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# Pine mortality at Fort Benning: a problem or an opportunity?

Robert Mitchell[1], Jeffrey Walters[2], Craig Hedman[3], and Rhett Johnson[4]

[1]Joseph W. Jones Ecological Research Center, RR 2 Box 2324, Newton GA 39770
[2]Department of Biological Sciences, Virginia Tech, Blacksburg, VA 24061-0406
[3]Ecology & Environment, Inc., 1974 Commonwealth Lane, Tallahassee, FL 32303
[4]School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849

**Abstract.** The increasing pine mortality observed at Fort Benning has caused some concerns that forest health may constrain the ability to meet the base's mission in the future. Specifically, pine mortality is thought to potentially cause difficulties in sustaining population targets for the red-cockaded woodpecker, and that will in turn further restrict military training. Questions have been raised as to how widespread mortality is and whether it applies to all pines generally or is it specific to a few species or site conditions. We show in this paper that high levels of mortality are largely found in loblolly and to lesser extent shortleaf pines. Loblolly and shortleaf pine are shorter lived than longleaf and more susceptible to insect and disease outbreaks. Mortality was shown to increase with increasing stand stocking reflecting normal self-thinning associated with stem exclusion phase of stand development. Furthermore, the woodpecker and military mission require aggressive burning of the landscape and loblolly is much more susceptible to mortality from fire than is longleaf. Since these stands are aging, and thus are improving in their quality of woodpecker habitat, their value to woodpeckers must be maintained if conservation goals are to be achieved. The installation wishes to convert many of the affected stands to longleaf to achieve a desired future condition of the landscape. Pine mortality will be a part of the conversion process that occurs across the forested landscape.

We also show that it is unlikely that mortality will influence the ability of managers to meet the base's mission, both in terms of training and conservation. However, several management approaches could be taken that would use mortality patterns as an opportunity to move toward the future desired condition, while other approaches would help mitigate difficulties in achieving a desired condition. First and foremost, RCWs require nesting and foraging habitat. Cavity tree needs are minimal in number and the post-Hurricane Hugo era on the Francis Marion National Forest shows that populations of the bird can be sustained with a low density of potential cavity trees. Artificial cavities provide further help in overcoming any bottleneck. Also, we propose that it may be possible to sustain foraging habitat value despite below standard basal areas of mature trees as long as several larger older trees are maintained per acre, and the stand is managed to produce a robust and diverse understory. This may make aggressive hardwood control a priority particularly in stands with high levels of pine mortality where fuels become insufficient to carry fire reliably. Silvicultural prescriptions should encourage uneven-aged stands when possible. When mortality is high precluding uneven-aged management, and patch clearcutting is used to accelerate the regeneration of longleaf pine, retention of some old trees and snags should be considered in the prescription. Aggressive recruitment of advanced regeneration, naturally in stands with mature longleaf and by under-planting in stands lacking sufficient overstory longleaf, could provide cohorts ready to be released by overstory mortality in the future.

Development of a monitoring program that can detect changes in the landscape coupled with landscape level simulation models of forest structure and woodpecker population demography should be a high priority. The stands at Benning have developed beyond much of the literature's ability to rigorously predict future dynamics or precisely anticipate their response to management. Monitoring data can be used to test between alternative scenarios for impacts of tree mortality on quality of RCW foraging habitat and on fire regimes. Development of a robust and interactive system of monitoring, simulation models, and management decision making models would allow the future stand and landscape development to be projected, then those predictions can be tested, and finally management can adapt where response to management did not achieve desired effect.

## Forest health at Benning: a problem?

Fort Benning, like many properties throughout the southeastern U.S., has a landscape molded by past land-use that differs from the desired landscape to sustain its missions (Healy 1985). Fort Benning's primary mission is to provide the nation with a sound and stable location to train infantry soldiers and units, while secondarily maintaining the ecological integrity and stewardship of the installation, particularly with respect to sustaining populations of endangered species. One such species, the red-cockaded woodpecker (*Picoides borealis*), requires frequent burning and older forests (Jackson 1994; USFWS 2003). Past land use has tended to convert sites from multi-aged stands, often dominated by longleaf pine (*Pinus palustris*), that were frequently burned to even-aged stands of younger southern pines, mostly loblolly (*P. taeda*) and shortleaf (*P. echinata*). Most of these stands have gone through periods of fire suppression that have promoted development of hardwood midstory and reduced groundcover. The desired condition for the red-cockaded woodpecker (RCW) and other species characteristic of southern pine forests on historic longleaf sites is open, mature longleaf stands with sparse hardwood midstory and a rich groundcover dominated by forbs and grasses (USFWS 2003). Understanding how the current landscape may be managed toward this desired future condition and the impact of that dynamic on land management goals is critical to meeting Fort Benning's mission.

An understanding of the demography of such forests across the landscape, which trees die and at what rate, and how regeneration will establish and develop into new forests, is complicated by gaps in both the silvicultural and ecological literature. While considerable information on stand dynamics and management influences exists for stands from the regeneration stage through development into even-aged stands of sawtimber (ages 0-50), considerably less silvicultural guidance is available for stand dynamics as mixed pine stands of shortleaf and loblolly move from sawtimber to senescence (70+ years old).

Second, the process of tree death, its causes, the patterns of mortality in forests and their ecological consequences, have been far less studied than the establishment and growth of forests. The purpose of this paper is to try to bring what understanding exists to the case of Fort Benning, and hopefully provide insight into how other places may grapple with similar issues.

To fully appreciate the state of the landscape at Fort Benning today and project its future dynamics, it is instructive to review its past. The majority of Fort Benning was established through land acquisitions between 1918 and 1942. It currently encompasses approximately 182,000 acres along the Chattahoochee River near Columbus, Georgia, 93% of which are in Georgia and the remaining 7% in Alabama. Fort Benning straddles the "Fall Line" – the landform that demarcates the Piedmont and Coastal Plain physiographic provinces. As such, Fort Benning possesses geologic, hydrologic, and ecologic characteristics of each province.

