CHAPTER 1

Interior West Forest Insects

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This chapter provides a synthesis and brief review of 11 Base Evaluation Monitoring (EM) projects and 7 Fire Plan projects in Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming. Base projects were distributed among the primary coniferous forest types in this region: spruce-fir, piñon-juniper, Douglas-fir, lodgepole pine, limber pine, and ponderosa pine. All but two of the Base projects were associated with bark beetle-caused tree mortality, the exceptions being a study examining the effects of a defoliating insect, *Nepytia janetae*, and a study assessing the occurrence, severity, and expanding distribution of the nonnative balsam woolly adelgid. Fire Plan funded projects were spread among Engelmann spruce, lodgepole pine, Douglas-fir, ponderosa pine, and piñon-juniper types. Six of these projects examined relationships between tree mortality, fuel accumulation, and fire modeling. The remaining project investigated the effects of prescribed burning on bark beetle populations.

An Overview of Base Evaluation Monitoring Projects

Insect defoliator and bark beetle outbreaks have had significant impacts on forests of the Intermountain West over the last decade. The principle factor responsible for the initiation and spread of these outbreaks is not always clear, but stand conditions, disturbance events, and climate are typically important contributors (Fettig and others 2007). Most of the defoliator impacts have occurred in mixed conifer and spruce-fir forest types. Although the importance of a few defoliators (e.g., western spruce budworm, Douglas-fir tussock moth) has been recognized for several decades, impacts of other forest defoliators (e.g., *Nepytia janetae*, spruce aphid in the Southwest) have been studied only recently. Because there was no previous record of an outbreak by *Nepytia janetae* or information on its basic biology, Projects INT-EM-99-05 and INT-EM-00-05 were funded to document the biology and associated impacts of this insect in Arizona. Nonnative insect species such as the balsam woolly adelgid continue to pose serious threats to forest ecosystems. Project INT-EM-07-02 documents a range expansion of balsam woolly adelgid in Idaho, providing valuable information on distribution, severity, and expansion rates.

Bark beetle outbreaks in the West have recently occurred across all major conifer forest types (Negrón and others 2008). In the Southwest, bark beetle outbreaks were most intense and widespread in ponderosa pine forests and piñon-juniper woodlands (Allen-Reid and others 2008, McMillin and others 2008, Negrón and others 2009). Outbreaks have also been occurring throughout many areas of mid- and high-elevation forest types in the Rocky Mountains (USDA Forest Service 2009). Although large bark beetle outbreaks have occurred historically throughout the West, recent interactions between climate effects and susceptible forests may have greatly increased the extent and severity of these outbreaks. Aerial detection surveys and special mission flights by the national Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, assist in mapping the extent of these events, but more specific information on the impacts at the stand and landscape levels is lacking. Most of these Base EM projects were funded to quantify impacts associated with stand structure and to look for correlations between stand structure, site conditions, tree mortality or other stand-level impacts. In addition, one project (INT-EM-07-04) developed protocols to monitor the effects of silvicultural treatments on spruce beetle impacts. The documentation of insect associated impacts under different forest conditions supplies important information to land managers.

An Overview of Fire Plan Projects

Tree mortality caused by bark beetles can influence attributes associated with fire behavior through increases in ignition probability and fuel loads, and through changes in stand

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structure leading to increased wind speeds and drying of fuels (reviewed in Jenkins and others 2008). Although not all forest types have been studied, recent results from mid- to high-elevation forest types (spruce-fir, lodgepole, Douglas-fir) suggest that effects are largely dependent on time since beetle-caused tree mortality and severity of the outbreak (Jenkins and others 2008, Lynch and others 2006). For example, during and shortly after outbreaks, probability of crown fire initiation is thought to increase because living canopy fuels have been converted into dryer dead canopy fuels. After dead needles are shed, it is thought that crown fire ignition and spread through the canopy are both temporarily reduced. Once branches and whole trees begin to fall, and regeneration occurs, risk of crown fire ignition and spread may begin to increase. Because rates of needle drop, tree fall, and surface fuel decomposition vary across forest types, elevation and latitudinal gradients, it is critical to quantify relationships between bark beetle outbreaks and potential fire behavior across this variability. Because few empirical studies have examined these relationships in lower elevation forest types (e.g., ponderosa pine, piñon-juniper) (Jenkins and others 2008) two projects (INT-F-06-02, INT-F-07-01) were funded to provide information on how bark beetle outbreaks in lower elevation forest types affect fuel loading and predicted fire behavior.

Past management practices have left many forests and woodlands in the Southwest with high tree densities that are particularly susceptible to bark beetle outbreaks and stand-replacing wildfires. Consequently, forest managers have been conducting understory burning in conjunction with overstory thinning to reduce stand density. Prescribed fires, however, may cause unwanted mortality of large residual trees because trees damaged during these burns have increased vulnerability to beetle attack. Project INT-F-07-02 examines these relationships, which have important implications for land management policies, especially for communities near the wildland-urban interface.

Descriptions of Specific Base Projects

Project INT-EM-99-03: Stand Level Impact of Douglas-Fir Beetle Infestations in the Greater Yellowstone Area—The focus of this study was to evaluate changes in the forest overstory and understory following a Douglas-fir beetle (*Dendroctonus pseudotsugae*) infestation in northwestern Wyoming on the Shoshone National Forest. Specifically, the study was designed to document significant effects of the Douglas-fir beetle in three general categories: (1) overstory effects, (2) regeneration effects, and (3) understory effects. The study evaluated forest condition changes in areas with high levels of mortality 5 or more years post-outbreak and quantified changes in the understory of previously infested stands. Line transects with a variable radius plot every 10 chains and a comparison of paired infested and uninfested plots were used to assess bark beetle impacts in affected sites.

Douglas-fir beetle caused significant changes in forest condition in the transect portion of the study (McMillin and Allen 2003). Douglas-fir basal area decreased by 46 percent, pre-outbreak basal area for all species decreased 43 percent and average stand diameter by 8 percent [1 inch (2.5 cm) reduction]. Statistically significant relationships were observed between Douglas-fir mortality and percentage of Douglas-fir stems, pre-outbreak basal area for all tree species, and Douglas-fir basal area.

