
Florida State University; M.S. June 1982 Advisor: L.G. Abele (1980 – 1982)
University of California, Berkeley; B.A. 1980 Phi Beta Kappa (1976 – 1980)

Selected Research and Professional Experience

Fulbright Fellow, 1993.. The Evolution of Altered Host Behavior. Research Award, University of Oxford, Great Britain. Visiting Researcher.
Ideas & Perspectives Editor, Ecology Letters (2005 – present)
Board of Editors, Journal of Biogeography (2004 – present)
Board of Editors, Oikos (2005 – present)
Board of Editors, Ecology Letters (2002 – present)
Board of Editors, Ecology (2001 – present)
Local Hosting Committee ESA Montreal Meeting (2005)
NCEAS Science Advisory Board (2002 – 2005)
Board of Editors, Biodiversity Letters (1992 - 1997)
Board of Editors, The American Naturalist (1994 - 1998)
Mercer Awards Committee Member, ESA (1997 - 1999)
Mercer Awards Committee Chair, ESA (1999 - 2001)

Publications

* = graduate student coauthor.

Gotelli, N. J., and A. M. Ellison. 2006. Food-web models predict species abundance in response to habitat change. *PLoS Biology* 44: e324.
Gotelli, N. J. and A. M. Ellison. 2006. Forecasting extinction risk with non-stationary matrix models. *Ecological Applications* 16: 51-61.
Gotelli, N. J. and B. J. McGill. 2006. Null versus neutral models: what's the difference? *Ecography* 29: 793-800.
Sanders, N.J., N.J. Gotelli, N.E. Heller, & D.M. Gordon. 2003. Community disassembly by an invasive species. *Proceedings of the National Academy of Sciences, U.S.A.* 100: 532-535.
Gotelli, N.J., & A.M. Ellison. 2002. Assembly rules for New England ant assemblages. *Oikos* 99: 591-599

- Gotelli, N.J., & A.M. Ellison. 2002. Biogeography at a regional scale: determinants of ant species density in bogs and forests of New England. *Ecology* 83: 1604-1609.
- Gotelli, N.J. and R.K. Colwell. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4: 379-391.
- Albrecht, M.* and N.J. Gotelli. 2001. Spatial and temporal niche partitioning in grassland ants. *Oecologia* 126: 134-141.
- Gotelli, N.J. and A.E. Arnett*. 2000. Biogeographic effects of red fire ant invasion. *Ecology Letters* 3: 257-261.
- Ellison, A.M., E.J. Farnsworth, and N.J. Gotelli. 2002. Ant diversity in pitcherplant bogs of Massachusetts. *Northeastern Naturalist* 9: 267-284.

Synergistic activities

My most visible synergistic activity is textbook writing. *A Primer of Ecology* (3rd edition 1996, 1999, 2001; Sinauer Associates) has been used by over 70,000 students and is required at over 100 colleges and universities around the world. It is currently being translated into Portuguese. My most recent textbook, co-authored with PI Aaron Ellison is *A Primer of Ecological Statistics* (2004; Sinauer Associates). Ellison and I are currently writing a new textbook with Sinauer Press on the analysis of large-scale ecosystem experiments. Finally, I have written with Gary Entsminger a widely-used software program, *EcoSim*, for null model analysis and randomization tests in community ecology (<http://www.garyentsminger.com/ecosim/ecosim.htm>).

AARON M. ELLISON

Harvard University
Harvard Forest
PO Box 68
Petersham, MA 01366

tel: 978-724-3302
fax: 978-724-3595
email: aellison@fas.harvard.edu

EDUCATION AND TRAINING:

Yale University	Asian Philosophy	B.A. 1982
Brown University	Evolutionary Ecology	Ph.D. 1986
Cornell University	Ecosystems Ecology	Post-doc 1986-1988
Tulane University/OTS	Community Ecology	Post-doc 1988-1989

RESEARCH AND PROFESSIONAL EXPERIENCE:

June 2002 – present: Senior Ecologist, Harvard Forest, and Senior Research Fellow, Department of Organismic and Evolutionary Biology, Harvard University

Sept. 2001-May 2002: Charles Bullard Fellow, Harvard Forest

July 1990 – June 2002: Assistant (1990-1993), Marjorie Fisher Assistant Professor (1990-1996), Marjorie Fisher Associate Professor (1996-2001), Marjorie Fisher Professor (2001-2002) of Environmental Studies, Department of Biological Sciences, Mount Holyoke College

July 1989-June 1990: Visiting Assistant Professor, Swarthmore College

PUBLICATIONS:

Sanders, N. J., N. J. Gotelli, S. E. Wittman, J. S. Ratchford, **A. M. Ellison**, and E. S. Jules. 2007. Assembly rules of ground-foraging ant assemblages are contingent on disturbance, habitat, and spatial scale. *Journal of Biogeography* (in press).

Dixon, P. M., **A. M. Ellison**, & N. J. Gotell. 2005. Improving the precision of estimates of the frequency of rare events. *Ecology* 86: 1114-1123.

Ellison, A. M., M. S. Bank, B. D. Clinton, E. A. Colburn, K. Elliott, C. R. Ford, D. R. Foster, B. D. Kloeppe, J. D. Knoepp, G. M. Lovett, J. Mohan, D. A. Orwig, N. L. Rodenhouse, W. V. Sobczak, K. A. Stinson, J. K. Stone, C. M. Swan, J. Thompson, B. von Holle, and J. R. Webster. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment* 9: 479-486.

