SYNTHESIS SESSION: 7TH NORTH AMERICAN FOREST ECOLOGY WORKSHOP
Compiled and Edited by Terry L. Sharik

Climate Change and Collapse of Whitebark Pine Ecosystems--Jesse A. Logan

Importance and Background

Whitebark pine (*Pinus albicaulis*) plays a major role in the ecological integrity of high mountain ecosystems in the northern US and southern Canadian Rocky Mountains since it functions as both a foundation and a keystone species. It forms the foundation of high mountain and alpine ecosystems by providing the major biomass and primary productivity, enhancing soil formation, and serving as "nurse trees" for other conifers. In the larger spatial context, it is a keystone species because of the driving influence high elevation forests have on snow dynamics, both in the distribution of snow during winter and subsequent temporal attenuation of spring melt. The hydrology for the Rocky Mountains in general is based in the high mountains. Whitebark pine also provides critical resources to iconic wildlife species. The documented mutualistic relationship between whitebark pine and Clark's nutcracker is well known. Its large, fleshy, highly nutritious seeds also provide an important food resource for a wide array of other wildlife ranging from squirrels to grizzly bears. The importance of whitebark pine seeds to iconic wildlife such as the grizzly is of particular importance in sensitive areas such as the Greater Yellowstone Ecosystem due to paucity of other high quality food during the critical time prior to entering hibernation.

Across the entire distribution of whitebark pine this ecosystem may be facing catastrophic collapse. The threats to this ecosystem arise from two primary sources: an introduce pathogen, white pine blister rust (WPBR); and, more recently, unprecedented outbreaks of a native bark beetle, the mountain pine beetle (MPB). Under historic climate regimes, these forests provided an inhospitable habitat for the MPB because most of the time they were simply too cold for the beetle to thrive. Although past tree mortality did occasionally occur during periods of unusually warm weather (e.g. the 1930s), these outbreaks were short lived and of limited scale. Unfortunately, with the level of anthropogenic climate warming that has already occurred, the harsh conditions that served to protect these forests have become increasingly rare. As a consequence, significant MPB mortality is taking place year after year, with the very real possibility of total collapse of this important ecosystem. Both primary threats are exacerbated by climate warming, which in itself poses serious long-term consequences for whitebark pine, particularly in its U.S.A. distribution. The consequences of whitebark pine loss are already being expressed in altered hydrology and wildlife interactions.

Research Priorities

The principal hosts of interest for MPB are lodgepole pine and ponderosa pine. Both of these ecosystems are vastly different from whitebark pine. A more extensive research knowledge base exists for white pine blister rust impacts on whitebark pine, Therefore, the majority of presentations and discussion in this session were with respect to MPB directly or the interaction between WPBR and MPB. Several research priorities were identified:

- *Tree defensive chemistry* – Very little is known about the defensive chemistry of whitebark pine to attacking MPB, although research has recently been initiated with interesting preliminary results. This is true for both primary and induced defenses. From field observations, it appears that both primary and induced defenses in whitebark are less effective than in either of the primary hosts. The reduced effectiveness of tree defenses may provide a critical key to observed differences in MPB population dynamics in whitebark pine.
- *Regeneration* -- Although the loss of essentially the entire cone-bearing overstory has been observed in many areas, documentation of the residual stand remaining is only beginning to be accessed. These data are critical for projecting future prospects for whitebark and for effective scenario development.
- *Community Interactions* – The loss of cone production has far-reaching impacts on whitebark pine and community associates. Of particular interest are the impacts on the mutualistic relationship between Clark's nutcracker and whitebark pine. Whitebark is almost entirely dependent on Clark's nutcracker for seed dispersal and planting. The nutcracker, however, is much more of an opportunistic species. In fact, below a recently determined cone-density threshold, Clark's nutcracker will seek other food resources. There is also mounting evidence for preferential selection of WPBR infected trees by MPB. Both of these community level interactions, and others just beginning to become apparent, have important implications for the future of whitebark pine.
- *Effective monitoring and assessment* – There is little doubt that MPB cause mortality in whitebark pine is severe and widespread; however, due to the spatial scale and speed with which the outbreaks have occurred, the full spatial extent is unknown. Due to the remoteness and ruggedness of whitebark pine habitat, effective assessment will require a combination of (1) on the ground stand survey, (2) aerial mapping from fixed wing aircraft, and (3) satellite image interpretation.
- *Need to address ALL high elevation 5-needle pines* – Limber, foxtail and bristlecone pines are suitable hosts for MPB and may be at risk for a similar fate to that whitebark pine is experiencing.
- *Key Refugia* – Although much of the distribution of whitebark has been impacted by MPB, due to microclimatic conditions some areas are more resistant to climatic disruption than others. The central core of the Wind River Range and the Beartooth Plateau are two such examples. Trees smaller than approximately 6 in (15.24 cm) DBH are not attacked by beetles. Therefore, understory and krumholtz provide a temporal buffer for maintaining whitebark on some landscapes (see regeneration). Gnome forests in some areas (i.e. the Beartooth Plateau) provide additional refugia. Potential refugia need to be identified through both on-ground surveys and/or model risk assessment.
- *BioClimatic modeling* – Landscape models for risk assessment and climatic vulnerability to MPB outbreaks have demonstrated predictive value for indicating both landscapes at risk, and those more resilient. These models can be improved to more fully represent the relationship between weather, host tree, and outbreak potential.

