Drought Impacts on Regional Ecosystems Network (DIREnet): Coordinating Studies on Southwest Forests & Woodlands.
DEB-0443526

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We request funding for our **Drought Impacts on Regional Ecosystems Network (DIRENET)** that will promote the coordination and synthesis of ecological research on drought effects and the potential role of global climate change. Intellectual Merit: A severe regional drought in the last nine years is rapidly and dramatically altering Southwest forest and woodland ecosystems. The drought has become a catalyst, bringing researchers and land managers together to assess the impacts of the drought. DIREnet will promote and enable research needed to address specific research questions that can not be addressed without effective pan-regional coordination. DIREnet will implement two mechanisms to foster collaborations of researchers from academia and land management agencies: **Cross-Pollination in Research and Education.** Organization of workshops and symposia will foster new research and lead to the synthesis of existing research. A student researcher exchange program will promote novel research opportunities, and establish uniformity of research techniques and data collection formats across the southwest to facilitate data integration and exchange. **Southwest Ecological Research Forum (SERF).** A sophisticated online information archive will serve as a globally accessible data clearinghouse, provide advanced analysis and visualization across datasets, and provide a forum for scientific discussion and communication. Broader Impacts: Outreach to Native Americans and the general public will help improve natural resource use planning and policy development. In combination, these efforts will greatly aid understanding of how major ecosystems function and respond to climatic perturbations.

1. Drought Impacts on Regional Ecosystems Network: Overview and Significance

We propose a regionally-based research network focused on the ecological impacts of an ongoing, long-term drought that has devastated southwestern forests & woodlands. The proposed Drought Impacts on Regional Ecosystems Network (DIREnet) brings together 40 core participants from 21 academic, federal and tribal institutions to address critical ecological questions about the role of extreme climatological events in shaping ecosystems and driving evolutionary trajectories. Specific DIREnet goals are to **1) Promote collaborative studies and syntheses** that will greatly increase our knowledge of extreme events and specifically the regional impact of a megadrought. DIREnet will also explore the relationship between drought impacts and global climate change. **2)**. **Implement cross-pollination of research and education** through face-to-face initiatives that will promote research collaboration and data dissemination among researchers, both within and among specific research areas. We will build upon our existing set of collaborations and establish a graduate student exchange program, informal education programs, and focused drought symposia and workshops. **3) Create a virtual collaboratory and online data archive** called the *Southwest Ecological Research Forum* (SERF) that will bring together researchers, educators, and managers with diverse interests within a secure, community-driven online research forum to share and jointly analyze drought-related data; create a comprehensive, integrated, pan-regional ecological data archive; develop conceptual themes and common methodologies; and explore land management alternatives. Specialized tools built into SERF will support robust critical commentary and scientific discussion related to SERF datasets for authenticated researchers/users; a public access portal will support sharing research summaries, white papers, and other drought data with affected communities.

DIREnet's combination of virtual and in-person coordination will generate a wide variety of publications spanning original research in both ecology and eco-informatics, conceptual reviews, and informal articles and white papers for land managers. Uniting the southwest research community and rooting this regional collaboration within the powerful SERF informatics infrastructure will allow us to develop the comprehensive models required to address regional-scale ecological questions, and to establish community-wide standards and conventions for relevant data types, data formats, and experimental methodologies. Our project is designed to evolve well beyond the lifetime of the project, either as a topically-focused sub-network within the rapidly evolving National Ecological Observatory Network (NEON) eco-informatics initiative, or by melding into one or more regional NEON nodes. In addition, the powerful SERF informatics substrate will be easily adaptable to provide online research and educational forums for other environmentally-based networks.

1.1 Background: Drought and the Resetting of Major Southwest Ecosystems

Ponderosa pine forests and Pinyon-Juniper woodlands (hereafter referred to as PJ) comprise 250,000 km^2 of the western United States and 79% of the tree-dominated landscapes in the Southwest. Southwestern forests and woodlands are a particularly important system to study in the context of drought and climate change because they are spatially extensive analogs for other semi-arid ecosystems globally; have been shown to be very sensitive to climate variation in the past (Allen & Breshears in press); are especially sensitive to land use (Gottfried et al. 1995); and are one of the few dryland systems for which detailed soil water and vegetation dynamics have been tracked over periods exceeding a few years (Breshears et al in review). Southwestern arid and semi-arid ecosystems may be particularly sensitive to climate changes (Risser 1995, Swetnam & Betancourt 1998); the primary production of these ecosystems is limited by water, exacerbating any changes in temperature and precipitation. Historically, southwest forests have experienced cycles of wet and dry periods lasting up to 200 years (Grissino-Mayer *et al.* 1997), resulting in significant ecosystem changes. For instance, the Pinyon pine (*Pinus edulis*) was restricted to two southern refugia during the Pleistocene (Betancourt *et al.* 1991), but subsequently expanded rapidly northward to its current

distribution throughout the Colorado plateau. Most recently, the 1950's drought (Betancourt & Diaz 2003) resulted in ponderosa pine mortality that shifted an ecotone by 2km in less than 5 years, an effect that persists today (Allen & Breshears 1998).

Over the last four to nine years (www.noaa.gov), *the Southwest has experienced moderate to severe drought*, resulting in extraordinary tree mortality throughout the region; this mortality is due to a combination of direct physiological tree stress and bark beetles feeding on susceptible, drought-stressed trees. **Figure 1** shows the distribution of forest and woodlands in the four corner states and the projected area of stands with tree mortality. Areas of tree mortality have *expanded by seven fold each year since 2000*. In 2004, the US Forest Service estimated that over 30 million trees have died in Arizona and New Mexico alone. At this rate, tree mortality ranging from 10-95% will occur in at least 60% of the ponderosa and PJ stands by Fall 2004. Additionally, human populations have increased up to 40% in the Southwest during the last decade (US Census Bureau, Census 2000), further exacerbating drought impacts via increased risk of fires in drought-killed tree stands.

1.2 A First Look at Impacts of Global Change Predicted Drought?

Predicting vegetation responses to drought is likely to become even more important and more pressing in the future as climate change progresses. Droughts are expected to increase in frequency and intensity, and temperatures associated with these droughts could be greater than for previous droughts, thereby exacerbating their effects. *Evaluating how ecosystems will respond regionally to climate variation and directional change is one of the most important socioeconomic factors for which scientists must develop a better process-based understanding* (IPCC 2002). Of particular importance is the need to understand how ecosystems respond to drought, because in general drought can cause rapid changes through mortality of dominant plants that occur much quicker than processes associated with plant migration (Allen & Breshears 1998).

Because the current drought exhibits characteristics consistent with global-change predicted drought - in which increased temperature amplifies the effect of reduced precipitation (**Figure 2**) - the regionally extensive mortality documented here may provide a first look at expected impacts of climate change. Regional scale metrics of climate indicate the special significance of the current drought: regional precipitation during this drought is low, somewhat similar to the reduced precipitation that occurred during the regional drought that occurred during the 1950s (**Fig 2**). However, regional temperature has been increasing dramatically over the last decade, a pattern that differs from the low temperatures that occurred during the 1950's drought and is unprecedented during the historic record for the region.

1.3 Cascading Ecological Impacts & Long-term Consequences.

Widespread plant mortality will undoubtedly alter a number of landscape-level processes, including increased **erosion** (Nyhan *et al.* 2001) and **invasive species** (e.g. *Bromus tectorum*). We predict that bark beetle outbreaks will be dramatically alter **fire regimes** by initially increasing the risk of crown fires while needles remain on the tree, but reducing crown fires in the long term (Bebi *et al.* 2003). Ecosystems will be flammable over a much broader range of climate conditions, and the increased continuities of surface fuels might allow substantial fire spread (C. Allen Pers. Comm.). The ecological consequences of drought induced beetle outbreaks could include shifts in the geographical range and species composition of forests, and increased loss in biodiversity.

The importance of droughts (Ogle *et al.* 2000) or any disturbance event in semi-arid environments is magnified because of the time it requires for ecosystems to return to equilibrium. For example, 700 years after Sinagua agricultural fields were abandoned in Northern Arizona, the impacts on native vegetation are still evident today (Berlin *et al.* 1977, Berlin *et al.* 1990). We emphasize that, *even if the drought ended tomorrow, crucial drought impacts will persist for decades* because the ecosystem effects of tree mortality that has already occurred will be massive. However, both the

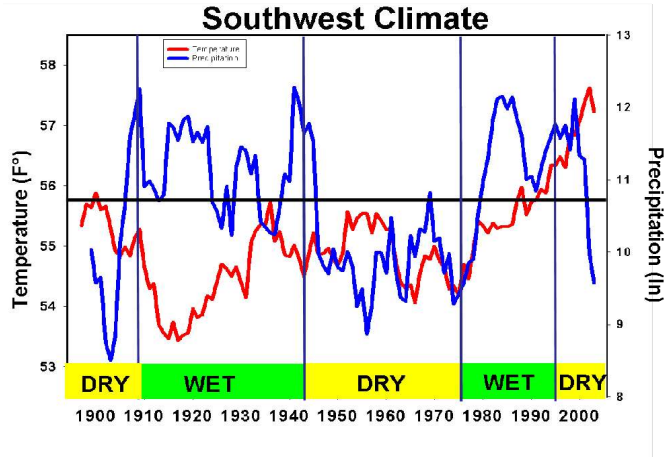


Figure 2. The major difference between the current drought and the two other droughts in the last century is that this drought is considerably warmer.

short-term ENSO and long-term multi-decadal oscillation forecasts suggest that 2004-5 will be another major drought year (Betancourt Pers. Comm.). Precipitation may fluctuate from year to year, but temperature is likely to continue increasing, leading to elevated evapotransportation. Additionally, warm winters are likely to increase survival of overwintering insect species that can incur massive outbreaks.

1.4 Need for a Coordinated Network.

Our ability to predict how ecosystems will respond to drought and associated threshold-like responses related to plant mortality in general is very incomplete; we have few studies that allow us to assess the rapidity, magnitude, extent, and complexity with which droughts could affect ecosystems regionally. The few studies documenting drought-induced woody plant mortality are either limited to specific locations (Allen & Breshears 1998, Ogle et al. 2000), are extrapolated to regions based only on casual observations (Allen & Breshears 2004, Brown et al, 2002), and generally lack specific information on the important links between precipitation, temperature, water availability, soil water content, and actual changes in tree survival, as well as to regional scale estimates of vegetation change from remotely sensed data. Although we have begun to at least *document* the effects of drought-produced synchronous tree mortality in more than 12,000 km^2 of piñon-juniper woodlands in the southwestern USA (Breshears et al., 2005), we currently lack a mechanism for comprehensive coordination of research efforts to allow the sort of cohesive analysis across multiple ecological factors that will lead to understanding of drought-related ecological dynamics and, ultimately, models for accurately predicting drought effects and evaluating land management alternatives. It is this research and informatics infrastructure that we propose to construct under the requested DIREnet funding.

In particular, DIREnet will provide infrastructure and venues necessary to address critical ecological questions that hinge on comparative analysis of region-wide ecological data or data from across many disciplines. DIREnet-promoted studies will conduct unprecedented multi-scale observations and modeling, based on how drought can reset ecosystems at regional scales. Examples of specific ecological hypotheses that require a well-coordinated community of researchers with shared access to compatibly formatted aggregations of diverse ecological datasets to fully explore include: **1)** Spatial and temporal climate variability (Comrie *et al.* 1998) correlate with tree mortality (Logan & Powell 2001), fire (Swetnam & Betancourt 1992) and ecosystem productivity across the region (Allen *et al.* 1998); **2)** Northern populations of Southwest tree species will experience less drought stress and hence less selection for drought tolerance (Figure 1); **3)** Evolutionary paths will be redirected. There is evidence that extreme events such as these droughts exert the major selection pressures (Gutschick & BassiriRad 2003) and may explain diverse patterns of trait associations; **4)** Drought & tree mortality will greatly alter fire regimes across the region in complex ways; **5)** Consequences of the death and changing distributions of dominant trees will be community-wide (Whitham *et al.* 2003). For example, with over 1000 species dependent upon pinyon pine (Brown *et al.* 2001), drought will affect diverse taxa from microbes to vertebrates and only a coordinated network can bring the findings of such diverse taxa and disciplines together; **6)** Ecosystems will be completely transformed (versus intact ecosystems moving upwards along gradients of temperature

and precipitation) (Scheffer *et al.* 2001); **7)** Invasive species will expand across the region as a result of wide-scale disturbance; and **8)** The recovery phase is prolonged and may account for major effects on inclusive fitness (Gutschick & BassiriRad 2003), implying that it is imperative to follow the patterns of resource use, growth, development, and reproduction over long periods and diverse geographic locations, by coordinating research of many groups and institutions.

None of these hypotheses can be addressed satisfactorily under the current research model**,** in which researchers work independently, share data sporadically, and use a plethora of incompatible data formats, notations, and measurement metrics. Documenting and analyzing this severe drought is crucial for understanding the resiliency and function of communities and ecosystems. Such disturbance events may be rare, but they represent bottleneck events that have long-term effects that entrain ecosystems for decades and longer. Given the ecological baseline established by extensive existing pre-drought information, DIREnet will allow us to accurately document and quantify the impact of the current drought, and to create strong models for ecosystem response to extreme drought events applicable to other semi-arid ecosystems worldwide.

Although our network emerged from a need to understand an extreme event that is regionally resetting major ecosystem types, the potential for DIREnet easily extends to other complementary themes and programs(**Figure 3**) including **1)** an examination of drought as a special case of extreme events (Gutshick & BassiriRad 2003), **2)** a global perspective on drought impacts (Kogan 1997), **3)** the major environmental challenges suggested by the national Research Council for NEON (Tilman et al 2003), and associated work on climate change (CLIMAS), and **4)** the socioeconomic implications of drought (www.mpcer.nau.edu/direnet/romme.htm).

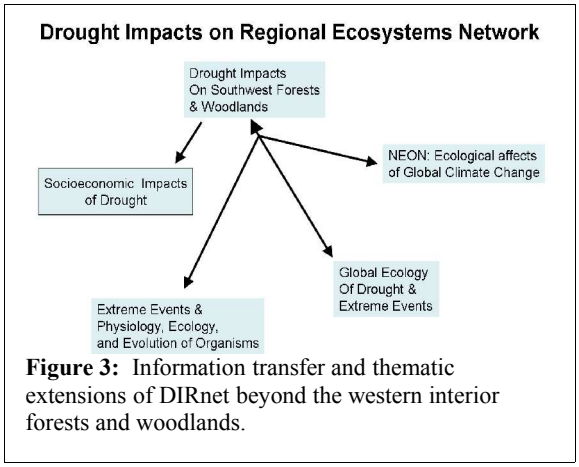


Figure 3: Information transfer and thematic extensions of DIRnet beyond the western interior forests and woodlands.

1.5 The Core Participants: A Brief Survey of Research Interests and Opportunities

To emphasize the broad potential value of coordinating research efforts under the proposed DIREnet initiative, the following paragraphs give an indication of the breadth of research interests among the 40 core participants and how those research interests interrelate. Names of core participants are listed in parentheses and reflect current or proposed research and collaborations; see *core participant supplement* for details on DIREnet research interesets of each participant.