A prominent physical characteristic of the Fall Line landscape is sand hills and ridges (northeastern part of Fort Benning) that are underlain by deep sandy soils, low in organic matter. Finer textured and more productive soils are associated with mesic sites, which are found south and west of the Fall Line sand hills. Upland and riverine habitats are found below the Fall Line and on both sides of the Chattahoochee River floodplain.
The land and water associated with Fort Benning and surrounding areas have been used and influenced by humans for roughly 18,000 years (Van Lear et al. 2005). Native Americans influenced much of this land-use history by clearing land (villages and agriculture) and altering and expanding natural (lightning-caused) fire regimes. European influences and impacts began in the 1800s through an intensification of land clearing for agriculture and settlements. Intentional burning of woods and fields continued and free-range livestock (especially hogs) were introduced (Wahlenburg 1947).

Cotton fields dominated the Fort Benning landscape from the late 1800s through the early 1900s. Decades of misapplied cotton farming had severe, negative impacts on much of the landscape as several feet of topsoil eroded from millions of acres across the south

(Van Lear et al. 2005). The boll weevil eventually decimated the cotton agricultural system and many cotton fields were subsequently abandoned. In response to this abandonment, millions of acres were afforested. Most of the naturally regenerated upland forests seen today on Fort Benning are dominated by loblolly pine, and shortleaf pine, which arose from these heavily degraded abandoned agricultural fields. Additionally, the vast majority of these current forest stands have not experienced the kind of fire regimes imposed by Native Americans or the earliest European settlers; instead fire was actively suppressed in these regenerated forests (Stoddard 1931).

The conversion of forests to agricultural fields (cotton and unfettered grazing), the widespread and unprecedented loss of topsoil, the subsequent abandonment of agricultural fields, afforestation of these fields, and the well-intended but deleterious fire policies (exclusion and suppression) for much of the 20th century, all combined to impact forest ecosystem composition, structure, and function across much of the region (Van Lear et al. 2005) and at Fort Benning. Some of the response variables stemming from these actions, events, and policies that occurred over several decades include the loss of native groundcover, fire-adapted flora and fauna, and late-successional habitats or communities (Trani 2003). The recovering forests of today are byproducts of this complex land-use history as well as other abiotic (drought) and biotic influences (insects and diseases). The afforestation of Fort Benning and the growth and development of subsequent forest stands continue to “hold the land together”.

Since its establishment as a military installation, land management at Fort Benning has been conducted to sustain the military training imperative while addressing soil conservation, timber management, water quality, forest health, wildfire prevention, and wildlife management. Twentieth-century timber management practices favored loblolly pine over longleaf and establishment of loblolly pine plantations was standard practice following clearcut harvests. Less frequently, non-native tree species such as slash pine (*Pinus elliottii*) and Virginia pine (*Pinus virginiana*) were also planted. In the late 1980s and 1990s, forest management shifted away from emphasizing timber production and fish-and-game management to ecosystem management. Central to this shift was a focus on RCW recovery, restoration of longleaf pine habitat, aggressive fire management, uneven-aged forestry, and protection of unique ecological areas.

**Future desired condition based on military mission and conservation goals**

Fort Benning is designated as one of the Army's 15 major power projection platforms and one of the two Individual Deployment Sites – two features that underscore its importance regarding current and future military training. Current mobilization plans call for approximately 72,000 troops to be trained at and deployed from Fort Benning per year. Since these units are on a constant training cycle, both light and mechanized forces can be training at any point in time. A realistic training environment is a prerequisite for effective training at Fort Benning and the presence of natural vegetation enables realistic training scenarios involving cover, concealment, or line-of-sight firing constraints. To ensure that Fort Benning can meet its mission now and in the future, the natural resources that provide the training context must be managed so that they are ecologically sustainable over the long term.

The potential impact of training on mission lands is considerable. Fort Benning mission lands currently are threatened by the impacts of mechanized training. Tracked vehicles disturb groundcover and soil thereby contributing to erosion that further impacts the land. Mechanized training can result in excessive soil loss, which has produced hazardous erosion gullies. Continued degradation of mission lands could lead to future regulatory conflicts concerning federally listed plant and animal species, cultural resources, and water quality. If left unchecked, conflicts could result in restrictions to training. Conversely, most other forms of training deployed at Fort Benning have little or no effect on mission lands (Fort Benning 2006).

Conservation-based desired future conditions described in the current natural resource management plan for the base (Fort Benning 2006) are centered on maintaining: (1) native species richness and biodiversity; (2) viability of all rare, threatened and endangered species and species of conservation concern; (3) upland areas in high-quality longleaf pine communities that grade downslope into rich hardwood slope and bottomland communities; and (4) intact riparian areas, wetlands, ephemeral ponds, and streams. It is also desirable to minimize point and non-point source pollution and the ecological impacts of invasive species and disturbances.

Longleaf pine conservation targets are the linchpin, because much of the biodiversity on Fort Benning is associated with the longleaf ecosystem and the land management efforts which favor associated rare species. When the management plan is fully implemented, longleaf pine is to be the dominant upland pine species occurring across a range of upland soil and topographic conditions (Fort Benning 2006). These longleaf stands are to have a characteristic “park-like” structure and be marked by multi-aged trees (many > 200 years old), standing snags and downed woody debris, a sparse, short midstory of mixed hardwoods, an abundant understory dominated by mixed grasses and forbs. Managers intend to maintain landscape-level native species richness and evenness, and minimize invasive species, disease, and disturbance impacts (Fort Benning 2006). All documented plant associations of conservation concern (The Nature Conservancy and NatureServe 2003a) are to be present and viable, and all quantitative RCW habitat values described in the RCW Recovery Plan (USFWS 2003) are to be met.

In total, in the desired future landscape longleaf pine forests will occupy 85,000-90,000 upland acres and grade downslope into high quality mixed hardwood-pine, and hardwood communities (Fort Benning 2006). Prescribed fire regimes will be variable in return interval (1-3 years), intensity, season of burn, and ignition pattern. Fire and forest management will be practiced with the goal of maintaining healthy, uneven-aged, open longleaf pine stands. These stands are to exhibit compositional variation, stability, and resilience to light anthropogenic or natural disturbance, and provide sustainable settings for military training.

Regarding RCWs, the management goal is to increase the Fort Benning population from the current 280 potential breeding groups to achieve the installation goal as a designated Primary Core Population (USFWS 2003) of 350 potential breeding groups, at which point the population will be recovered. Most or all suitable upland longleaf pine habitat on Fort Benning is to be occupied by RCWs at a level that fluctuates naturally around the carrying capacity of the habitat. Current restrictions on training to protect the woodpecker will be lifted when recovery is achieved, so that management for continued maintenance of the RCW population will not impact military training activities.