Management Response

Effective management response is complicated by the fact the almost everything we know about managing MPB is based on interactions with lodgepole pine, or to a lesser extent, ponderosa pine, both significantly different from whitebark pine. Given this caveat, however, several management responses were discussed:

- *Seed and cone collection and tree planting* – In-place programs to collect and propagate WPBR-resistant whitebark needs continued and increased support. This effort helps maintain genetic resources in both laboratory seed banks and on the landscape through re-planting efforts.
- *Vegetation management* – Although serious questions were raised regarding thinning as a tool to decrease whitebark vulnerability to MPB, this strategy has potential in some situations to reduce competition with subalpine fir.
- *Fire management* – Fire is known to play an important role in whitebark pine ecology. However, the issue of disturbance scale and community interactions when large-scale removal of seed sources by MPB has occurred were raised.
- *Direct tree protection* – Chemical spray applications and pheromone (verbenone) packets have a place in protecting valuable (e.g. plus trees) individual trees. There is a need to follow up and document performance of verbenone applications.
- *Scenario Evaluation* – There is a critical need to anticipate to the best of our ability what comes next. Important and far-reaching loss of whitebark pine ecosystems already has and will continue to occur. The critical question is: What are the likely community trajectories and are there ecologically based strategies that will help maintain whitebark pine on the landscape?

Forest Detritus under Changing Climate and Disturbance Scenarios--Christopher Woodall and Mark Harmon

The contribution of standing, down, and buried dead wood to forest ecosystem processes and carbon fluxes is often ignored or underappreciated. It appears that dead wood may be a controlling factor in many forest ecosystem processes such as regeneration establishment, soil C efflux, and soil stability. Ultimately, the entire C cycle of forest stands may be controlled by dead wood following disturbances, especially in higher latitude forests (e.g., boreal). Dead wood C stocks may not be as ephemeral as assumed, since buried dead wood in boreal systems can remain for 200-300 years. Beyond lacking basic ecological information regarding dead wood decay cycles, increased utilization of residual dead wood biomass following harvest operations threatens dead wood resources. Only through expanded dead wood research can the negative effects of dead wood removal be mitigated. Individual presentations highlighted notable forest detritus research findings many of which are critical knowledge gaps under climate change scenarios. Specific findings included: 1) empirical studies of downed dead wood in boreal ecosystems has indicated that it may be greatly underestimated using standard simulation models due to buried wood, 2) the drivers of dead wood decay processes across the diverse forest ecosystems of North America are a vast unknown, 3) dead wood simulation models typically do not include climatic variables thus are not sensitive to climatic effects on accumulation/decay processes and related climate change effects, 4) current sample intensity of national dead wood inventories may be too low to statistically detect even substantial changes in dead wood C stocks, 5) increased utilization of harvest residues to meet bioenergy demands may threaten dead wood ecosystem processes/resources and 6) dead wood and its decay often ignored in large scale C/disturbance studies although it may act as control of many ecosystem processes such as seedling establishment and disturbance recovery (e.g., soil stabilization).

Overall, expanded, systematic, long-term research in the areas of dead wood decay processes is suggested. Furthermore, a joining of forest inventories with dead wood simulation models is suggested to benefit refined forest ecosystem C stock estimation. Across North America dead wood resources systematically impact forest ecosystems, why not systematically study them?

Disturbance Interactions during Ecological Change--Douglas J. Shinneman & Brian J. Palik

Disturbance interactions are ubiquitous in forest ecosystems. Yet, not only do individual disturbance agents often have complex relationships with ecosystem components and processes, but disturbance interactions often result in equally complex spatial and temporal dynamics, which can dramatically alter successional trajectories, forest landscape patterns, and ecological processes through time, and may result in non-linear ecological responses. Thus, understanding these dynamics, and predicting the magnitude and scale of future disturbance interactions, is a challenging area of ecological research. Studies in this session used a variety of methods, including field-based research, simulation models, and theoretical models, to address interactions among various disturbance agents, including insect outbreaks, windthrow, and timber harvest (and to a lesser extent, other key disturbance agents, such as fire). Researchers investigated these interactions at various temporal and spatial scales, but focused mainly on large landscapes and relatively long-time periods. Key points identified in the research included: 1) the ability of past disturbance events to affect future disturbance intensities and severities; 2) how spatial legacies of past disturbance events can affect the spatial patterns of future events; 3) the effects of spatial legacies from past disturbance events on the frequency and synchrony of future events; and 4) the potential for synergistic interactions among disturbance agents to affect forest ecosystem composition, structures, and processes (including future disturbance events) across time and space.

Session participants also identified important future research directions, many of which were addressed by presenters in their research. Key among these were the need to: 1) incorporate the influence of climatic variability and assess the likely influence of global climate change on disturbance interactions and their effects; 2) better assess the influence of disturbance interactions on key ecosystem processes, such as carbon dynamics; 3) address the role of socio-economic and political influences on disturbance interactions and their effects, such as different management histories among different land-owners; 4) address disturbance interactions at appropriate scales, including determination of scale-sensitive detection of disturbance interactions and their effects; 5) consider the degree to which forest management can (or should) emulate more complex disturbance interactions; and 6) use iterative approaches between research (e.g., modeling) and management, whereby research informs possible new management directions and the results of management in turn informs and guides future research. Finally, there was also a recognition that better data are needed to inform management and future research in this area, including acquiring and using better empirical data via continued field-research and long-term monitoring, but also by developing better access to, or compilations of, existing datasets that encompass large landscapes and long time periods.

Ecosystem Recovery Following Disturbance--Craig DeLong

The combined influence of climate change and human intervention on forest ecosystems has lead to a recent focus of research on the recovery of ecosystems following disturbance. The concern is that novel stresses from disturbances foreign to the ecosystem may hamper its ability to recover due to lack of adaptation of the species to these stresses (Kelly and Harwell 1990). Human disturbances in the past have severely hampered the recovery of ecosystems due to the magnitude, severity, and extent of the disturbance and poor adaptation of the species to recovery to this disturbance. A classic example is the widespread burning of the native vegetation of New Zealand by Polynesian settlement and the poor adaptation of the native vegetation to recover from this disturbance (McGlone 1989).