Significant differences in forest overstory conditions were found between paired infested and uninfested plots. Douglas-fir basal area was reduced by 80 percent in the infested plots. Post-outbreak tree diameters averaged 4.3 inches (11 cm) less in infested plots and a relative increase occurred in the percentage of other tree species (Engelmann spruce, white pine and lodgepole pine).

Douglas-fir beetle had a significant effect on understory (grass, forbs, and shrubs) abundance. Infested plots averaged a three-fold increase in total abundance compared to uninfested plots. Forbs were the most prevalent in both infested and uninfested plots; grass species had the largest percent increase (nearly 12-fold) among the three groups. Average understory height tripled in infested plots. The relatively low coefficient of determination for each understory component suggests that there are other important, but unexplained sources of variation accounting for differences between uninfested and infested plots. Variation could be associated with timing of measurement (plots with older mortality), grazing pressure, short-term and long-term fire effects, aspect, and moisture.

Regeneration in infested plots was more than three times greater than in uninfested plots. Approximately 90 percent of the regeneration was Douglas-fir in both plot types. The other 10 percent included Engelmann spruce, subalpine fir, and lodgepole pine.

Projects INT-EM-99-05, INT-EM-00-05: Impact Assessment of *Nepytia Janetae* (Lepidoptera, Geometrida) on Engelmann Spruce-Subalpine Fir Forests on Mt. Graham, Coronado National Forest and on Fort Apache Indian Reservation—*Nepytia janetae* severely defoliated over 4 000 ha of spruce-fir forests between 1996 and 1999 in the White and Pinaleño Mountains of eastern Arizona, defoliating both corkbark fir and Engelmann spruce (USDA Forest Service Region 3, Insect & Disease Conditions Reports). The objectives of this project were to determine the impacts of defoliation by *N. janetae* and to more fully understand the biology of the insect. Permanent plots were established throughout impacted areas to collect mensurational information, levels of defoliation, and tree mortality data.

Based on two separate outbreaks in Arizona, investigators concluded that *N. janetae* is a univoltine, winter-feeding looper with 3- to 4-year long outbreaks in high elevation spruce-fir forests (Lynch 2005) (Lynch and Fitzgibbon).[5] Both Engelmann spruce and corkbark fir were found to be highly susceptible to defoliation, while Douglas-fir and southwestern white pine were not defoliated. Both defoliation intensity (74 versus 32 percent) and tree mortality (76 versus 5 percent) was higher in the Pinaleño Mountains than in the White Mountains. Differences in impact severity between the two sites were caused in part by the Pinaleño outbreak lasting one year longer. Defoliation was found to increase tree susceptibility to spruce beetle and western balsam bark beetle in the Pinaleño Mountains, with most of the mortality attributed to the combined effects of defoliation and bark beetle attack.

Project INT-EM-99-04, INT-EM-00-04: GIS-Based Landscape-Scale Prediction System for Pinyon Pine Decline in the Southwestern United States— This project focused on preparing a predictive model for piñon mortality from pinyon ips and black stain root disease in southwestern Colorado. Modeling included the use of aerial photos to define the extent of the piñon mortality in combination with ground surveys and soil information from GIS-based data provided by the Forest Service and the U.S. Geologic Survey. The aerial photos were taken in 1998 followed by 14 months of photo interpretation. Geo-rectifying of the photos was time-consuming and, therefore, was not completed. The field survey was completed and combined with soil data to develop mortality models.

In recently formed tree mortality centers, 68 percent of all piñon were dead, 76 percent of piñon were affected by black stain root disease, and 70 percent had evidence of pinyon ips attack (Kearns and Jacobi 2005). Incidence of mortality was highest in piñon stands characterized by high densities of small diameter trees with below average amounts of non-piñon vegetative cover. Relationships between tree mortality and topography were inconclusive, as were relationships between mortality and site disturbance by humans. This study also provided information on insects associated with black stain root disease (Bishop and Jacobi 2003) and persistence of piñon snags and logs (Kearns and others 2005).

[5] Lynch, A.M.; Fitzgibbon, R.A. In preparation. Biology and impact of Nepytia janetae (Lepidoptera: Geometridae) in spruce-fir forests in Arizona, U.S.A.

Project INT-EM-00-01: Stand Level Impact of Subalpine Fir Decline in Spruce-Fir Forest Type of the North-Central Rocky Mountains—Western balsam bark beetle caused widespread mortality of subalpine fir in western North America throughout the 1990s. The objectives of this study were to document the effects of this mortality, relate mortality to preexisting stand conditions, and investigate the role of storm-damaged fir to beetle population dynamics in north central Wyoming. Transect cruise lines and pairs of infested and uninfested plots were installed to detect changes in the forest overstory and understory and to determine associations between stand conditions and beetle-caused fir mortality.

On average, western balsam bark beetle killed more than 70 trees per acre (28 trees per hectare) over 5 years in the Bighorn Mountains of Wyoming (McMillin and others 2003). This mortality resulted in significant decreases in subalpine fir basal area, trees per acre, stand density index, and the percentage of subalpine fir stems in the overstory. Small, but significant increases were detected in the understory; herbaceous plant abundance increased in the infested plots compared to noninfested plots. Moreover, significant positive linear relationships existed between the amount of fir mortality and the percentage of subalpine fir trees in a stand, subalpine fir basal area, and subalpine fir stand density index.

Western balsam bark beetle successfully colonized down trees. A significant positive linear relationship was observed between the percentage of wind-caused downed fir logs in an area and the percentage of logs utilized by western balsam bark beetle. The blowdown events that occurred in the mid-1990s in combination with a high percentage of subalpine fir in the overstory provided ideal conditions for continued beetle expansion.

Projects INT-EM-01-05: Subalpine Fir Mortality Caused by Western Balsam Bark Beetle: the Importance of Blowdown in Beetle Population Increase—The objectives of this project were to determine (1) if western balsam bark beetle successfully attacked and produced brood in downed subalpine fir, (2) if attaching beetle attractants to downed trees increased attack densities and subsequent brood production, and (3) if successful brood production varies by location on the tree bole; and (4) to examine the lifecycle of western balsam bark beetle in downed subalpine fir.