Ellison, A. M., J. Chen, D. Díaz, C. Kammerer-Burnham, and M. Lau. 2005. Changes in ant community structure and composition associated with hemlock decline in New England. Pages 280-289 in B. Onken and R. Reardon, editors. *Proceedings of the 3rd Symposium on Hemlock Woolly Adelgid in the Eastern United States*. US Department of Agriculture - US Forest Service - Forest Health Technology Enterprise Team, Morgantown, West Virginia.

Ratchford, J.S., S. E. Wittman, E. S. Jules, **A. M. Ellison**, N. J. Gotelli, and N. J. Sanders. 2005. The effects of fire, local environment, and time on ant assemblages in fens and forests. *Diversity and Distributions* 11: 487-497.

- Ellison, A. M.** 2004. Bayesian inference in ecology: historical antecedents, current developments, and future prospects. *Ecology Letters* 7: 509-520.
- Gotelli, N. J., and **A. M. Ellison**. 2004. *A Primer of Ecological Statistics*. Sinauer Associates, Sunderland, Massachusetts.
- Gotelli, N. J. & **A. M. Ellison**. 2002. Assembly rules for New England ant assemblages. *Oikos* 99: 591-599.
- Ellison, A. M.**, E. J. Farnsworth & N. J. Gotelli. 2002. Ant diversity in pitcher-plant bogs of Massachusetts. *Northeastern Naturalist* 9: 267-284.
- Gotelli, N. J. & **A. M. Ellison**. 2002. Biogeography at a regional scale: determinants of ant species density in bogs and forests of New England. *Ecology* 83: 1604-1609.

SYNERGISTIC ACTIVITIES:

2006 – present: Co-PI, Harvard Forest LTER.

2005 – present: Program Director, Harvard Forest Summer Research Program in Ecology (NSF REU site)

2002 – present: Associate Editor-in-Chief, *Ecology* and *Ecological Monographs*

2004 – present, Board of Editors, *Ecology Letters*

1998 – 2001: Founding Editor, *Ecological Archives*

Current and Pending Support Appendix

Current and Pending Support, Rob Dunn

Proposal title: Effects of ants and ant-mediated dispersal on speciation rates, biogeography and diversity of Southwestern Australian and Fynbos plants. I lead the grant. Others involved are Jonathan Majer (Curtin University) and Tim Barraclough (Imperial College).

Source of support: Australian Research Council.

Total award amount: AU\$230,000.

Starting date: 06/01/05

Ending date: 05/30/08

Proposal title: Quantifying long-distance seed dispersal and its role in the meta-population dynamics of plants with contrasting life histories and dispersal modes. I am one of several collaborators on this grant, including Neal Enright (Melbourne University), Byron Lamont (Curtin University), and Siegy Krauss (King's Park Botanical Garden).

Source of support: Australian Research Council.

Total award amount: AU\$670,000.

Starting date: 06/01/05

Ending date: 05/30/10

Proposal title: Nutrient flux as a potential driver of ant diversity in Australia. PI along with Terry McGlynn.

Source of support: National Geographic.

Total award amount: US \$19,000.

Starting date: 06/01/06

Ending date: 05/30/07

Proposal title: The Causes and Consequences of Invasion by a Ponerine ant, *Pachycondyla chinensis*.

Source of support: CALS Pilot funds.

Total award amount: US \$10,000.

Starting date: 06/01/06

Ending date: 05/30/08

Proposal title: Fragmentation in tropical rainforests, a study of 200 islands.

Source of support: National University of Singapore. CI, along with PI Prof. Navjot S. Sodhi and three other researchers.

Total award amount: US \$200,000.

Starting date: 06/01/06

Ending date: 05/30/08

Proposal title: Using equilibrium tests and historical data to improve distribution models – a study with ants

Source of support: NICCR/DOE

Project location: southeastern US

Total award amount: \$120,508

Starting date: 06/01/07

Ending date: 05/30/08

Support type: Pending

Person-months per year committed to the Project: 1 month/summer

Current and Pending Support, Nicholas Gotelli

2006-2010. National Science Foundation. Moths, ants, and carnivorous plants: the spatial dimension of species interactions. Co-PI Aaron Ellison. US **\$645,000**.

Current and Pending Support Appendix, Aaron Ellison

Current:

Project/Proposal Title: REU Site: Harvard Forest REU Program in Forest Ecology 2005-2009:

Multi-scale investigations of a forested ecosystem in a changing world

Source of Support: National Science Foundation

Project Location: Harvard Forest

Total Amount Requested: \$732,042 (Lead PI)

Starting Date: 03/01/2005

Ending Date: 02/28/2010

Person Months per Year Committed to Project: 1.5 (calendar)

Project/Proposal Title: Collaborative Research: Moths, ants, and carnivorous plants: the spatial dimension of species interactions

Source of Support: National Science Foundation

Project Location: Harvard Forest, University of Vermont, New England, New York

Total Amount Requested: \$585,000 (Lead PI)

Starting Date: 4/1/2006

Ending Date: 3/31/2011

Person Months per Year Committed to Project: 2.0 (calendar)

Project/Proposal Title: LTER-IV: Integrated studies of the drivers, dynamics, and consequences of landscape change in New England (co-PI)

Source of Support: National Science Foundation

Project Location: Harvard Forest

Total Amount Requested: \$4,920,000

Starting Date: 10/1/2006

Ending Date: 9/30/2012

Person Months per Year Committed to Project: 1.0 (calendar)

Pending:

Project/Proposal Title: Collaborative research: What factors govern the rate of spread of an invasive species? The importance of dispersal and selection in range expansion

Source of Support: National Science Foundation

Project Location: Harvard Forest, University of Massachusetts, University of Rhode Island

Total Amount Requested: \$180,295 (Collaborator)

Starting Date: 9/1/2007

Ending Date: 8/31/2010

Person Months per Year Committed to Project: 0.5 (calendar)

Project/Proposal Title: Collaborative Research: Are ecosystem dynamics governed by direct or indirect effects associated with the loss of foundation species?