Ten talks at the ecosystem recovery session of NAFEW 2009 focused on the recovery of stand structure, vegetation composition and structure, rural landscapes, productivity, and carbon and nutrient stores in response to disturbance from fire, insects, wind and human interventions. The ecosystems examined included sub-boreal pine, boreal aspen/spruce, boreal black spruce, wet cedar hemlock, and northern hardwoods. One universal conclusion in the context of these systems and attributes that were examined, is that these ecosystems do recover depending on how narrowly one defines the ecosystem properties. If it is just processes or biomass or even relatively similar stand structure and species composition, then in most cases the ecosystems recover to the same condition. If one narrowly defines the ecosystem based on the full suite of species and structure that was present in the pre-existing "natural" condition, then this is not necessarily true. However, this goal is questionable given that we are trying to manage for diversity in the system. The exceptions to this general rule of recovery may be the impacts of harvesting on deadwood and multiple harvest entries targeting single tree species. Several talks highlighted the large differences between deadwood levels in younger managed stands as compared to all ages of natural stands. Two of the talks stressed the implications of continued harvest entries focused on single or few tree species to tree species loss and understory changes.

Recovery assumes having a target condition in mind so identifying that target condition and what important elements of the condition are important in recovery over is critically important. Often the assumed condition is that of old forest, but for one talk in the session the target of management was an earlier condition of the long-term successional process of paludification in boreal black spruce ecosystems. Another important factor is to define the relative length of time in which recovery is desired. The expression "time is thy enemy, know it well" is apropos in relation to recovery research. Some elements of stands structure (e.g., large deadwood), species composition (e.g., some rarer arboreal lichens) require hundreds if not thousands of years to recover. Recovery may not be possible if a shorter time frame is desired, which means representative areas of the original condition need to be excluded as best as possible from anthropogenic influences. Even with protection, however, there is no guarantee that a particular condition of an ecosystem is practical to achieve--especially in light of climate change and increased human pressures. The question of how important to ecosystem and landscape function this condition is must be addressed. One must also be cautious with human interventions that are designed to speed up or restore a particular target condition. Although well intentioned, these interventions may lead to undesirable consequences. Our long history of fire management in an effort to maintain timber values resulting in increased fire risk or unprecedented insect outbreaks underlines this risk

Future direction in this area of research should focus on the synthesis of the relatively large pool of data on recovery of multiple components of well studied ecosystems. There was agreement that there was a lack of inclusion of a wildlife component in most of the ecosystem recovery studies, and thus future research should be attempting to make the link between habitat and wildlife use. With the rapid advance in new statistical and modeling techniques, mathematicians need to be encouraged to pursue this field of ecology research.

Kelly, J.R. and M.A. Harwell. 1990. Indicators of ecosystem recovery. Environmental Management 14: 527-545.

McGlone, M.S. 1989. The Polynesian settlement of New Zeal and in relation to environmental and biotic change. New Zealand Journal of Ecology 12: 115-129.

Disease and Insect Disturbances--Fred A. Baker

This session had only 6 presentations and we “adopted” 3 posters. Only one student presented in the session. Although there was another session on mountain pine beetle, there is concern about the apparent lack of interest in these key ecosystem drivers. Despite the small numbers, very interesting results were presented with lively discussion. A key point is that we still need a better understanding of host physiology and how it affects host defense and reproductive capabilities. Millions of trees die, but we still do not understand how! Insects and fungi not only kill trees, but they cause cascading effects in ecosystems. Mountain pine beetle not only affects timber volumes and future stand composition, but they can affect water yield in quantity and timing, a key societal demand at least in US forests. Other insects and fungi are changing species composition with unknown consequences. For example, dogwood anthracnose is reducing the dogwood population by more than 50% over much of the host range, yet we know little about what this means for those ecosystems.

Mixed Severity Fire Regimes--Thomas Spies

The workshop session explored various aspects of the mixed severity regime in the western U.S. Participants examined regional patterns of the regime, definitions of fire severity, roles of fire history, climate, topography and vegetation in explaining fire severity in several different forest types, and potential effects of climate change.

Fire regimes are often classified into three types: low, mixed, and high. The basis for this classification is typically the percent of the canopy that is killed by fire. For example, low is often defined as fires that kill less than 25-30% of the overstory and high is defined as fires that kill more than 70-75%. In this context, ponderosa pine forests of the SW US are classified as low severity regimes and higher elevation lodgepole pine forests of the Rocky Mountains are considered high severity. The regime classes are also often distinguished in terms of the factors limiting fire occurrence and the fire management strategies that are needed to reduce the probability of high severity fire. Low severity regimes are typically considered fuel limited and it is generally agreed that management actions can effectively reduce fire hazard in these types. In many high severity regimes, on the other hand, fire behavior is considered weather- or climate-limited and management actions to lower the risk of loss of the canopy to fire are typically considered ineffective. The regime between low and high severity, mixed severity, occupies a wide range of canopy mortality levels and a large portion (at least 50%) of western forest types fall into this broad category. Given its wide geographic spread and abundance, the mixed severity regime is one of the most important but is also the least understood.

The scientific and management basis of this intermediate class of fire severity is problematic for several reasons: 1) The class contains such a large variety of forest types, fire behaviors, and ecological responses that it has limited value as an operational concept; 2) the concept of severity (damage to live and dead vegetation) is itself problematic because it manifests itself in many ways (e.g., not just canopy but surface and soil effects) that are not part of the current classification; 3) given that mixed severity regimes straddle fuel-limited and climate-limited fire regimes, classification of a site as "mixed severity" does not necessarily say much about the efficacy of fuel treatments to reduce the probability of canopy death or losses of soil organic matter from wildfires.