Over 200 long-term study plots have been established in N. Arizona in PJ woodlands (Cobb, Gehring, Whitham) and ponderosa forests (Bailey, Moore). A comparable number of plots exist in New Mexico (C. Allen, M. Allen, Balice, Breshears), Nevada (Tausch) and Utah (Schupp & others). The mycorrhizal work on the N. Arizona PJ plots (Gehring) is linked with studies at Sevilleta LTER (Allen) and mutual opportunities arise for hydro-ecological studies to be implemented at both sites modeled after current northern New Mexico studies (C. Allen, Breshears), thus integrating abiotic soil dynamics, mycorrhizal ecology, and tree mortality. As a result of these collaborations, water-stress and augmentation experiments are initiated at several sites (C. Allen, M. Allen, Balice, Breshears, Gehring, Whitham). Additional sites are envisioned for southern New Mexico for sampling populations currently unaffected but at risk.

The long-term plots throughout the region allows for comparisons of healthy and dying study trees to understand the physiology of tree mortality (Breshears, Gutshick, Kolb, Koch), ecosystem dynamics (Hungate), responses of species dependent on trees (Theimer, Whitham), and selection for drought tolerance (Mitton, Ortega, Whitham). Data on mortality ascribed to bark beetles is also

gathered, which can then be compared with data from ongoing USFS sponsored studies that specifically focus on bark beetle population dynamics (Kolb, McMillin, Negron). The bark beetle studies have inspired the initiation of new studies to expand the regional coverage of mortality and stand dynamic work (Balice, Collins, Floyd, Natori, Ortega, Romme). These data can be compared to comparable data from ongoing federal monitoring programs (Miller) to obtain a regional picture of tree mortality and population structure. Mortality patterns will be scaled-up from ground data to landscapes-regions using remotely-sensed data [Quickbird to TM] (Pennington, Prather, Rich, Yu).

Large-scale mortality of dominant trees and subsequent erosion provides opportunities to study the population dynamics of invasive species and altered fire regimes (C. Allen, Bailey, Balice, Floyd, Kolb, Muldavin, Romme). Vegetation zones are shifted up in elevation (Allen & Breshears 1998) and studies will examine changes in the biotic transitions from PJ to grassland (Collins, Sisk) and from ponderosa to PJ (Koch, Kolb). Having numerous large data sets from different spatial scales will allow modelers to predict long-term demographic patterns (Ogle, vanMantgem), ecosystem dynamics (Breshears), and spatial patterning (Barber). To put the drought in historical perspective, population and community ecologists (Allen, Collins, Whitham) collaborate with historical ecologists (Moore), dendroecologists (Swetnam), and paleoecologists (Betancourt, Anderson). The modeling and historical perspective will help us understand the implications of all this research for global climate change issues. For example a funded USGS project is using DIREnet collaborators now to frame the scientific questions for pinyon-juniper management, and to develop adaptive modeling approaches for resource management decisions on the Colorado Plateau (Turner).

The discussion above illustrates the breadth and mutual relevance of existing research with respect to understanding drought effects and climate change in the Southwest region. The proposed DIREnet would leverage these existing interests by *coordinating* research, establishing a *common* set of data formats and methodologies, and providing an *informatics infrastructure* for sharing, aggregating, and analyzing data produced by various projects in a uniform, comprehensive fashion.

2. DIREnet: A Coordinated Ecological Research Community.

To establish DIREnet as a vibrant, highly-coordinated research community, we propose a set of activities that promote cross-pollination of research and education, and support strong personal interactions among regional researchers. These in-person activities are centered around and complement a powerful online research informatics cornerstone (the SERF system, see Section 3), and will promote current core participant involvement, attract additional researchers and graduate students into the network, encourage participation by Native Americans, and provide information to students and the general public.

2.1 DIREnet Activity: Advancing Researcher Collaborations

The coordinators (Clark & Nassar) and PI's (Cobb & Doerry) will be responsible for promoting collaborative field studies, data collection standards, modeling, and teams for synthesis work. At annual meetings we will explore general themes that will result in synthesis manuscripts (e.g, Breshears et al., in prep for Science), original research, standardized methods, and technological advancements, and participants will give formal presentations on past, current, or future research to stimulate discussion and ideas for future collaborations.

Integrating field studies and data collection standards will involve encouraging **1)** new measurements taken on existing studies; for example, new ecosystem level studies to be conducted in areas where there are long-term population studies (e.g., LANL and NAU); and **2)** initiation of new collaborative studies. An example of a new collaboration that is already underway is researchers from U of Arizona, Los Alamos lab, NAU, Prescott College, and Dine College sharing methodologies in tree mortality studies to construct a regionally coherent GIS model. The combination of meetings, correspondence with individual researchers, and on-site visits will bring

researches together to coordinate drought-study strategy and collaborative efforts, and will also ensure that participants learn how to interact within SERF and provide input on how it functions.

2.2 DIREnet Activity: A Student Researcher Exchange Program

The student-researcher exchange program is designed with three main objectives: **1)** provide high-level, multi-disciplinary research training to students, **2)** foster uniformity of methods and replication across space, and **3)** bring young researchers into DIREnet. Major obstacles in the coordination of research efforts include a lack of familiarity with complementary research efforts and a significant lack of uniformity in experimental methodologies, data formats, and analytic techniques. Although the SERF site will provide critical motivation for such coordination, it must be supported with grass-roots efforts at the graduate and undergraduate education levels. Students will gain is insights into variation in drought effects across space and into different approaches to exploring the mechanisms leading to drought effects. Student exchanges would promote interdisciplinary work where it takes root best - when people are young and not so set in their ways. Faculty will be promoting similar idea exchanges at the annual meetings, but the students will really help to implement it and, in doing so, gain a broader understanding of drought triggers, mechanisms of mortality, and consequences of changes in vegetation distribution.

To promote visits of graduate students among labs, we will provide limited funds for travel and housing. We will solicit applications for this funding via multiple avenues such as online through community websites and listservers and through email to relevant departments at Colleges and Universities. Evaluation of student exchanges will be provided by documenting and archiving outcomes (data, talks, papers, proposals, etc) on SERF. By bringing student researchers into the community we will be integrating these critical participants, our future faculty, into DIREnet.

2.3 DIREnet Activity: Involvement of Native Americans & Other Minority Stakeholders

A regional examination of drought impacts in the Southwest cannot be complete without participation by Native Americans, the Navajo Nation alone comprises over 17 million acres. Tomoe Natori, a faculty member at Dine College, a Navajo tribal college, will lead efforts to integrate studies of drought impacts on Native American lands into DIREnet, bringing Native American students and researchers into the network. She will identify students to participate in DIREnet and coordinate internship programs at the DIREnet institutions. She will also work with core participants interested in leading DIREnet research projects on Navajo Nation lands. When motivated Dine College students are identified, DIREnet will collaborate with the faculty and students in data sharing or website development. We will work towards additional internship programs for DIREnet participating researchers to assist Navajo Nation agencies and community groups, including chapter houses, grassroots organizations, and local non-profit organizations on Navajo Reservation. In addition to NAU, most of the other universities are minority-serving institutions, with up to 50% Hispanic and other minority enrollment, and over 12 federal and state programs to enhance participation by underrepresented groups (MARC, MBRS, RISE, SCORE, BRIDGES, etc.).

2.4 DIREnet Activity: Community Outreach

Results from DIREnet are expected to be of great interest to students, the general public and policy makers. Hence it is important that we exchange information more broadly than just among researchers. This will be accomplished by making some summaries of DIREnet data and researchers results available via the publicly-accessible areas of SERF. Currently MPCER is developing web-based resources and course modules though a Virtual Environmental Learning Space that will provide tutorials, background information and data to students. SERF resources and data will be integrated in this effort to expand the resources available to VELS users. INRAM provides extensive outreach to K-12 students and teachers and to the general public, particularly via Web-based and classroom-based activities in its Virtual Center for the Environment.

3. SERF: A Dynamic Online Collaboratory

As indicated in Section 1.5, core DIREnet participants are widely distributed, both geographically and by research specialty; other important DIREnet participants are drawn from a broad community of academic, government, and tribal stakeholders in the ecology of the southwest region. To provide for comprehensive coordination and communication within this highly diverse, widely distributed community, we propose to establish a cutting edge *Online Research Forum* to serve as the informatics cornerstone of the DIREnet initiative.

3.1 The Southwest Ecological Research Forum (SERF)

The Southwest Ecological Research Forum (SERF) will weave together diverse and widely-distributed researchers into a dynamic, well-coordinated research community, allowing us to promote collaborations that can span the globe. Over the past decade, online data archives have established themselves as a critical catalyst for research in a number of areas. A primary reason for the ongoing surge of progress in genetics, for example, can be directly attributed to the establishment of powerful online bioinformatics resources, both at the national level, e.g., NCBI (**www.ncbi.nlm.nih.gov/**), and within specific communities devoted to the study of individual organisms, e.g., MGI (lab mouse; **www.informatics.jax.org/**), Flybase (drosophila; **flybase.bio.indiana.edu/**), and GDB (human; **gdbwww.gdb.org**), providing researchers the world over easy access to the full range of research results available within the community, along with, in most cases, powerful visualization and analytic mechanisms (e.g. visual genetic maps) for exploring data to answer specific research questions. We will also build on the integrated database on biodiversity, climate, land use and ownership, and remotely-sensed data embodied in several digital projects, including the Institute for Natural Resource Analysis and Management (**www.inram.org**), initially developed as an NSF-EPSCoR project for New Mexico, the Southwest Information Node (swin.nbii.gov) CLIMAS (**www.ispe.arizona.edu/climas/**), and ForestERA (**www.forestera.nau.edu**) and scores of other information portals..

The *Online Research Forum* (ORF) concept extends the digital library metaphor established by conventional online data archives to create a comprehensive virtual research community in which access to shared archives of continually updated research data is embedded within a rich interconnection of community member information (researchers, labs, publications) and research resources (nomenclature guidelines, terrain maps, federal agency databases). Sophisticated tools for online data analysis, secure user-controlled access, and online commentary and critique will make SERF not only a central clearinghouse for research data, but also a "place" for the research community to meet, engage in critical discussion, collaboratively analyze datasets, and otherwise interact. In short, SERF will bring together all aspects of research – data, researchers, critical discussion, and analytic tools – situating them in a secure, interactive space to create a single virtual research campus.

SERF will enable meaningful analytic queries designed to elucidate the relationships among diverse data types; a uniform, logical data model will be developed to define the various data types and a uniform set of attributes that describe them. We have developed a prototype data model for climatic data on the Colorado Plateau to explore pitfalls and establish feasibility of the SERF initiative (denali.cet.nau.edu/MPORG); a comprehensive data model centered on drought impact studies will be collaboratively developed by representatives of DIREnet. Once established, we will populate SERF with the data from existing data archives, and provide semi-automated mechanisms for extending and updating all datasets.

In sum, the goal of an Online Research Forum is to provide access to data, embedded in a rich context that includes interaction between data producers, data consumers, and opportunities for collaboration. Eck Doerry has extensive experience in this area, having successfully pioneered the

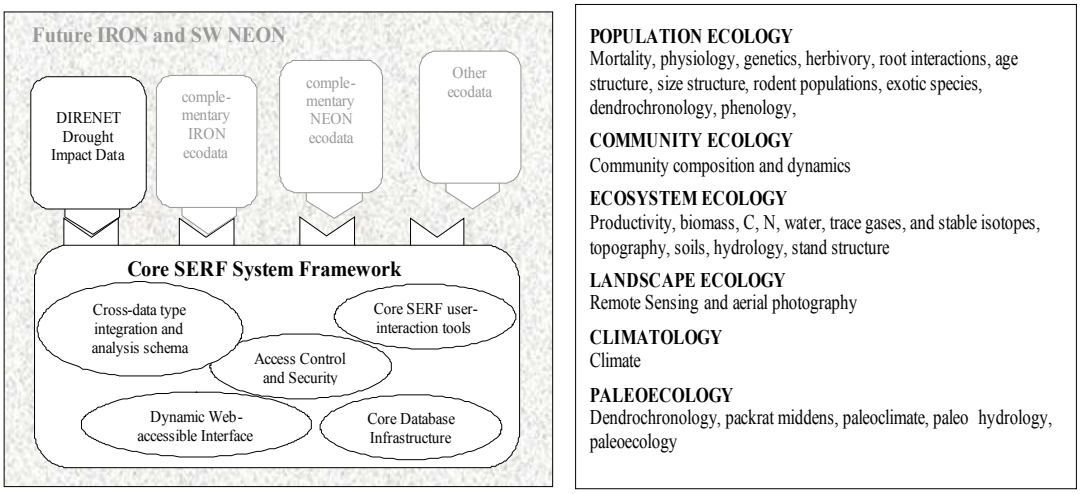
key concept of an Online Research Forum as director of the Oregon Center for Distributed Bioinformatics and lead designer of ZFIN (www.zfin.org), the informatics hub for the zebrafish genetics community. We propose to draw on this experience (Sprague, 2000; Westerfield, 1999a&b; Westerfield, 1997; Doerry, 1997a&b) in developing the SERF system. In addition, we expect recent innovations in ORF technologies developed by Eck Doerry (e.g., the Modular Online Forum Infrastructure) and to be included in SERF to generate several publications in research informatics.

3.2 SERF Content

SERF will contain shared datasets DIREnet participants and publicly available data relevant to drought impact studies. The core SERF framework will be centered around a secure, web-accessible database and research forum capable of supporting an indefinite variety of ecological data types (**Figure 4a**). **Figure 4b** provides examples dataset types to be included. The elements shown in light gray in **Figure 4a** indicate the potential for future development of the SERF system; other data modules can be added to the established foundation, supporting a growing variety of novel cross-type data analyses to address regional ecological questions. Ultimately, SERF will complement developing IRON and NEON eco-informatics initiatives.

Unlike conventional online data archives, SERF extends beyond indexing and archiving of research datasets. **Figure 5** overviews the full scope of information and research resources included in the SERF, illustrating how SERF situates access to the research datasets outlined in **Figure 4b** within a rich *research context*, complemented by a powerful set of *research resources*.

Research context. SERF datasets are embedded in and comprehensively interlinked with information on the researchers, labs, programs and projects that produced the datasets, as well as the



(a) (b)

Figure 4: (a) Current focus (in black) and future directions (in gray) of SERF; and (b) specific DIRENET data types to be collected and made available in SERF under this proposal.

research publications in which the *significance* of the datasets was discussed. This integration of data and research context supports flowing opportunistic exploration of information. For example, one might begin searching for Craig Allen, then, while viewing his record, note that he is collecting long-term population data and associated remote sensing data in northern New Mexico. Clicking on a population or remote-sensing link, one would learn about similar DIREnet studies. Seeing a reference of particular interest, one might click to view it, then click the first author shown in the publication record to find her contact information and email her a question about the status of the project described in the publication. Because each of these screens is generated dynamically ("on the fly") from the underlying database, updates and additions are instantly and automatically reflected.

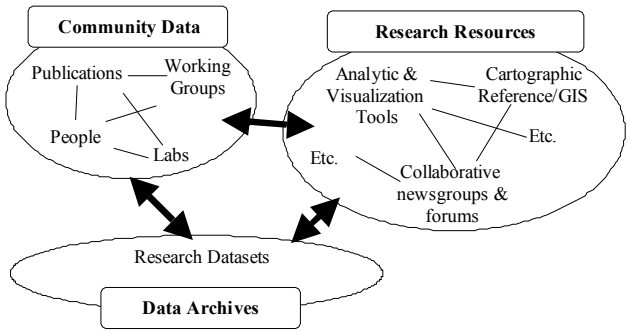


Figure 5: Complete overview of data and research resources contained in SERF. All data shown will be comprehensively interlinked with a single uniform search and display interface model.