The Bighorn and Shoshone National Forests in north central Wyoming were selected as study sites. Five subalpine firs were felled at four locations on each Forest. In two of the study sites on each Forest, felled trees were baited with attractants and on the other two sites, no baits were attached to the downed trees.

In September of 2001, trees were sampled to determine life stage and brood production from the top and bottom aspects of the trees, at diameter at breast height (d.b.h.), at mid-bole, and in the upper crown. Brood sampling was repeated in the spring, summer, and fall of 2002.

Results indicate western balsam bark beetle does attack and produce successful brood in downed trees (Allen and others 2002, 2003) and suggest a 2-year life cycle in north central Wyoming. The use of attractant baits did not increase brood production in the felled trees. Rather, bark beetle populations were almost double in the trees where no attractants were used in 2001 and 2002. A higher percentage of brood was produced in the mid portion of the bole compared to successful brood production at d.b.h. and in the upper portion of the tree bole. More beetles were produced in the bottom aspect of the bole than the top surface. Higher brood production occurred in felled trees located on the Shoshone National Forest than on the Bighorn National Forest.

Based on this analysis, it was suggested that resource managers employ management strategies in downed subalpine fir to mitigate western balsam bark beetle population increases. Prompt removal or chipping of the down material should be conducted within 2 years of a blowdown event. Downed trees may also serve as trap trees to concentrate local populations of the insect as part of a management strategy to suppress western bark beetle populations.

Project INT-EM-03-01: Stand Level Impacts of Ips and Dendroctonus Bark Beetles in Pine Forest Types of Northern Arizona—Landscape-level bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands occurred throughout the Southwest between 2002 and 2004 in response to severe drought and susceptible forests conditions. FHM aerial detection surveys found more than 3 million acres of ponderosa and piñon impacted by bark beetles during 2002 and 2003 (USDA Forest Service Region 3, Insect & Disease Condition Reports). Several bark beetles worked in concert to kill the ponderosa pine: *Ips* spp., western pine beetle, and roundheaded pine beetle. Piñon was killed primarily by pinyon ips and twig beetles. Investigators established over 1,100 permanent plots across five national forests in Arizona during 2003 and 2004, which were designed to quantify overstory impacts (reductions in trees per acre and basal area) and correlations with preexisting stand conditions.

Tree mortality resulted in significant reductions in basal area, tree density, stand density index, and mean tree diameter for ponderosa and piñon pine (McMillin and others 2008, Negrón and others 2009). Ponderosa pine mortality was positively correlated with tree density and negatively correlated with elevation (all national forests combined) and reduced tree diameter (Prescott National Forest). Most of the observed ponderosa pine mortality was in the 10-35 cm diameter class, which comprise much of the increase in tree density over the last 100 years as a result of fire suppression and grazing practices.

Piñon mortality was found to range from 0 to 48 percent on the national forests, with mortality positively correlated with tree density and negatively correlated with elevation on most forests (McMillin and others).[6] Piñon mortality occurred across all diameter classes; however, a higher percent of trees were killed in the largest diameter classes. In addition, up to 40 percent of piñon that died between 2002 and 2003 had already fallen to the ground based on plot remeasurement in 2005.

Project INT-EM-04-03: Severity and Extent of Douglas-Fir Beetle Infestations in Northern Wyoming—The project was designed to evaluate the extent and severity of Douglas-fir beetle infestations at the stand level in the Bighorn Mountains of northern Wyoming. Objectives included determining the effects of outbreaks on residual stand structure and understory vegetation following an outbreak. Fifty-six fixed-radius plots were installed on the west side of the Bighorn National Forest. In each plot, the following measurements were recorded for all trees larger than 4 inches (10.1 cm) d.b.h.: tree species, crown class, and condition/damage class. Plots were installed in Douglas-fir beetle infested sites and uninfested stands of Douglas-fir. Year of attack was determined for infested/dead Douglas-fir. Number and species of seedlings greater than 6 inches (15.2 cm) in height were counted in 11.8-foot (3.6-m) fixed-radius plots around plot center. Along a 10-foot (3-m) transect line in cardinal directions from plot center, grass, forb, and shrub cover was measured in centimeters. Understory canopy height was measured at its highest point along transects in each cardinal direction.

Summary statistics indicate that Douglas-fir beetle was significantly impacting forest overstory conditions (Allen and others 2006). Basal area was reduced by 82 percent in the infested plots. Live d.b.h. in the infested plots averaged 6.4 inches (16.2 cm) compared to uninfested plots where d.b.h. averaged 9.4 inches (23.8 cm). Infestations caused a 33 percent reduction of Douglas-fir tree density in infested plots compared to the pre-outbreak Douglas-fir percentage.

Understory vegetation (shrubs, forbs, and grasses) increased within the infested plots as a result of overstory Douglas-fir mortality. The largest response in understory vegetation

[6] McMillin, J.D.; Negrón, J.F.; Anhold, J.A. Stand level impacts of Ips confusus on piñon-juniper woodlands of southwestern United States and northern Mexico. In preparation.

occurred in the shrub component where ground cover increased by 7 percent.

Project INT-EM-05-01: Piñon and Juniper Mortality—Extent, Severity, and Causal Agents—This work examined tree mortality levels and their causes in piñon-juniper woodlands in Arizona, Colorado, Utah, and Nevada. The study analyzed data from the Annual Inventory Program conducted by the Forest Inventory and Analysis (FIA) Program of the Forest Service.

Investigators concluded that widespread mortality in the piñon-juniper forest type is associated with several years of drought in the Southwestern United States (Shaw and others 2005). A complex of drought, insects, and disease was responsible for piñon mortality rates approaching 100 percent in some areas, while other areas experienced little or no mortality. Implementation of FIA annual inventory in several States coincided with the onset of elevated mortality rates.