The following are some of the key findings and conclusions that arose from the talks and ensuing discussion:

Despite its weaknesses as a term, the class "mixed severity" has some value in identifying a large set of forest types and disturbance regimes that are characterized by spatially and temporally variable patterns of fire behavior and effects.

Fire behavior and effects within the "mixed severity" regime are driven by complex interactions of climate, fuels, topography, and vegetation.

At present the most salient feature of the mixed-severity regimes is its spatial and temporal variability in fire behavior and ecological effects. Consequently, emergent characteristics of fires and fire regimes such as patch size distributions may be a useful metric in characterizing differences among different mixed severity regime types and providing some guidance to managers.

New typologies and definitions are needed that characterize the major domains of variability within the mixed severity regime. To be most effective these new typologies should be based on fundamental drivers of fire behavior and ecological responses. Elements of these would include climate, fuel levels and succession, topography, vegetation, productivity, and fuel moisture and spatio-temporal dynamics.

Mixed severity regimes are not necessarily synonymous with forest ecosystems in which fire suppression has modified fire hazard or with situations where fuel treatments are effective in reducing risk of high levels of canopy mortality or soil damage from wildfires. Some mixed severity regimes may fit these situations while others may not.

Scientists and managers need to do a more careful job of characterizing fire effects related to the concept of “severity”. When used alone, the term “fire severity” has relatively little value--it must be more precisely defined to really understand the effects of fire on biodiversity and ecosystem goods and services and to enable development of more robust scientific models and effective management responses. Comparisons across fires and fire regimes must be made using the same definitions of severity; even then, ecological responses to the same level of severity are likely to be different across species, communities, and ecosystems.

Topography plays an important role in structuring the spatial and temporal patterns in fire behavior in many mixed severity systems. Topography can be an important basis for manipulating fuels to modify fire behavior.

Landscape-level legacies of past fires and landuse practices on forest structure and composition can alter future landscape responses to fire, creating a spatio-temporal dynamic in forest structure and composition that wanders through ecological space, never following the same path. For example, the proportion of late successional tree species has increased in many forests, increasing the probability that future disturbances will be colonized by seedlings from surviving individuals of these species. Conversely, past removal of pines and other seral dominants from mixed conifer forests has reduced the probability that future disturbance patches will be colonized by these early successional species. Management actions (e.g. thinning, prescribed fire, and planting) may be needed to alter these trajectories to achieve specific or general ecological and social outcomes.

Climate change will affect the spatial and temporal dynamics of fire regimes, possibly increasing the proportion of high severity patches within forests that were historically characterized by bounded ranges of low, moderate and high fire severity. Using the historical range of variability (HRV) as a goal for management will not be realistic in many regions given climate change and the cumulative effects of past landuse practices.

An alternative to HRV as guidance for managers may be to insure the “resilience” of forests, where resilience is defined as the capacity to sustain biological diversity and produce desired goods and services following disturbances. However, for this concept to become more operational, terms such as resilience must be defined and specific metrics of desired ecological conditions and behaviors must be developed.

Linking Fuel Heterogeneity to Fire Behavior and Effects--Joseph O’Brien

The goal of organizing the session “Linking Fuel Heterogeneity to Fire Behavior” was to bring together investigators interested in capturing and understanding the impacts of fuel heterogeneity on wildland fires. Fuel heterogeneity can be defined many ways and at many scales. This heterogeneity can manifest itself obviously through mosaics of burned and unburned patches but also more subtly by altering fire intensity within burned areas. Although ubiquitous and recognized as important, fuel heterogeneity has been largely ignored. Understanding the processes both creating this heterogeneity and their impacts on fire behavior and subsequent fire effects offers an opportunity to generate mechanistic explanations linking combustion science and ecology in an evocative way.

There were five presentations in the session covering issues related to the three main types of fuel heterogeneity: fuel type, fuel quantity, and fuel spatial arrangement. The presentations focused on how fuels-mediated fire behavior and subsequent fire effects including quantifying kinds and amounts fuels; identifying the need for new fuel models in northeastern deciduous forests to parameterize fire behavior prediction systems; and determining how fuels drive fire effects on soils (lethal temperatures, nutrients and soil C), tree mortality, and fire behavior itself.

The participants identified unifying themes at the conclusion of the session and focused on the following topics:

1) Heterogeneity is ubiquitous yet understudied.

2) Cumulative impact of small-scale events often drive larger scale dynamics.

3) Spatially-explicit measurements are critical for deriving mechanistic explanations for fire behavior, especially for understanding fuel-fire-atmosphere interactions.

4) Spatial heterogeneity in fuels can lead to unanticipated fire behavior such as increased fire intensity in the wake of fuel-free patches.

5) Soil heterogeneity is extensive and problematic because it often occurs at fine scales and is inherently difficult to capture.

The synthesis also included some recommendations relative to the topic. Since there are multiple definitions of heterogeneity, users of the term must clarify the scale and dimension, and incorporate practical nomenclature useful for communicating with managers when discussing heterogeneity. Furthermore, the identification or development of a simple metric of heterogeneity that is relevant for guiding management activities was seen as necessary. Heterogeneity would be useful as a unifying theme for fire research over broad geographic regions, bringing eastern and western researched together. This would facilitate the exploration of both the commonalities and differences related to geography and different ecosystems and would also encourage broader approaches. The participants thought that novel technologies such as LIDAR (LIght Detection And Ranging) and infrared thermography offered promising means for addressing some of the measurement issues raised above. Finally, the participants thought it critical to explore scalability to answer the question: How much knowledge of local detail is enough to explain landscape-scale patterns?