Source of Support: National Science Foundation

Project Location: Harvard Forest, Coweeta Hydrological Lab

Total Amount Requested: \$585,534 (Lead PI)

Starting Date: 7/1/2007

Ending Date: 6/30/2010

Person Months per Year Committed to Project: 0.5 (calendar)

Project/Proposal Title: Genetic analysis of pitcher morphology and insectivory in *Sarracenia*

Source of Support: National Science Foundation

Project Location: University of Georgia, Harvard Forest

Total Amount Requested: \$72,675 (subcontract)

Starting Date: 9/1/2007

Ending Date: 8/31/2011

Person Months per Year Committed to Project: 0.5 (calendar)

Project/Proposal Title: Collaborative Research: SDCI Data: A New Approach to Using Process Definitions to Derive and Maintain Dataset Provenance

Source of Support: National Science Foundation

Project Location: University of Massachusetts, Harvard Forest

Total Amount Requested: \$449,498 (PI of sub-award)

Starting Date: 9/1/2007

Ending Date: 8/31/2010

Person Months per Year Committed to Project: 0.5 (calendar)

Project/Proposal Title: FSML: The New England Center for Ecological Synthesis

Source of Support: National Science Foundation

Project Location: Harvard Forest

Total Amount Requested: \$350,000 (co-PI)

Starting Date: 11/1/2007

Ending Date: 10/31/2010

Person Months per Year Committed to Project: 0.0 (calendar)

Project/Proposal Title: Impacts of elevated temperature on ant species, communities and ecological roles at two temperate forests in eastern North America

Source of Support: DOE

Project Location: Harvard Forest, North Carolina State University

Total Amount Requested: \$1,125,030 (PI of sub-award)

Starting Date: 1/1/2008

Ending Date: 12/31/2011

Person Months per Year Committed to Project: 0.5 (calendar)

Current and Pending Support Appendix, Nathan Sanders

CURRENT AND PENDING SUPPORT - SANDERS

Proposal title: Dissertation Research: The role of seed dispersal mode in determining current and future patterns of plant diversity in Western Australia

Source of support: NSF

Project location: University of Tennessee

Total award amount: \$8,464

Starting date: 07/01/2007

Ending date: 07/01/08

Support type: Pending

Person-months per year committed to the Project: 0

Proposal title: Dissertation Research: A Genes to Ecosystems Approach: the Above- and Below-ground Consequences of Plant Genotypic Diversity

Source of support: NSF

Project location: University of Tennessee

Total award amount: \$10,863

Starting date: 07/01/2007

Ending date: 07/01/08

Support type: Pending

Person-months per year committed to the Project: 0

Proposal title: Potential of 18 SER Parks as Reserves for Conservation of Aquatic Insect Species

Source of support: USGS

Project location: southeastern US

Total award amount: \$243,974

Starting date: 04/01/05

Ending date: 04/01/08

Support type: Current

Person-months per year committed to the Project: 0 month/summer

Proposal title: En-Gen: From Genomics to Ecosystems: Plant Genotypic Diversity Affects Soil Microbial Assemblages and Ecosystem Processes

Source of support: NSF

Project location: southeastern US

Total award amount: \$991,335

Starting date: 07/01/07

Ending date: 06/30/10

Support type: Pending

Person-months per year committed to the Project: 1 month/summer

Proposal title: Collaborative Research: Are ecosystem dynamics governed by the direct or indirect effects associated with the loss of foundation species?

Source of support: NSF

Project location: southeastern US
Total award amount: \$351,120
Starting date: 07/01/07
Ending date: 06/30/10
Support type: Pending
Person-months per year committed to the Project: 1 month/summer

Proposal title: Using equilibrium tests and historical data to improve distribution models – a study with ants

Source of support: NICCR/DOE
Project location: southeastern US
Total award amount: \$41,669
Starting date: 06/01/07
Ending date: 05/30/08
Support type: Current
Person-months per year committed to the Project: 1 month/summer

Identification of Potential Conflicts of Interest, Nathan J. Sanders

Collaborators and other affiliations

Nick Gotelli, University of Vermont
Erik Jules, Humboldt State University
Aaron Ellison, Harvard Forest
Diane Wagner, University of Alaska
Kasey Barton, University of Colorado
Michael Collins, University of Tennessee
Diego Vasquez, NCEAS
Brad Hawkins, UC Irvine
Christy McCain, University of New Mexico
Chris Nice, Texas State
Nicole Heller, UC Santa Cruz
Ed Connor, San Francisco State University

Advisors

Postdoctoral advisor: Dan Simberloff, University of Tennessee
PhD advisor: Deborah Gordon, Stanford University

Advisees

Greg Crutsinger, PhD
Jaime Ratchford, MA (2005)
Kristin Lane, MA (2006)
J-P Lessard, PhD
Matt Fitzpatrick, PhD
Windy Bunn, MA
Maggie Patrick, MA
Lara Souza, PhD

