CHAPTER 16

Drought and Climate

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In the time covered by this synthesis, researchers of six Evaluation Monitoring (EM) projects under the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, presented findings on the effects of drought and other weather- or climate-related phenomena on specific aspects of forest health in the United States. (The term “weather” refers to the short-term behavior of the Earth’s atmosphere at the scale of minutes to months, while the term “climate” refers to long-term weather patterns.) One project mapped coastal forest mortality and change in the Big Bend region of Florida attributed to sea-level rise, a phenomenon that has been linked to climate change. Another project examined the predictability of forest health impacts caused by extreme weather events, which may in turn be linked to broader climatic trends. Two related projects investigated the different effects of drought on the health of distinct tree species groups in forests of the Southeastern United States, as well as the influence of drought on forest carbon balance. In addition, two projects analyzed the impact of climatic factors on the health of particular Alaskan tree species, with both of these projects considering the role of ongoing climate change in exacerbating these impacts.

Project SO-EM-98-01: Coastal Forest Health Monitoring Within the Big Bend Region of Florida

During the early 1990s, abundant and presumably recent mortality of cabbage palm (*Sabal palmetto*) and other tree species was observed in the Big Bend region of Florida, a greater than 155 mile (250 km) portion of the State’s north and central Gulf of Mexico coast (Barnard 1999). An in-depth study of forest replacement processes in this region (Williams and others 1999) linked coastal forest change to the effects of ongoing sea-level rise, the rate of which has been predicted to increase due to climate change. In particular, this study found that increased exposure to tidal water and increasing groundwater salinity were associated with failed regeneration of cabbage palm and other tree species historically found in the region (e.g., redcedars, *Juniperus* spp.), ultimately leading to forest retreat inland as well as shifts in species composition.

In 1992, researchers in the Southern Region office of the Forest Health Protection (FHP) Program of the Forest Service performed an initial investigation of the observed mortality, procuring aerial photography of four flight lines within affected areas of the Big Bend region. As part of a 1998 EM project (E.L. Barnard, investigator), follow-up aerial photography was acquired for these flight lines. The primary objective of this study was to document any observed differences in forest type or condition between these two dates. In terms of methodology, vegetation types were mapped and compared for the two dates using a combination of photogrammetric, photointerpretive, and geographic information system (GIS) techniques. The classification scheme included “stressed vegetation” classes for describing areas with dead and/or fallen trees, stressed canopies, or other indications of damage or decline.

The most frequently observed vegetation change between 1992 and 1998 was a shift from the Mixed Forested (i.e., all healthy forest communities with cabbage palm comprising < 50 percent of forest cover) to the Stressed Mixed Forested category (Patterson 1999). Another relatively common change was a shift from the Mixed Forested to the Dominantly Palms forest category. A transition from the Dominantly Palms to the Stressed Palms category was less common. In all cases where vegetation change occurred, the percentages of affected acres were relatively modest. This apparently slow rate of change seems consistent with the observations of Williams and others (1999), who suggested that several decades may elapse between initial tree regeneration failure due to sea-level rise and the elimination of a species from affected sites. In any case, the described methodology could be applied for any future change analyses deemed to be necessary, with the resulting vegetation maps serving as a record of historic forest condition.

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Project NC-EM-01-01: Climate and Air Quality Indicators of Risk to Forest Health: An Online GIS for Integrating Climate and FHM Information

The investigators for this project (A.N.D. Auclair and W.E. Heilman) argued that field data, by themselves, are insufficient for real-time monitoring of forest health impacts because there is usually a time lag before distinct patterns emerge. Nonetheless, forest managers may be asked to anticipate when, where, and what type of impacts are likely to happen. Therefore, the investigators proposed the development of a comprehensive forest health decision support system. They outlined the concept of an archive of climate, air quality, and forest health indicator data, from which a series of statistical models could be constructed to relate historical observations of forest health impacts to explanatory factors. Under their concept, the system would also incorporate real-time data streams, such as recent weather forecasts and longer-term El Niño-Southern Oscillation (ENSO) forecasts, as well as available FHM/FIA phase 3 plot data. By combining historical models and real-time data, the system would thus provide managers with an early warning capability regarding forest health outcomes.