Ecological Impacts of Mastication Fuel Reduction Treatments--Mike Battaglia

Recent large-scale, severe wildfires have prompted extensive fuel treatment programs to reduce potential wildfire size and severity. Often, unmerchantable material is mechanically masticated because removing the material is cost-prohibitive. Mastication treatments involve shredding, chopping, or chipping small trees and/or shrubs into small chunks and leaving the material on site. Managers and the public are interested in understanding the impacts of the addition of this woody material on forest ecosystems so that they can evaluate the potential benefits and costs of these treatments. The aim of this session was to bring together researchers from a variety of ecosystems to present and discuss the state of knowledge of the ecological impacts of these treatments and identify future research priorities. Results were presented for several ecosystems along the latitudinal gradient of the northern and central Rocky Mountains, including pinyon/juniper, ponderosa pine/Douglas-fir, mixed conifer, and lodgepole pine forests. Ecosystem type and time since treatment were important factors that determined the ecological impact of mastication.

In all cases, mastication substantially decreased tree density and increased the amount of surface fuel loadings. However, the size distribution of the surface fuel was dependent upon the machinery, operator, and silvicultural prescription. The general trend was that the majority of the fuels were <2.54 cm in diameter, although the northern Rocky Mountain wet forest site had larger chunks due to its prescription. After 2 years, the fuel loads in this wet forest decreased substantially due to the quick decomposition rate, but it was unclear if similar results would apply to the dry forests of the central Rocky Mountains. Different measurement techniques to estimate fuel loads were explored and it was determined that the cover-depth-bulk density method was the best. Changes in fuel bed composition with a shift from needle-dominated fuel beds to woody-dominated fuel beds were reported. These new fuel bed types will have vastly different fire behavior and effects.

Herbaceous plant cover was found to increase after mastication treatments in pinyon/juniper and ponderosa pine/Douglas-fir ecosystems, but not in mixed conifer or lodgepole pine ecosystems. It was suggested that 2 to 4 years post-treatment might not be long enough to detect any discernable differences in these two ecosystems because of the lack of developed herbaceous community before treatment. The size distribution of mulch seemed to impact herbaceous cover. Areas that were chipped showed a species compositional difference, but areas that were chunked did not. Mulch depth was found to negatively impact herbaceous cover in pinyon/juniper and ponderosa pine/Douglas-fir ecosystems, but not in mixed conifer or lodgepole pine ecosystems. Exotic species were more prevalent in treated areas. Mastication in pinyon-pine/juniper did not negatively impact tree regeneration densities, but the impact in other ecosystems was not reported.

The addition of the mulch to the forest floor altered soil moisture and temperature in pinyon/juniper, ponderosa pine/Douglas-fir, mixed conifer, and lodgepole pine ecosystems. The mulch moderated the fluctuation in temperatures and the largest difference was during the growing season where soils were cooler and wetter in the mulched areas.

The effect of adding mulch to the forest floor on nitrate and ammonium levels varied among ecosystems. Some pinyon-juniper sites showed no change in nitrogen mineralization, while others showed an increase in ammonium. Nitrogen was shown to decline with increased mulch depth for the pinyon/juniper and lodgepole pine ecosystems, but not for the ponderosa pine/Douglas-fir ecosystem. Within the lodgepole pine ecosystem, nitrate and ammonium was higher in the areas that were chipped (smaller pieces) than in areas with larger residual material. It was suggested that the chips represent a proxy for the later stages of decomposition (e.g., larger material breaking down into smaller material) and that over time, mulch effects may become positive. The addition of mulch to the forest floor was not shown to alter the C:N ratio in the pinyon/juniper ecosystem. However, the loss of AMF fungi richness after 2.5 years in the pinyon/juniper ecosystem was noted.

Because of the infancy of this novel management treatment, the ecological impacts of this fuel reduction treatment are still unclear. While we did see some general trends in the data, future research is needed. It was clear that ecosystems differ in their initial and short-term (2 to 4 years post-treatment) response to the addition of woody material. However, it was unclear if changes within a site between years were a result of climatic differences or ecosystem recovery. This highlights the need for continued longer-term studies of these treatments.

The group identified several studies that would help address the ecological impacts of these mastication treatments. Data presented in this session were short-term in nature, ranging from initial effects to 4 years post-treatment. Therefore, chronosequence studies of mulch sites in each of the ecosystems along the latitudinal gradient are needed to examine changes in C:N of the woody material, soil microbial communities, decomposition rates, soil nitrogen, tree regeneration, and tree growth. In addition, studies that assess the long-term impact on herbaceous plant community composition and production are still needed. These longer term studies will also help determine the longevity of these treatments to reduce crown fire risk. Many of the studies were unable to address the effect of thinning separately from the effect of thinning plus addition of woody biomass. In addition, it was suggested that we highlight the need for managers to leave reference controls within the treatment area so we can assess the impacts of the treatments and provide feedback for adaptive management. It was also stated that we should consider the impact that wildlife (micro-and macrovertebrates) are having on vegetation recovery and nutrient dynamics in these ecosystems. The lack of fire behavior fuel models to describe these new fuel beds hinders our ability to determine the fire behavior and effects on these treatment areas. More research in the development of new fuel models to estimate fuel loads and their physical properties is still needed for each of these ecosystems.