Identification of Potential Conflicts of Interest, Nicholas Gotelli

Collaborators and Co-editors

Buckley, Hannah (Lincoln University, NZ)	collaborator/co-author
Butler, Jessica (Harvard University)	collaborator/co-author
Colwell, Robert K. (Univ. of Connecticut)	collaborator/co-author
Dixon, Philip (Iowa State University)	collaborator/co-author
Ellison, Aaron M. (Harvard Univ.)	collaborator/co-author
Entsminger, Gary (Acquired Intelligence, Inc.)	collaborator/co-author
Farnsworth, Elizabeth (New England Wild Flower Society)	collaborator/co-author
Farnsworth, Elizabeth (New England Wild Flower Society)	collaborator/co-author
Gotelli, Nicholas (University of Vermont)	collaborator/co-author
Graves, Gary (Smithsonian Institution)	collaborator/co-author
Hochberg, Michael (University of Montpellier)	co-editor
Jules, Erik (Humboldt State University)	collaborator/co-author
Lewis, Thomas (University of Vermont)	collaborator/co-author
Lundberg, Pehr (University of Sweden)	co-editor
Miller, Tom (Florida State University)	collaborator/co-author
Miller, Tom (Florida State University)	collaborator/co-author

Naczi, Rob (Delaware State University)	collaborator/co-author
Rahbek, Carsten (University of Copenhagen)	collaborator/co-author
Sanders, Nathan (University of Tennessee)	collaborator/co-author
Sanders, Nathan (University of Tennessee)	collaborator/co-author
Strong, Don (University of California, Davis)	co-editor
Wakefield, Amy (University of Vermont)	collaborator/co-author
Whittaker, Robert (University of Oxford)	co-editor
Wittman, Sarah (University of Vermont)	collaborator/co-author

Advisors

Abele, Lawrence (Florida State University)	M.Sc. Advisor
Bossert, Bill (Harvard University)	Post-Doctoral Advisor
Moore, Janice (Colorado State University)	Post-Doctoral Advisor
Simberloff, Dan (University of Tennessee)	Ph.D. Advisor

Advisees

Albrecht, Marc (University of Nebraska)	Ph.D. Advisee
Arnett, Amy (Unity College)	Ph.D. Advisee
Buckley, Neil (SUNY Plattsburgh)	Post-Doctoral Advisee
Farrell, Kate (University of Vermont)	M.Sc. Advisee
Hart, Ted (University of Vermont)	Ph.D. Advisee
Hudman, Stephen (University of Kansas)	Ph.D. Advisee
Inchausti, Pablo (SUNY Stony Brook)	Ph.D. Advisee
Johnson, Jerry (Brigham Young University)	Ph.D. Advisee
McCabe, Declan (St. Michael's College)	Ph.D. Advisee
Peres-Neto, Pedro (University of Regina)	Ph.D. Advisee
Wakefield, Amy (University of Vermont)	M.Sc. Advisee
Wittman, Sarah (University of Vermont)	Ph.D. Advisee

Identification of Potential Conflicts of Interest, Rob Dunn

Collaborators and Co-editors

Maria Cancela (Curtin University)
Greg Crutsinger (U. of Tennessee)
James Danoff-Burg (Columbia University)
Michael Gavin (University of Wellington)
Melissa Gerhaghty (U. of Tennessee)
Aaron Gove (Curtin University)
Kevin Gross (North Carolina State University)
Nick Haddad (North Carolina State University)
Brian Hetterick (Curtin University)
Lian Pin Koh (Princeton University)
Bryon Lamont (Curtin University)
Deborah Lawrence (University of Virginia)
Andrew Latimer (University of Connecticut)
Terry McGlynn (San Diego University)
Jean Pierre Lessard (U. of Tennessee)
Jonathan Majer (Curtin University)
Christie McCain (NCEAS)
Ben Miller (Curtin University)
Juan Manuel Morales (Cambridge University)
Monica Sanchez (University of Connecticut)
Jen Solomon (University of Florida)
Navjot Sodhi (National University of Singapore)
Jake Weltzin (U. of Tennessee)

Advisors

Robert K. Colwell (U. of Connecticut)

Advisees

Matt Fitzpatrick (U. of Tennessee)
Neil McCoy (North Carolina State University)
Benoit Guenard (North Carolina State University)

Identification of Potential Conflicts of Interest, Aaron Ellison

Collaborators and other affiliations:

- a. *Collaborators in addition to co-authors listed above (last 48 months)* – Marco Albani (Harvard), Leszek Bledzki (Mt. Holyoke College), J. Stephen Brewer (U. Mississippi), Hannah Buckley (Florida State), Jessica Butler (Harvard Forest), Aimée Classen (U. Tennessee), Lori Clarke (U. Massachusetts), D. Liane Cochran-Stafira (St. Xavier U.), Philip Dixon (Iowa State), Joe Elkinton (U. Massachusetts), Elizabeth Farnsworth (New England Wild Flower Society), David Foster (Harvard Forest), Nick Gotelli (U. Vermont), Clarisse Hart (Mt. Holyoke College), Julia Jones (Oregon State), Erik Jules (Humboldt State), Jamie Kneitel (Florida State), Tom Miller (Florida State), Paul Moorcroft (Harvard), Callan Ordoyne (Mt. Holyoke College), Lee Osterweil (U. Massachusetts), Dave Orwig, (Harvard Forest), Annie Paradis (U. Massachusetts), Adam Porter (U. Massachusetts), Evan Pressier (U. Rhode Island), Nathan Sanders (U. Tennessee), Noreen Tuross (Harvard), Amy Wakefield (U. Vermont), Sarah Wittman (U. Vermont), Anne Worley (U. Manitoba), Regino Zamora (U. Granada, Spain).