The researchers selected a small geographic area (the upper Midwest) as their initial test region. They selected crown dieback as a test forest health indicator, and selected two climate indices as explanatory variables: annual winter thaw-freeze occurrences [+50 ºF/-50 ºF (+10 ºC/-10 ºC)] and annual occurrences of extreme cold temperatures [< -22 ºF (< -30 ºC)]. In describing their early progress (Auclair and Heilman 2002), the researchers highlighted a particular example (Wisconsin in 1996) where above-normal dieback appeared to correlate with above-normal thaw-freeze and extreme cold frequencies. Noting evidence that forest dieback in the Northern United States is strongly affected by ENSO, they suggested that predictions of colder-than-normal winters or other anomalies based on ENSO forecasts could be used to forecast frequency of thaw-freeze and extreme cold events that could potentially impact forest health.

In subsequent work (Auclair and Heilman 2003), the researchers detailed their integration of GIS data on historic forest health-climate interactions into an on-line database, the Atmospheric Disturbance Climatology System. In addition, one of the researchers cataloged dieback events in northern hardwood forests from 1950 to 1995 based on Forest Service and State insect and disease surveys (Auclair 2005). When compared to ENSO data spanning the time period, two major dieback episodes (starting in 1954 and in 1976) in northern hardwood forests were found to have been preceded by extreme La Niña events. The researchers suggested that a La Niña event around 2000-01 might predict another period of dieback for 2003 to 2015. They also looked at 23 historical dieback episodes in northern hardwood forests and explored whether these periods could be linked to various climate stresses; they discovered that decreasing snow-pack depth was consistently and significantly associated with onset of dieback, while increasing snow-pack depth was associated with recovery. The researchers asserted that this work provided the first model for projecting future dieback incidence in northern hardwood forests; more importantly, they argued that this simple model demonstrated the potential for archived climate and forest health data to provide effective decision support.

Project SO-EM-04-01: Drought Impact on Forest Health in the Southeast—An Analysis Based on FHM/FIA Data

The investigators for this project (G.G. Wang and W.L. Bauerle) noted that weather is a key contributing factor to tree mortality in the Southeastern United States. In particular, periods of severe drought in the latter half of the 20th century, especially during the 1950s and 1980s, had significant effects on tree growth and mortality in the region. Wang and Bauerle also remarked that periods of drought are predicted to occur more frequently, and with greater intensity, in the Southeastern United States under most global climate change models. To detail the relationship between drought and forest health at a regional scale, the researchers analyzed FHM/FIA phase 3 plot data from 1998 to 2001, another period of drought in the Southeastern United States, and assessed how drought severity affects patterns of tree growth, mortality, and crown condition (Klos and others 2007a). They used remeasurement data from plots in Alabama, Georgia, and Virginia to perform the analysis. The researchers employed mixed modeling to relate five dependent variables (annual growth rate, annual percent mortality rate, annual percent change in crown density, crown dieback, and foliar transparency) to a drought severity class (no drought versus mild, moderate, or severe drought) based on the Palmer Drought Severity Index. They included several variables to account for stand conditions: total basal area, tree density, tree species richness, percent slope, and stand age. They analyzed the dependent variables by tree species group (pine, oak, and mixed mesophytic species, including maple, birch, and yellow poplar) and drought severity class in order to identify, for each species group, any noteworthy differences between drought classes with respect to the dependent variables.

A key finding from the analysis was that the pine and mesophytic species groups displayed significant decreases in growth rate and increases in mortality rate with increasing drought severity, suggesting both groups are sensitive to drought (Klos and others 2007a; Klos and others 2009). In contrast, the oak group exhibited no significant difference in growth or mortality rate due to drought severity, suggesting that the group is drought-tolerant. The analysis did not detect a significant change in crown condition due to drought, but the researchers described the difficulty in discerning a meaningful signal from the crown condition variables over a short measurement interval. Regardless, their results suggested that, if droughts are likely to be more common and/or intense in the Southeastern United States due to climate change, forest managers might anticipate a subsequent region-wide shift in species composition.