Fire and Fire Effects--Justin DeRose

The Fire and Fire Effects (FFE) session covered a diverse range of topics, including the reconstruction of fire regimes; the influence of pre-fire landscape heterogeneity on patterns of fire severity; and the effects of high-severity fire on post-fire wildlife habitat, regeneration dynamics, and fuel loading. Fire severity quickly emerged as a key component of each study, whether used to define levels of canopy mortality, characterize microsites for post-fire regeneration establishment, describe the nature of historic fire regimes, or as a categorical fire effect from which to sample. The broad usage of the term fire severity warranted scrutiny and resulted in the identification of key topic areas for future work in FFE research.

The area of FFE has primarily described the myriad of interactions between the pre-fire environment and fire-severity on post-fire system characteristics and responses. Regardless of ignition, fires are driven by climatic, vegetation, and edaphic factors that may or may not interact to result in variation of fire severity. In turn, fire severity affects a whole host of post-fire attributes such as percent mortality, snag dynamics, fuel loading, wildlife habitat, etc. Furthermore, geographic differences in species composition and spatial scale apparent in fires across North America add complexity to fire effects. As a result, definitions of fire severity are usually study-specific and driven by the response variable of interest, which makes comparisons between studies difficult and often limited to qualitative analyses. As an example, a given fire event will influence the overstory, understory, duff and litter layer, and soil differently although fire severity is likely to be defined by its effect on overstory vegetation.

Most FFE studies are focused on the immediate post-fire effects of severity rather than on the influence of the pre-fire environment on the fire (e.g., the influence of pre-fire stocking on post-fire fuel loads), or the long-term, post-fire response to fire activity (e.g., snag dynamics over time). This short-term focus might be driven by the immediate post-fire reaction of the public and the availability of funding to explain these fires. Longer-term information with respect to specific fire events, both pre- and post-fire, provides a more complete picture of what drives the fire and fire effects and how the ecosystem responds providing some predictability for future events. As an example, long-term, post-fire studies of fuel dynamics are relatively rare but would be useful for describing how the heterogeneity of fuels (both live and dead) could influence subsequent fire behavior.

In conclusion, two key points that should drive future research emerged from this session: 1) the need to develop objective metrics of fire severity that are spatially and temporally explicit so comparisons between studies are possible and they can be of potential use for wildland management, 2) the need to emphasize longer-term studies of ecosystem dynamics both before and after specific fire events. Any advances in FFE research will lead to improved models of fire behavior and should therefore be incorporated into regionally appropriate fire behavior models (e.g., incorporating snag fall rates and subsequent decomposition rates identified for dry-site ponderosa pine and Douglas-fir in eastern Washington and Oregon into the local fire simulation models to improve model prediction). Furthermore, the identification of these key points should help to influence funding gaps from sources such as the Joint Fire Science Program.

Adaptive Ecology Systems--Sarah L. Taylor

Adaptiveness (or adaptation) is the ability of an individual tree or a forest community to evolve in response to changing circumstances. Adaptations may include an array of behavioral and physical attributes that respond to temporal and/or spatial environmental gradients at a wide range of scales. The ability to adapt to changing circumstances can enhance the resilience of forest systems, enabling them to cope with unexpected events, such as those forecasted by climate change scenarios. Hence, there is a growing need to better understand and quantify the response of forest systems to spatial and temporal heterogeneity of key abiotic and biotic factors. As such, the term adaptive ecology systems is a very broad area, which was certainly demonstrated by the breadth of research topics covered in the session. The oral papers investigated changes in gap characteristics (size, age) across topological gradients, persistence of gap makers (snag decay) over time, impact of crown canopies and canopy gaps on understory light levels, and changes in canopy cover as a result of harvesting and fire suppression on the succession of ground and woody vegetation. The basic principles of adaptation are integral to the concepts of ecological forestry and adaptive management, which was highlighted by a talk on the longleaf pine ecosystem. Part of the challenge of the wrap-up discussion was to identify a unifying factor that drew the many threads of the multidisciplinary research papers together. A key emerging point was the role of canopy gaps on stand dynamic processes. In terms of future research directions, if gaps are the construct on which to examine adaptive ecology systems, then should we be modeling the forest gaps and not the forest crowns as traditional models do, and should these models be at the scale of a tree, tree neighborhood, stand or landscape? The need to make this kind of research more accessible and relevant to forest managers was highlighted in terms of emulating natural processes.

Forest Ecological Processes--William Adair

Authors (arranged in order of their contribution to the discussion): John Seiler, Tom Dean, Carolyn Copenheaver, Enrique Doblas-Miranda, Jacob Dyer, Michael Bridgen, Lionel Humbert, and Henry McNab.

Because this was a *diverse* session, it is difficult to summarize the content of the presentations. If any single theme emerged from this series of presentations, it was that conventional studies of limited duration have proven inadequate for examining ecological processes that depend on many complex interactions and function over longer time scales. This observation suggests that we should start a formal discussion concerning the pressing need for coordination among studies, with an initial emphasis on a synthesis of current studies of ecosystem processes across geographic regions and ecological circumstances. As a first step, these studies could be gathered together into an international catalog and database, perhaps using the Ecological Society of America (ESA) and Federal Geographic Data Committee’s (FGDC) National Vegetation Classification (NVC) as a model. A comprehensive meta-analysis of these studies could then be used to identify the most pressing unanswered questions, and to set priorities for establishing more extensive long-term studies that encompass the full range of natural variability.

Ecological Lessons from Long-Term Studies in Experimental Forests--Andrew Youngblood and Brian Palik

This year the United States Department of Agriculture Forest Service is celebrating the 100th anniversary of its network of experimental forests. For a century, experimental forests have contributed immensely--both in the US and around the world--to the practical understanding of the environment and to the formation of management approaches and policies that affect our use of forests and the natural resources they contain. The system provides places for long-term science and management studies in major vegetation types on the 195 million acres of public land administered by the Forest Service. This network of experimental forests provides an incredible wealth of records and knowledge of environmental change in natural and managed forest ecosystems across the United States. These sites are living laboratories where discoveries are made and research results are demonstrated for cooperators and stakeholders. As part of the centennial celebration, speakers representing seven US experimental forests were selected to discuss some of the ecological lessons from long-term studies. Two additional speakers provided perspectives from similar research forests in Canada.

