Chapter 12
Restoration of Southern Pine Forests After the Southern Pine Beetle

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12.1 Introduction

Pine (*Pinus* spp.) forests in the southern United States have changed dramatically in the past 100 years. Historically, pine-oak woodlands and forests dominated much of this region before Europeans settlement (Walker and Oswald 2000). The land-use history of the US South in the twentieth century, including clearing for farming, logging, abandonment after degradation, and natural forest reinvasion, has led to an increase of southern pines than naturally should have distributed. In the recent past, the pine dominated forests, especially pine plantations, have expanded their ranges as a dominant forest type in many areas of the US South as a result of development of the timber industry and the plantation forestry. The large pine trees and overstocked pine stands are highly conductive to varied forest insect pests, in particular to southern pine beetle (*Dendroctonus frontalis* Zimmermann (Coleoptera: Scolytinae), SPB).

Southern pine forests have been subjected to multiple native and exotic forest pests and varied environmental threats such as severe droughts, large hurricanes, periodic fires, and impacts of decades of other natural disasters. The SPB is the most

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destructive insect pest that attacks pine stands in the South and it continues to be a significant pest affecting pine forest ecosystems in the southern United States. Increased pine plantations, coupled with severe periodic natural disturbances, greatly increased the probabilities of these pine forests be damaged by SPB. Since 1960s, major SPB outbreaks have resulted in substantial timber losses (>$2.5 billion) and long-lasting ecological impacts in the US South (Coulson et al. 2004).

Effective restoration of the damaged southern pine forests by SPB and management of impacted forests is critically important for forest health and sustainability in the southern United States. Restoration of damaged forests has been identified as an important task and priority in the South (Coulson et al. 2004; Nowak et al. 2008). Restoration is a complex and comprehensive task because many factors must be considered concomitantly (Stanturf and Madsen 2005). While our knowledge on how to restore and manage those damaged pine forests has been continuously growing, a ready-to-use, scientifically sound and field proven strategy, has yet to be developed to meet the needs of forest managers and landowners.

This chapter is designed to help readers understand how forest restoration after SPB outbreaks could be integrated and implemented in the US South. It provides a synthesis of new and existing knowledge of restoration goals, frameworks, implementation, and social and political impacts in a context of SPB and sustainable forest management. Although our emphasis is mainly on the post-damaged southern pine forests, certain preventative silvicultural strategies are also discussed in the context of reducing impacts of SPB. A better understanding of effective restoration strategies and their implications is important. The information we synthesize in this chapter may assist forest managers and landowners in their efforts to reduce the economic, ecological and social impact of SPB.

12.2 Southern Pine Forests and Southern Pine Beetle

12.2.1 The Southern Pine Forests

12.2.1.1 The Southern Pine Species and Distribution

Pines in the southern United States consist of ten hard pine (also called yellow pine) species (Sternitzke and Nelson 1970; Gaby 1985). Those pines are generally shade-intolerant and fire-resistant (Walker and Oswald 2000). Among them, four major species, including loblolly pine (*Pinus taeda* L.), shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), and longleaf pine (*P. palustris* L.), are the principal sources of timber products (make up about 90% of the total inventory) in the region (Sternitzke and Nelson 1970; Stanturf et al. 2003). The individuals of these four pine species ranges overlap and extend from the upper areas of the South Atlantic States across the Southern States to Oklahoma and Texas (Gaby 1985). In the southern United States, roughly 26.3 million ha of forest land supports stands dominated by the four major southern pines. Those southern pine forests have been classified into two forest types: longleaf-slash pine forest type (~5.61 million ha) and loblolly-shortleaf pine forest type (~21 million ha). In addition to the relatively pure pine stands, about 12.2 million ha are classified as oak-pine forest type, which is usually of natural origin (Smith et al. 2009).

The native range of loblolly pine extends through 14 states from southern New Jersey south to central Florida and then west to eastern Texas (Burns and Honkala 1990). Loblolly pine is found in pure pine stands and in mixtures with other pines or hardwoods, and in association with a great diversity of other vegetation. When loblolly pine predominates, it forms the forest cover type Loblolly Pine (Walker and Oswald 2000). Loblolly Pine is an adaptable species that has been successfully planted along the periphery of its natural range. It is the most commercially important forest species in the southern United States, and has been widely used as important pine species for the plantation forestry in the South (Sternitzke and Nelson 1970; Gaby 1985).

Shortleaf pine has the widest range of the four major pines in the southern United States. It grows in 22 States over from southeastern New York and New Jersey west to Pennsylvania, southern Ohio, Kentucky, southwestern Illinois, and southern Missouri; south to eastern Oklahoma and eastern Texas; and east to northern Florida and northeast through the Atlantic Coast States to Delaware (Burns and Honkala 1990). Natural stands occur from the Gulf Coastal Plain to the edges of the Appalachian Mountains. It grows in most of the ranges of loblolly pine, but extends far to the north (Walker and Oswald 2000). Shortleaf pine is one of the most important commercial pines in the southern United States (Sternitzke and Nelson 1970; Gaby 1985).

Slash pine has the smallest native range of the four major southern pines. Its native range includes the lower Coastal Plain, part of the middle Coastal Plain, and the hills of southern Georgia (Burns and Honkala 1990). It is a major component of three forest cover types including Longleaf Pine-Slash Pine, Slash Pine, and Slash Pine-Hardwood. Slash pine is the most prolific North American tree in production of gum naval stores. In the west of natural range (e.g., western Louisiana and eastern Texas), Slash pine has been widely used in restoration on longleaf pine sites, and in the north of the species range in Georgia and the Carolina Sandhills for pine plantations (Walker and Oswald 2000).