Project SO-EM-06-03: Modeling Drought Effects on Forest Health in the Southeast—An Analysis at the Sub-Regional and Regional Level

An associated study (W.L. Bauerle and G.G. Wang, investigators) examined the impact of drought on forest carbon balance in Southeastern United States forests using MAESTRA, a spatially explicit biological process model that integrates environmental, forest structure, and tree-level physiological variables to simulate a response to a factor of interest. The researchers again used remeasurement data from FHM/FIA phase 3 plots in Alabama, Georgia, and Virginia, this time for 1991-2005 and focusing on a single species, red maple (*Acer rubrum*). They again employed mixed modeling to relate drought severity class to annual growth rate and, in turn, identify any significant differences in mean growth rate between the drought classes. For the MAESTRA model, the researchers simulated a 100-tree stand of red maples in three size classes (small, medium, and large trees). They incorporated real-world hourly weather data for 1998-2005, and calibrated soil moisture deficit, a key model parameter, to drought severity class. The researchers then used MAESTRA to simulate the effects of droughts of different severity on annual growing season carbon gain.

The researchers found no significant difference in net carbon gain between the non-drought, mild drought, and moderate drought classes (Klos and others 2007b). However, carbon gain under severe drought was significantly lower than that seen with the other three classes, at approximately one-third of the gain observed under a condition of no drought. The results suggest that if droughts become more intense in the Southeast due to climate change, growth and productivity of some tree species could decline, with a detrimental effect on sequestered carbon. The researchers acknowledged that the MAESTRA model was calibrated for red maple as a test case, but argued that it could be similarly parameterized for other species to determine a regional response to climate change.

Project WC-EM-06-03: Ecological Impacts of Drought Stress in Alaska Birch Stands

Alaska has been experiencing a change in climate, with well-documented increases in mean annual temperatures, maximum daily temperatures, minimum daily temperatures, growing degree days, and duration of the frost-free season. The summer of 2004 in the south-central portion of the State was consistent with this observed warming trend, with record hot and dry weather across much of the region. Similarly, in August 2005, a massive high-pressure cell persisted over much of the State, causing record and near-record temperatures along with low precipitation levels. The result was two consecutive years of below-normal August rainfall. Forest health professionals believed they were beginning to observe effects of this continued warming and drying in Alaska's boreal forests. In 2003, numerous Alaska birch (*Betula neoalaskana*) trees in urban and suburban landscapes had begun to exhibit symptoms commonly associated with drought stress (e.g., scorched leaf margins, beginning in the tops of tree crowns; early leaf fall; mortality of individual trees and small groups of trees). In 2005, similar symptoms were observed for the first time on birch trees in native forest stands, and FHM aerial surveys documented substantial acreage of birch forest exhibiting crown thinning. Site visits indicated that these birch stands had produced leaves a fraction of their normal size or none at all, suggesting acute drought stress.

A 2006 EM project (R.A. Ott, investigator) explored the factors behind this documented crown dieback of Alaska birch. The study had three objectives: (1) to characterize site conditions where drought-stressed stands of Alaska birch were identified; (2) to characterize the nature of drought stress conditions in overstory trees in Alaska birch stands; and (3) to determine the extent to which insect pests may have been associated with drought stress conditions in these stands. Two days of aerial surveys were conducted in the early spring of 2006, the time of birch leaf-out in south-central Alaska. Aerial surveyors identified and mapped birch stands that had thin crowns or were not leafing out at all. These symptoms were assumed to be associated with drought stress, because significant defoliator activity would not have occurred so early in the season. A total of 622,400 acres (251 876 ha) were aerially surveyed, mostly in the vicinity of Anchorage and north along the Glenn Highway to the town of Wasilla, and 3,800 acres (1 538 ha, 0.6 percent) were classified as stressed. The majority of stressed forest stands were composed of Alaska birch. Site visits to stressed and adjacent healthy birch stands were conducted from mid-July through August 2006, and 18 birch stands (10 stressed, 8 healthy) were sampled.