Project INT-EM-05-04: Monitoring Host Selection Behavior and Progression of Infestation by the Mountain Pine Beetle in Mixed Stands of Limber and Lodgepole Pine—This project examined the host selection behavior of mountain pine beetle in mixed stands of limber and lodgepole pines in southeastern Wyoming (Medicine Bow National Forest). Investigators monitored the parameters of the life cycle, phenology, and host selection behavior of mountain pine beetle using ten 0.32 acre (0.13 ha) plots with the following objectives: (1) to determine the phenology of main developmental stages and developmental success in hosts of mountain pine beetle; (2) to assess the course of infestation progression in mixed stands of lodgepole and limber pines; and (3) to identify the host of origin of mountain pine beetle in mixed stands.

In May 2004, sampling from research plots demonstrated that a higher proportion of limber pines and a lower proportion of lodgepole were colonized by mountain pine beetle; suggesting that limber pine was the preferred host in the mixed stands of limber/lodgepole (Dean 2007, Dean and others 2007). Intermediate and large-diameter size classes of limber were almost eliminated from these mixed stands. This study suggests a possible shift in host preference from limber pine to lodgepole pine, but a longer term study would clarify the progress of the infestation. In 7 out of 10 cases more mountain pine beetle emerged from limber than from lodgepole. Mountain pine beetle emergence periods varied between limber and lodgepole, but peak emergence was identical.

Project INT-EM-07-02: Ground-Based Distribution Surveys for Exotic Balsam Woolly Adelgid (*Adelges piceae*) in Idaho—Balsam woolly adelgid has been spreading rapidly in Idaho since it was first discovered there in 1983. In 2006, Idaho Department of Lands personnel found balsam woolly adelgid infestations on sites well outside the area previously reported from ground and aerial surveys conducted in 1997-98, indicating a dramatic range increase in the State. These discoveries highlighted the need for another survey to determine the current extent of balsam woolly adelgid infestation across Idaho. Ground surveys were considered necessary to fully capture the current extent, as trees may be infested for many years before a signature is detectable from the air.

Project objectives were to identify factors contributing to the decline of subalpine fir and other true firs in Idaho, determine the current distribution and severity of balsam woolly adelgid in subalpine fir, determine the extent to which balsam woolly adelgid was infesting grand fir in areas where it was also infesting subalpine fir, and examine the relative utility of balsam woolly adelgid distribution maps generated from ground versus aerial detection surveys. Trained crews conducted a roadside survey in 2006 and 2007. Survey plots were located along roads at 1- or 2-mile intervals in subalpine fir stands. Plots were georeferenced, and presence/absence data were collected for each true fir species present. A plot was considered infested when gouting was present or at least one balsam woolly adelgid was found after 10 minutes of searching.

Field crews sampled a total of 1,016 plots distributed throughout the roaded portions of the subalpine fir vegetation type and also in many urban areas, finding about 58 percent of them infested with balsam woolly adelgid. Balsam woolly adelgid was present on 73 percent of the plots located below 4,500 feet (1 375 m) elevation, while 53 percent of the plots located above this elevation were infested. During the approximately 10 years elapsing since the previous ground survey, balsam woolly adelgid advanced 91 miles (146 km) north to the Canada border, 26 miles (42 km) east to the Montana border, 10 miles (16 km) west to the Washington border, and about 111 miles (178 km) south.

Project INT-EM-07-04: The Effects of Silvicultural Manipulations on Spruce Beetle Populations—The project was designed to monitor the extent, severity and causes of spruce beetle caused mortality in southwestern Colorado. Evaluations of previous silvicultural treatments were conducted to determine if these treatments mitigated spruce beetle activity and impacts. The project was also designed to examine the interactions of current stand conditions and high levels of spruce beetle activity to subsequent tree mortality.

The project was funded for 3 years beginning in 2007 to quantify spruce beetle impacts in areas where recent activity was evident. Candidate stands were selected on five national forests using two criteria: (1) at least 50 percent of the stand's total basal area is spruce, and (2) some type of silvicultural manipulation occurred within the stand previously. In 2007, candidate stands were selected using “most similar neighbor” GIS analysis (Moeur and Stage 1995). The GIS exercise selected stands based on stand conditions, previous silvicultural management and spruce beetle activity. In 2008, data collection began on the five national forests with data collection continuing through the 2009 field season. Managed stands will be compared to unmanaged stands in areas with current and recent spruce beetle activity for degree and cause of tree mortality (Eager and Mask 2008).

Descriptions of Specific Fire Plan Projects

Project INT-F-04-02: Characterization of Fuel Complexes in Stands Affected by the Spruce Beetle—The original project title was later changed to Bark Beetle Induced Changes in Conifer Fuel Complexes in the Intermountain Region. Fuel complexes in mature stands of spruce-fir, Douglas-fir, and lodgepole pine were compared under different levels of bark beetle activity (endemic, epidemic, and post-epidemic) to quantify bark beetle-caused changes to the fuel complexes. Study sites were selected using FHM aerial detection survey data in conjunction with FIA data. Survey data were used to delineate stands with endemic, epidemic, and post-epidemic beetle populations. Variable-radius plots were systemically established within each selected stand. From plot center, a Brown’s (1974) planar transect method was used to determine 1-, 10-, 100- and 1,000-hour fuel class sizes, duff, and litter. Data were also collected for shrubs, herbaceous vegetation, and regeneration from fixed micro-plots. Year since attack in addition to d.b.h. and proportion of needles remaining on the tree were recorded for all bark beetle attacked trees.

Results from this project (Jenkins and others 2008, Page and Jenkins 2007a, 2007b) demonstrated that fuels change over time, creating periods where the potential for high intensity, severe fires or both either increases or decreases. The net result of bark beetle epidemics was a substantial change in species composition and a highly altered fuel complex. Early in the epidemic there is an increase in the amount of fine surface fuels compared to endemic stands. In post-epidemic stands, large dead woody fuels and live surface fuels dominate. Results indicated that for surface fires both rates of fire spread and fireline intensities were higher in the current epidemic stands than in the endemic stands. Higher rates of spread and fireline intensities in epidemic stands were caused by decreased vegetative sheltering and its effect on mid-flame wind speed rather than changes in fuels. Passive crown fires were more likely in post-epidemic stands, but active crown fires were predicted to be less likely because of decreased aerial fuel continuity.