## Barriers to achieving future desired condition through time

Until recently, the overall impact of environmental compliance on the ability of the military to train has been minimal (Fort Benning 2006). Most of the forest management practices utilized at Fort Benning create or accommodate realistic training conditions. Some of these compatible practices include uneven-aged management of upland pine stands, prescribed burning, clearcutting select stands (to accommodate ranges and tracked vehicle maneuvers), longleaf pine ecosystem restoration, elimination of off-site pine plantations (those in which the species and the site are not compatible), and landscape-level considerations (ecologically-based mix of pine and hardwood stands).

RCW clusters and cultural sites affect training to some degree, but the impact of the former has been minimized by several practices that provide mission flexibility while protecting RCWs. These are described in the Management Guidelines for the Red-cockaded Woodpecker on Army Installations (US Army 1996). Only transient activities lasting < 2 hours are allowed within a 200 foot buffer around RCW clusters, and tracked vehicles must stay > 50 feet from cavity trees. Fixed positions are not allowed within the buffer, and certain other activities such as production of smoke are prohibited there. These restrictions can detract from realism of training in areas of high RCW density. However, installations are allowed to set a Mission Compatible population goal (MCG) and exclude some RCW clusters (termed supplemental clusters, as opposed to the primary clusters which are counted), which are not counted toward that goal, from these restrictions (US Army 1996). Installations may also exclude groups in impact areas from their MCG and long-term RCW management plan. These provisions allow managers to exclude areas that are especially important to the training mission from some aspects of RCW management, thus reducing conflicts between RCW conservation and training needs. Managers can exchange designations between supplemental and primary clusters, further increasing flexibility in establishing the desired training environment.

Ability to remove habitat for new range construction is another issue. Since each RCW group is allocated 120 acres of foraging habitat, this potentially is a larger constraint than restrictions within a 200’ buffer around the cluster pose to training realism. Thus, the ability to designate supplemental clusters and make reassignments between supplemental and primary clusters is particularly critical to maintaining flexibility with respect to range development and other forms of construction.

Fort Benning has sufficient habitat to support an RCW population roughly twice the size of the population goal. Hence, the installation has considerable capacity to establish supplemental clusters in order to maintain mission flexibility with respect to both training realism and range construction, not only once the MCG is reached but also while growing the population toward that goal. Therefore, achieving RCW conservation goals is not expected to impact ability to train. However, this compatibility could be compromised by a forest health problem. For example, if some areas can no longer support a RCW group because of excessive tree mortality, then the quantity and distribution of habitat on which the MCG will have to be achieved will change. This could result in loss of mission flexibility and in the extreme, loss of training land.

BRAC will result in the incorporation of future weapon systems, more ranges, and increased usage of and impacts to mission lands and natural resources. This could make mission flexibility a larger issue if poor forest health results in a reduction of habitat suitable for RCWs. Irrespective of changes stemming from BRAC, air quality issues that will limit the implementation of prescribed fires are anticipated.

Since USFWS issued Fort Benning a jeopardy opinion for unauthorized taking of RCWs nearly 20 years ago, providing for RCWs has driven forest management on the base. Current forest management practices are derived from guidelines provided in the recent revision of the Recovery Plan for the species (USFWS 2003). The restrictive, specific criteria for foraging habitat requirements in the Plan could limit forest management options to the point where progress toward desired future condition of the forest might be unintentionally jeopardized. Foraging guidelines are designed for the pine type appropriate to a particular location, and include a provision to harvest stands of off-site pines and regenerate the stand with the appropriate pine species. They do not address the situation such as occurs on Fort Benning where stands of loblolly and shortleaf pine must continue to provide suitable habitat for RCWs while being converted to longleaf. Attempting to adhere to the guidelines in managing such stands can lead to counter-productive actions. For example, dead or dying trees are sometimes left standing and healthier, smaller trees that would otherwise fill the age class gap are harvested in order to meet requirements for minimum number of large trees and maximum basal area (BA). Being able to maintain habitat for RCWs while transforming the forest to the desired future condition is a serious challenge. We discuss this issue in detail below.

**Evidence of problem with tree/ stand death**

The Fort Benning landscape is dominated by loblolly and shortleaf pine, with a scattering of upland hardwood forests sometimes mixed with pines, notwithstanding the past decade of longleaf pine restoration. Unpublished data from Benning’s monitoring program documents that pines were found on more than 85% of the sites inventoried across the base, and of pine types, loblolly, mixed pine (mostly loblolly and shortleaf), and mixed pine hardwood (mostly loblolly and shortleaf) were the dominant types. Longleaf stands were only encountered across slightly more than 15% of the base, and represented only 24% of the overstory trees encountered.  This landscape pattern in pine species influences the rate of tree death experienced in the landscape.

Tree death rates at Fort Benning differ largely due to species. Tree death assessed through an ecological monitoring program showed the vast majority of trees that were dying or of low vigor were loblolly and shortleaf pine. Greater than 16% of loblolly trees were dead or low vigor, while shortleaf showed almost 10%. This is in contrast with only 1.7% of the longleaf encountered dead or judged to be of low vigor. Since dead trees can accumulate over time, and this was a one-time assessment, it is difficult to determine death rates. Nonetheless, Palik and Petterson (1996) suggested that snags persist in this frequently burned landscape as standing dead for 5-7 years. Given this value of snag residence (5-7 years), at Fort Benning maximum life span would be approximately 350-500 years (total number of trees inventoried divided by (dead trees/5-7). This crude estimate is similar to the two best data sets available for longleaf mortality (Platt et al 1988, Palik and Patterson 1996) which report a similar maximum lifespan.

The perceived forest health problem on Ft. Benning, i.e., “pine decline”, has been observed (personal communications with managers and Rhett Johnson) at other properties that straddle the fall line in Alabama (portions of the Talladega National Forest, some industrially-owned forestlands, private non-industrial forestland between Prattville and Birmingham) and Georgia (Piedmont National Wildlife Refuge). Interestingly, similar forest health issues do not appear to be occurring in forestlands along the fall line in South and North Carolina. However, the perception of the landscape and inventory data at Benning is not entirely congruent. High rates of mortality at Benning are largely restricted to loblolly and shortleaf pine, but may appear to be a more general phenomenon due to the prominence in the landscape of the two species that show the greatest rates of tree death given the current landscape age structure and fire management.