Compared to healthy birch stands, unhealthy stands had larger diameter trees, lower tree densities, smaller basal areas, and less canopy cover. Unhealthy birch stands were older and many trees had extensive internal decay. In unhealthy stands, 86 percent of overstory trees exhibited dieback (>5 percent crown mortality); average mortality of those tree crowns was 46 percent. In healthy stands, 30 percent of overstory trees exhibited dieback; average mortality of those crowns was 6 percent. Drought stress was likely a factor in the apparent sudden decline of these birch forests, but stand age and history were also implicated as contributing variables to the overall decline of these stands. The apparent decline of open-canopied birch stands in response to warmer, drier summers is consistent with predictions of climate change impacts on Alaska's boreal forests.

Project WC-EM-07-01: Yellow-Cedar Decline: Evaluating Key Landscape Features of a Climate-Induced Forest Decline

Yellow-cedar (*Callitopsis nootkatensis*) is a culturally, economically, and ecologically important tree species in coastal Alaska. Widespread mortality of the species, known as yellow-cedar decline, has been occurring in the southeastern portion of the State for about 100 years. Annual FHM aerial detection surveys have delineated nearly the entire distribution of the problem, which totals over 500,000 acres (200 000 ha) in Alaska. While this broad-scale approach has been useful in determining the general occurrence of this forest decline, mapping from aircraft produces large polygons that are too coarse for practical evaluation of relevant landscape features. The investigators for this project (P.E. Hennon and D.T. Wittwer) argued that a finer spatial scale was required to test associations of the decline with factors such as slope, elevation, and aspect.

The researchers chose Mount Edgecumbe on Kruzof Island near Sitka, AK, as a location to conduct mid-scale analysis of yellow-cedar decline. Mount Edgecumbe is a dormant volcano with radial symmetry and wet plant communities that likely support abundant yellow-cedar at a range of elevations. The project had the following objectives: (1) to compare the occurrence of yellow-cedar decline as mapped by aerial survey and from aerial photographs; (2) to determine the association of elevation, aspect, and slope with the presence of yellow-cedar decline; and (3) to develop methods to detect healthy yellow-cedar populations. A secondary phase of the project modeled snow accumulations in order to identify future suitable habitat on Mount Edgecumbe for yellow-cedar.

Aerial survey methods and photo interpretation documented yellow-cedar decline in similar locations, but with widely different spatial results (Wittwer and others 2008). Photo interpretation produced about 25 times the number of polygons of yellow-cedar decline, but only about 25 percent of the acreage compared to aerial survey. Thus, the two methods differed in their spatial resolution of the problem, with aerial photography producing a more resolute map, which was used for subsequent landscape analyses. Elevation, aspect, and slope were all associated with the occurrence of yellow-cedar decline. Foremost, the decline problem appeared to be largely restricted to low elevations, with considerably less decline above approximately 600 feet (183 m). The researchers also detected an elevation-aspect interaction, where yellow-cedar decline occurred at higher elevations on warmer, southerly aspects than on northerly aspects. In addition, decline was associated with gentle slopes compared to steep slopes.

Helicopter surveys produced a reliable method for detecting yellow-cedar in apparently healthy forests at higher elevations; this represented the first successful remote sensing approach for verifying the amount of yellow-cedar in healthy forests. A kriged map produced from the helicopter survey points indicated a substantial population of healthy yellow-cedar above the decline zones, and ground checks verified the results of the surveys. Thus, the researchers' sampling approach to detect live and dead yellow-cedar forests incorporated an increasingly detailed hierarchy of detection methods: aerial detection surveys (i.e., sketch mapping), air photo interpretation, helicopter surveys, and ground plots.