Research Resources. SERF will also provide sophisticated research tools (see Budget Justification) via which researchers can discover and investigate meaningful patterns within and across datasets, including sophisticated graphing, statistics, exploratory data analysis and visualization tools, reference maps and GIS tools. Additional resources will include publicly available data from federal agencies, species and morphological dictionaries, nomenclature references, and a broad variety of tools to support intra-community collaboration and critical discussion (see Section 3.4). By defining a common set of analytic and reference resources, we encourage discussion of and evolution towards community-wide conventions and definitions; the communicative and collaborative tools that collectively comprise a 'virtual research forum' ensure the inclusion of a broad spectrum of opinions from throughout the SERF research community.

Finally, SERF will support real-time online collaborative analyses of research data by distributed researchers, reflecting the social, negotiated nature of the scientific enterprise. comprised of data about the evolving information on researchers, their labs, ongoing projects, and contact information.

3.3 Specific SERF Functionalities http://denali.cet.nau.edu/SERF

The preceding discussion outlined organization and information that will be contained in SERF. The true power of SERF, however, arises from its dynamic characteristics as an interactive community forum and research resource. The following paragraphs highlight the most unique and powerful SERF features:

Cross-data type analytic tools. Because all data types are contained within the uniform SERF framework, analytic tools can be applied both within and among data types, supporting efficient, intuitive exploration of ecological hypotheses, e.g., correlations of ecological factors documented across a variety of studies and datasets.

Authentication and per-user data access control. Although guests may access generic, public facets of the SERF site, community members may log in and be authenticated. Once authenticated, SERF is able to provide users with individually customized access to data and other resources, depending on the privileges accorded to a given user. A sophisticated security model allows a variety of permissions to be assigned to individual users for datasets; this yields extremely powerful yet efficient access control. We will follow the same data management policies set by the LTER network and will also interface closely with INRAM, drawing on the efficient access management models developed by INRAM, i.e., a "central accumulator model", in which individuals (curators, field or lab researchers) control data locally with simple software, preparing it for upload to a central database; filters at the central database will enforce release policies and quality control, in automated fashion. SERF search interfaces will allow Web-based as well as programmatic (e.g., DIGIR) access, and will meet standards for biodiversity and GIS data (ITIS, Darwin core (FGDC).

Secure data submission/update. Curation has proven to be one of the most daunting challenges for online research archives, requiring an army of highly-trained data editors to collect, upload, and update data in the archive. Authenticated access and an intuitive user interface will encourage researchers to update research datasets they administer, update their personal bio and contact information, and contribute directly to online discussion forums. Intervention of a database administrator will be required only as an exception.

Data-specific discussion forums. A key to understanding the significance of a given dataset lies in the discussion and interpretation by the research community. Traditionally, such discussion is limited mostly to hardcopy forums (e.g. journals). Some communities have tried to establish online discussion in, for example, a USENET newsgroup, but have been hamstrung by the difficulty of restricting access to only community members, or the difficulty of locating "of interest" discussions in the flood of commentary. SERF corrects these problems by allowing "discussion forums" to be attached to any dataset or data category in the system; a researcher viewing a dataset may find attached to it one or more discussion forum containing critical discussion or commentary associated with that data. Authentication ensures that the identity (and integrity) of all participants is associated with all correspondence.

Personalized research tools. Because data on ecological impacts of this drought is expanding so rapidly, maintaining awareness of available data is extremely challenging. In an online research archive, the results from a query will change over time, as new data are added. SERF will provide powerful tools for maintaining data awareness: researchers may "paste" the results of a query into a personal online "research notebook", either as static snapshots, or as "dynamic pages" in which the query is re-run to update results each time the researcher views the notebook. Researchers will also be able to set "event triggers", specifying events to watch for, e.g., collection of new data. When the event occurs, SERF will email the researcher, including a hotlink to the new data.

The above features emphasize the dramatic difference between an Online Research Forum and conventional research informatics sites that exist today. In essence, SERF combines the best features of successful commercial sites like Amazon, Ebay, and Yahoo - discussion forums, secure (data) marketplaces, and active notification of (database) updates – to weave together a group of widely-distributed researchers into a coordinated, efficient online research community.

3.4 SERF Architecture Overview

In preparation for this proposal, we constructed a proof-of-concept system to ensure feasibility of key technical elements and to frame our future development effort[1]. Our aim was to articulate a technological substrate that (a) would satisfy the requirements of an Online Research Forum; (b) was not tied to proprietary commercial software or database solutions, and (c) had strong potential for future expansion. This analysis supported our choice of a dynamic interface generated by a PHP-engine, backed by a PostgreSQL database, all running on a Linux server. The SERF architecture can be divided into several functional modules (**Figure 6**). The web-accessible interface is provided by a standard (Apache) WWW server, driven by a PHP engine that dynamically generates interface webpages. Data are indexed, extracted from the underlying PostgreSQL database (RDBMS), and presented within interface displays specifically designed for ecologist end-users. All interaction between the web interface and the underlying database is strictly controlled by the Security/Access Manager, which authenticates users, and ensures that a given user is presented only with data viewing/updating options that he or she is authorized to perform on requested datasets.

In the middle "tool layer", the Interaction/Collaboration Module provides the key intra-community interaction elements of the virtual research forum, e.g., collaborative analysis (CA) tools to allow distributed researchers to access SERF in synchrony, data-specific discussion (DSD) groups, online research notebooks, and other groupware tools. The Analysis and Display Engine provides a broad suite of analytic tools for searching out, analyzing, comparing, and displaying datasets with emphasis on visual GIS-based representations. The actual SERF database appears as a "data access" layer, providing physical storage not only for experimental datasets, but also for user configuration preferences, transaction state information, and other administrative functions. **Figure 6** also shows how we plan to integrate access to powerful eco-data indexing engines being developed elsewhere

[1] See our pilot project development site: http://denali.cet.nau.edu/SERF

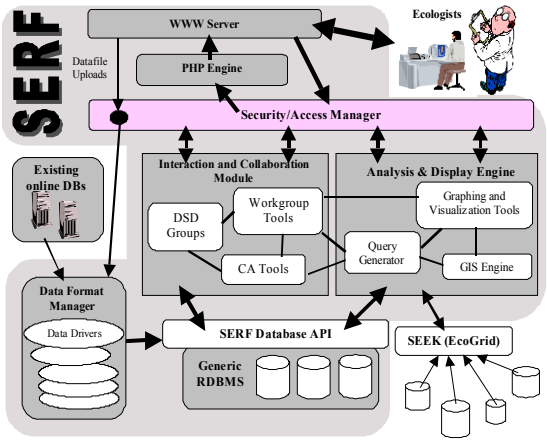


Figure 6: Overview of SERF (light grey background) architecture and complementary data archives.

(e.g. pbi.ecoinformatics.org/projects.html). SERF users will be able to search not only across local SERF data, but also draw on datasets indexed by the SEEK engine; SERF will provide a single, uniform interface for all eco-data access.

3.5 Data Flow: Where do SERF Data come from?

SERF data curators. Identifying and organizing datasets to be including in SERF (**Figure 6b**) is a primary focus during the initial project years. Collected from a range of disparate existing archives, and through liaison with individual researchers and labs, we will develop a uniform data model for each data type that normalizes variations in sampling frequency, measurement metrics and so on. Although we expect most updates to be automatic once SERF is primed with existing datasets, experience has shown that at least one administrative data curator is necessary.

Researcher-initiated uploads. An important feature of SERF effort is that it pioneers a model for research informatics that distributes the enormous effort of maintaining a data archive across the research community, by empowering individual researchers to curate their own datasets. Simple upload interfaces will streamline this process; an evolving set of "data drivers" (**Figure 6**) will serve as "formatting engines", mediating between the plethora of data collection formats used in different labs, and the uniform data models in the SERF system. Secure, access to SERF will ensure that only authenticated researchers submit, edit, and update data. Motivation to upload data will be provided by funding agencies[2], by the desire to use SERF analytic tools to analyze new data with respect to existing SERF datasets, and by the desire to disseminate and establish new collaborations.

Automated extraction from other informatics resources. In addition to data providers already mentioned (e.g., INRAM), a variety of web-accessible informatics resources exist that make available datasets relevant to SERF, e.g., the Climate Diagnostics Center (www.cdc.noaa.gov/), Sevilleta LTER (sevilleta.unm.edu/data/), and the Utah Automated Geographic Reference Center (agrc.its.state.ut.us/). Depending on the interface capabilities of these external data archives, SERF will either provide integrated mechanisms for dynamic query and access to external data archives, or implement automatic mechanisms for periodically querying these data sources, and uploading new information to SERF

4. Coordinating Team and Management Plan

A community of DIREnet ecologists that number well beyond the core participants listed in this proposal already exist; conversations about drought-related mortality already dominate professional meetings. The central aim of the proposed DIREnet initiate is to provide the centralized leadership and coordination necessary to enable this highly-diverse research community to tackle the broad, pan-regional ecological hypotheses outlined in Section 1.4. The following subsections outline the central elements of our proposed coordination and management plan.

[2] It is increasingly common for funding agencies to require upload of data generated by funded projects to a community informatics system. We hope to establish this model in the Southwest ecological community as well.

4.1 The Merriam-Powell Center for Environmental Research (www.mpcer.nau.edu)

The management of DIREnet will be the primary responsibility of the NAU coordination team (i.e., Merriam-Powell Center for Environmental Research staff), who will work with the steering committee and other core participants. PI-Cobb is the Director of MPCER, and core participant Whitham is the Executive Director of MPCER. The mission of MPCER is to promote interdisciplinary environmental research in the Southwest and Colorado Plateau region; DIREnet thus represents a direct extension of the MPCER mission.

The DIREnet project is a top priority, along with building our new EnviroInformatics Center (www.mpcer.nau.edu/eic) that will eventually house SERF activities. In addition to regional NEON efforts through the Intermountain Regional Observatory Network and the Southwest Ecological Observatory Network, MPCER has been engaged in a number of activities that make it a natural locus for DIREnet administration, including: **1)** Coordination of Research In Pinyon-Juniper Woodlands. MPCER has hosted numerous meetings on the ecology of PJ woodlands, and is actively working with the Bureau of Land Management on the research component of their PJ Research Strategy, including mapping the over 1000 P-J treatments on BLM lands on the Colorado Plateau. **2)** Long-term research on Stress Ecology of Pinyon Pine and Insect Herbivory. The Pinyon Ecology Research Group (PERG; pinyon.bio.nau.edu), lead by Thomas Whitham has conducted research on PJ woodlands since 1982. PERG members are currently conducting five separate NSF sponsored research projects and have produced over 50 publications on pinyon ecology. **3)** Promoting Drought Research. MPCER hosted the "2003 Southwest Drought Summit", attended by over 200 researchers and decision makers from federal, tribal, state, and local agencies and offices in Arizona to assess drought impacts and research-management needs for the future. At the 2003 Biennial Conference on Colorado Plateau Research, MPCER coordinated a meeting of federal agencies to address cross-agency research and management needs in response to the drought and hosted a full-day research symposium. **4)** Web-Based Infrastructure for Coordinating Research and Outreach. MPCER is developing a NAU Environmental Research Database, which compiles research project information on US Forest Service lands via ArcMap projects. MPCER is also developing the Virtual Environmental Learning Space that incorporates environmental research data into course content in multiple disciplines. In sum, MPCER has a proven record of encouraging novel research collaborations, providing a clearinghouse for regional ecological information, and hosting meetings of regional researchers to coordinate research directions.

Neil Cobb (**Ecology**) will serve as the overall project leader and will be directly responsible for all aspects of the project. He will maintain at least bi-monthly correspondence with the steering committee, direct all project meetings and supervise the project coordinator, work closely with Dine College, and coordinate with the co-PI **Eck Doerry** on informatics aspects**. Eck Doerry (Bioinformatics),** associate professor in Computer Science, will be responsible for all aspects of the development and implementation of SERF. Dr. Doerry will oversee lead software developer **Karim Nassar (Computer Science)**. **Matt Clark (Ecology)** will be the overall project coordinator, and will obtain and curate key data sets, regularly update the steering committee and all participants, arrange meetings, coordinate the student exchange program, oversee ecological material maintained in the SERF database, and serve as the liaison between individual research projects and SERF. Additional Merriam-Powell Center staff will support DIREnet activities by providing integration with other center programs, coordinating housing and facility use for visiting DIREnet participants, and providing technical and outreach support.

4.2 DIREnet Governance & Planning

Core DIREnet participants were selected based on their participation in DIREnet-related activities within the last two years and the relevance of their research interests. They are current or upcoming leaders in their respective fields of study and, as a whole, represent a wide range of research areas.

We restricted formal invitations to researchers working on Southwest forests, woodlands, and climatology; we contacted 92 university researchers and federal personnel, later narrowing this group to the 40 people most interested in and able to contribute to a coordinated effort. We will maintain an open door policy of participation; we expect to attract a wide variety of new participants via DIREnet programs and other eco-informatics networks (NEON, QUASHI, regional LTER's, scientific societies). The student exchange program will be a primary mechanism for increasing graduate and undergraduate student involvement.

Steering committee. Because of the large number of core participants, we have created a steering committee that provides a blend of expertise and experience across ecological disciplines and research informatics. The steering committee will provide DIREnet oversight for and ensure the appropriate allocation of group resources. Oversight will be shaped by a work plan that will be developed in the first year and adopted by a majority of the core participants. All core participants will collectively assess the makeup & organization of the Steering Committee in year two.

Ensuring diversity. Our initial group of core participants come from: Dine College, Colorado State University, Edinboro University of Pennsylvania, Fort Lewis College, Montana State University, New Mexico State University, Northern Arizona University, Prescott College, University of California-Riverside, University of Arizona, University of Colorado, University of New Mexico-Sevilleta LTER, Utah State University, NPS, USFS, USGS, and Los Alamos National Laboratory. **Tomoe Natori** is a biology faculty member at Dine College; she will provide leadership in integrating data managed by the Navajo Nation (and possibly BIA) into SERF and coordinate the Navajo Nation's collaboration with DIREnet.

Coordination plan. The NAU coordination team will operate under the philosophy of creating an atmosphere where participants from diverse backgrounds are fully empowered and excited about working towards a common goal. This will require multiple strategies for involvement. We will develop a work plan within the first six months in conjunction with the steering committee that will detail **1)** Key themes for collaboration and associated publication targets (e.g., reviews, original research & technique papers **2)** Standard protocols, **3)** DIREnet directory of resources, **3)** Graduate student exchange program, **4)** Workshop and meeting structure, **5)** Governance, **6)** Funding opportunities, and **7)** SERF development and data population priorities. The workplan will be updated each year, and we will maintain close contact with individual core participants to advise them of progress and incorporate their input over time. The steering committee will meet by video-conferencing twice a year to evaluate progress and make student researcher funding decisions. We will solicit feedback and ideas on SERF from the community at annual meetings. As SERF is developed it will play a growing coordination role, promoting discussion and discovery of collaborative opportunities. Further coordination will be generated by the student researcher exchange program, and participant visits among partnering institutions as part of ongoing seminar series.