Many experimental forests were established during or after other dominant land uses had already occurred. For example, the Bent Creek (North Carolina), Coweeta (North Carolina), Crossett (Arkansas), Cutfoot Sioux (Minnesota), Fort Valley (Arizona), and Santee (South Carolina) experimental forests still contain legacies of landscape-scale tree harvesting and railroad logging, fire suppression, livestock grazing, or diversion of water for agriculture. A common issue across many experimental forests was establishment of stands and forests that best represented natural stand structure, such as early work at Cutfoot Sioux, Santee, Bent Creek, Crossett, and at the Canadian Petawawa Research Forest in Ontario. Experimental forests frequently were sites for early research designed to evaluate methods of harvesting and regeneration techniques that aided the timber management industry, including Bent Creek, Crossett, Petawawa, Fort Valley, and Pringle Falls (Oregon). This support, almost universal across the network, now rarely exists.

While the value of long-term research, especially in dedicated sites such as experimental forests, includes opportunities to observe changes in forest composition and structure over extended periods, many experimental forests are undergoing shifts in research missions as societal demands and needs shift. Long-term research sites provide opportunities to address new questions with existing research infrastructure, such as using nearly a century of recorded vegetation dynamics at Coweeta or Fort Valley to evaluate the effects of introduced disease, introduced insects, and climate change; or nearly a century of recorded vegetation dynamics under known management regimes at Crossett, Cutfoot Sioux, Petawawa, Fort Valley, and Pringle Falls to evaluate opportunities for biomass conversion and carbon sequestration. Long-term research at experimental forests also provides a unique opportunity for building networks of similar sites to calibrate and validate landscape- and regional-scale models supporting policy decisions. As a first step, workshop attendees recommend that a catalog of long-term data sets should be developed based on the prototype designed by the Canadian Forest Service in British Columbia.

Ecological Applications of Stand Density Indices--Mark Ducey

We examined the ideas, applications, and new developments for measuring stand density taking Reineke’s (1933) original work on Stand Density Index (SDI) as a starting point. After a great overview by John Shaw, we enjoyed 5 research presentations spanning a broad geographical and conceptual range. From boreal mixedwoods in the north, to tree hammocks in south Florida in the south; from Oregon in the west to New England in the east, Reineke’s ideas continue to provide raw material for a variety of exciting work. Several themes emerged from these presentations and our discussions. The first was the challenge of using SDI in mixed species stands and landscapes: Reineke’s original work was in monocultures. For example, Andrew

Gray compared a variety of stand measures for predicting canopy cover in Oregon. A challenge with SDI was that while it may provide a good measure of stand density within stands of a particular species, between species or in mixed species stands it may be less appropriate and other measures may perform better. Rachel Knapp presented work adapting the basic ideas of SDI for mixed species stands in New England, while Valentin Reyes-Hernandez explored SDI within boreal mixedwoods. Michael Ross presented evidence that SDI can be used to better understand the dynamics of subtropical tree islands in Florida. These investigations suggest that SDI can be adapted to more complex environments. Finally, Chris Woodall presented intriguing ideas about the connection between stand density and dead wood pools at a national scale. Here again, discussion focused on interpreting stand density ecologically over a broad range of species composition and dead wood decomposition rates. In group discussion and synthesis, issues of scale featured prominently. In short, while SDI has been a useful tool for a long time, we have much to learn and many fascinating avenues for new inquiry and new applications.

Advances in North American Aspen Ecology--Paul C. Rogers

The *Advances in North American Aspen Ecology* session was conceived with the idea of exploring several sub-disciplines of quaking aspen (*Populus tremuloides*) research with the ultimate objective of communicating new knowledge to land managers. This goal was derived from anecdotal evidence from field visits and conversations with land managers that practitioners are operating with assumptions based on 20 to 30-year-old science. With this in mind, the aspen session at NAFEW was structured thus: two national overview presentations (Canada and U.S.), nine technical presentations describing recent research, and a discussion/synthesis session where participants were encouraged to derive overarching themes and future research needs from the session.

As a precursor to the synthesis discussion, national representatives – Simon Landhäusser (Canada); Paul C. Rogers (U.S.) – presented a brief synopsis of differences in national land management policies that strongly influence decisions regarding aspen. In short, much of Canadian national and provincial forest management is strongly influenced by commercial timber harvesting, whereas U.S. policy and practice has, in recent years, been dominated by public involvement favoring conservation of species, recreational interests, and aesthetics. It was pointed out that land management geared toward conservation is more prominent in areas where aspen – and forest harvest generally – is less commercially viable for various reasons (i.e., growth habits, ease of access, and political/economic climates). In the U.S. Lake States and boreal Canada, aspen is considered a prime commercial tree species.

Despite these divergent policy agendas, the group was able to coalesce around a few prominent themes that emerged from our talks. A central theme of the country overviews was that there is not a single “aspen forest,” but many functional aspen types. Thus, we agreed that it would benefit managers and researchers to focus on specifics of how these types differ ecologically and how they might be managed more effectively with that base of knowledge. Key indicators of aspen health (i.e., sustainability) were touched on by several speakers and it was acknowledged that pooling these findings for application in monitoring would advance the field. For example, recent Canadian research (Landhäusser & colleagues) clearly points to the high value of examining root system status as an indicator of aspen health. Another theme of the session was the need to improve monitoring via standardization of methods and terminology. Often researchers have conflicting results in functionally similar aspen communities and thus send mixed messages to earnest land managers. Upon further scrutiny, differing conclusions are rooted in dissimilar definitions or approaches. A final overarching message from this session was that policy makers throughout aspen's range either have not understood, or are reluctant to act on, ecological pleas for the benefits of large-scale disturbance (primarily fire) to aspen systems. One benefit that has been widely discussed is the need to "overwhelm" ungulate herbivory of suckers by affecting much bigger areas of the landscape with prescribed natural fire.