The project results supported the contention that patterns of snow accumulation dictate the health of yellow-cedar forests. In the second phase of the project, the researchers used GIS tools applied to gridded climate data, a new elevational adjustment technique, and general circulation models to produce snow accumulation models for Mount Edgecumbe (Wittwer and others 2009). Output maps included estimated snow patterns in the early 1900s to the present as well as future predictions to 2080. A conservative general circulation model (i.e., under a B2 emissions scenario, with greenhouse gas emission levels projected to increase continually but slowly) was used for future predictions. The amount of annual snow accumulation sufficient to protect yellow-cedar, using the current distribution of yellow-cedar decline as a benchmark, was determined and shown in each of the past, present, and future scenarios. The maps showed substantially more snow in the early 1900s, but shrinking zones of adequate snow to the present and into the future. By 2080, little of Mount Edgecumbe was projected to have sufficient snow to protect yellow-cedar from the root freezing injury, represented by only a small area near the cone of the dormant volcano. The principal investigators are now looking to extend these approaches to the entire distribution of yellow-cedar in coastal Alaska.

Summary of Key Findings

- Using aerial photography to map changes to coastal forest vegetation in the Big Bend region of Florida during a 6-year period, Barnard (SO-EM-98-01) found modest evidence of inland forest retreat and increased stress in some forest stands. While modest, the observed changes are consistent with expected impacts of sea-level rise, the rate of which has been predicted to increase due to climate change.

- Examining historical dieback episodes in northern hardwood forests, Auclair and Heilman (NE-F-01-01) discovered that snow-pack depth was consistently associated with onset of, and recovery from, dieback. Their work provided a simple model for projecting future dieback incidence in northern hardwoods, while also demonstrating the potential for archived climate and forest health data to provide effective forest management decision support.

- Evaluating forests in the Southeastern United States, Wang and Bauerle (SO-EM-04-01) determined that pine and mesophytic species are drought-sensitive, displaying decreased growth and increased mortality with increasing drought severity, while oak species are apparently drought-tolerant, exhibiting no significant difference in growth or mortality rate due to drought severity. Their results suggest that, if droughts are likely to be more common and/or intense in the Southeastern United States due to climate change, forest managers might anticipate a subsequent region-wide shift in species composition.

- Using red maple in the Southeastern United States as a test case, Bauerle and Wang (SO-EM-06-03) ascertained that annual growing season carbon gain was significantly lower under severe drought than under moderate, mild, or non-drought conditions. Their results suggest that if droughts become more intense in the Southeast due to climate change, growth and productivity of some tree species could decline, with a detrimental effect on sequestered carbon.

- Investigating sudden and widespread incidence of dieback in Alaska birch (*Betula neoalaskana*) forest stands, Ott (WC-EM-06-03) concluded that drought stress was likely a major factor, with stand age and history also implicated as contributing variables. Notably, this apparent decline in response to warmer, drier summers is consistent with predictions of climate change impacts on Alaska's boreal forests.

- Mapping and analyzing yellow-cedar decline in coastal Alaska, Hennon and Wittwer (WC-EM-07-01) found that decline was generally more prevalent at lower elevations and on gentler slopes, but also extended to higher elevations on warm, southerly aspects. Their results support the contention that snow accumulation protects yellow-cedar forests, primarily by buffering soil temperatures and preventing fine-root freezing injury. However, the researchers projected that annual snow accumulation could diminish to insufficiently protective levels, for at least some Alaskan locations, under climate change.

Utilization of Project Results

These EM projects have yielded insights about climatic factors related to specific, regionally noteworthy forest health issues. Some of these insights have subsequently led to publications in peer-reviewed and widely cited academic journals (e.g., Auclair 2005, Klos and others 2009). Such information also may be critical for forest health decision makers charged with crafting short- and long-term policies and practices. For instance, a conservation and management strategy for yellow-cedar, developed in part from the study by Hennon and Wittwer, is currently being implemented at locations in coastal Alaska. Information from the Mount Edgecumbe project is providing guidance on where to favor yellow-cedar management (Hennon and others 2008). For example, the Tongass National Forest recently conducted a planting project for yellow-cedar regeneration near Yakutat, an area known for considerable late winter snowpack. Other planting projects at higher elevation are planned for the next few years.