Sustainability. The Merriam-Powell Center is committed to DIREnet beyond proposed project timeframe as a core element in MPCER's mission to promote regional environmental research. Accordingly, MPCER will support SERF through our upcoming EnviroInformatics Center and seek to partner with other information networks, and education outreach opportunities as they arise. In particular, the SEEK program, INRAM, and SWIN are highly complementary initiatives and will improve ecological data access through new database technologies. Additionally, DIREnet is a direct result of meetings organized to develop a framework for NEON efforts in the Southwest region; we expect that DIREnet will either evolve into a regional NEON observatory or complement regional NEON observatories as they come online.

Timeline. There will be three phases to the project. Phase 1 will involve the assessment of data/information associated with studies and monitoring programs. Priority will be given to

identifying regional ground and remote-sensed data obtained prior to the onset of the drought, which will constitute baseline comparison data for present and future studies. Simultaneously we will work to promote new collaborations. Phase 2 will focus on the development of SERF and formalizing collaborations, and Phase 3 will emphasize testing and implementation of SERF, and promoting the publication of synthesis work. Evaluation of the goals established for DIREnet will be obtained by several methods, including steering committee processes, annual meetings, and requested input by all core participants. Specific project milestones include:

Year 1 Write a formal work plan that will incorporate DIREnet structure and specific activities, research coordination priorities and timeline, and plan for maintenance and growth within DIREnet. Coordinate a meeting for all DIREnet participants to give a complete overview of project. Identify all sources of existing data and catalog current and proposed research projects. Establish a SERF development server. Install the prototype from our pilot project; collect and enter complete community information; begin development of Interaction and Collaboration and Analytic Tools modules based on the existing datasets. Primary development goal will be to establish SERF as a resource for information on community members, projects, labs, and publications.

Year 2 Initiate student exchange program, continue research coordination activities and participant meetings. Continue work on SERF infrastructure and tools, and experimental datasets. Development goal is to provide complete coverage of several useful datasets, plus prototype interactive research forum resources and analytical tools. By demonstrating the conceptual potential, we aim to generate enthusiasm and buy-in within the community.

Year 3 Develop mid-project progress report, emphasize development of working sub-groups. Strong focus on full implementation of SERF infrastructure, along with a complete range of research resources, and at least initial coverage of all target data types. Establish user uploading and curation of datasets and move the system into "production" mode. SERF will be a useful informatics and analytic resource by year-end.

Year 4 Continue with basic year 1-3 activities. Continued intensive development of SERF. Focus on refinement and expansion of analytic tools, ArcIMS support, and advanced visualization interfaces, as well as improving the virtual forum resources (e.g. discussion groups, online research notebook, etc.). SERF will be complete and fully-functional by the end of year 4.

Year 5 Develop final report and initiate activities for the continuation of efforts begun under DIREnet. Evaluate and refine the SERF infrastructure. Focus on evaluating usage and usability of SERF, with an eye towards refining interfaces and accommodating evolving access dynamics, e.g., streamlining access to commonly requested data, queries, and analytic resources. We will explore long-term funding models, e.g., mandatory "informatics costs" written into future grants.

5. Summary

Understanding the impact and consequences of regional catastrophic disturbance events that have great biological, conservation, economic, management, and sociological consequences requires a coordinated and integrated approach to extract and synthesize disparate data sets and perspectives from diverse agencies and disciplines. Our proposal establishes an infrastructure that meets these needs by providing both strong support for building personal and professional relationships between researchers, and a modern research informatics infrastructure to bring together a diverse, widely-distributed research community. Because of our extensive past experience in both research informatics in general, and research coordination in this area, we are ideally suited to implement and administer DIREnet, moving regional ecological research to the next level via a community focus and a data archive capable of coordinating, streamlining, and stimulating ecological research in the Southwest for the foreseeable future.

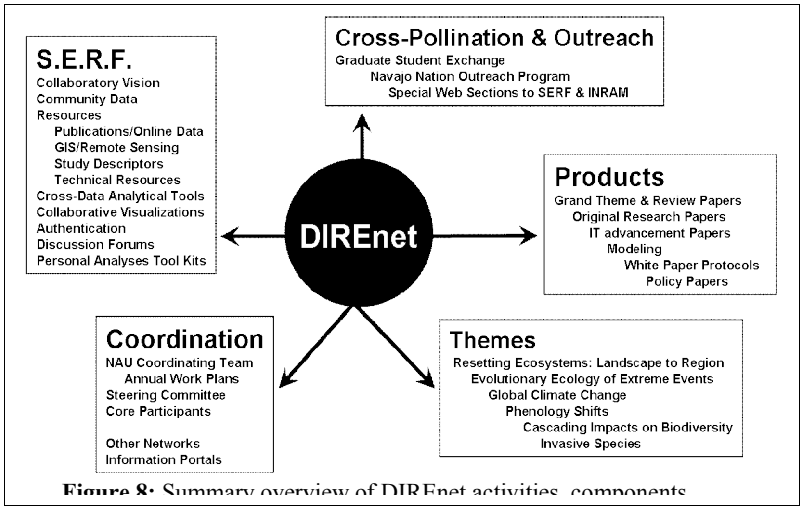


Figure 8: Summary overview of DIREnet activities, components

The research coordination effort proposed here represents a cutting-edge combination of online resources and traditional scientific interaction and coordination (**Figure 8).** The DIREnet initiative respects and supports the established conventions of our scientific community , while coordinating and streamlining research interactions with a modern informatics infrastructure to yield improved information exchange, new opportunities for collaboration, and higher research productivity. By supporting not only data archiving, but also researcher exchange, creation of educational resources, and scientific discussion and debate with the community, our proposed effort provides a model for scientific communities of the 21st century.

DIREnet Core Participants DIREnet Related Research
Table of Contents

We received a strong response to our request for participation in DIREnet. Due to the large number of core participants we have identified a subset of those to serve on a steering committee that will provide oversight for the entire project. Below is a listing of the participants that have provided letters on the following pages. PI* CO-PI **

Core Participants (Steering Committee)

Craig Allen	Plant Ecology	USGS, Bandelier NP
Mike Allen	Soil/Ecosystem Ecology	U. California-Riverside
Julio Betancourt	Paleoecology/Climate Change	USGS/U of Arizona
David D. Breshears	Ecosystem Ecology	University of Arizona
Neil Cobb*	Population Ecology	Northern Arizona U.
Scott Collins	Community Ecology	University of NM, Sevilleta LTER
Eck Doerry**	Bioinformatics	Northern Arizona U.
Vince Gutshick	Ecophysiology	New Mexico State University
Lisa Floyd	Population/Fire Ecology	Prescott College
Jeff Mitton	Evolutionary Ecology	UC-Boulder
Eugene Schupp	Population Ecology	Utah State U.
Tom Swetnam	Dendroecology	University of Arizona
Robin Tausch	Population Ecology	USFS-Rocky Mountain Research Station

Core Participants

Scott Anderson	Paleoecology	Northern Arizona U.
John Bailey	Restoration Ecology	Northern Arizona U.
Jarret Barber	Spatial Ecology/ Statistics	Montana State University
Karen S. Eisenhart	Disturbance & DendroEcology	Edinboro University of Pennsylvania
Catherine Gehring	Soil Ecology	Northern Arizona U.
Bruce Hungate	Ecosystem Ecology	Northern Arizona U.
George Koch	Plant Physiological Ecology	Northern Arizona U.
Tom Kolb	Plant Physiological Ecology	Northern Arizona U.
Joel McMillin	Insect Ecology	USFS –FHM Arizona
Mark Miller	Plant Ecology	National Park Service
Margaret Moore	Community &Restoration Ecology	Northern Arizona U.
Esteban Muldavin	Landscape & Fire Ecology	U. New Mexico
Tomoe Natori	Population Ecology/Education	Dine College
Jose Negron	Insect Ecology	USFS-Forest Health Colorado
Kiona Ogle	Ecological Modeling	Montana State University
Catherine Ortega	Population Ecology/Genetics	Fort Lewis College
John Prather	Wildlife Ecology/Spatial Modeling	Northern Arizona U.
Deana Pennington	Remote Sensing & Ecoinformatics	LTER Network Office
Paul Rich	GIS & Remote Sensing	Los Alamos National Laboratory
Bill Romme	Fire & Disturbance Ecology	Colorado State University
Tom Sisk	Landscape Ecology	Northern Arizona U.
Tad Theimer	Vertebrate Ecology	Northern Arizona U.
Christine Turner	Science-Management Integration	USGS

Phillip vanMantgem	Demography/Disturbance Ecology	USGS
Thomas Whitham	Community & Evolutionary Ecology	Northern Arizona U.
Yaguang Xu	Spatial Analysis/Remote Sensing	Northern Arizona U.

PRINCIPAL INVESTIGATOR

NEIL S. COBB
NORTHERN ARIZONA UNIVERSITY

As the Principal Investigator for this project, I primarily bring the skills of coordinating interdisciplinary environmental research, as the Director of the Merriam-Powell Center for Environmental Research. I have personally collaborated with almost all of the core participants, with several collaborations going back decades. Through the Merriam-Powell Center I am responsible for promoting collaborations among NAU environmental scientists, and linkages with NAU and other universities. I am confident in my ability to bring people together and make them productive. Thus, I am in a perfectly positioned to coordinate a network that focuses on a theme that is a key issue for the center. Additionally, I am directing the construction in the EnvirInformatics Center, a facility that will open in 2006. This facility will have all of the key support personnel and infrastructure that will be required to ensure Direnet will evolve in perpetuity.

My research is highly relevant to the proposed project because it involves examining responses of pinyon-juniper woodlands **(1)** and ponderosa pine forests **(2)** to drought, either directly or indirectly through increased susceptibility to outbreaking insect herbivores. The third project **(3)** involves the development of GIS databases covering pinyon-juniper woodlands and ponderosa pine forests. My specific research interests include the role of abiotic stress mediating the population and community ecology of arthropods associated with pinyon pine, the population dynamics of pinyon pine across stress gradients, and spatio-temporal dynamics of pinyon-juniper woodlands. Below are three major projects that will contribute significantly to the project and also benefit from future collaborations resulting from network activities.

A. <u>The Roles of Stress & Time In Insect Outbreaks: The Effect Of A One Million Year Successional Gradient & A 100-Year Regional Drought On The Pinyon Needle Scale</u>. In collaboration with Thomas Whitham [NAU], Rodolfo Dirzo [UNAM], & Jeffry Mitton [UC-Boulder]) We are examining how scale outbreaks are created in response to pulses of drought. This study addresses four questions that are central to understanding what factors promote and maintain irruptive insects: **1)** Are scale populations high stress sites inherently stable, and serve as epicenters for outbreaks? **2)** Conversely, are outbreaks at low-stress sites ephemeral, occurring only following drought years? **3)** How important is host-tree resistance in limiting the expansion of scale populations? and **4)**, How does local climate, soil type, and genetically-based differences in pinyon populations affect scale performance?

B. <u>Stand level impacts of bark beetles in pine forest types of Northern Arizona</u> In collaboration with John Anhold, Joel McMillin, and Jose Negron USDA-USFS-FHM) We are quantifying the impact, extent and severity of bark beetles on ponderosa and pinyon pine at the stand level through an extensive plot network on a portion of Arizona's northern National Forests. .

C. <u>Inventory of Past Pinyon-Juniper Management Treatments on Bureau of Land Management Lands on the Colorado Plateau</u> (In collaboration with Jill Rundall, NAU) We are developing a GIS map/database of the ~1,000 pinyon-juniper range improvement projects completed on BLM lands on the Colorado Plateau. We are also performing spatial analyses BLM trend data that characterize size, distribution, habitat quality, and treatment types. The database and GIS products will be made accessible through a WWW interface and will provide a substantial resource for DIREnet. The mapped treatments will provide excellent potential study sites.

CO- PRINCIPAL INVESTIGATOR

ECK DOERRY
NORTHERN ARIZONA UNIVERSITY

My research interests fall generally in the area of Computer-Supported Cooperative Work (CSCW), with specific emphasis on the area of *groupware technologies*, which explores new ways in which networked computing applications can support distributed groups in their collaborative efforts. Specific topics of interest include design and evaluation of user-centered web interfaces, group communication dynamics in distributed contexts, and support for small, agile working groups. Scientific communities provide an excellent application domain for exploring these issues: they are relatively sparse and widely-distributed, have critical information sharing, coordination, and communication needs, and are highly-receptive to new technologies.

My particular interest in the DIRENET/SERF project proposed here lies in further developing the concept of an "Online Research Forum", which was pioneered in my work with the Zebrafish genomics community and the development of the Zebrafish Information Network (ZFIN; www.zfin.org). The development of ZFIN, originally conceived of as a more user-friendly extension of conventional research data archives, revealed a host of opportunities for better supporting-dynamic scientific communities - for bringing not just data, but all of the core communicative processes of the scientific enterprise online. Tentative exploration of mechanisms that might achieve this goal spawned many of the central ideas proposed for implementation and further exploration in the SERF system, including database-integrated online research notebooks, data-specific discussion forums, and secure, community-driven data curation. I look forward contributing my interest and energies towards exploring these and other ideas related to Online Research Forums within the context of the DIRENET/SERF project.

Collaborative Scientific Visualization. Our SERF model has focused primarily on supporting access by individual researchers and long-term research community development. Integrating recent developments in real-time collaborative visualization will enhance SERF functionality, allowing large, distributed collaborative research teams to collectively analyze data sets interactively, promoting collaborative research at both regional and continental scales. As shown in Figure A-1, scientists using these tools share the same interface and visualizations, and may interactively explore computation, real-time measurement, and experiment ecological data made publicly available via SERF. The remote collaborators will apply a variety of visualization techniques; interactively roam, rotate, scale and zoom collections of data; and to interact in other ways, using a chat utility, that can include audio/video streaming, a visualization capturing whiteboard, streaming audio/video, streaming media, tele-pointers, or remote screen-capture as if sitting together in front of the same workstation. We are working on complementary projects to make collaborative visualization available to DIREnet participants.

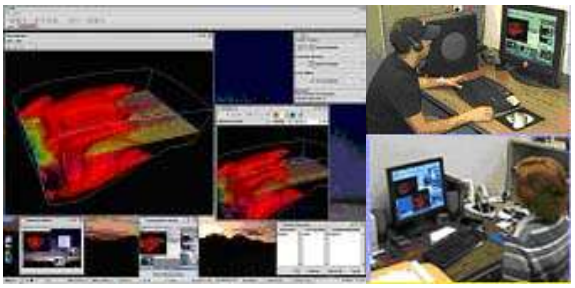


Figure A-1: Collaborative Scientific Visualization Environment: Two people working through the GRID can manipulate Very Large data sets in order to apply visualization to their data and achieve key insights into patterns that would not be evident otherwise.

CORE PARTICIPANTS (STEERING COMMITTEE)

CRAIG D. ALLEN
United States Geological Survey, Bandelier National Monument, New Mexico

Craig Allen is a research ecologist with the U.S. Geological Survey, and is the Leader of the Jemez Mountains Field Station based at Bandelier National Monument. Craig conducts research on the ecology and environmental history of Southwestern landscapes. Ongoing research topics involving a variety of colleagues and collaborators include: responses of semiarid forests and woodlands to drought (with links to global change issues); development of vegetation and fire histories in the Southwest; fire effects on Mexican spotted owls, Jemez Mountains salamanders, and nitrogen cycling; erosion, and restoration of, piñon-juniper watersheds; and development of long-term ecological monitoring networks across landscape gradients in the Jemez Mountains. I have been studying drought-induced mortality of Southwestern forests and woodlands for over 15 years, including reconstructing the impacts of past droughts such as the 1950s drought.