Co-editors – Candace Galen (University of Missouri), Donald R. Strong (University of California – Davis), Joseph B. Yavitt (Cornell University)

- b. *Graduate and Postdoctoral Advisor*
 - i. Ph.D. Advisor – Mark Bertness (Brown)
 - ii. Postdoctoral advisors – Barbara Bedford (Cornell), Julie Denslow (USFS – Honolulu), Karl Niklas (Cornell), Deborah Rabinowitz (Cornell, *deceased*)
- c. *Thesis Advisor and Postgraduate-Scholar Sponsor*
 - i. 13 undergraduate honors theses and 30 undergraduate senior independent projects (1990-2002); 6 REU interns (2003-2005)
 - ii. Melissa Iszard-Crowley (M.S., 1992); Kelley Sullivan (M.L.A., 2005)
 - iii. Sydne Record (current Ph.D. student)
 - iv. Demetrios (Jim) Karagatzides (current post-doc)

Equipment Appendix

North Carolina State University

Lab equipment includes standard materials for the processing and study of ants, including five microscopes.

University of Tennessee

Lab equipment for chemical analyses will includes: glass dessicators, 40 sample digest block, pipettes and re-pipetors, vortex, stir- and hotplates, conductivity and pH meters, sonicator, benchtop centrifuge, Beckman ultracentrifuge, water bath, rotary evaporator and N-evaporator, Lachat AE flow-injector auto-analyzer with in-line digest capacity, Molecular Devices microplate spectrophotometer, lyophilizer, Ankom fibre analyzer, and CHN autoanalyzer. The Ecosystem Ecology Laboratory facility ORNL includes a Costech ECS 4010

University of Vermont

Lab equipment includes standard materials for the processing and study of ants, including an Olympus dissecting scope.

Harvard Forest

Equipment for experimental manipulations, construction, and maintenance includes a back-hoe, bulldozer, crawler, skidder, tractor, dump truck, flat bed truck, vehicles including pick-ups, a van, SUVs and a sedan, a wood-working shop, maintenance garage and a sawmill. A mobile lift provides access for up to four researchers to 20-m forest canopies

Literature Cited

- Intergovernmental Panel on Climate Change (2001) **Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the IPCC** (Cambridge Univ. Press, Cambridge, U.K.
- National Assessment Synthesis Team **Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Report for the US Global Change Research Program**, Cambridge University Press, Cambridge UK, 620pp., 2001.
- Agosti, D., editor. 2000. **Ants: standard methods for measuring and monitoring biodiversity**. Smithsonian Institution Press, Washington, D.C., 280 p.
- Agosti, D., J. D. Majer, L. E. Alonso, and T. R. Schultz, editors. 2000. **Ants: standard methods for measuring and monitoring biodiversity**. Smithsonian Institution Press, Washington, D. C.
- Araujo, M. B., R. G. Pearson, W. Thuiller, and M. Erhard. 2005. **Validation of species-climate impact models under climate change**. *Global Change Biology* 11:1504-1513.
- Araujo, M. B., and C. Rahbek. 2006. **How does climate change affect biodiversity?** *Science* 313:1396-1397.
- Banschbach, V. S., N. Levit, and J. M. Herbers. 1997. **Nest temperatures and thermal preferences of a forest ant species: is seasonal polydomy a thermoregulatory mechanism ?** *Insect. Soc.* 44:109-122.
- Beattie, A. J. 1985. **The evolutionary ecology of ant-plant mutualisms**. Cambridge University Press, New York.
- Bestelmeyer, B. T. 2000. **The trade-off between thermal tolerance and behavioral dominance in a subtropical South American ant community**. *Journal of Animal Ecology* 69:998-1009.
- Binkley, D. 1984. **Does forest removal increase rates of decomposition and nitrogen release?** *Forest Ecology and Management* 8:229-233.
- Bourke, A. G. F. and N. R. F. 1995. **The diversity of Life Histories in ants**. *Social Evolution in ants*.
- Carney, S. E., M. B. Byerley, and D. A. Holway. 2003. **Invasive Argentine ants (*Linepithema humile*) do not replace native ants as seed dispersers of *Dendromecon rigida* (Papaveraceae) in California, USA**. *Oecologia* 135:576-582.
- Cerdá, X., J. Retana, and A. Manzaneda. 1998. **The role of competition by dominants and temperature in the foraging of subordinate species in mediterranean ant communities**. *Oecologia* 117:404-412.
- Chapin, F. S. I., E. S. Zavaleta, V. T. Eviners, R. L. Nalor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack, and S. Diaz. 2000. **Consequences of changing biodiversity**. *Nature* 405:234-242.
- Chapman, R. E., and A. F. G. Bourke. 2001. **The influence of sociality on the conservation biology of social insects**. *Ecology Letters* 4:650-662.
- Cogbill, C. V., J. Burk, and G. Motzkin. 2002. **The forests of presettlement New England, USA: spatial and compositional patterns based on town proprietor surveys**. *Journal of Biogeography* 29:1279-1304.
- Convey, P., W. Block, and H. J. Peat. 2003. **Soil arthropods as indicators of water stress in Antarctic terrestrial habitats?** *Global Change Biology* 9:1718-1730.