Results from this and related projects suggest that treatments to mitigate impacts caused by bark beetle outbreaks, such as moderate thinning, may result in less potential for extreme fire behavior compared with unmanaged stands. Greater fuel depths, mid-flame wind speeds, and lower fuel moisture might increase potential fire behavior compared to unmanaged stands. Bark beetle management strategies should be designed to address post-harvest fuel treatments that reduce surface fuels to lower the risk of severe wildfire. Management plans that consider bark beetle/fire interactions can provide resource managers with better guidance for meeting important resource objectives, reducing treatment costs, minimizing adverse ecological impacts, and avoiding potential controversy. The mitigation of potentially adverse bark beetle and fire effects is maximized when treatments occur at landscape scales and integrate the spatial arrangement of forest types and stand conditions.

Project INT-F-06-02: Potential Fire Hazard Following Bark Beetle Outbreak in Piñon-Juniper Woodlands—An extensive, drought-driven pinyon ips epidemic occurred in New Mexico from 2000 to 2004. Special FHM aerial detection surveys conducted in New Mexico mapped significant piñon mortality on more than 770,000 acres, with an estimated 44 million piñon killed in year 2003 alone. Objectives were to quantify the extent, severity, and impact of bark beetles on piñon throughout the 14,000 acre woodland type on the Santa Clara Pueblo. In addition, the project was designed to examine effects of the outbreak on fuel loading and potential fire hazard, and to relate site and stand factors (e.g., elevation, stand density, and dwarf mistletoe infection) to outbreak intensity. Forty-nine 0.05-acre impact plots were installed in 1995 on a 750 x 750 m grid throughout the Tribe’s 14,000 acre “commercial” woodlands. Plots were revisited in 2006 to collect mensurational and fuels data.

No results or reports from this study were available at the time of this review. However, the collected data will be used to provide information on impacts to assist the Pueblo in their forest management planning activities.

Project INT-F-06-03: Mountain Pine Beetle in Lodgepole Pine: Mortality and Fire Implications—Objectives for this project were to (1) characterize changes and extent of tree mortality in stands attacked by mountain pine beetle during an epidemic, (2) describe stand conditions associated with mountain pine beetle in lodgepole pine forests of north central Colorado, and (3) use fire simulation models to portray fire behavior and potential for crown fire in stands affected by mountain pine beetle. FHM aerial survey data and data collected on the Sulphur Ranger District were used to identify areas where mountain pine beetle populations were active from 2000 to 2007. Fixed-radius plots (1/20th acre) were established in infested and uninfested stands with data collected on diameter class, basal area, trees per acre, and stand density index. Brown's (1974) fuel transects were used to quantify downed woody debris and regeneration data were collected from a 1/500th acre in 2007. Potential fire behavior and effects were modeled using Forest Vegetation Simulator-Fuels and Fire Extension (FVS-FFE) (Reinhardt and Crookston 2003) under severe fire weather for lodgepole pine stands infested with mountain pine beetle and for uninfested stands. Modeled tree fall rate was used to project potential fuel loads when 10 percent and 80 percent of the trees were down.

Results from this project include the finding that mountain pine beetle-infested plots had significantly higher lodgepole pine basal area and stand density index compared to uninfested plots prior to the outbreak. There were reductions in lodgepole pine of 42 percent, 69 percent, and 34 percent in tree density, basal area, and quadratic mean diameter, respectively, between 2000 and 2007. Density of total regeneration was significantly higher in uninfested plots compared to infested plots (West and others 2008).

Surface fine and coarse woody debris fuel loads were not different among categories of infested plots and uninfested plots. The median litter depth was significantly greater in plots in the 2000-03 category compared to plots in the 2004-07 category and uninfested plots. Modeling of future downed woody debris accumulations indicated no differences for downed woody debris at 10 percent tree fall. However significant increases in downed woody debris classes are anticipated when 80 percent of the trees are down.

Active fires were modeled as the most frequent fire type to occur in uninfested plots, while in mountain pine beetle infested plots, passive fires were modeled. For infested plots, torching index (wind speed required for a fire to move from a surface to a crown fire) was not different than uninfested plots, but crowning index (wind speed required for a fire to move from tree crown to tree crown) was greater. However, for stands projected to have 80 percent tree fall, the torching index was greater in uninfested plots compared to infested plots. The percent of basal area killed from a fire was modeled to be > 95 percent, with uninfested plots projected to have greater mortality than infested plots.

Project INT-F-07-01: Contribution of Landscape Level Bark Beetle Outbreaks to Fuel Loading and Fire Behavior in Pine Forests of the Southwest—Bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands occurred throughout the Southwest from 2002 through 2004 in response to severe drought and susceptible forests conditions. An FHM-funded project (INT-EM-03-01) resulted in the establishment of over 1,100 permanent plots across Arizona during 2003 and 2004, which were designed to quantify overstory impacts (reductions in trees per acre, basal area) and correlations with preexisting ponderosa and piñon stand conditions. Using a subsample of the previously established plots, investigators collected data on canopy and surface fuels using Brown's (1974) planar intercept methods 4 to 5 years after the bark beetle outbreak collapsed. In 2007, data were collected from 133 plots in ponderosa pine forests on the Prescott, Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests. For statistical purposes, plots containing ponderosa pine mortality were paired with plots having no mortality with respect to site (elevation, topography) and percent ponderosa pine in the stand.

Investigators found that, in comparison to plots with no ponderosa pine mortality, bark beetle-caused tree mortality resulted in significantly decreased tree density, basal area, and live canopy fuel loadings; and also resulted in increased crown base height, fuel bed depth, and surface fuels in all size classes (Hoffman and others 2008; Hoffman and others, in review).[7] Torching and crowning indices were found to increase due to increased crown base height when weather, topographic, and surface fuel loading were held constant; when differences in surface fuels and basal areas were added, there was no difference in torching index. These findings suggest that there may be a trade-off between elevated canopy base height and reduced live canopy fuel (both decreasing fire hazard) with increased surface fuel loading and wind speed (both increasing fire hazard) as a consequence of bark beetle outbreaks in ponderosa pine 4 to 5 years post-tree mortality.