Currently we have 14-year long datasets on the weekly growth rates (using dendrometer bands) of 8 pinyon and 30 ponderosa pine trees along an elevational gradient, showing clear drought effects. All 10 of the low elevation ponderosa pine trees died during the drought in 2002 (since replaced), and all of the banded pinyon trees died in 2003. We just banded 5 Douglas-fir trees to begin monitoring their growth. We have detailed demography data from all pinyon trees in several 0.5 to 1 hectare plots, not only showing the effects of the current drought but also past droughts through dendrochronological analyses of live and dead wood. We also work with data from ~100 permanent fire monitoring plots (0.1 ha.) at Bandelier that provide baseline for the ongoing dieback phenomenon. We have amassed a series of repeat aerial and ground-based photographs documenting rapid dieback of woody species, including aerial photography from 2001 and 2004 that bracket the recent (ongoing) dieback event. I recently analyzed the just-compiled USFS digital records of forest insect and disease maps for the western US, showing the recent spikes in regional dieback for multiple tree species. I am pleased to participate in DIREnet, as it will provide important context for, and help regionalize, the findings from our work.

MIKE ALLEN
UNIVERSITY OF CALIFORNIA, RIVERSIDE

Drought results in severe impacts on native ecosystems. But, when viewed as one component in a complex network of impacts, the problems become even more dramatic. We have fertilized pinyon-juniper ecosystems since 1997. During wet El Nino years, we can see dramatic increases in both above and belowground root production as the N is taken into the leaf tissue. However, during dry La Nina years, the production of new root tips declines dramatically. Surprisingly, many of the older root tips persist, especially in the N fertilized plots. However, pinyon pine trees begin to shed needles, and by the peak of the drought, experience mortality. This level of mortality was not observed in unfertilized plots.

In southern California, in areas subjected to N deposition, we are observing almost complete mortality in some species of conifers, and severe mortality in others. However, in regions without N deposition, although clearly drought stressed, little tree mortality has been observed. The interacting impacts of fire control (greater leaf area), N deposition associated with urban expansion, and normal or climate change-induced drought cycles, could have dramatic effects on southwestern forests.

We anticipate that this funding would be utilized for three activities that would strengthen our research program. First, interactions among researchers in our group (M. Allen, E. Allen, R.

Minnich) could take the form of workshops. Second, it would facilitate graduate student and post-doc interactions among labs focusing on the different topic areas. We would focus our expertise on mycorrhizal and minirhizotrons technologies to interface with ecophysiologists from the collaborating institutions. Finally, it should contribute to some joint field projects to test and share technologies and concepts. These could focus around our high N deposition sites in southern California (James Reserve), the Sevilleta LTER, as yet a relatively clean region , where we have our N fertilization studies.

JULIO BETANCOURT
United States Geological Survey, Arizona

My USGS group is housed on the grounds of the University of Arizona's Desert Laboratory on Tumamoc Hill, an 800-acre ecological reserve on Tucson's westside with a 100-yr legacy in ecological research (http://wwwpaztcn.wr.usgs/). Among the relevant resources and activities at the Desert Lab are permanent vegetation plots measured repeatedly since 1906, four 11-ha permanent saguaro plots measured since 1908, permanent winter annual plots studied annually since 1982, a repeat photography archive for the western U.S., digitized plant distributional databases for the Southwest, ongoing studies of paloverde mortality, and a variety of other life history studies. We are also conducting several studies relevant to DIREnet, and are interested in contributing data and insights to the network.

My colleagues (Tom Swetnam, Steve Jackson, Steve Gray, Craig Allen) and I are currently involved in developing tree-ring chronologies from the central Rockies, high-resolution demographic histories for pinyon pine in central New Mexico and northern Utah, and migrational histories for dominant species in the western U.S. (Utah juniper, pinyon pine, ponderosa pine). We are particularly interested in how megadroughts initiate multidecadal periodicities in precipitation, ecological disturbances, and demographic trends, embodying a powerful mechanism for broad-scale vegetation change.

Based on synoptic field studies, we have developed the following model for the long-term behavior of pinyon-juniper woodlands. First, megadroughts cause broadscale mortality, release existing seedlings and saplings from competition for light, water and nutrients, and open up niches for recruitment. A preferred niche might be the footprint of a dead tree (a pool of soil and carbon and nitrogen, some bioavailable), which persists for at least 100 years. Recruitment pulses tend to occur in the first sustained wet period following the drought and the associated mortality.

In the context of ongoing and future migration, megadroughts cause widespread mortality of incumbent taxa, creating recruitment opportunities for invading species. Examples of such disturbance-driven invasions may be looming in the West. Critical fuel thresholds have been exceeded, a warming North Atlantic and cooling tropical Pacific have now shifted the climate from wet to dry, stand-replacing fires are consuming large patches of the western landscape, and the last freeze now comes two weeks earlier in the spring. Some important distinctions between past and future invasions include the extent of modern landscape fragmentation and, for at least some native and non-native species, routine long-distance dispersal via human traffic.

DAVID D. BRESHEARS
Los Alamos National Laboratory

My work focuses on ecological and hydrological interrelationships in semiarid woodlands, including drought, plant water relations and mortality, and associated changes in erosion and carbon. I have focused on multiple aspects of the water budget in these systems, including incoming solar radiation, soil temperature, soil evaporation, runoff, snow dynamics, and soil

water content. These factors are being related to key plant responses such as plant water potential and tree growth. I have also focused on modeling studies of drought duration and intensity as related to tree mortality.

I bring unique long-term data sets to the project, including more than 15 years of soil water measurements and more than 11 years of plant water potential data, both data sets being globally unique to our knowledge in terms of length. These data sets span conditions prior to and following drought, and hence provide unique insight into plant response to the drought. In addition, with Allen, I have extensively studied the 1950s drought impacts, documenting an important case study of ecotone shift via tree mortality in response to drought. We have also developed unique, long-term data sets on erosion tied to post-drought conditions. I have installed an experimental drought plot, which is providing insights into species differences in drought response. Participation in DIREnet allows myself and collaborators to link very detailed local measurements to regional scale observations and in turn provides other network members with more insights into soil water and physiological thresholds related to the ongoing extensive mortality. I believe this project is very timely and I am delighted to participate in DIREnet.

SCOTT L. COLLINS
University of New Mexico

For over 20 years I have been interested in research on community structure, particularly the organization of communities along gradients and the factors that affect species composition in time and space. My research interest and experience in community ecology has given me the background I need to conduct studies on factors that affect species diversity, and the distribution and abundance of species in grassland ecosystems. I have used both empirical studies and manipulative experiments to quantify factors that create and maintain plant species diversity in tallgrass prairie. Much of my past work occurred as part of the Konza Prairie LTER site in northeastern Kansas. Although I remain an active member of the Konza Prairie LTER Program, I am now the Principal Investigator on the Sevilleta LTER site in central New Mexico. This interaction provides me with access to research sites and opportunities in both mesic and semi-arid grassland ecosystems. My current interests are on how key resources, particularly water, nitrogen and phosphorus, affect community structure, composition and dynamics in different in grassland ecosystems.

As PI of the Sevilleta LTER program it is my responsibility to foster a broadly based research program on the causes and consequences of biotic transitions for ecosystem structure and function. The Sevilleta LTER site contains extensive pinyon-juniper woodlands in the Los Pinos Mountains. We have initiated preliminary work on tree mortality at one of our long-term research sites, and we plan to continue with that effort in the future. Therefore, I am very pleased to be asked to participate in this RCN project on drought impacts in forests and woodlands of the southwestern United States. The Sevilleta will provide data, as needed, and can serve as a host site for one of the RCN workshops.

M. LISA FLOYD
Prescott College

For the past 13 years, our research group (William Romme Colorado State University, Henri Grissino-Mayer, University of Tennessee, David D. Hanna and Paul Sneed, and myself, Prescott College) has been investigating fire history patterns in southwestern Colorado. This

involves the piñon- juniper woodlands in Mesa Verde and ponderosa pine, aspen, and spruce-fir forests in the southern San Juan Mountains The piñon-juniper woodlands of Mesa Verde have a centuries-long fire cycle, creating dense canopies; canopy gaps have been created by black stain root disease *Leptographium wageneri* during at least the last century. Recently, an *Ips confusus* epidemic is creating larger openings in the canopy; its historically unprecedented activity is no doubt enhanced by recent droughts that have weakened the terpene defenses of conifers. Piñon trees in southwestern Colorado are particularly susceptible, perhaps because of unique climatic factors, or because of the relationship with black stain infestations. This is of concern not only for it's magnitude, but also these gaps are becoming dominated by several invasive species, some with the potential to shorten the fire cycle. Therefore, our on-going work at Mesa Verde must be informed by the effects of drought and other climate changes and would greatly benefit.

Our group is also investigating fire history and the effect of *Ips* infestations in the ponderosa pine forests of central Arizona's Prescott National Forest. The proposed online research forum and conferences will allow integration of research on fire history, recent insect and plant infestations, and other drought effects in southwestern Colorado and in central Arizona. We must effectively communicate our integrated findings with researchers in other regions who may not be experiencing this particular drought event, but for whom climatic change is likely in the future.

Students at Prescott College participate in our research program; we plan to integrate graduate students from Colorado State University in the coming year. The proposed "Student Exchange Program" would broaden the student opportunities, allowing students from other schools in the network to participate in the experiential, research-based activities that are the basis for Prescott College's unique educational system.

VINCENT P. GUTSCHICK
New Mexico State University

Extreme events, climatic and biotic, have become the focus of research for us of late. We have proposed a more comprehensive framework for studying extreme events (Gutschick and BassiriRad, 2003) and we seek to apply it in current proposal development for research on PJ and Ponderosa dieoffs. The foci we are developing are on the (1) physiology of drought "fitness" (combined tolerance, resistance, avoidance) and especially of the recovery phase that is prolonged and that we propose may dominate in fitness effects; this focus on physiology complements most of the DIRENet efforts directed at spatial and temporal patterns; (2) resource acquisition and use, particularly nutrients and water uptake and photosynthetic utility thereof; (3) intraspecific variations in traits related to the recovery and resource use; in the medium term, we hope to extend to ecological genetics of the traits, applying population-level tools for relatedness measures developed at NMSU by Milligan (2003). My research over the past two decades has focused on the ecophysiology of plant resource acquisition and use - light, water, nutrients, CO2. From my highly quantitative background (chemical physics Ph. D.), I ground much research in physiological and abiotic-process modelling, and also develop field instrumentation as needed (e.g., patent 4,678,330 on leaf-mounted light sensors). Our research sites center on semi-arid lands, especially the Jornada LTER, in which I am a participant, while extending to mesic forests and agricultural lands. Our major focus recently has been on heat and water stress on woody plants, by field experiments and by collaborating on the statistical analysis of extremes in meteorological driving variables.

Relevant to the information management effort conceived for DIRENet, I have been (from June 2003) director of the Institute for Natural Resource Analysis and Management (INRAM; www.inram.org)), an NSF-EPSCoR institute. The core of INRAM is setting up state-of-the-art infrastructure (database, query engines) for biodiversity data (museum and field specimens) and a wide range of environmental data (climate, soils, topography, land cover) with spatial resolution and ability to search and overlay data by spatial coverage. We also offer GIS services and analyses, environmental chemical analyses, land management analyses, and educational outreach. These activities are readily scaled up from New Mexico to the multi-state area of DIRENet, using modest incremental effort and funding. DIRENet funding would be used at NMSU for (1) expanding the information management system embodied in INRAM; (2) extending the spatial and statistical analyses of driving variables, particularly in the framework of extreme events; (3) workshops and conferences on these topics, involving graduate and undergraduate students.

JEFFRY B. MITTON
University of Colorado, Boulder

The proposed project would be beneficial to my research, which focuses on 1) phylogeographies of ponderosa, limber, and piñon pines, 2) examines historical relationships between the parasitic mistletoe and its five host species of piñon, and 3) explores the role of the glycerate dehydrogenase polymorphism in adaptation of piñon to moisture stress.

1) Phylogeographies of ponderosa, limber, and piñon pines. We are using mtDNA and cpDNA sequences to characterize genetic variation within and among populations throughout the ranges of these species. The primary goals of this research are to describe the phylogenetic relationships among populations, and to infer the historical changes in the geographic range of each species.

2) Mistletoe and its hosts. My graduate student, Kristy Duran, is examining the genetic variation of the parasitic dwarf mistletoes, *Arcethobium divaricatum*, within and among its five host species of piñon pines. We are using this system to study both host race formation and the degree to which geographic variation in a parasite reflects the variation in its host.

3) Glycerate dehydrogenase. Glycerate allelic frequencies vary in a predictable way on both microgeographic and range-wide scales. On dry sites, growth rates, viabilities, and stomatal sizes and shapes differ among piñon glycerate genotypes. We are currently sequencing the alleles of this polymorphism to better understand their ecological and evolutionary dynamics.

I am pleased to be part of this group, for it has been a productive collaboration. The people involved have complementary experiences and skills, and they work together well.

EUGENE W. SCHUPP
Utah State University

Broadly speaking, a major aspect of my research concerns the population ecology of woody species in stressful environments. I am presently focused on recruitment and mortality of piñon (*Pinus edulis* and *P. monophylla*) and juniper (*Juniperus osteosperma*) in the Great Basin and the Colorado Plateau. My research addresses both biotic (competition, facilitation, herbivory, etc.) and abiotic (soils, drought, etc.) aspects. Of particular interest to the present proposal, I am initiating a new Utah Agricultural Experiment Station Project that addresses the impacts of climate (across an elevational gradient on a common parent material and landform), including climate change, and soils (two distinct soil types at a common site) on tree recruitment and

mortality. This research incorporates both observational and experimental studies to address these issues.

I bring to this project extensive experience with piñon and juniper woodland dynamics and an ongoing research program that is directly related to the core issue, drought impacts. My research sites in western and southern Utah expand the geographical range of studies involved, thus adding to the value of a coordinated project. The proposed network will greatly benefit my research program by providing a larger perspective to the overall issues I am concerned with, facilitating my involvement in collaborative research and other intellectual interactions, promoting discussions, making more information and ideas available to me and my program, and simply providing continued inspiration to my research program. I am very excited about being a part of Drought Impact on Regional Ecosystems (DIREnet) and expect to gain immensely from my involvement.

TOM SWETNAM
University of Arizona

Both my research interests, and my position as the Director of the Tree-Ring Lab at the University of Arizona, provide a nice fit with the DIREnet project. My general research interests include the long-term climate and fire history of forests and woodlands, and the paleoecology of insect outbreaks. My research areas include the Southwestern United States, northern Mexico, Sierra Nevada of California, and parts of the Northern Rockies and interior Pacific Northwest (east of the Cascades). My research projects in the Southwest which would directly benefit from, and contribute to DIREnet include: (1) development of fire history networks from forests and woodlands throughout the region, from subapline to pinyon-juniper zones, (2) demographic studies of pinyon-juniper woodlands in a network of permanent plots in Arizona and New Mexico, including tree-ring reconstructions of mortality and natality patterns over the past 300 to 500 years, (3) development of networks of insect outbreak histories (including western spruce budworm, Pandora moth, aspen tent caterpillar) in Arizona and New Mexico, and associations with climatic variability.