- Convey, P., P. J. A. Pugh, C. Jackson, A. W. Murray, C. T. Ruhland, F. S. Xiong, and T. A. Day. 2002. Response of antarctic terrestrial microarthropods to long-term climate manipulations. *Ecology* 83:3130-3140.
- Cottingham, K. K., J. T. Lennon, and B. L. Brown. 2005. Knowing when to draw the line: designing more informative ecological experiments. *Frontiers in Ecology and Environment* 3:145-152.
- Coulson, S. J., H. P. Leinaas, R. A. Ims, and G. Sovik. 2000. Experimental manipulation of the winter surface ice layer: the effects on a High Arctic soil microarthropod community. *Ecography* 23:299-306.
- Coviella, C. E., and J. T. Trumble. 1999. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. *Conservation Biology* 13:700-712.
- Davidson, D. W. 1977. Species diversity and community organization in desert seed-eating ants. *Ecology* 58:711-724.
- Davis, A. J., L. S. Jenkinson, J. H. Lawton, B. Shorrocks, and S. Wood. 1998a. Making mistakes when predicting shifts in species range in response to global warming. *Nature* 391:783-786.
- Davis, A. J., J. H. Lawton, B. Shorrocks, and L. S. Jenkinson. 1998b. Individualistic species responses invalidate simple physiological models of community dynamics under global environmental change. *Journal of Animal Ecology* 67:600-612.
- Dollery, R., I. D. Hodkinson, and I. S. Jonsdottir. 2006. Impact of warming and timing of snow melt on soil microarthropod assemblages associated with *Dryas*-dominated plant communities on Svalbard. *Ecography* 29:111-119.
- Dukes, J. S., and H. A. Mooney. 1999. Does global change increase the success of biological invaders? *Trends in Ecology & Evolution* 14:135-139.
- Dunn, R. R. 2005. Modern insect extinctions, the neglected majority. *Conservation Biology* 19:1030-1036.
- Dunn, R. R., C. R. Parker, M. Gerhaghty, and N. J. Sanders. in press. Reproductive phenologies in a diverse temperate ant fauna. *Ecological Entomology* XX:XXX.
- Dunn, R. R., C. R. Parker, and N. J. Sanders. 2006. Disentangling the roles of competition and the environment as drivers of phenological patterns of ant diversity. *Biological Journal of the Linnean Society* XX:XXX.
- Dunne, J. A., S. R. Saleska, M. L. Fischer, and J. Harte. 2004. Integrating experimental and gradient methods in ecological climate change research. *Ecology* 85:904-916.
- Ellison, A. M., E. J. Farnsworth, and N. J. Gotelli. 2002. Ant diversity in pitcher-plant bogs of Massachusetts. *Northeastern Naturalist* 9:267-284.
- Elmes, G. W., and J. C. Wardlaw. 1983. A comparison of the effect of temperature on the development of large hibernated larvae of four species of *Myrmica* (Hymenoptera:Formicidae). *Insect. Soc.* 30:106-118.
- Erasmus, B. F. N., A. S. Van Jaarsveld, S. L. Chown, M. Kshatriya, and K. J. Wessels. 2002. Vulnerability of South African animal taxa to climate change. *Global Change Biology* 8:679-693.
- Fellers, J. H. 1987a. Interference and exploitation in a guild of woodland ants. *Ecology* 68:1466-1478.
- Fitzpatrick, M. C., and J. F. Weltzin. 2005. Ecological niche models and the geography of biological invasions: A review and a novel application. *in* Inderjit, editor. *Invasive*

- plants: Ecological and agricultural aspects. Birkhauser-Verlag AG, Basel, Switzerland.
- Fitzpatrick, M. C., J. F. Weltzin, N. J. Sanders, and R. R. Dunn. in press. The biogeography of prediction error: why does the introduced range of the fire ant over-predict its native range? *Global Ecology and Biogeography* 000:000-000.
- Foitzik, S., and J. Heinze. 1998. Nest site limitation and colony take over in the ant, *Leptothorax nylanderi*. *Behav. Ecol.* 9:367-375.
- Folgarait, P. J. 1998. Ant biodiversity and its relationship to ecosystem functioning: a review. *Biodiversity and Conservation* 7:1221-1244.
- Gaston, K. J. 2003. The structure and dynamics of geographic ranges. Oxford University Press, Oxford.
- Gonzalez, G., and T. Seastedt. 2001. Soil fauna and plant litter decomposition in tropical and subalpine forests. *Ecology* 82:955-964.
- Gotelli, N. J., and A. E. Arnett. 2000. Biogeographic effects of red fire ant invasion. *Ecology Letters* 3:257-261.
- Gotelli, N. J., and A. M. Ellison. 2002a. Assembly rules for new England ant assemblages. *Oikos* 99:591-599.
- Gotelli, N. J., and A. M. Ellison. 2002b. Biogeography at a regional scale: Determinants of ant species density in New England bogs and forests. *Ecology* 83:1604–1609.
- Gotelli, N. J., and A. M. Ellison. 2004. *A Primer of Ecological Statistics*. Sinauer Associates, Inc.
- Gove, A. D., R. R. Dunn, and J. D. Majer. In press. A keystone ant species promotes seed dispersal in a “diffuse” mutualism. *Oecologia*.
- Hampe, A. 2004. Bioclimate envelope models: what they detect and what they hide. *Global Ecology and Biogeography* 13:469-471.
- Harmon, M. E., K. J. Nadelhoffer, and J. M. Blair. 1999. *Standard soil methods for long-term ecological research*. Oxford University Press, New York, NY.
- Harte, J., and R. Shaw. 1995. Shifting Dominance within a Montane Vegetation Community - Results of a Climate-Warming Experiment. *Science* 267:876-880.
- Heithaus, E. R., P. A. Heithaus, and S. Y. Liu. 2005. Satiation in collection of myrmecochorous diaspores by colonies of *Aphaenogaster rudis* (Formicidae : Myrmicinae) in central Ohio, USA. *Journal of Insect Behavior* 18:827-846.
- Herbers, J. M. 1989. Community structure in north temperate ants: temporal and spatial variation. *Oecologia* 81:201-211.
- Holec, M., and J. Frouz. 2005. Ant (Hymenoptera : Formicidae) communities in reclaimed and unreclaimed brown coal mining spoil dumps in the Czech Republic. *Pedobiologia* 49:345-357.
- Hölldobler, B., and E. O. Wilson. 1990. *The ants*. The Belknap Press of Harvard University Press, Cambridge, MA.
- Holway, D. A., L. Lach, A. V. Suarez, N. D. Tsutsui, and T. J. Case. 2002a. The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics* 33:181-233.
- Holway, D. A., A. V. Suarez, and T. J. Case. 2002b. Role of abiotic factors in governing susceptibility to invasion: A test with Argentine ants. *Ecology* 83:1610–1619.
- Hooper, D. U., F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A. J. Symstad, J.