Suggestions for Further Investigation

The six EM projects completed between 1998 and 2008 focused on specific climatic factors, weather events, or both as forest disturbance agents. This is logical in the context of climate change; in particular, if climate change will cause hurricanes, droughts, or other weather events to be more frequent and intense, then forest managers will need tools and techniques to project the impacts of these disturbances on forest resources and to predict when and where they will occur. The projects presented here, particularly the project evaluating yellow-cedar decline in Alaska, suggest what may be possible given current data resources. For instance, a wide variety of spatially referenced data are available that describe recent and historic trends in fundamental climatic variables (e.g., National Climatic Data Center daily summary of weather station observations) and extreme weather events (e.g., National Weather Service storm events data, National Oceanic and Atmospheric Administration historical hurricane track data). Although these data vary in quality, reliability, and spatial and temporal scales, by examining their associated metadata, it is possible to understand limiting assumptions pertinent to their analysis. Moreover, many of these data have been summarized and filtered into more refined data products by other groups (e.g., monthly climate variable maps available from the PRISM Climate Group at Oregon State University, drought maps from the National Drought Mitigation Center).

At the same time, the quantity of FIA phase 3 data, as well as remeasurement data on FIA phase 2 plots, is growing nationally. These diverse data streams suggest the potential to relate forest health indicators to patterns observed in many climate-related phenomena, whether extreme events (e.g., ice, wind, or lightning storms) or broad climatic trends (e.g., the ENSO patterns highlighted by Auclair and Heilman). The previously described EM projects illustrated a couple of ways to relate climate to forest health while also offering some predictive capabilities. However, there is a clear need to expand the scope of such analyses, not only in terms of quantity and time frame of the utilized data but also in their geographic areas of interest. Foremost, more climate-related EM projects could be completed in the western conterminous United States. For example, many parts of the West have experienced severe drought conditions for the last decade or longer; while it is generally understood that this has impacted pine-juniper woodlands severely, analyses about the effects in other forest types would be informative. Perhaps more critically, there may be potential to construct informative models of future climate-related disturbances simply by linking current and historic observations to trends anticipated under various climate change scenarios. The calibration of spatially explicit, high-resolution climate data (which typically span only about the last 120 years) using sparse but long-term data (e.g., dendrochronological data) may better enable such analyses.

Climatic conditions indirectly affect forest health through their influence on biotic (e.g., insects and diseases) as well as abiotic (e.g., wildfire, atmospheric pollution) disturbance agents. Although there have been recent EM projects relating emerging pest problems to climatic factors, there may be opportunity to expand the scope of such analyses given the available data streams. For instance, the several years of insect and disease aerial survey data compiled by the Forest Health Technology Enterprise Team might be analyzed nationally or regionally in relation to mapped drought data or storm events data. With respect to pollutants, it may be possible to construct better regional models of ozone injury to forests by including drought as a covariate. To cite another example, previous studies of climate-pest interactions have often employed variables that broadly summarize climatic conditions (e.g., annual means or extremes), thus inadvertently marginalizing important phenological (i.e., seasonal) patterns that, if included in new analyses, might enable better impact predictions. Regardless, as with analyses of climate or weather events as direct disturbance agents, there seems to be good potential for making projections with respect to future climate-pest or climate-pollution interactions, or the combination of both, by linking historic and current data to patterns expected under likely climate change scenarios. Such work could be pertinent for initiatives such as the National Insect and Disease Risk Map, which does not currently incorporate climate change. Furthermore, since geographic patterns of forest disturbance might shift dramatically under climate change, it is also important to consider how cross-border analyses related to climate might fit within the EM mission.

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