In 2008, investigators used similar methodology for collecting fuels in piñon-juniper woodlands of Arizona (McMillin and others 2009). Data on canopy and surface fuels were collected from 40 pairs of tree mortality and no mortality plots on the Coconino, Kaibab, and Apache-Sitgreaves National Forests. In addition to collecting the standard Brown's fuels intercept data, investigators measured fine fuels (grass, forbs), mid-canopy fuels, and the spatial arrangement of canopy and surface fuels. These additional data were collected because little is known about fire modeling and fuel models in piñon-juniper woodlands, and because of the spatial heterogeneity of fuels in these woodlands. Results from data collected in 2008 were still being analyzed at the time of this review.

Project INT-F-07-02: Bugs and Burns: Effects of Fire on Ponderosa Pine Bark Beetles—This study is a continuation and expansion of a previous study (Breece and others 2008) and was ongoing at the time of review.

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[7] Hoffman, C.; McMillin, J.D.; Sieg C.H.; Fulé, P.Z. Influence of bark beetle-caused tree mortality on fuel loadings and crown fire hazard in southwestern ponderosa pine forests. In review.

The objectives of the study were to (1) quantify long-term effects of operational prescribed fire on bark beetle attacks in ponderosa pine-dominated stands of Arizona and New Mexico, (2) identify species of bark beetles attacking ponderosa pine damaged by prescribed burns in Arizona and New Mexico, and (3) assess the utility of using measures of pre-fire bark beetle populations as predictors of future bark beetle-caused tree mortality at prescribed fire sites. In the previous study, four sites in Arizona and New Mexico were burned in the fall of 2003 or spring of 2004 and then monitored in 2004, 2005, and 2006 for bark beetle-induced mortality (Breece and others 2008). Four additional sites composed of a paired treatment and control (~300 ha each) were established in ponderosa pine forests in northern Arizona in the summer of 2007. Controlled burning occurred in the fall of 2007, with the exception of one site that was burned in July 2007. All sites were revisited in 2008 to record crown scorch and consumption, tree mortality, and sample bark beetle attack activity by removing bark samples from dead trees. In addition, bark beetle activity was monitored using funnel traps baited with lures for Scolytinae commonly found in ponderosa pine forests of Arizona (*Ips pini*, *I. lecontei*, *Dendroctonus brevicomis*).

Preliminary findings by the investigators suggest that under endemic beetle population levels, bark beetle-induced tree mortality levels may be expected to return to background levels within 4 years after burning (Hayes and others 2008). Based on funnel trap catches, bark beetle activity was greater in burn plots compared with control in three of the study sites. *Ips pini*, *D. frontalis*, and *D. valens* were the most commonly trapped beetle species in the burned plots. The investigators also found differences in the ratio of predators to bark beetles between study sites. This finding presents an opportunity to study the importance of such relationships on post-fire beetle-induced tree mortality. This project was completed in 2009.

Project INT-F-07-03: Monitoring Bark Beetle-Caused Mortality and Relation to Fire Occurrence—The primary objective of this project was to determine if there is a relationship between bark beetle outbreaks and subsequent ignition of forest fires. To test this relationship a number of factors needed to occur concurrently. Fuels accumulated from bark beetle-caused mortality needed to be present along with signs of a subsequent fire. This study identified locations of historic mountain pine beetle (MPB) outbreaks having occurred from 1980 through 1987 by converting 176 hardcopy aerial detection survey maps (Arapaho, Roosevelt, Routt, White River, Uncompahgre National Forests) into a digital format (TIFF images and GIS shape files). Locations in three national forests (Arapaho, White River, and Uncompahgre) were identified from 68 of 176 scanned aerial detection maps as having experienced MPB outbreaks beginning in 1980 through 1990. Fire point records from 1980 through 2007 were overlaid in a geographic information system with the historic mountain pine beetle outbreak locations. Sixty-nine fire ignitions in combination with the mapped historic mountain pine beetle-caused mortality were identified for field assessment from June to August 2008. Mountain pine beetle-caused lodgepole pine mortality and fire presence were recorded at each location. Ignitions from the Arapaho and White River National Forests are currently under analysis while ignitions from the Uncompahgre National Forest were not clearly identifiable in the field due to post-fire forest management practices. Temperature and precipitation data from weather stations close to the fire points and historic mountain pine beetle outbreaks have been gathered and annual departures from a 30-year average have been calculated.

Preliminary findings include approximately 22 700 ha and 71 900 ha mapped as mountain pine beetle-caused lodgepole pine mortality on the Arapaho and White River National Forests, respectively, from 1980 through 1987. Fifty-seven fire ignitions were located in the field from the Arapaho and White River National Forests. Twelve fire ignitions were not evaluated due to erroneous point data, private property boundaries, adverse mountainous terrain, or excessive travel distance. Two fire ignitions were identified as having occurred with older mountain pine beetle-caused lodgepole pine mortality.

Project INT-F-07-05: Modeling Fire Spread and Intensity Across Bark Beetle-Affected Landscapes—The objectives of this project were to use custom fuel models and landscape scale fire behavior models FARSITE and FlamMap (Finney 1998) to simulate fire spread across bark beetle-affected landscapes. Bark beetle impacted areas were identified using FHM Detection Monitoring (DM) tools and data from the LANDFIRE project (Landscape Fire and Resource Management Planning Tools Project) (Rollins and Frame 2006). The study quantified changes in three forest fuel complexes (lodgepole pine, Engelmann spruce/subalpine fir and Douglas-fir) caused by bark beetle-induced tree mortality and developed custom fuel models to make more accurate estimates of fire behavior.