- Vandermeer, and D. A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* 75:3-35.
- Hughes, L. 2003. Climate change and Australia: Trends, projections and impacts. *Austral Ecology* 28:423-443.
- Human, K. G., and D. M. Gordon. 1996. Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia* 105:405-412.
- Iverson, L. R., and A. M. Prasad. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. *Ecological Monographs* 68:465-485.
- Kaspari, M. 2004. Using the Metabolic Theory of Ecology to predict global patterns of abundance. *Ecology* 85:1800-1802.
- Kaspari, M., L. Alonso, and S. O'Donnell. 2000a. Three energy variables predict ant abundance at a geographical scale. *Proc. R. Soc. London Ser. B Biol. Sci.* 267:485-489.
- Kaspari, M., S. O'Donnell, and J. R. Kercher. 2000b. Energy, density, and constraints to species richness: ant assemblages along a productivity gradient. *The American Naturalist* 155:280-293.
- Kaspari, M., and T. J. Valone. 2002. On ectotherm abundance in a seasonal environment - Studies of a desert ant assemblage. *Ecology* 83:2991-2996.
- Kaspari, M., M. Yuan, and L. Alonso. 2003. Spatial grain and the causes of regional diversity gradients in ants. *American Naturalist* 161:459-477.
- Kennedy, T. A. 1998. Patterns of an invasion by Argentine ants (*Linepithema humile*) in a riparian corridor and its effects on ant diversity. *Am. Midl. Nat.* 140:343-350.
- Klein, J. A., J. Harte, and X. Q. Zhao. 2004. Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau. *Ecology Letters* 7:1170-1179.
- Klein, J. A., J. Harte, and X. Q. Zhao. 2005. Dynamic and complex microclimate responses to warming and grazing manipulations. *Global Change Biology* 11:1440-1451.
- Koh, L. P., R. R. Dunn, N. S. Sodhi, R. K. Colwell, H. C. Proctor, and V. S. Smith. 2004. Species co-extinctions and the biodiversity crisis. *Science* 305:1632-1634.
- Lawton, J. H. 2000. *Community Ecology in a Changing World*. Ecology Institute, Oldendorf/Luhe.
- Lessard, J. P., R. R. Dunn, and N. J. Sanders. in press. Rarity and diversity in forest assemblages of the Great Smoky Mountains National Park. *Southeastern Naturalist* XX.
- Lobry de Bruyn, L. A. 1990. The effects of ants and termites in modifying soil properties in naturally vegetated and agricultural environments. Ph.D. thesis, The University of Western Australia, Perth.
- Lyford, W. H. 1963. Importance of ants to brown podzolic soil genesis in New England. *Harvard Forest Paper*:1-18.
- Midgley, G. F., L. Hannah, D. Millar, W. Thuiller, and A. Booth. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* 112:87-97.
- Midgley, G. F., G. O. Hughes, W. Thuiller, and A. G. Rebelo. 2006. Migration rate limitations on climate change-induced range shifts in Cape Proteaceae. *Diversity and Distributions* 12:555-562.