I would greatly benefit from the personal interactions with current and future participants of DIREnet. A wide variety of my past and current projects involve a range of collaborations, with researchers at other universities and federal agency scientists. My students could benefit from the student exchange program and we are well suited to accommodate visiting student researchers. A particularly exciting research potential would be to map the past climate, insect outbreaks and fire of the Southwest onto the present-day distributions that have or will result from the current drought.

The Tree Ring lab's application of dendrochronology to a wide range of scientific inquiry, e.g., global change, climatology, hydrology, anthropology, archeology, forest ecology, tree physiology, quaternary studies, geomorphology, geophysics, and geochemistry provides an important resource for DIREnet. The Lab's provision of education and training in dendrochronology, including extensive training of scientific visitors from around the world will provide a global exposure for DIREnet. Curation and utilization of our large, internationally diverse and unique sample collection also provides a network research resource. Likewise we would greatly benefit from the products of the online Southwest Ecological Research Forum (SERF). In summary, I am delighted about being involved in DIREnet, and I think it will be a very productive project.

ROBIN TAUSCH

United States Forest Service, Rocky Mountain Research Station, Nevada

Dr. Tausch's research interests are on the ecology and paleoecology of Great Basin Pinyon/juniper woodlands and their associated sagebrush dominated ecosystems. These systems have been changing rapidly over the last 150 years, primarily through the expansion in the area dominated by woodlands. Research is being conducted into the associated ecological changes by describing the patterns and rates of the changes in community composition, biomass, dynamics, and structure. Associated with these changes has been an increase in fuel loads, followed by an increase in the size and intensity of wildfire. Current research is also tracking the outcomes of those fires, including the potential that the overall vegetation changes, combined with fire, have for facilitating the expansion of invasive species such as cheatgrass. Research results are being used to estimate the continuation of these changes, and possible associated changes in disturbance patterns, that can be expected over the next 50 years. A recent addition to the other ongoing changes has been large areas of tree mortality in the woodlands of the Great Basin in response to the recent drought. This large-scale loss of trees will have significant short and long-term affects on community dynamics, on fire potential, and on the expansion and dominance of exotic species such a cheatgrass in the affected areas. Research is being initiated to incorporate studies of these additional changes from drought into other studies that are already underway. I am enthusiastic about participating in this proposal for determining Drought Impacts on Regional Ecosystems (DIREnet) because the collaboration of an interdisciplinary group of scientists across the region will provide more of the needed integration of information than any of us working alone could provide.

Because of the regional nature of the drought affects over the southwest there is the opportunity to investigate the similarities and differences of those affects across a wide range of woodlands with varying community composition, and differing environmental, ecological, and successional conditions. What I can bring to the DIREnet project is many years of ecological experience in the Great Basin portion of the affected area that has been focused on the communities with the most extensive adverse affects from the current drought. What the project can do to advance my research efforts is to provide a broader base of information on the affects of the drought that can be used to better compare and interpret the research results from the Great Basin of Nevada.

CORE PARTICIPANTS (NON-STEERING COMMITTEE)

R. SCOTT ANDERSON
Northern Arizona University

My current research interests center around the influence of long-term climate change and human activities on (1) the distribution of former plant communities, primarily forests and woodlands, and (2) disturbance regimes and community ecological response, primarily the effect of fire and insect infestation on former plant communities. I am also interested in (3) global change issues, especially as they relate to human activities in forested ecosystems.

My current research projects include (1) vegetation, climate and disturbance histories of the subalpine and mixed conifer forests on the Colorado Plateau, the southern Rocky Mountains and Jemez Mountains, southern California, and southeast Alaska (Kenai Peninsula); (2) biogeography and disturbance history of mixed conifer forests of the Sierra Nevada, California, and the relationship between long-term drought and fire event frequency; (3) interannual variation in climate and vegetation as recorded in annually laminated sediments from lakes in California and Colorado; and (4) vegetation change in the deserts of the Southwest.

Coordination with DIREnet: Research on the long-term history of climate, vegetation and ecosystem disturbance is by its nature interdisciplinary and necessarily involves multiple disciplines and investigators. My own research builds upon the work of ecologists and climatologists to examine cycles of climate and its impact on fire, insect infestation and vegetation in the past. So, our collective understanding of modern ecosystem processes is enhanced by an analysis of the paleo-historical record of similar events. Similarly, our interpretation of events of great magnitude, such as drought or insect infestation, in the past is clarified by analysis of modern phenomena. For example, what role does periodic shifts in the PDO contribute to increased drought frequency in the Southwest (a modern phenomenon), and what does the sedimentary record tell us about the long-term history of similar events? I see an important result of DIREnet as providing a forum for investigators from different disciplines working on multiple timescales to work on problems such as drought history and effects for the greater understanding of all. I look forward to being a participant in the Drought Impacts on Regional Ecosystems Net.

JOHN BAILEY
Northern Arizona University

I am pleased to be invited to participate in DIREnet. My research is highly relevant to the proposed project because it centers on broad ecosystem health issues in ponderosa pine forests and pinyon-juniper woodlands/savannas. Current forest health issues are directly related to past management practices, other current human impacts (e.g., recreation), intrinsic biotic factors (e.g., insects) and abiotic factors such as **drought**. The following three research projects demonstrate this focus and should provide important information for DIREnet and SERF. Likewise we hope to develop new collaborations on these and other projects through various DIREnet activities.

1. **Insects as ecological indicators for fuel treatment effects in ponderosa pine forests**. In cooperation with Mike Wagner, Tom Kolb and Steve Hart [NAU] and Karen Clancy [RMRS].We are examining how insects may be the simplest indicator or complex ecological processes (net primary production, decomposition and/or stress resistance in trees) across a range of stand conditions associated with typical forest management practices in the Southwest: thinning to moderate tree densities with and without fire.

Ecological processes are contrasted with relatively unmanaged control areas (high density) and a variety of management treatments.

2. **Restoring Age Structure, Spatial Arrangement and Watershed Health in Pinyon/Juniper Woodlands.** In cooperation with Pete Fulé [NAU] and Carl Edminster [RMRS]. We are examining age structure, size distribution, allometrics and spatial arrangement of juniper and pinyon pine trees in woodland and savanna conditions across three fundamental soil types in northern Arizona. The purpose to quantify such items to address: 1) the debate on juniper encroachment and in-fill in the Southwest, 2) possible relationships with climatic change, and 3) guides for the proper restoration and long-term management of these woodlands and savannas. Drought years can be identified in the historic dendrochronological record and related to current conditions in the Southwest, including mortality rates. Research areas show differential impacts of the current *Ips* outbreak.
3. **Using Group Selection, Multi-aged Management Practices to Enhance the Use of Prescribed Fire in the Southwest.** In cooperation with Carl Edminster [RMRS], Brian Oswald [S.F. Austin University] and Jon Keeley [USGS Kings Canyon]. We are examining how spatially-explicit mechanical removal of overstory trees, with and without prescribed burning, begins a cascade of ecosystem changes including understory vegetation richness and diversity, insect populations, wildlife habitat and behavior, decomposition and accumulation of carbon, other soil processes, and natural fire behavior over time.

JARRETT BARBER
Montana State University

I am interested in developing methodology for modeling space-time data, with focus on environmental and ecological applications. Much ecological data is spatial and/or temporal in nature and provide motivation for the development of new analysis techniques that address the spatial/temporal aspect of the data. My current projects (below) are examples of the application of recent developments in statistical modeling of space-time data. The DIREnet will enhance opportunities to contribute to the methodology and analysis of such data.

1. Spatial Modeling of Population Size. With Alan Gelfand (Duke University). We propose an alternative to finite sampling base methods for determining individual counts within some population over space. Our approach is based on the concept of an underlying (latent) population intensity surface, which upon integration, gives an estimate of total population.

2. Modeling Map Feature Location Error. With Alan Gelfand (Duke University). We are investigating a Bayesian model averaging approach to combining information in different maps to produce a single map with indications of feature position uncertainty. Thus, this approach offers a solution to the problem of map conflation ("rubber-sheeting"). One map may be considered as "truth" (e.g., a larger scale map) to which other maps will be adjusted. Or, ground truth coordinates (via, say, GPS or survey) of a subset of map features may be used instead.

3. Dynamic Spatial Modeling of Precipitation Events. With Alan Gelfand (Duke University) and Doug Nychka (National Center for Atmospheric Researcher, Boulder, CO). Here we develop a statistical model for precipitation event data collected from a spatial network of monitoring stations. The model allows for precipitation events to evolve over time while incorporating spatial dependence among nearby stations in space.

KAREN S. EISENHART
Department of Geosciences, Edinboro University of Pennsylvania

My research interests currently include long-term dynamics in pinyon-juniper woodlands on the Uncompahgre Plateau in southwestern Colorado. I am interested in interactions between climate, disturbance, and woodland development. Work to date includes intensive and extensive reconstruction of stand dynamics in 135 plots in several distinct parts of the study landscape, including woodland stands in Black Canyon of the Gunnison National Park. The plots form a chronosequence of stand ages up to about 700 years, based on ages of living trees. The historic fire regime for the majority of the woodland zone in this region was dominated by stand-replacing fires prior to the introduction of livestock, with the result that many of the woodlands are several hundred years old. The persistence of ancient woodlands in this landscape may be related to the position of this region between climate regimes dominated by winter vs. summer moisture. Studying the differential persistence and mortality of trees over several centuries should provide important information about vegetation response to drought events as well as contributing data that will describe a gradient across climate regions. This relationship will be investigated using tree-rings to reconstruct historic drought and subsequent response of woodland trees. Work is now in progress to develop long tree-ring chronologies dating to the 1500s or earlier in order to compare reconstructed climate to woodland dynamics. A network of chronologies in the study area sample tree growth-response from a range of topographic positions that simulate a moisture gradient. These data will provide deeper understanding of dynamics and disturbance with respect to climate fluctuations at a range of temporal and spatial scales in the study area as well as contributing coarse-scale information to the drought network (DIREnet). An additional project is currently underway to sample soil depth and texture in previously inventoried sites in order to relate growth-increment patterns to soil characteristics. Future work will follow the course of development in permanent plots with different disturbance histories. Permanent plots are located in areas with and without significant recent mortality of pinyon pine.

CATHERINE GEHRING
Northern Arizona University

My research group examines the effects of drought on pinyon pine and its associated community with a belowground focus. We currently are addressing two main questions: **1)** How do belowground factors contribute to pinyon mortality during severe droughts? and **2)** What effects do drought and associated host mortality have on the ectomycorrhizal fungi (EMF) associated with pinyon pine? Our emphasis for Question 1 is on the edaphic factors associated with low vs. high mortality sites and the influence of belowground competition with heterospecifics on pinyon mortality. We have compared soil parameters at sites that vary in rates of pinyon mortality due to drought, but are in close physical proximity to reduce other sources of variability. We also have set up two long-term experiments to assess the influence of heterospecific belowground competition with non-conspecifics on pinyon growth and survival during drought. Junipers and shrubs can act as nurse plants during the early life of pinyons, but once the trees mature, pinyons associated with shrubs or junipers are 3-5X more likely to die than neighbors without these associations. Our emphasis for Question 2 is on the effect of drought, associated pest outbreaks, and plant-plant interactions on the EMF communities of pinyon pine. Pinyon pines are the only hosts for EMF in many pinyon- juniper woodlands and loss of pinyons may mean the loss of these fungi from vast areas. Because of the importance of these fungi in

improving the ability of pinyons to take up nutrients and water, their loss could negatively influence pinyon re-establishment into areas of high mortality. Studies to date suggest that EMF abundance and diversity decline by 50-66% in areas of high (70%) pinyon mortality. Pinyon seedlings grown in soil from these sites survived poorly and had low rates of colonization by EMF. Pests such as insect herbivores and mistletoe also profoundly change EMF communities and we are currently examining the consequences of these changes.

I am interested in furthering collaborations and data exchange with researchers in the southwest through Drought Impacts on Regional Ecosystems Net (DIREnet). My research on belowground interactions can help the group understand the mechanisms that contribute to drought-induced mortality and the impacts of these changes on community members that can be critical to the maintenance of the ecosystem (e.g., EMF and their role in ecosystem carbon and nutrient dynamics). We will provide the following to the network: 1) information on pinyon-juniper; pinyon-shrub interactions including data on root biomass and root growth and root turnover through minirhizotron imaging, 2) data on EMF community dynamics from 10 sites in AZ and 4 in NM. We utilize molecular techniques to characterize EMF communities and are developing an RFLP and sequence database of the >100 spp that we have found in our studies. This data base will be available to others and we will provide training to students in the use of these techniques. I believe DIREnet will assist my group in broadening our scale of focus and understanding of the landscape changes that drought is having on the southwest and I am excited to be part of this network.

BRUCE HUNGATE
Northern Arizona University

My research involving ecosystem responses to climate change (1) and documenting effects of mycorrhizae on biogeochemical cycles (2) would both complement and benefit from the proposed Research Coordination Network. **Ecosystem responses to rising CO_2 and climate change: feedbacks through the nitrogen cycle**. We are examining the impacts of climate change – including both increased temperature and altered (increased and decreased) precipitation – on carbon and nitrogen cycling in four different ecosystem types. Our study site is the C. Hart Merriam Elevational Gradient, and includes four major temperate ecosystem types that naturally occur along this climatic gradient. The fundamental question driving this research is: do different ecosystems respond to climate change in qualitatively similar ways, or are their responses largely idiosyncratic? Water exerts strong control over biogeochemical cycling. One of our working hypotheses is that differential tolerance and exposure to drought stress along this climatic gradient will cause idiosyncratic responses to climate change. For example, the ongoing drought has already caused differential mortality among these different ecosystems, greater among our study plots in the Pinyon-Juniper ecosystem compared to higher-elevation sites. Though death of the dominant plant will certainly alter carbon and nitrogen cycling, our preliminary data suggests greater sensitivity to water addition in the sites where plants are still alive, suggesting that catastrophic drought elicits threshold changes in biogeochemical responses to climate change. By identifying regions subject to varying degrees of drought stress (e.g., those experiencing drought-induced mortality or not), the proposed DIREnet will allow us to test our understanding of interactions between drought and climate change on a broader scale.

The influence of mycorrhizae on fine root decomposition and soil carbon processing

We are investigating how mycorrhizal infection alters fine root decomposition and soil biogeochemistry. Because mycorrhizal infection fluctuates with drought stress, these studies will also inform and be informed by the proposed DIREnet . Our preliminary data show that Pinyon

roots infected with mycorrhizae decompose in the field at rates 50% slower than uninfected roots. Because drought stress alters mycorrhizal infection, a major influence of drought on soil biogeochemistry could be an indirect effect, altering the proportion of roots that are mycorrhizal and thus their subsequent rates of decomposition and associated nutrient mineralization. Plant and ecosystem productivity are strongly influenced by nutrient availability, largely determined by rates of decomposition of plant litter. In this way, our work with the RCN has the potential to substantially advance understanding of the controls over litter decomposition and nutrient availability in terrestrial ecosystems.