The extent (distribution patterns) and degree (moderate – severe) of decline at all locations mentioned above are unknown at this time. Initial impressions of on-site conditions at Ft. Benning do not appear to be atypical for 60-70-year old loblolly-shortleaf pine in this part of the species range – especially given its land-use history (detrimental and long-term agricultural practices, accelerated prescribed burning program, intensive military training). A monitoring survey showed that mortality increased with increasing density of overstory, similar to patterns modeled in self-thinning of loblolly pine (Martin and Brister 1999), thus rather than decline, this source of death is associated with the stem exclusion phase of stand development. Using a landscape model of loblolly decline developed by Eckhardt (2003), based on site factors (soil type, depth, slope, aspect etc.), most of Fort Benning is of moderate to high risk of mortality for loblolly. However, when checked against the actual mortality observed, high risk sites showed only slightly more mortality than did low risk sites. One might expect that if decline was accelerating mortality, high risk sites would be more significantly affected. A further review of the Southern Forest Resource Assessment (2003) and long-term forest inventory and analysis (FIA) data collected by the U.S. Forest Service may help answer the question as to whether the apparent forest health issue at Fort Benning is an anomaly or typical when it is viewed in a regional context.

Mortality over the landscape has multiple causes, and often the agent of death, e.g. pine bark beetles, may result from low vigor associated with competition, and/or drought (Craighead 1925). Mortality patterns also differ with stages of stand development and among various species (Franklin 2002). This complexity with respect to the causes of mortality is exacerbated by a lack of ecologically based literature on the ecological consequences of mortality (Franklin et al. 1987). Nonetheless, we do know that longleaf pine is more tolerant of fire than other southern pines, and less sensitive to common insect pests and diseases (Wahlenburg 1947). The deep tap root, canopy structure and bole strength collectively provide greater wind firmness (Mitchell et al. 2007) than other pine species; however, on wet sites tap root development of longleaf pine is restricted making it more susceptible to blow down (Palik and Peterson 1996). While longleaf pine tends to be more resistant to sources of overstory mortality than other southern pines, tree death is an important part of stand dynamics, and often when sources of mortality are documented, unknown source of mortality is as frequently encountered as those sources that are determined (Palik and Peterson 1996). Infrequently across the landscape, islands of relatively large areas of unknown mortality have been documented, even in landscapes in which longleaf pine is largely healthy and vigorous (Patterson and Palik 1996). Thus, finding some patches of dead longleaf in the landscape is not necessarily outside of expected variation in tree death rates.

## Consequences and management actions

Managers can respond to unacceptably high rates of tree death in two ways. Several actions can be taken that would reduce the rate of loblolly and shortleaf death, and other actions can be taken that begin the establishment of longleaf pine cohorts as quickly as possible and reduce the negative consequences associated with overstory disturbance. Much of the death of loblolly and shortleaf may be a manifestation of self thinning (see above). Thinning mixed pine stands, and removal of hardwoods in some of the mixed pine hardwood stands either by harvesting, burning regimes over time, or herbicide, will reduce losses of pines from density dependent mortality. This would allow the remaining pines to live longer creating habitat for the RCW until their ultimate conversion to multi-aged longleaf pine. Mortality of mixed pine could also be reduced by using a burn prioritization to select mixed stands, particularly those with a high percentage of loblolly to be burned during less severe conditions (cooler, moister conditions, and more frequent but lower intensity burns). It should be noted, however, that leaving some mixed pine hardwood stands in the landscape will aide in maintaining landscape heterogeneity, particularly as the landscape is converted to a longleaf pine dominated state.

In addition, advanced longleaf regeneration in stands of longleaf and mixed pine stands with sufficient adult longleaf pine for natural regeneration could be initiated by modifying burning regimes to capture regeneration during the next large seed crop. While longleaf pine is classified as intolerant to shade (Wahlenburg 1947), advanced regeneration develops in stands that have at least 30% gap fraction (the fraction of canopy open to sky, Pecot et al. 2007). Where adult longleaf are not present in sufficient quantity, underplanting of seedlings throughout the stand could be used to establish regeneration (Kirkman et al. 2007). This advanced regeneration once established can respond to overstory death and be released (Mitchell et al. 2007). Thus, with sufficient advanced regeneration established throughout the landscape, pine mortality can be seen as an opportunity to start a new cohort of longleaf rather than a problem.

## Potential implications of a forest health problem for RCW recovery

Fort Benning has been increasing its RCW population at a rate of 7-8% per year and thus is rapidly approaching achieving a recovered population. As discussed above, mission flexibility will be increased when recovery is achieved, and therefore a forest health problem that impedes RCW recovery would compromise both conservation and training objectives. USFWS requires Fort Benning to provide two resources for the birds, nesting habitat and foraging habitat. We will evaluate the potential impacts of a forest health on both, and in both cases the potential impacts can be characterized in considerable detail because the requirements of the birds are well known and the management requirements highly specified.

The RCW is unique in excavating cavities for nesting and roosting in living pine trees (Jackson 1994; Conner et al. 2001; USFWS 2003). The birds excavate an entrance tunnel through the sapwood and into the heartwood, and then excavate the cavity chamber within the heartwood. To be suitable for excavation a tree must contain sufficient heartwood to contain a cavity, and since heartwood diameter is a function of tree age the birds require old trees. Based on this fact, USFWS (2003) requires that old growth, specified as >120 years of age for longleaf and >100 years of age for loblolly and shortleaf, be provided on the landscape as nesting habitat. On Fort Benning, 120 acres is the standard area of habitat assigned to each group, so the nesting habitat requirement is to provide sufficient old growth within the 120 acre range of each group to support cavity excavation.

Ability to provide sufficient nesting habitat will be compromised by a forest health issue only if mortality is so pervasive that few trees survive to the age required for cavity excavation. RCW territories are sufficiently large that the density of old growth required to support nesting is quite low – even 1 tree per acre would represent an abundance of potential cavity trees. Furthermore, proven techniques for providing the birds with artificial cavities when natural cavities become deficient exist (Copeyon 1990; Allen 1991; Copeyon et al. 1991). Thus, even in areas where tree mortality is severe, it seems unlikely that nesting habitat will become limiting for RCWs. In fact, it is difficult to envision that forest health could be so poor that the density of potential cavity trees in the future would be less than the current density of such trees, which are remnants of the clearing of the southern forests at the beginning of the 20th century.