- Milton, Y., M. Kaspari. 2007. Bottom-up and top-down regulation fo decomposition in a tropical forest. *Oecologia*. DOI 10.1007/s00442-007-0710-6
- Morales, M. A., and E. R. Heithaus. 1998. Food from seed-dispersal mutualism shifts sex ratios in colonies of the ant *Aphaenogaster rudis*. *Ecology* 79:734-739.
- Ness, J. H., and I. L. Bronstein. 2004. The effects of invasive ants on prospective ant mutualists. *Biological Invasions* 6:445-461.
- Parmesan, C., S. Gaines, L. Gonzalez, D. M. Kaufman, J. Kingsolver, A. Townsend Peterson, and R. Sagarin. 2005. Empirical perspectives on species borders: from traditional biogeography to global change. *Oikos* 108:58-75.
- Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37-42.
- Petchey, O. L., P. T. McPhearson, T. M. Casey, and P. J. Morin. 1999. Environmental warming alters food-web structure and ecosystem function. *Nature* 402:69-72.
- Peterson, A. T., M. A. Ortega-Huerta, J. Bartley, V. Sanchez-Cordero, J. Soberon, R. H. Buddemeier, and D. R. B. Stockwell. 2002. Future projections for Mexican faunas under global climate change scenarios. *Nature* 416:626-629.
- Ratchford, J. S., S. E. Wittman, E. S. Jules, A. M. Ellison, N. J. Gotelli, and N. J. Sanders. 2005. The effects of fire, local environment and time on ant assemblages in fens and forests. *Diversity and Distributions* 11:487-497.
- Retana, J., and X. Cerdá. 2000. Patterns of diversity and composition of Mediterranean ground ant communities tracking spatial and temporal variability in the thermal environment. *Oecologia* 123:436-444.
- Robertson, G. P., and E. A. Paul. 2000. *Methods in ecosystem science*. Springer-Verlag, New York.
- Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003a. Fingerprints of global warming on wild animals and plants. *Nature* 421:57-60.
- Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003b. Fingerprints of global warming on wild animals and plants. *Nature* 421:57-60.
- Roura-Pascual, N., A. V. Suarez, K. McNyset, C. Gomez, P. Pons, Y. Touyama, A. L. Wild, F. Gascon, and A. T. Peterson. 2006. Niche differentiation and fine-scale projections for Argentine ants based on remotely sensed data. *Ecological Applications* 16:1832-1841.
- Samways, M. J., R. Osborn, H. Hastings, and V. Hattingh. 1999. Global climate change and accuracy of prediction of species' geographical ranges: establishment success of introduced ladybirds (*Coccinellidae*, *Chilocorus spp.*) worldwide. *Journal of Biogeography* 26:795-812.
- Sanders, N. J., and D. M. Gordon. 2002. Resources and the flexible allocation of work in the desert ant, *Aphaenogaster cockerelli*. *Insectes Sociaux* 49:371-379.
- Sanders, N. J., and D. M. Gordon. 2004. The interactive effects of climate, life history, and interspecific neighbours on mortality in a population of seed harvester ants. *Ecological Entomology* 29:632-637.
- Sanders, N. J., J. P. Lessard, M. C. Fitzpatrick, and R. R. Dunn. In press. The metabolic theory of diversity gradients: biochemical kinetics and resource access, but not

- geometry, predict ant species richness across spatial grains. *Global Ecology and Biogeography*.
- Sinclair, B. J. 2002. Effects of increased temperatures simulating climate change on terrestrial invertebrates on Ross Island, Antarctica. *Pedobiologia* 46:150-160.
- Smith, S. D., T. E. Huxman, S. F. Zitzer, T. N. Charlet, D. C. Housman, J. S. Coleman, L. K. Fenstermaker, J. R. Seemann, and R. S. Nowak. 2000. Elevated CO₂ increases productivity and invasive species success in an arid ecosystem. *Nature* 408:79-82.
- Southerland, M. T. 1988. The effects of temperature and food on the growth of laboratory colonies of *Aphaenogaster rudis* Emery (Hymenoptera: Formicidae). *Insect. Soc.* 35:304-309.
- Terborgh, J., L. Lopez, P. Nunez, M. Rao, G. Shahabuddin, G. Orihuela, M. Riveros, R. Ascanio, G. H. Adler, T. D. Lambert, and L. Balbas. 2001. Ecological meltdown in predator-free forest fragments. *Science* 294:1923-1926.
- Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. 2004a. Extinction risk from climate change. *Nature* 427:145-148.
- Thomas, C. D., S. E. Williams, A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, and O. L. Phillips. 2004b. Biodiversity conservation - Uncertainty in predictions of extinction risk - Effects of changes in climate and land use - Climate change and extinction risk - Reply. *Nature* 430.
- Thuiller, W., S. Lavorel, M. B. Araujo, M. T. Sykes, and I. C. Prentice. 2005a. Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences of the United States of America* 102:8245-8250.
- Thuiller, W., D. M. Richardson, P. Pysek, G. F. Midgley, G. O. Hughes, and M. Rouget. 2005b. Niche-based modeling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biology* 11:2234-2250.
- Tillberg, C. V., D. P. McCarthy, A. G. Dolezal, and A. V. Suarez. 2006. Measuring the trophic ecology of ants using stable isotopes. *Insectes Sociaux* 53:65-69.
- Uvarov, A. V. 2003. Effects of diurnal temperature fluctuations on population responses of forest floor mites. *Pedobiologia* 47:331-339.
- Venables, W. N., and B. D. Ripley. 2002. *Modern applied statistics with S*. Springer-Verlag, New York, NY.
- Walther, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. *Nature* 416:389-395.
- Williams, S. E., E. E. Bolitho, and S. Fox. 2003. Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society of London Series B-Biological Sciences* 270:1887-1892.
- Witt, A. B. R., H. Geertsema, and J. H. Giliomee. 2004. The impact of an invasive ant, *Linepithema humile* (Mayr) (Hymenoptera : Formicidae), on the dispersal of the elaiosome-bearing seeds of six plant species. *African Entomology* 12:223-230.

Zettler, J. A., T. P. Spira, and C. R. Allen. 2001. Ant-seed mutualisms: can red imported fire ants sour the relationship? *Biological Conservation* 101:249-253.