GEORGE W. KOCH

Northern Arizona University

Thank you for the invitation to be a Core Participant of the Drought Impacts on Regional Ecosystems network (DIREnet). Please count me "in". As you know, my students and I work in the general area of plant ecophysiology and ecosystems ecology. In recent years my publications and presentations have included studies of plant and ecosystem response to rising atmospheric CO_2, mycorrhizal interactions and global change, water relations of ponderosa pine forests, and most importantly in the context of DIREnet, the physiological and ecosystem ecology of piñon pine woodlands in northern Arizona. The piñon pine research has indicated how insect herbivory interacts with plant moisture stress and soil microclimate to affect litter production, litter chemistry, decomposition and nutrient cycling. Two areas of developing interest include: 1) understanding the seasonal and interannual controls on ecosystem metabolism using coupled micrometeorological and eddy-covariance measurements (the initial tower for which was recently established in ponderosa pine on the Centennial Forest), and 2) understanding the basis for variation in drought-related mortality within populations of ponderosa, piñon pine, and juniper in northern Arizona.

I see great potential for synergism between DIREnet and my current research and teaching activities. First, DIREnet's proposal to serve as a clearinghouse for drought-related research in the Southwest would greatly facilitate preparation of papers and grant proposals that currently require ever-more-sophisticated approaches to literature searching. In addition, I would welcome with open arms the establishment, with DIREnet support, of a GIS-based data I also am very interested in the idea of student exchanges among laboratories in the DIREnet partner institutions. I can foresee, for example, my students spending time at the University of Arizona learning aspects of eddy-covariance or dendrochronology. I can contribute to DIREnet in a number of ways:1) by making available to DIREnet existing and future datasets and publications on plant and ecosystem responses to drought, 2) by participating in annual meetings, 3) by contributing to writing of collaborative grant proposals with DIREnet partners, 4) by involving undergraduates from my plant physiology laboratory classes in DIREnet community research endeavors.

Given that we're moving into a period of increasing climatic uncertainty in the Southwest, the proposed DIREnet is timely and important. I'm very pleased to participate.

THOMAS KOLB

Northern Arizona University

My research is directly related to the proposed project because it involves examination of responses of ponderosa pine forests in northern Arizona to forest management and disturbance that must be interpreted in the context of extreme water stress and frequent

droughts that characterize the Southwestern US. Moreover, direct effects of drought on tree growth, resource uptake, and resistance to bark beetles, and establishment of exotic, invasive plants, are being addressed. Selected examples of this research are below. I in turn would benefit by the increased exposure to other people's research and the new opportunities for collaborative research as well as the products SERF would provide to my lab.

1. Ecophysiological controls on latency in dwarf mistletoe. A combination of field and greenhouse experiments is being used to assess influences of light and water stress on establishment and growth of dwarf mistletoe parasitic plants on four tree species. **2. Variation in tree radial growth response to drought among environments, tree ages, and species.** Effects of historic droughts on tree growth and leaf carbon stable isotope composition are being compared among forest community types, ecotones, soil types, elevations, and tree species.**3. Effects of restoration thinning on ponderosa pine forest water use.** (with George Koch [NAU] and Mario Montes-Helu [NAU]). The goal of this research is to compare stand-level water flux and its components (tree and herbaceous transpiration, soil evaporation, canopy interception) between a thinned and unthinned ponderosa pine stand to better understand biophysical controls on stand water balance. **4. Seasonal dynamics in bark beetle flights and ponderosa pine growth and physiology** (with Michael Wagner [NAU]) The goal of this research is to describe seasonal and yearly variations in bark beetle activity, water and carbon relations, and resin defenses of ponderosa pine trees to better evaluate mechanisms leading to bark beetle outbreaks in northern Arizona forests. **5. Effects of fire, precipitation, and competition from native plants on knapweed invasion in southwestern ponderosa pine forests** ((with Karen Clancy [USDA Forest Service] and Carolyn Sieg [USDA Forest Service]) The goal of this research is to better understand how fire disturbance, drought, and competition from native plants affect establishment and growth of an exotic, invasive plant, diffuse knapweed, in northern Arizona ponderosa pine forests.

JOEL MCMILLIN
United States Forest Service, Forest Health Monitoring, Arizona

Drought, fire, forest stand conditions, and bark beetles are all interconnected in the Southwest. My current research and technology development projects focus on these interactions. Specific studies include: 1) documenting bark beetle-caused tree mortality and related forest impacts in the Southwest using ground-based, aerial, and remote sensing techniques. 2) Developing guidelines for land managers to minimize bark beetle-caused impacts associated with fire fuels reduction activities. 3) Determining fire-bark beetle relationships in ponderosa pine forests. Below are three examples of projects that will contribute significantly to the proposed project and also benefit from future collaborations resulting from network activities. The development of DIREnet will enhance these projects by improving the synthesis and dissemination of results, inclusion of other scientists from more diverse backgrounds, and increased access to related research.

1. Stand level impacts of bark beetles in pine forest types of Northern Arizona (In collaboration with John Anhold, Neil Cobb, and Jose Negron). We are quantifying the impact, extent and severity of bark beetles on ponderosa and pinyon pine at the stand level through an extensive plot network on a portion of Arizona's northern National Forests. Specifically we are examining forest conditions in areas that have experienced moderate to high levels of mortality induced by recent drought and bark beetles in order to correlate between stand and site conditions and pine mortality.

2. Ips and Chips: Effective Slash Management for Hazardous Fuel Reduction Treatments in the Wildland Urban Interface or A Recipe for Disaster? In collaboration with John Anhold, Christopher Fettig). A relatively new method of treating green thinning slash is to chip or shred the material on site. The purpose of this study is to determine the most effective means of minimizing impacts caused by *Ips* bark beetles when treating slash, by chipping, generated during hazard fuel reduction projects in the wildland urban interface (WUI). Based on the findings of this study we will develop guidelines for land managers to mitigate unwanted tree mortality associated with thinning projects.

3. The role of wildland fire and subsequent insect attack on ponderosa pine mortality In collaboration with Linda Wadleigh, Carolyn Hull Sieg, Jose Negrón, Ken Gibson, Kurt Allen, and John Anhold). The unprecedented fire year of 2000 provided an opportunity to quantify cumulative impacts of wildland fires and subsequent insect attack on ponderosa pine mortality over a large region. Permanent plots were established in 4 National Forests: Black Hills in South Dakota, Custer in Montana, Arapaho-Roosevelt in Colorado and Coconino in Arizona. In each area, we sampled 1500+ trees in burned areas and 500 trees in unburned areas. Tree mortality will be monitored for at least 3 years post burn. Our goal is to provide land managers with quantitatively based guidelines for assessing potential tree mortality following wildland burns.

MARK MILLER
U.S. Geological Survey, Utah

I am happy to participate in the proposed DIREnet project. As an ecologist for the U.S. Geological Survey's (USGS) Southwest Biological Sciences Center, I am involved in the development and coordination of long-term ecosystem monitoring protocols for National Park Service (NPS) units in the Colorado Plateau region. USGS conducts this work to support two NPS Inventory & Monitoring (I&M) networks consisting of 35 separate units – many of which are characterized by significant pinyon-juniper woodlands and/or ponderosa pine forests. This subset of parks includes Zion National Park (NP), Bryce Canyon NP, Capitol Reef NP, Canyonlands NP, Arches NP, Natural Bridges National Monument (NM), Colorado NM, Mesa Verde NP, Grand Canyon NP, Glen Canyon National Recreation Area, Walnut Canyon NM, Sunset Crater Volcano NM, Canyon De Chelly NM, El Morro NM, El Malpais NM, Chaco Culture National Historic Park, and Bandelier NM.

Two major components of the I&M program are of particular relevance to DIREnet and SERF:

1. **Vegetation Mapping** – The I&M program has embarked on an ambitious project to map the existing vegetation of all network parks. To support this project, 1:12,000 true-color aerial photographs (stereo pairs) and 1:12,000 true-color digital orthophotos (scanned to 1-m resolution) have been acquired. Aerial photographs for many Colorado Plateau parks were acquired during the 1999-2002 period. These high-quality aerial photographs will provide an important set of baseline data on woodland and forest structure prior to the onset of widespread mortality associated with the recent drought.
2. **Vital-Signs Monitoring** – The I&M program is tasked with identifying and monitoring key indicators of environmental change, or "vital signs." Vital signs are measurable indicators of changes that could impair the long-term health or integrity of park ecosystems. Both I&M networks on the Colorado Plateau have identified **vegetation composition and structure** as key vital signs to be included in their long-term monitoring programs. In tree-dominated systems, drought-caused changes in vegetation structure will provide an early indicator of changes in fire probabilities, hydrologic conditions, and habitat structure. It is likely that temporal and spatial

trends of tree demography, as well as numerous other vital signs, will be monitored via periodic (~5-yr) reaquisition of aerial photographs or high-resolution digital imagery. Components of the proposed project (e.g., online research forum, conferences and workshops) will enable USGS and NPS units to share comparable data and understand the condition of NPS ecosystems within a broader, ecoregional context.

MARGARET M. MOORE
Northern Arizona University

General research interests: areas of plant community ecology, restoration ecology, landscape ecology, and historical ecology. ***Specific research interests***: My research interests pertinent to this research proposal lie in the area of plant community changes in southwestern plant communities since Euro-American settlement. In particular, I am quantifying the structural characteristics (i.e., age, density, and diameter distributions), species composition, and spatial pattern changes in trees; and production and compositional changes in herbaceous plants and shrubs; and changes in disturbance regimes (specifically fire). The vegetation types I have focused on are ponderosa pine-oak, lower elevation mixed conifer, and montane meadows and grasslands. All of these vegetation types were affected by a number of factors that occurred almost simultaneously with Euro-American and Hispanic settlement, such as climate changes, livestock overgrazing, fire suppression, high-grade logging, and road building. I use a variety of tools to study change in these systems, including direct measurements of current age, structure, and pattern, as well as dendrochronological techniques and historical record to determine past conditions. In addition, landscape ecology tools (such as GIS, satellite remote sensing and spatial statistics) are used to determine how these patterns and changes may apply on a landscape level. All of this information provides a critical baseline for ecological restoration of these southwestern plant communities.

2) What I can bring to the project? ***Permanent plot research:*** My research group has relocated and remeasured a set of long-term, permanent plots (n=50) established between 1909 and 1915 in the ponderosa pine type of Arizona and New Mexico. These permanent plots were stem-mapped and then remeasured every 5 years from 1909 until the 1950s. Herbaceous and shrub understory were also mapped and measured on a subset of the larger plots. We model structural and functional changes on those plots from the disruption of the natural frequent-fire regime (late 1800s) to present, and project these changes into the future. These long-term permanent plots provide an opportunity to detect and quantify vegetation changes over time and provide a context for interpreting these changes. Various agents, such as drought, fire exclusion, shading, overgrazing, climate change, etc., may be implicated in plant population or community change or decline, but cause and effect are not easily shown without data from long-term studies.

The DIREnet project: The DIREnet will provide access and visibility to my research project(s) and promote collaboration and synthesis with researchers. DIREnet will also provide funding and opportunities for my students to travel and gain experience in other labs around the Southwest. My research is very relevant to the proposed project and I am enthusiastic about being a part of this network.

ESTEBAN MULDAVIN
University of New Mexico

A major focus in my current research is the long-term stand dynamics of pinyon-juniper (P-J) woodlands in the Southwest with an emphasis on the interactions of fire and climate. Under a

grant from the Department of Defense, I am collaborating with Dr. Thomas Swetnam at the University of Arizona in a historical analysis of the development of old-growth P-J woodlands in nearly-pristine stands on White Sands Missile Range in central New Mexico. Using a combination of tree-ring, historical aerial photos, and land survey record analyses, we are evaluating the P-J the fire frequencies and extent, as well as tree recruitment in the context of regional droughts and wet-periods. The key question involves detecting century-scale patterns of fire and stand development across large pieces of landscape and correlating this pattern to climatic patterns.

I feel that this historical context is highly relevant to the proposed project in that it can help provide a backdrop for evaluating the significance of current drought episodes and their effect on woodlands in the Southwest. Conversely, the project will be useful to our work in helping us understand the regional context for the patterns we are seeing locally. Furthermore, I see participating in DIREnet as an important way to facilitate regional integration and synthesis of our knowledge of the impacts of droughts in the Southwest.

TOMOE NATORI
Dine College

I am very happy to participate in your proposed RCN project. One of my current projects (in collaboration with Neil Cobb) is documenting tree mortality on Navajo Nation lands. This and other projects provides an important conduit for integrating Navajo students in ecological studies. I will take a leadership role at Dine College to collaborate with the Navajo Nation (and possibly BIA) on studies related to drought, fire, tree and insect. I can collaborate with the DIREnet to support these agencies in maximizing their sharing and use the Southwest Ecological Research Forum (SERF). **II. Cross-Pollination in Research and Education** I will work with SERF to establish a collaborative support system between the DIREnet partner institutions and tribal agencies. For example, I will search and identify the faculty and students interested in a process of developing database for the Nation. When motivated students are identified, DIREnet (or other salary and internship fund identified) will support the faculty and students who wish to work in a process of data sharing or website development to increase the communication between the parties. A possibility of internship program for graduate students advised by the DIREnet staff participating researchers to assist Navajo Nation agencies and community groups, including chapter houses, grassroots organizations, and local non-profit organization on Navajo Reservation will be explored. **III. Leadership in Coordinating Research Interaction** The DC coordinator will work collaboratively with SERN to identify DC students and to organize their internship programs at the SERN partner institutions. The DC coordinator will also search faculty members interested in leading Forest and Woodland research projects in Navajo Nation. The DC partner will work collaboratively with NAU and other SERN participation institutions to support the internship and research initiative. For example: The DC coordinator will plan for training to enhance summer internship program that teaches methods and objectives of related research projects conducted by the SERN researchers. The DC partner will explore possibility in developing and offering one semester of general research method course that introduces the basics of ecological research to prepare the students for summer internship as well as in articulating the course credit, with the completion of following summer internship, into the SERN partner programs.

JOHN W. PRATHER
Northern Arizona University

The Forest Ecosystem Restoration Analysis project is involved in developing GIS layers related to forest structure and composition across Northern Arizona and Western New Mexico using remote sensing data. In addition I have the specific role of developing GIS-based models of fire behavior and wildlife habitat using the vegetation structure and composition layers. All of this could be influenced by large-scale beetle kill which significantly alters wildlife habitat and fire behavior. **The Forest Ecosystem Restoration Analysis Project:** We are creating tools that will help prioritize the timing and location of forest management (particularly forest restoration treatments) in the Ponderosa Pine dominated forest belt extending from the Kaibab Plateau in Northern Arizona to the Gila National Forest in west-central New Mexico. I believe the project has a lot to provide DIREnet in terms of data and methodology and conversely I see the DIREnet project as providing and important gateway for increased collaborations on the Colorado Plateau that will increase our understanding of southwestern forest and woodland dynamics.

JOSE NEGRON
United States Forest Service, Colorado

For the past 10 years I have been working as a research scientist at the US Forest Service, Rocky Mountain Research Station. My primary area of responsibility is conducting research in the biology, ecology, and management of western bark beetles. Areas of interest include, but are not limited to: (1) developing a better understanding of insect-caused tree mortality in western conifers, (2) examination of life history and biological aspects on the biology of bark beetles, (3) developing sampling protocols for bark beetles, (4) the development of simple models to estimate the probability of infestation and extent of mortality caused by bark beetles. Some studies that relate to this project include:

1. Quantifying fuel loads associated with roundheaded pine beetle outbreaks in the Sacramento Mountains of New Mexico.
2. Landscape-level Geostatistical Analysis of Bark Beetle-caused mortality in Arizona. (In cooperation with Joel McMillin, Forest Health, Flagstaff, AZ.)
3. Attributes associated with probability of infestation by the piñon ips, *Ips confusus*, (Coleoptera: Scolytidae) in piñon pine, *Pinus edulis*.