In contrast, a forest health problem is quite likely to make it difficult to meet RCW foraging habitat requirements. Each RCW group must be provided 120 acres of good quality foraging habitat, and to be considered good quality, habitat must meet seven criteria (USFWS 2003). (There are two additional criteria that have to do with the location of the habitat rather than its features.) These criteria capture the features of open, mature longleaf stands that are the desired future habitat condition on Fort Benning. One criterion has to do with canopy hardwoods and is irrelevant to the forest health problem. Two others, having (1) hardwood midstory ranging from none to sparse and < 7’ in height and (2) groundcover consisting of at least 40% herbs and grasses, may be affected by a forest health problem through effects of forest health on fire. These effects are discussed below. Otherwise, at least in the case of groundcover, excessive mortality of canopy trees might actually enhance ability to meet the criterion by increasing penetration of light, if hardwoods can be controlled through use of fire or other means.

The remaining four criteria have to do with pine ages and densities. To qualify as good quality, foraging habitat must have (1) > 18 stems/acre of pines > 60 years of age and > 14” dbh that constitute > 20 ft2/acre ba, (2) 0-40 ft2/acre ba of pine 10-14” dbh, (3) < 50 stems and < 10 ft2/acre ba of pines < 10” dbh, and (4) > 40 ft2/acre ba of pine > 10” dbh. Excessive mortality of older canopy pines might make it more difficult to meet criterion 3 if this mortality promoted regeneration, but much more problematic are criteria 1, 2 and 4. Simply, a forest health problem might well make it difficult to maintain sufficient basal areas of mature pines to meet RCW foraging habitat recommendations detailed in the 2003 Recovery Plan. First, this clearly would have a regulatory effect because if Fort Benning were less able to meet USFWS requirements for RCWs it would be more likely that proposed actions would result in ruling of possible take and jeopardy opinions, particularly with respect to range construction, reducing flexibility in planning and executing the military mission. Second, this will have a biological effect if RCWs whose foraging habitat does not meet quality guidelines do indeed fare poorly. Poor performance could be manifested in poor reproductive success, increased territory sizes (and thus more acres allocated to each group) or both. Ability to reach the RCW recovery goal might be compromised as a result of these impacts, and the population might even decline below its current size. These eventualities could further reduce mission flexibility and thus lead to conflict between RCW conservation and the military training mission.

Regulatory consequences will persist only if assumptions about biological consequences prove accurate. Primarily on public lands, there is clear evidence that RCWs prefer to forage in open stands with large, mature pines with relatively few medium-sized and small pines, sparse or no hardwood midstory, and a rich groundcover with a high grass and forb component, and that they do better (i.e., are more productive and live in larger groups) the more such habitat they have within their territory (Hardesty et al. 1997; Engstrom and Sanders 1997; James et al. 1997; 2001; Walters et al. 2002; Convery 2002). Thus the USFWS requirement for open, mature stands is well justified, and in fact generally each specific criterion is backed by direct evidence. There is strong evidence of negative effects of hardwoods, that more groundcover is better than less and that the forb and grass component has a positive effect and the woody component a negative effect, that too many small and too many medium-sized pines have negative effects, and that high overall pine ba has a negative effect (USFWS 2003). Significantly, the only exception to criteria being clearly related to direct evidence are the criteria for minimum ba of large (> 20 ba) and all (> 40 ba) pines. These criteria are based on evidence that the birds prefer stands with intermediate ba of large pines (e.g., Walters et al. 2002), but generally the avoided stands have low ba of large pines because they are comprised mainly of medium-sized and small pines. In contrast, Wigley et al. (1999) found that RCWs inhabiting industrial forestland foraged in pine plantations characterized by small (10.1 to 25.4 cm) and young (<25 years old) loblolly pines when larger and older pines were absent. Hence, it is not clear that a very open mature stand, composed of very low densities of mostly mature trees, represents poor foraging habitat. Such stands have abundant groundcover, and groundcover consistently is the most important variable to foraging preferences and effects on fitness (James et al. 1997; 2001; Convery 2002; Taylor and Walters 2004). In fact, the foraging habitat guidelines are designed to steer managers toward stand conditions that promote development of a rich, diverse groundcover, the source of much of the prey of RCWs (James et al. 1997; Hanula and Franzreb 1998; Taylor 2003) and provide mature pines, the preferred substrate for foraging for this prey. One line of evidence supporting minimum ba requirements is that RCW home ranges are larger in areas where pine densities are lower (USFWS 2003). This may be because of low pine densities are associated with low productivity, but it may also be that home ranges expand when stand ba is low. This would result in lower RCW population densities.

Thus, there are several reasonable, alternative impacts a forest health problem that resulted in very low density (i.e., 10-30 ba), mature pine stands could have on RCWs on Fort Benning. First, such stands might prove to be high quality foraging habitat and thus the birds would continue to thrive despite excessive pine mortality. Second, RCW groups might continue to do well but would expand territory sizes such that population density was reduced, and thus allocations of space to groups would have to be altered. Third, RCW foraging conditions could be compromised, resulting in effects on fitness and ultimately population dynamics, making it difficult or impossible to achieve current recovery objectives. Research on use of such stands by RCWs and impacts on fitness, both on Fort Benning and elsewhere, is needed to distinguish between these possibilities. On Fort Benning, appropriate research is already underway: Doresky and Costa (personal communication) have developed a partition vulnerability index that measures the impact of tree mortality on the foraging habitat allocated to particular groups (i.e., foraging partitions). They are examining the relationships among group size, productivity, territory size and basal areas of foraging stands. Interestingly, they have already documented groups that are performing well subsisting on 100 acres of foraging habitat with 30-40 pine ba (recall that the criteria for minimum total ba is 40).

Elsewhere there has been little research on the forage value of mature stands with very low ba because such stands currently are rare in the Southeast. Generally pine stands are too dense, not too open, relative to RCW foraging habitat guidelines. The low ba stands that do exist generally are much too young to be useful to RCWs, or have excessive hardwood midstory and insufficient groundcover. One exception is the Francis Marion National Forest, which contains a large RCW population foraging in relatively mature stands reduced to very low ba (typically 10-20) by Hurricane Hugo in 1989. Interestingly, the RCW groups on the Francis Marion are highly productive despite foraging in stands that are so open that some groups have only 300 large and medium-sized trees within their foraging partition (Lohr et al. 2004). It is unlikely that a forest health problem will reduce pine densities to this level on Fort Benning, yet the Francis Marion population is increasing (Lohr et al. 2004). It is thus conceivable, based on the limited available evidence, that low ba due to excessive tree mortality will not have a negative impact on RCW foraging conditions on Fort Benning, provided the stands can be burned properly to promote groundcover and inhibit hardwood midstory.