Aerial detection maps, custom fuel models, historic weather data, and data from the LANDFIRE project were used to create FARSITE/FlamMap fire growth and intensity simulations in a lodgepole pine forest on the Sawtooth National Forest, ID, prior to a mountain pine beetle outbreak and currently infested with epidemic populations. Historic weather data input consisted of 30 three-day weather windows within the fire season that were randomly selected. Similar ignitions and FARSITE options were used in each simulation. Model simulations were also run in a post-outbreak, lodgepole pine forest on the Ashley National Forest, UT. Historic weather data input consisted of 60 five-day weather windows within the fire season that were randomly selected. These simulations were calibrated with actual fire events that occurred in lodgepole pine types on the Sawtooth and Boise National Forests in 2006.

Preliminary conclusions generated from this project indicate that the probability was greater for larger fire sizes throughout the range of historic fire weather conditions in lodgepole pine forests during the mountain pine beetle epidemic. The greatest change in fire size, however, occurred under the most extreme fire weather conditions. This result is probably due to the greater likelihood of fires transitioning from surface to crown fires under extreme fire weather conditions. Extreme fire weather conditions, largely attributed to higher wind speed, were more prevalent in landscapes modeled on the Sawtooth National Forest. However, moderate fire weather conditions, such as those characterizing the landscape modeled on the Ashley National Forest, provided better comparisons of differences in fire behavior attributed to fuels. Interpretation of these FARSITE model simulations should consider the weather windows used and limitations inherent in conventional surface fire spread models (i.e., live canopy fuel moisture). All else being equal, the collection of fuels data in bark beetle-affected forests should prioritize those geographic locations more prone to extreme fire weather conditions. These simulations also can provide land managers with other information necessary to evaluate the ecological impacts of bark beetle activity and associated fire risk, intensity, and spread.

Summary of Key Findings from Base Projects

INT-EM-99-03, INT-EM-04-03—Douglas-fir beetle outbreaks in Wyoming changed both overstory and understory conditions of the forest (Allen and others 2006, McMillin and Allen 2003). Significant reductions in the forest overstory resulted in subsequent increases in the understory (grass, forbs). Magnitude of bark beetle-caused impacts was correlated with pre-outbreak stand conditions such as measures of stand density.

INT-EM-99-05, INT-EM-00-05—*Nepytia janetae* outbreaks in Arizona last 3 to 4 years and seem to be limited to mature spruce-fir stands near the top of mountains [Lynch and Fitzgibbon (see footnote 5)]. Defoliation was found to increase tree susceptibility to spruce beetle and western balsam bark beetle in the Pinaleño Mountains, and most of the mortality occurred from the combined effects of defoliation and bark beetle attack.

INT-EM-99-04, INT-EM-00-04—In recently formed piñon mortality centers, the majority of piñon was affected by black stain root disease and had evidence of pinyon ips attack (Kearns and Jacobi 2005). Incidence of tree mortality was highest in piñon stands characterized by high densities of small diameter trees with below average amounts of non-piñon vegetative cover.

INT-EM-00-01, INT-EM-01-05—A western balsam bark beetle outbreak significantly altered forest overstory and understory conditions in Wyoming (McMillin and others 2003). Based on the relationships between the amount of subalpine fir killed and fir stand density index, fir basal area, and the percentage of fir found in a stand, manipulating these stand components should reduce stand susceptibility to western balsam bark beetle. Blowdown events may play an important role in initiating western balsam bark beetle outbreaks (Allen and others 2002, 2003; McMillin and others 2003). Salvaging blowdown quickly and entirely may prevent epidemics.

INT-EM-03-01, INT-EM-05-01—Impacts caused by bark beetle outbreaks in ponderosa pine forests and piñon-juniper woodlands of the Southwest were highly variable at the stand level; tree mortality levels ranged from 0 to 100 percent [McMillin and others 2008, Negrón and others 2009, McMillin and others (see footnote 6), Shaw and others 2005]. Tree mortality in both pine types was correlated with stand and site characteristics that are indicative of stress. Mortality was typically greatest in areas near the lower elevation distribution of each pine species, stands with relatively high tree densities, and areas of poor site quality (rocky, south-facing slopes).

INT-EM-05-04—Limber pine seemed to be the preferred host during initial stages of a mountain pine beetle outbreak in mixed conifer stands in Wyoming (Dean 2007, Dean and others 2007). As the outbreak progressed, however, there may have been a shift towards lodgepole pine being favored. In general, there was greater beetle emergence from limber pine than lodgepole pine hosts.

INT-EM-07-02—The range of balsam woolly adelgid in Idaho dramatically increased during a 10-year period. Balsam woolly adelgid was found on more than half of the sample plots, and was more frequently encountered below 4,500 feet elevation. Range expansions to the north and south were significantly greater than expansions to the east and west.

Summary of Key Findings from Fire Plan Projects

INT-F-04-02—The net result of bark beetle epidemics in Douglas-fir, lodgepole pine, and spruce-fir forests was a substantial change in species composition and a highly altered fuel complex (Jenkins and others 2008, Page and Jenkins 2007a, 2007b). Fuel complexes change over time, creating periods where the potential for high intensity and/or severe fires either increases or decreases.

INT-F-06-03—Based on mountain pine beetle outbreaks in lodgepole pine forests in Colorado, active crown fires were modeled as the most frequent fire type to occur in uninfested plots, while passive fires were modeled to occur in mountain pine beetle infested plots (West and others 2008). For stands projected to have 80 percent tree fall, the torching index (wind speed required for fire to transition from surface to crown fire) was greater in uninfested plots compared to infested plots.

INT-F-06-02, INT-F-07-01—Four to five years after bark beetle outbreaks in ponderosa pine forests of Arizona, there seems to be a trade-off between increased surface fuel loadings and increased canopy base heights [Hoffman and others (see footnote 7)]. The end result of this exchange is predicted to be the same: a surface fire can transition into the canopy; however, the physical properties driving this mechanism have switched from low surface fuels and low crown base heights to higher surface fuels and higher crown base heights. Data from piñon-juniper studies on the Santa Clara Pueblo in New Mexico (INT-F-06-02) and in Arizona are forthcoming. Results from these studies will have important implications for forest management and restoration.

INT-F-07-02—In the Southwest under endemic beetle population levels, bark beetle-induced ponderosa pine mortality levels may be expected to return to background levels within 4 years after burning (Hayes and others 2008).