The group proposed several areas of research need during the national overviews, as well as through synthesis dialogue. The following, in no particular order of importance, are the major research topics in need of further investigation: 1) genetics & phytochemistry; 2) management applications; 3) wildlife habitat; 4) monitoring methods and range of natural variability; 5) connecting ecology to policy; 6) effects of climate warming/drought (i.e., Sudden Aspen Decline in U.S. Southwest; aspen expansion in Canadian Rockies); 7) incorporating social science (e.g., clarify aspen benefits to society); and 8) aspen's ecological relation to conifer beetle kill. Research has already begun in topics 1-4, while topics 5-8 have seen little or no emphasis to date. In sum, the group felt strongly that each of these topics is deserving of priority status directed, ultimately, toward answering our respective constituency's concerns about aspen ecosystem status and health.

Ecological Classification Systems--Louise Levy and Tony D'Amato

Ecological classification systems have existed in North America for several decades; however, the importance of these systems in guiding the conservation and management of forest ecosystems has increased substantially within recent years. In particular, policy mandates for the use of ecosystem-based approaches for forest management, driven in large part by forestland certification programs[1], have created a need for the development and verification of systems that classify terrestrial vegetation into ecologically and administratively meaningful units on the landscape. Nationwide efforts, such as the development and refinement of the map of ecological subregions by the US Forest Service, are facilitating efforts to develop forest-wide plans for National Forests and other federal lands. Likewise, regional efforts, such as those in the central Rocky Mountains, Lake States, and British Columbia, are providing locally calibrated classification systems[2] that offer a framework for addressing management and conservation challenges within environmentally complex landscapes.

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[1] Such as SFI (Sustainable Forestry Initiative) and FSC (Forest Stewardship Council).

[2] MN DNR. 2005. Field Guide to the Native Plant Communities of Minnesota: The Laurentian Mixed Forest Province. Minnesota Department of Natural Resources, St. Paul, MN.; Kotar, J. and T.L. Burger. 2000. Field Guide to Forest Habitat Type Classification for North Central Minnesota. Terra Silva Consultants. Madison, WI.; Kusbach, A. et al. Ecosystem Classification in the Central Rocky Mountains, Utah. 7th NAFEW; McNab, W. et al. US Forest Service Ecological Subregion map.; *Other relevant publications:* Barnes, B.V., K.S. Pregitzer, T.A. Spies, and V.H. Spooner. 1982. Ecological Forest Site Classification. J. For. 80:493-498;

Collectively, these classification approaches provide an invaluable platform for communicating information about site-level ecological concepts and processes across management and conservation agencies and research institutions. As such, these classification systems are a valuable tool for seeking commonalities across scientific investigations examining issues such as the decline of aspen in the western United States, as well as in evaluating the response of managed ecosystems to novel ecologically based silvicultural treatments. Ultimately, the relevance and utility of these approaches and tools hinge on outreach and education programs that translate the concepts of ecological classification systems to scales relevant to foresters, wildlife biologists, planners, and scientists. Without these efforts, the ability of these tools to facilitate the development of ecosystem management approaches is limited.

Silviculture--Scott D. Roberts and Emily J. Comfort

The silviculture session examined several silvicultural approaches designed to maintain or restore more ‘natural’ forest conditions in forest systems throughout North America. The studies included examinations of variable retention harvesting approaches designed to accelerate the development of late-successional stand structures; an examination of silvicultural practices, including the reintroduction of fire, into oak-hickory forests to facilitate achievement of oak regeneration; and modeling of the effects of silvicultural practices on long-term development and productivity of northern hardwood and boreal mixedwoods forests.

While specific results of individual studies provided interesting insights, some key points emerged from our follow-up discussions. One of these was that making long-term inferences from short-term responses is obviously difficult, and points out the critical need for continued support of long-term studies. It also argues for the importance of combining field results with modeling approaches, with the continual calibration of models using empirical field data.

A second point to emerge was whether we have adequately defined what we are trying to achieve through large-scale, long-term silvicultural studies. Is simply creating greater structural diversity really the goal? We need to do a better job of defining what we are trying to achieve, and then we need better metrics to measure the attainment of our objectives. And finally, we need to do a better job of linking the specific results of silvicultural studies back to our larger ecosystem goals and objectives.

Carvell, K.L. and A.W. Perkey. 1997. Using Diagnostic Plants to Evaluate Site Class. USDA For. Ser. Northeastern Area State and Priv. For. NA-TP-03-97; Cook, J.E. 1996. Implications of Modern Successional Theory for Habitat Typing: A Review. For. Sci. 42(1): 67-75; Sims, R.A., Towill, W.D., Baldwin, K.A., Uhlig, P. and Wickware, G.M. 1997 (revised). Field guide to the forest ecosystem classification for northwestern Ontario. Ont. Min. Nat. Resour., NWST, Thunder Bay, Ont. FG-03. 176 p.

And finally, we need to do a better job looking at trade-offs. Many of the studies show that alternative silvicultural approaches can be successful in achieving specific objectives, but this often comes at the expense of reduced productivity. In other cases, the approaches may not always be readily acceptable to the general public or to the individual landowner.