How then should stands with excessive tree mortality be managed for RCWs? We suggest that it will be difficult, and frankly pointless, to attempt to meet the USFWS foraging habitat criteria in mature loblolly stands that are being converted to longleaf in any case, let alone when such stands are subjected to high mortality rates of mature trees. Instead, Fort Benning should develop its own foraging habitat guidelines for such stands, driven by the objectives of providing a rich, herbaceous groundcover to provide prey for RCWs and mature trees on which the birds can forage. This could mean allowing stands to fall to very low basal areas of mature trees (loblolly and shortleaf) and may sometimes mean maintaining basal areas of medium-sized and small trees (longleaf) that are above the USFWS criteria. Research and observations in pine plantations indicate that higher than preferred basal areas of smaller and younger trees should not have a negative effect with respect to foraging since RCWs utilize trees of this size (Wigley et al. 1999, Bowman et al. 1998, Butler 2001, J. McGlincy and C. Hedman personal communications). It also means that salvage cuts that remove all older trees should be avoided, as mature trees will be a scarce, essential resource. As long as the groundcover is in the desired state, and some mature trees are available, strict adherence to basal area criteria will not be necessary. We assume that managing for desired groundcover will result in appropriate management of hardwood midstory (Hires et al. 2007). To be able to use installation-specific guidelines for these stands, Fort Benning will have to show that these guidelines result in foraging habitat that enables groups to be large and productive. The study by Doresky and Costa will be critical to this requirement.

## Effects of forest health on fire regimes

Being able to develop desired groundcover condition and inhibit development of hardwood midstory requires being able to burn the habitat effectively. Without fire, the release of hardwoods in gaps created by heavy mortality can be problematic in this ecosystem. Hardwoods respond immediately to the reduction in competition with the overstory and can quickly capture a site (Pecot et al. 2006, Jack et al. 2006). The timing of gap creation becomes critical in part because longleaf pine seed production is episodic; most trees produce large quantities of seeds only every 7-15 years. Even if gap creation is coincident with good seed production, longleaf seedlings still require an additional 2-10 years to begin height growth due to the stemless, grass-stage period of growth (Pecot et al. 2007). Thus, if no seedlings are established prior to gap creation, it may take a decade or longer before longleaf pine regeneration can capture a site. By that time, established hardwoods will occupy the gap. As hardwood dominance increases, a cascade of negative impacts on species diversity begins, first with declines in the fire-dependent groundcover community (Kirkman et al. 2004), followed by loss of keystone faunal species (James et al. 2004, Guyer and Hermann 1997).

The links among pine overstory disturbance, hardwood release and loss of species diversity could be largely driven by changes in fuels and fire behavior. Frequent fires suppress hardwoods, killing the aboveground portion of the plant (Williamson and Black 1981) and maintaining these species in low stature as understory shrubs (Jaqmaine et al. 1999). Frequent fire also encourages both grasses and pines that produce the fine fuels that allow for frequent fire return intervals. Gaps have the potential to create openings with insufficient fine fuel necessary for fire spread. This effect is exacerbated in larger gaps. Pine needle accumulation declines exponentially with distance from a tree bole

(Grace and Platt 1995). Moreover, fire frequency and intensity are further reduced due to the simultaneous increase in hardwood litter (Williams and Black 1981) and decline in pine/grass fuel loads (McGuire et al. 2001). Fire intensity has been shown to be positively correlated to pine litter accumulation and negatively correlated to hardwood litter (Williamson and Black 1981, Ferguson et al. 2002, Glitzenstein et al. 1995). Increased resprouting of hardwoods, coupled with decreased fire intensity, results in a higher likelihood of hardwood survival in gaps. Surviving a single burn gives hardwoods a significant competitive advantage over pines, resulting in greater height growth, leaf area, and the development of thicker bark, which increases the probability of surviving future fires. The alteration of forest structure and fuels from gap-based silviculture resulting from the lack of overstory and release of hardwoods represents an important feedback loop that determines future stand structure but the spatially explicit nature of this feedback make predictions about stand development more difficult (Mitchell et al. 2007).

We think it unlikely that pine mortality will be sufficient to create difficulties in applying fire at the landscape scale that cannot be resolved by varying fire prescriptions. However, we conclude that at the stand level, pine mortality quite likely will make it difficult to conduct effective burns (i.e., fires that suppress hardwood midstory and promote desired groundcover) in some locations. Pine mortality can influence within stand fire regimes in a number of ways. The loss of pine fuels and the release of hardwoods in parts of the stand with aggregated mortality may require control of midstory hardwoods beyond that than can be achieved by fire alone (e.g. herbicides). Secondly, accelerated mortality of stands may induce harvesting of the stand and regeneration of longleaf. If the mortality rates are low and sufficient pine overstory remains such that uneven-aged approaches are possible, this will help in sustaining pine fuels that allow for frequent fire (Mitchell et al. 2007). If mortality within a stand leaves insufficient overstory to warrant uneven-aged management, silviculturists should consider what legacies will be retained in the stand (both snags and large old live trees), and how they will be distributed. Mortality of stands is often patchy, thus leaving the opportunity to leave aggregated live (or dead) trees in part of the stand. Besides enabling a fire regime necessary to maintain desired midstory and groundcover conditions, the trees that remain will be of value to RCWs and other cavity-nesting species (see below).

## Forest health as a regional issue for RCW recovery

We do not see the forest health problem as a regional issue, but rather one restricted to areas, chiefly along the Fall Line in Alabama and Georgia, where mature stands of loblolly and shortleaf pine exist and are burned frequently. Within this domain, forest health is an issue for RCW recovery only where a management unit must maintain these stands as RCW habitat while converting them to longleaf (as opposed to not including such stands in foraging partitions and simply clearcutting them and replanting in longleaf, as recommended in USFWS 2003). The other military installation where this situation exists is Marine Base Camp Lejeune in North Carolina, but at Camp Lejeune as yet there is no indication of excessive mortality in mature, off-site loblolly pine.