INT-F-07-03—This project is continuing and data analysis has not been completed. Preliminary findings include: 57 fire ignitions were located in the field from the Arapaho and White River National Forests, and 2 fire ignitions were identified as having occurred with MPB-caused lodgepole pine mortality.

INT-F-07-05—Probability of achieving larger fire sizes throughout the range of historic fire weather conditions in lodgepole pine forests of Idaho and Utah was greater during mountain pine beetle epidemics (Jenkins and others 2008). Collection of fuels data in bark beetle-affected forests should prioritize those geographic locations more prone to extreme fire weather conditions.

Utilization of Project Results

While it is difficult to track how project results have been utilized by land managers and forest health practitioners, we assume that most have been used in a variety of forest management decisions, strategic planning, and monitoring activities. For example, two Base EM projects focused on Douglas-fir beetle impacts in Wyoming influenced National Environmental Policy Act decisions regarding sanitation and salvage treatments on the North Fork Project (Shoshone National Forest) and the Bench Project (Bighorn National Forest). In addition, these same projects plus those centered on western balsam bark beetle have been integrated into recent Forest Plan Revisions on both the Bighorn and Shoshone National Forests in Wyoming. Specifically, because western balsam bark beetle has caused dramatic changes to stand conditions in the spruce-fir type on the Bighorn National Forest, and this forest type provides critical wildlife habitat, results emanating from EM projects provided vital input in the Forest Plan Revision process. Similarly, results from projects on bark beetle and defoliator impacts in the Southwest have been incorporated in the Forest Plan Revision process on five national forests in Arizona. Results are also routinely used in project level specialist's reports by defining potential impacts and focusing silvicultural treatments to reduce stand susceptibility.

Results from Fire Plan EM projects have and will continue to be used by resource managers. For instance, EM projects examining relationships between bark beetle outbreaks and fuel loading generated custom fuel models that have been incorporated into the FARSITE and FlamMap fire behavior models. Thus, these projects are providing fire and fuels specialists with better guidance for meeting important resource objectives, reducing treatment costs, minimizing adverse ecological impacts, and ultimately avoiding potential controversy. In addition, these projects have supplied baseline data on temporal and spatial patterns of fuel loading that will be critical when projecting future impacts and fire risk under different climatic conditions.

Suggestions for Further Investigation from Base Projects

Long-term effects of bark beetle outbreaks have really never been measured. Long-term effects could be evaluated through permanent plots measured at 5-year intervals for the next 20 to 25 years, or perhaps using old aerial survey maps to locate beetle impacted areas that occurred from 20 to 50 years ago.

If trap trees are used by resource managers to suppress local populations of western balsam bark beetle, there are many questions associated with this recommended strategy. Further research should be undertaken to determine if brood production is significantly different between down (felled) versus standing trees. Also, would baiting standing uninfested trees produce more brood than downed trees? If trees are intentionally felled to serve as trap trees, how many, what size, and how should they be spatially distributed on the landscape? Western balsam bark beetle studies were conducted only in north central Wyoming; results may differ in other portions of the Interior West.

Future monitoring projects in the Southwest could focus on the interaction of insects and climate in creating disturbance events in mixed conifer forest types. For example, FHM aerial detection surveys recorded extensive mortality of white fir and Douglas-fir during the severe drought of 2002-04, but on-the-ground impact studies have not been conducted. Mortality has been caused by a complex of defoliators (budworm, tussock moth, loopers, needleminers) and bark beetles (fir engraver, Douglas-fir beetle).

Although INT-EM-07-04 is continuing, it will complement the results from a similar study conducted in adjacent States and in other portions of Colorado. This evaluation (A Retrospective Assessment of Partial Cutting to Reduce Spruce Beetle-related Mortality in Southern Rocky Mountains) by Matt Hansen (Forest Service, Rocky Mountain Research Station) and others is in the final stages of completion for journal submission.

As the range of balsam woolly adelgid continues to expand throughout Idaho, additional periodic ground surveys to document changes in extent, occurrence, and severity on subalpine fir and grand fir would be warranted. Future studies documenting and evaluating changes in fire risk and behavior, wildlife habitat, and hydrologic function associated with balsam woolly adelgid establishment in new areas would provide basic impact information that is currently lacking. Other worthwhile topics for investigation are how balsam woolly adelgid interacts with the recognized insect, disease, and drought complex associated with subalpine fir decline, or with climate change.

Suggestions for Further Investigation from Fire Plan Projects

Because spatial arrangement and distribution of bark beetle-caused tree mortality and associated fuel accumulations vary considerably across the landscape, further development of fire spread models in various bark beetle affected landscapes may help land managers to identify high priority stands for treatment. Fuel appraisals and estimated fire prediction models are currently being used to develop photo appraisal guides for bark beetle-affected fuels, which will facilitate collecting large amounts of actual surface fuels data for modeling purposes. This information will be used to model fire spread and predict probable fire size (FARSITE) through bark beetle affected forests. The resulting models will be similar to those generated and used in the Wildland Fire Decision Support System.

Monitoring studies in the Southwest could examine the effects of multiple causal agents on spruce-fir and mixed conifer tree mortality on subsequent fuel loading and fire behavior. For example, in the White Mountains and Pinaleño Mountains of Arizona, and in the Sacramento Mountains of New Mexico, defoliator and bark beetle outbreaks in combination with drought have resulted in dramatic ecosystem alterations within these forest types. How these multiple disturbance events influence spatial and temporal patterns of surface and canopy fuels and future fire behavior remains unknown.

Future studies examining interactions between prescribed burns and bark beetles could focus on other forest types besides ponderosa pine, and should be conducted during periods of higher bark beetle populations.

Recently, entomologists (in the Forest Health Protection Program of the Forest Service) from all western regions met with research entomologists from the western research stations of the Forest Service to discuss western bark beetles research priorities for the future (Negrón and others 2008). Future research is recommended to be focused in the following areas: vegetation management; ecological, economic, and social consequences of bark beetle outbreaks; fire and bark beetle interactions; climate change; and chemical ecology.

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