Kiona Ogle
MONTANA STATE UNIVERSITY

My past and current research activities compliment the proposed project in the two main ways:

Pinyon-juniper woodland dynamics. I have been working on the role drought plays in structuring pinyon-juniper woodlands since 1996 and documented patterns of drought-induced pinyon mortality at both the population and individual scales [Ogle, Whitham & Cobb (2000) Tree-ring variation in pinyon predicts the likelihood of death following severe drought. *Ecology* 81:3237-3243]. In collaboration with colleagues at NAU, I am developing a simulation model to help elucidate potential effects of biotic interactions (facilitation, competition, herbivory) and climate change (variation in drought severity and frequency) on pinyon-juniper woodland dynamics (e.g., distribution, composition). I presented preliminary results at the 6th Biennial Conference of Research on the Colorado Plateau (Flagstaff, AZ, Nov. 5-9, 2001).

Integrative informatics. I have recently been awarded an NSF Integrative Informatics Postdoctoral Fellowship. The goal of the project is to quantify key linkages between plant physiology and population biology, thereby improving our predictive understanding of how plants and ecosystems respond to environmental variation. I am employing a mulit-step approach

that integrates mathematical models, Bayesian statistics, and a diverse set of empirical data. First, the theoretical foundation for linking plant physiology, growth and population biology is being established by developing a stochastic model that couples these processes. Second, a large database from the NSF Long-Term Ecological Research network, which spans a range of species and sites, will be compiled. Finally, Bayesian melding methods, the stochastic model, and the database will be combined to quantify correlations between specific physiological (e.g., photosynthetic rates) and population (e.g., population growth rate) quantities for a variety of species and habitats. My postdoctoral work will 1) contribute methods for explicitly merging the fields of physiological and population biology, 2) identify new approaches for scaling in space and time, 3) produce improved statistical tools for evaluating complex models and data, 4) employ new procedures for dealing with missing data, and 5) identify those physiological characters that are fundamental to large-scale population processes. Points 2, 3, and 4 are particularly relevant to the proposed project. Methods developed and experience gained during my postdoc will be important to synthesizing the large amount of information associated with the proposed project.

CATHERINE ORTEGA
Fort Lewis College

I am pleased to participate in the RCN project. I am currently conducting a study on drought induced mortality in La Plata County, Colorado, which has been under severe drought conditions for four years. This project is relevant to the proposed projects on several levels: (1) geographic location, (2) genetic vs. environmental components, (3) GIS database, (4) involvement of students, and (5) partnership. **Geographic location**. To my knowledge piñon pine mortality during the current major drought is not being investigated in southwest Colorado. To fully understand the geographic extent of the drought, it is critical to have representation from a variety of geographic regions. Also, to better understand the genetic component of piñons most and least affected by the drought, it is important to have wide geographic representation. **Genetic vs. environmental components**. For the purposes of habitat management, it is important to determine why some individuals or groups of individuals seem to be able to withstand beetle infestations. For example, if there is an environmental component, such as stem density, thinning might be a reasonable management tool to reduce catastrophic losses in future droughts. It will be important to share the information from this study with others conducting related research as well as with land managers. The proposed project will fulfill these needs. **Involvement of students**. Five Fort Lewis College students are involved in this project. These students would greatly benefit from the opportunities offered by a student exchange, and researchers would benefit from the help of students who already have a familiarity with drought projects. **Partnership**. In addition to working on BLM lands, I am partnering with the Southern Ute Tribe by working on their lands. Approximately 70% of my study sites are on Southern Ute land, and I will be sharing my results with them. I am also collaborating with Jeff Mitton, who is another Core Participant.

DEANA PENNINGTON
LTER Network Office, Sevilleta LTER

My research is primarily in two arenas: 1) geocomputational methodologies for assessing landscape change from remotely sensed imagery, 2) ecoinformatics and cyberinfrastructure for ecology. I am interested in analysis of remotely sensed imagery, using spatially-explicit techniques that incorporate a dynamic component. Most of my work includes statistical,

geostatistical, and/or modeling approaches. I am also interested in the use of artificial intelligence in landscape analysis. I am involved in the development of automated image processing using web-services infrastructure (the Spatial Data Workbench), and infrastructure for distributed computing and analysis of ecological data (Science Environment for Ecological Knowledge; SEEK project).

Relevant research I have conducted includes a statistical analysis of drought effects within Sevilleta LTER grasslands. That project used spatially-explicit z-scores to identify times and locations where drought-effects were severe, between 1989 and 2002. I am currently doing comparable analysis with the pinyon-juniper woodlands at Sevilleta, where drought effects are still relatively minor. My hypothesis is that this methodology could predict areas that are significantly water stressed before the trees die, so that field experiments can be set up to monitor water potential and bark beetle dynamics. DireNet will provide an opportunity to link my computational approaches with strong ecological field experiments. Although my time is limited, I am excited about the opportunity to collaborate with DireNet. Additionally, my IT expertise may be helpful in organizing the web portal such that it may take advantage of future advances in grid and web services technologies.

WILLIAM H. ROMME
Colorado State University

My research interests include vegetation patterns, disturbance history, and the influence of contemporary disturbance processes, including drought, on vegetation structure and dynamics in southwestern Colorado. I have examined fire history and responses to recent fire in pinyon-juniper woodlands and ponderosa pine - mixed conifer forests. I am also investigating the interactions among natural disturbances, drought, and invasive non-native species in pinyon-juniper woodlands, as well as techniques and effectiveness of ponderosa pine forest restoration efforts. My current research projects in the region include the following: **1)** Ecological Impacts and Potential Methods for Control of Invasive Weeds following Fires in Mesa Verde National Park; and **2)** Fire History and Landscape Dynamics in Mixed Conifer Forests of the San Juan Mountains, Southwestern Colorado

I wish to be a core participant in the DIREnet outlined in this proposal. I can contribute extensive knowledge and experience with the ecosystems of southwestern Colorado, based on my 20 years of ecological research in this region. I am also a member of the Mesa Verde Pinyon Team. The purpose of this team is to help identify and prioritize research questions and potential funding sources related to pinyon-juniper vegetation in Mesa Verde National Park and nearby areas, especially with regards to the dramatic pinyon mortality now occurring in this region as a result of drought, insects, and possibly other stress agents. I foresee many good opportunities for communication and cooperation between this small local research network and the larger southwestern network described in this proposal. In addition, Colorado State University has a strong program in fire ecology that will attract graduate students who are interested in research related to fire, insects, climatic variability, and interactions among disturbance processes in the Southwest. In sum, I am very excited about the prospect of being a core participant in DIREnet as outlined in this proposal.

THOMAS SISK
Northern Arizona University

I have two projects that are directly relevant to the DIREnet project. The Forest Ecosystem Restoration Analysis (ForestERA) Project ForestERA Project provides a framework for assessing the impacts of ponderosa pine restoration treatments at landscape and regional scales. This framework will provide a means for analyzing cumulative effects of multiple restoration treatments, and integrating consideration of fire and forest ecology with consideration of wildlife and biodiversity issues. This project has been a large-scale collaborative effort, with over 20 participants from academic institutions, local, state and federal agencies and non-governmental organizations. ForestERA's end product will be a modeling tool developed for use in the ArcGIS environment that will allow ponderosa forest restoration stakeholders to create hypothetical scenarios and explore the potential outcomes of various management strategies.

The Colorado Plateau Land Use History of North America CP-LUHNA project (www.cpluhna.nau.edu) provides a history of the relationship between human land use and land cover change on the Colorado Plateau. This project was a continuation of the LUHNA (Land Use History of North America) project, funded by USGS and NASA's Earth Sciences Enterprise. CP-LUHNA highlights the environmental history of the Colorado Plateau through a collection of essays about the people, geography, wildlife, plants, and change over time (climate, land use, and land management). The goal of both LUHNA projects is to educate researchers, resource managers, educators, and the general public so that they can assess current trends and make informed decisions about environmental issues.

Both of these projects offer an applied landscape-scale perspective that can be useful in incorporating drought as a factor influencing the ecology of Southwest forests and woodlands. They are both examples of projects based on a large collaborative effort, and will be tools that DIREnet participants can use. For ForestERA specifically, DIREnet, in turn, may assist us in focusing on how drought affects the fire regime of ponderosa pine forests. DIREnet has the potential to be a dynamic forum for research collaboration and development regarding the current drought and I would be pleased to participate.

TAD THEIMER
Northern Arizona University

My research group examines the effects of drought and fire on seed dispersal by rodents in grassland, pinyon-juniper and ponderosa pine habitats. Although rodents often act primarily as seed predators, recent work in our lab and others has shown that they may be most important as dispersal agents in systems where constraints on seed germination are most severe. In these systems, the microsite in which a seed is placed may be critically important for future recruitment. The tendency of rodents to place seeds near nurse shrubs or rocks, to bury seeds beneath the soil surface and to preferential cache in soil types most conducive to germination are examples of behaviors that increase the importance of rodents as seed dispersal agents. Increasing drought and drought effects gives us the unique opportunity to see whether drought, and its concomitant restriction of potential recruitment sites, shifts the importance of rodent seed dispersal compared to other dispersal modes. Drought also brings increased probability of fire to these systems, and how rodents and their seed dispersal behavior is influenced by fire is another major area of research. We are currently investigating the relative rates of seed caching by rodents in burned and non-burned areas and testing the hypothesis that seed cache recovery will be lower in burned areas due to the reduced ability of rodents to detect seeds via olfaction in charred soils. In the long term, this work may allow us to develop management strategies for revegetating burned areas by manipulating caching behavior of wild, native rodents.

I am very interested in working through the Drought Impacts on Regional Ecosystems Net (DIREnet) in order to better understand how drought is affecting rodent populations across a larger landscape. Several labs have been monitoring rodent populations across the southwest, and our work may help predict what those patterns in rodent abundance may mean to future plant recruitment and forest structure. We will provide the network with current results from our-on-going research as well as the methods we are using. Hopefully, the latter will stimulate a collaborative studies using similar methodologies that will yield a more accurate understanding of the role of rodents as seed dispersal agents in a variety of habitats and the potential impacts rodent population fluctuations have on ecological processes. I believe DIREnet will assist my group by giving us a better understanding of the regional abundance and population fluctuations of small mammal populations across a broader landscape and will allow us to more effectively place our own work into a regional perspective.

CHRISTINE TURNER
U. S. Geological Survey

I am a principal investigator for a USGS project that is directly relevant to the DIREnet project. The goal of the USGS project entitled "Integrating Science with Resource Management with Resource Management through Collaborative Approaches and Adaptive Modeling Systems" is to frame the science questions for pinyon-juniper management to develop adaptive modeling approaches for resource management decisions on the Colorado Plateau. I am joined by three other principal investigators from the USGS, representing all four science disciplines in the Bureau, and 10 collaborators from the Colorado Plateau Cooperative Ecosystem Study Unit (CPCESU), the Merriam-Powell Center for Environmental Research, the National Park Service, the Bureau of Land Management, the National Forest Service, universities, and the USGS. Pinyon-juniper management is severely affected by the drought on the Colorado Plateau, and our goal is to bring the appropriate science to bear on the associated management decisions. Because this is a large-scale collaborative effort, it will be invaluable to have a formal network that we can draw feedback from for models that will be developed in our project. The interchange between our project members and DIREnet participants will provide a dynamic forum for research collaboration and I would be pleased to participate.

PHIL VAN MANTGEM
USGS, Western Ecological Research Center

I am an ecologist with the USGS stationed at Sequoia and Kings Canyon National Parks. My research interests include forest demography, and the effects of fire and other disturbances on trees and tree populations. Along with Dr. Nate Stephenson and Dr. Jon Keeley, I am involved in managing a multiple long-term forest monitoring plots arrayed across an elevation gradient in the Sierra Nevada of California. We would be able to bring a mature and well-documented data set to DIREnet which would extend the scope of the network to California. We strongly believe that data integration and synthetic research are key avenues for progress in modern ecological research. We would be pleased to be part of the DIREnet network.

THOMAS WHITHAM
Northern Arizona University

My collaborative research is related to the proposed project because it involves examining responses of pinyon-juniper woodlands **(1)** and cottonwood riparian habitat **(2)** to drought, either directly through stress or indirectly through increased susceptibility to pests that respond to stressed plants. My research focuses on how plant stress affects dominant trees, which in turn as community drivers affect biodiversity, community structure, genetic structure and ecosystem-level processes. Following is a major NSF funded study that will contribute significantly to the project and also benefit from future collaborations resulting from network activities.
LTREB: Rapid Ecotonal Shifts, Pest Outbreaks, and Mortality of a Dominant Tree Species in Response to Record Drought. PI Tom Whitham, Co-PI's, Catherine Gehring, Neil Cobb & George Koch. This research supports an ongoing 21 year projects to study how chronic stress and record drought affect the mortality of a dominant tree (pinyon pine) that characterizes the 3rd largest vegetation type in the US. We have documented how approximately 1000 species of bacterial decomposers, fungal mutualists, arthropods, birds, and mammals are affected by the interaction of drought and several keystone herbivores. Major attributes of this research are our long-term surveys and experiments that were in place before the current drought. This allows us to critically address how the current drought will affect ecotonal shifts, pest outbreaks, community structure, biodiversity, and the genetic structure of this dominant tree. We believe that this drought represents a major evolutionary event that is affecting the genetic structure of this dominant tree and the rest of the dependent community.

YAGUANG XU
Northern Arizona University

My current research focuses on the following three fields: **1) Tools/interfaces development in GIS environment for wild-life modeling, fire-risk estimation and forest management** Interfaces/tools for forest management have been developing for the Forest Ecosystem Restoration Analysis (ForestERA) project. These interfaces/tools, built on the most popular GIS platform (Arc/Info), let users easily access, analyze and integrate a variety of spatial data, select priority areas of treatment and build the optimal treatment plan based on the landscape scale analysis. **2) Remote sensing data processing and the technical method study in order to map structural parameters of forest, wood land and grass land for landscape scale analysis** Forest structural parameters (total basal area, tree density, canopy cover and tree composition) for over 200 million acres forest are mapped by using TM, RADAR and ground data. The study of practical technical methods for mapping large forest area is in process. **3) Building object-oriented technical methods for extraction of individual tree related information on high spatial resolution images.** Extracting information of individual trees from high spatial resolution datasets such as QuickBird and DOQ has been tested to the different sub-ecosystems (forest, wood land and grassland). A object-oriented method developed in GIS environment appears working well to this task.
What can I bring to DIREnet and what can the project do to advance my research? I would like to contribute my GIS and remote sensing expertise to the projects and shear my multiple years working experiences on spatial data analysis with others through the DIREnet. It has been noted that lack of qualified spatial datasets is the major obstacle for analysis of impacts of drought that must be observed in different scales. I definitely will be benefited a lot from the well-formatted communication provided by the project, with the other researchers who have the same research objective and different expertise. Building a platform using today's internet technology for people exchange ideal and data is critical for success on the research that has such

a broad scoop, and a efficient way to integrate efforts from the people with diversity of scientific background. I would be very happy to be apart of Drought Impacts on Regional Ecosystem Net.

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