## Implications of forest health for other species

Excessive mortality of mature loblolly and shortleaf pine may have interesting effects on not just the RCW, but the community of cavity-nesting birds as a whole. These species rely on two resources for nesting, RCW cavities in live pines (or dead pines after these cavity trees die) and cavities in dead pines and dead hardwoods. Hardwood snags are a relatively minor, but important, resource in longleaf grassland ecosystems (Blanc and Walters in 2007). The other two resources both are common, and their relative usage is likely to be impacted by forest health because it will result in an abundance of mature pine snags Mature pine snags are the preferred resource for many of the cavity-nesting species in Longleaf pine ecosystems (Blanc and Walters 2008), and thus these species likely will increase as long as dead trees are not cut. Further, usurpation of active RCW cavities by other species is likely to decrease when more mature pine snags are available, which could possibly benefit the RCW. Mature trees are much more valuable as snags than are younger trees because they persist longer in the environment due to having more heartwood and because they provide a better substrate for excavation due to having a greater volume of sapwood, to which cavity excavation is confined (Blanc 2007).

### Economic impacts of altered age structure on forestry programs

The first step in gauging potential economic impacts is to analyze the current age-class distributions, timber volumes, and growth rates of each forest type, e.g., natural pine, pine plantation, pine-hardwood, etc., on Fort Benning. The next step would be to review (or develop) forest management objectives for each timber type and installation lands as a whole. By using a computer simulation program that recognizes landscape-scale parameters (since multiple objectives are core to Fort Benning management), a series of "what if" scenarios based on various forest health conditions could be run.
For example, if the "base case" represents the best estimate of current forest health conditions, the model would generate estimates of timber volume removed and timber revenue generated (based on current, local market prices by product class) over a prescribed planning period. Subsequent simulation runs, based on various forest health conditions, would yield different volume and value estimates over the same planning period. Results would provide an estimate of economic impact stemming from a change in timber revenue. Like all models, this tool would be limited by the data available for input by the user, i.e., forest inventory data that includes accurate estimates of standing volume and forest health per forest type or stand would be critical to its utility.

### Impacts on military training

The low basal area stands that may result from any forest health crisis and/or from the implementation of the RCW guidelines should have minimal direct impact on the military training mission on Fort Benning or, in fact, on other military installations as well. The open stand conditions should allow most exercises to continue with little change. If basal areas become too low, the ability to use fire effectively to control woody brush and maintain the open, grass-dominated understory favored by both woodpeckers and the military may be jeopardized (see above). Although other techniques (chemical and/or mechanical) can approximate the short-term effect of prescribed fire, none have proved to be effective in the long term in sustaining this ecosystem without fire (Provencher et al. 2002). In the long term, regeneration must be accommodated to sustain this forest. Where longleaf is significantly present in the overstory, it may be regenerated naturally and compatibly with RCW habitat requirements. Where it is not, long term goals will require stand conversion to longleaf in some manner.

Woodpecker foraging habitat goals require the retention of stands with specific requirements for large and medium-sized pines (see above). The area and stands allocated to regeneration and conversion as opposed to those needed to provide this vital habitat component will be critical and, if compounded by a real health crisis in many areas, may be impossible unless installation-specific foraging guidelines that allow for lower basal areas of mature pines are adopted. Managers cannot relocate stands showing signs of poor health to areas of less importance to woodpeckers nor can they relocate woodpeckers to areas where foraging and nesting conditions may be less threatened. Instead it will be necessary to retain RCW foraging value of stands continuously through time.

Finally, training is ideally planned to avoid areas where and when woodpecker breeding and brood rearing activity is taking place. It is conceivable that fewer alternative sites may be available as stands are lost or lost to woodpeckers due to stand conversion practices. One alternative would be stand conversion via clearcutting and replanting with longleaf seedlings, with the resulting short term loss of these areas to both training and woodpeckers. Another is under-planting with longleaf seedlings into low basal area stands of other pines, in some instances with subsequent re-entries into those stands to gradually remove the overstory. This may allow continued use of those stands for training and as foraging habitat for woodpeckers.

Although we think it unlikely, if there is indeed a burgeoning health crisis on Fort Benning that causes accelerated forest loss and stand conversion, it may be necessary to reach outside the base for both training and replacement woodpecker habitat. This may require the employment of long term leases, outright fee purchases, and conservation easements until the installation forest is capable of supporting the military mission and the targeted woodpecker population again. If this should become necessary, lessons learned in this ever-developing landscape might be instructive on both military and other public lands across the region.

## Indicators or surrogates of relative forest health

Gauging the relative severity of a forest health problem is enhanced by knowing which specific forest stands are declining. A first step in understanding severity would be to obtain and analyze mortality data for overstory trees, e.g., snags per acre, relative age of snags, pattern of mortality (aggregated, randomly distributed, etc.), potential causes, etc., on a stand/compartment basis. Additional location-specific data (stand/compartment), e.g., slope, aspect, land-use history, stand stocking, known pathogens, and burn regime could be used to determine patterns in mortality. Additionally understanding baseline or typical mortality rates for each species could be helpful in determining if the patterns observed locally are cause for added concern. Data sources include forest, fire, and endangered species management data sets and remote images/photos of the installation (captured over time). As previously stated, it would also be helpful to obtain and analyze regional forest health data in order to gain a better understanding of the relative condition of Fort Benning stands. An analysis of such data could then be used to develop distribution maps of “relative forest health” across the installation.

Given these data one could then identify the range of forest health conditions by compartment/stand based on the above-referenced data sets. Next an initial classification of each compartment/stand based on overall forest health condition could be mapped. Ideally, the forest health condition of each compartment/stand would be analyzed based on similar aged stands on similar sites with similar land use and management histories. Stands should be characterized as: Poor: Stand health conditions are characterized by dying or dead trees (concentrated pockets or dispersed) that exceeds what is considered typical/expected; Fair: Characterized by scattered, random mortality of overstory trees that would be considered typical/expected Good: Mortality and/or signs of weakened trees are not evident or are less than what would be considered typical/expected. Ground-truthing of these initial classifications would allow refinement as needed.

Following an accurate landscape classification of stand health, the development of specific, objective-based forest management prescriptions for each forest health condition could take place. The silvicultural objective should be to fix what is broken, mend what is breaking, and finally sustain what is thriving. Specifically, silvicultural prescriptions in stands should at a minimum address the following: Poor: Assess current fuel loads and fire history. If conditions warrant, follow guidelines established by the Longleaf Alliance for restoring fire to long-unburned stands of longleaf (modify for loblolly and shortleaf pine as needed). Employ patch clearcuts/group selection harvests (with retention) within pockets of dying and /or dying trees (include a buffer zone to ensure containment). Regenerate these newly created pockets as soon as possible and restore to longleaf pine. In other stands where mortality is relatively high but scattered, run a cool, fast-moving fire through them (consider fuel loads and time since last fire) and mark to upgrade stand quality and health. Remove as much overstory basal area as necessary to foster successful survival, growth, and development of underplanted longleaf pine. Fair: Conduct cool, fast moving fire if not burned in the past 3-5 years. Mark stands to upgrade stand quality and health. Remove as much overstory basal area as necessary to foster successful survival, growth, and development of underplanted longleaf pine. Develop a multi-year action plan in accordance with the triage goal and prioritize the allocation of time, money, and resources. Good: Continue to burn these stands at the appropriate time and place them lower on the priority list for selection harvests and conversion to longleaf pine. This monitoring and management action plan should be implemented as soon as possible, and continued monitoring will be needed to determine effectiveness and adapt when needed.

## Monitoring and Adapting

In part, the difficulty in determining if the tree mortality at Benning represents an accelerated mortality associated with a decline, or if it reflects a natural consequence of an aggressively burned landscape that is aging, is the lack of solid monitoring data at Benning and similarly strong data sets in the region to put patterns seen at a place in a regional context. A robust monitoring program would need to include site characteristics, past land use, information on current stand conditions and spatially explicit distribution of unique habitats and rare species populations to allow assessment of causes and consequences of patterns in mortality to be more fully evaluated. Connecting monitoring of mortality and its causes to a landscape simulation model could predict how forest structure would change over time, how landscape patterns vary with time, and if connected to a population dynamic model of a focal species such as the RCW (or others of interest), it could predict consequences.

Moreover, any monitoring and projection of stand dynamics and endangered species response ideally would incorporate forest management (timber, fire, wildlife etc.) monitoring data, management activities and plans and simulation models seamlessly into a common architecture so that each could inform the other. Monitoring program information could be used to validate and better calibrate model projections through time. Management practices could be used to test and improve upon the ability to detect change in forests through time, and the monitoring and simulation program could be used to prioritize management (Hiers et al. 2003). Both monitoring and simulations could be used to test management options.

## Conclusions

In conclusion, we suggest that the future extent of the forest health problem and its impacts cannot be known with certainty. Therefore, it will be essential to manage adaptively as the landscape changes and learning about the effects of these changes on RCW fitness and other aspects of interest occurs. The desired future condition of pine habitat does not match current conditions, and a central piece in the conversion of the landscape is to replace loblolly and shortleaf pine with longleaf across much of the installation. Therefore, mortality of loblolly and shortleaf can be viewed as an opportunity rather than a problem, if management can adapt to mortality rates in ways that enables maintenance of key functions, such as supporting RCW foraging, in affected stands. Accomplishing this effectively will require monitoring changes in the landscape and the key functions, using the monitoring data to test hypotheses about the relationships between them, and taking management action based on the results.

We conclude that providing nesting habitat for RCWs will not be an issue because the density of mature trees required is very low, and even where trees for natural excavation are insufficient artificial cavities can be provided readily. Several alternative outcomes exist for ability to provide foraging habitat, however. Rather than attempt to adhere strictly to foraging habitat quality guidelines (USFWS 2003), we suggest that if driven by natural mortality, basal areas of mature trees should be allowed to drop below the standards. In stands experiencing high levels of mortality of mature longleaf pine, cutting of other mature trees should be avoided as they will provide opportunities for natural regeneration. The impact of this on affected RCW groups should be monitored to distinguish the possibilities that (a) low ba stands, as long as hardwoods are suppressed and rich, diverse groundcover exists, provide good quality foraging habitat, (b) presence of low ba stands cause RCWs to expand their foraging range, thereby necessitating increases in foraging partition size, and (c) low ba stands provide insufficient foraging, causing decreases in group size and productivity of affected groups. The outcome of this exercise will determine how RCWs, as well as the forest, must be managed in order to maintain the military mission as the landscape is converted to the desired future condition.

The use of less desirable species (e.g. loblolly pine) to bridge the time required to develop a landscape to a multi-aged (old) longleaf pine grassland has only recently been published (Kirkman et al. 2006), and contains many uncertainties. The conditions and management needed to regenerate longleaf across the range of conditions at Benning is not known. Under-planting of longleaf beneath a canopy of loblolly and slash pine has successfully established seedlings. Longleaf has been shown to establish under a wide range of canopy densities (gap fraction above 30%); however growth of seedlings only is accelerated in larger openings (> 65% gap fraction). Growth rates of planted seedlings underneath a canopy are much slower than in clearcuts. Developing more precise predictions of the rate of development of regeneration under a wide range of conditions will be needed to more accurately project how long it will take cohorts of under-planted seedlings to develop into overstory trees. Establishing longleaf seedlings as advanced regeneration, and releasing them latter from either mortality and/or selective harvesting may be a strategy that allows for slow conversion while the undesirable pine species provide habitat until longleaf is able. In sites where it is desirable to more rapidly establish and grow longleaf, patch clearcut is an option. However, considerable thought as to the type, density, and pattern of arrangement of legacy trees that are retained in the patch cut needs to be incorporated into silvicultural prescriptions. The efficacy of the retention should be closely monitored (e.g. do live trees that are retained have greater risk of mortality), as well as the consequences (e.g. is greater foraging habitat sustained in clearcuts with retention of some large old pines than in those without; does density and type of snags influence the diversity of cavity nesters ?).

Little guidance as to how low pine basal area stands due to mortality will respond to fire. Pine mortality influence fuels several ways. Pine fuels are critical in maintaining frequent fire needed for diverse southern pine grassland woodlands (Mitchell et al. 2007). Secondly, hardwoods in the mid- and understory can be released by disturbance to pine overstory. Since fire sensitive hardwoods have fuel characteristics that differ widely from pine grassland fuels, prescribed fire prescriptions will need to be altered to deal with changing stand structural conditions. Monitoring hardwood dynamics in stands, and treating them when necessary should be a high priority.

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