While the natural range of longleaf pine includes most of the Atlantic and Gulf Coastal Plains from southeastern Virginia to eastern Texas and south through the northern two-thirds of peninsular Florida, the longleaf pine stretches into the Piedmont, Ridge and Valley, and Mountain Provinces of Alabama and northwest Georgia (Burns and Honkala 1990). Longleaf pine once was the most important pine in the southern United States for lumber and now plays a minor role in the timber economy due to continued logging, fire exclusion, and reforestation with other pine species (Sternitzke and Nelson 1970; Gaby 1985). Longleaf pine ecosystems are among the most species-rich ecosystems outside the tropics, and there have been increasing efforts for their restoration in the US South (Brockway et al. 2005; Jose et al. 2006).

Six minor southern pine species, including Virginia pine (*P. virginiana* Mill.), pitch pine (*P. rigida* Mill.), pond pine (*P. serotina* Michx.), sand pine (*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.), and Table-Mountain pine (*P. pungens* Lamb.), occur throughout the ranges of the four major southern pine species and are generally found in mixed forest stands (Sternitzke and Nelson 1970; Gaby 1985). Although none of the six minor pines are regionally important, some of them have economic or conservation significance for a given locality (Walker and Oswald 2000). For example, Table-Mountain pine is an Appalachian endemic distributed along the ridges of the Appalachian Mountains and occupies mainly xeric sites of rocky mountainous areas. It grows almost entirely within the range of pitch pine and Virginia pine, but is less frequent. The heavy heath layer in Table Mountain pine stands provides plentiful wildlife food and cover. Also it is an important soil protector, minimizing erosion and runoff (Burns and Honkala 1990).

12.2.1.2 Natural Disturbances

Natural disturbance events of various size and scale, including fires, hurricanes, tornados, ice storms, drought, and SPB, are natural components of southern pine forests and strongly influence forest structure, composition and dynamics in the southern United States (Stanturf et al. 2007). The effects of a disturbances event are variable and complex, depending on the severity of a disturbance event and the timing of its occurrence (Pickett and White 1985). Whereas these disturbance events have negative effects on a forest by killing trees and decreasing stand productivity, they often also have a positive impact on the forest ecosystem by contributing biodiversity, improving habitat for various flora and fauna, and hastening decomposition and succession of the forests (Coulson and Witter 1984; Pickett and White 1985; Coulson et al. 2004).

Fire has played a pivotal role in the evolution and spread of pines, and the maintenance of the structure and composition of the southern pine forests (Vose et al. 1993; Stanturf et al. 2002; Richardson et al. 2007). The pines have evolved morphological and life-history adaptations to fire, conferring resilience to natural fire regimes (Richardson et al. 2007). In fact, most pines depend upon fire for their regeneration or survival (Vose et al. 1999; Stanturf et al. 2002). For example, the Table Mountain pine forests of the Southern Appalachians require periodic fire to maintain their structure and diverse species assemblages (Vose et al. 1993, 1999). The southern pine forests typically have a substantial evergreen shrub component which limits regeneration of future overstory species. Wildfires provide microsite conditions conducive to pine regeneration and reduce understory species competition (Vose et al. 1993). Before Native Americans arrived, lightning-ignited fires were the predominant disturbance type modifying structure and composition of southern pine forests. Native Americans increased both the frequency and season of this natural fire regime. The chronic lightning and Native American fires combined with periodic high-intensity wind- or high severity drought-driven fires created a wide range of fire-adapted communities.

Windstorms, including hurricanes, tornados, downbursts, gales and severe windstorms are damaging agents causing mortality of southern pine forests (Stanturf et al. 2007). The windstorms strike somewhere in the US South every year, accounting for thousands of hectares of disturbed areas (Platt et al. 2000; Peterson 2000). They cause extensive forest damage by uprooting, bending, and breaking trees.

Most wind disturbances result in the post-disturbance vegetation being comprised of surviving canopy trees, and varying amounts of sprouts, released understory stems, and new seedlings (Xi et al. 2008b, c). Standing water, which often accompanies hurricanes, can cause additional stress and mortality (Platt et al. 2000). In terms of the relative importance among these types of windstorms, more damage results from hurricanes in the coastal areas, while tornadoes, downbursts, gales and severe windstorms are the most important type of wind disturbance in the inland areas (Peterson 2000).

Along with fires and wind, ice storms (major freezing rain events) are a frequent and major natural disturbance factor in southern forests. Ice storms periodically disturb southern pine forests in southern United States and have strong damaging effects on more northern portion of pine forests (Bragg et al. 2003). Ice storms occur from October through April. They vary considerably in their severity and frequency and are one of the most devastating winter weather events. Because they usually develop from the clash of weather systems, ice storms often occur on a monumental scale (Hauer et al. 2006). Tree branches or even whole trees may break from the weight of ice during an ice storm. The damage may vary spatially, especially in complex terrain (Lafon 2006). Ice storms annually result in millions of dollars in loss. In extreme cases that occur once every 10–20 years, ice storms have the potential to cause losses in the billions of dollars (Bragg et al. 2003).

Droughts that periodically occur in the southern United States are an environmental stress that commonly triggers lost vigor of pines (Hanson and Weltzin 2000). The immediate response of forests to drought is to reduce water use and growth (Dale et al. 2001). The reduction of growth and consequent mortality may have long-term impact on stand structure and functions. The direct effect is damage and death of the roots, and a significant secondary effect of drought is that it weakens plants and predisposes trees to opportunistic pests. When drought occurs in southern pine forest areas, it also may trigger major outbreaks of SPB (Vose et al. 1993). Consequences of long-term drought are generally proportional to the area affected; during the past few decades, an increasing portion of the United States has experienced longer lasting droughts, particularly during the warm season (Karl et al. 1995). This trend has important implications on the pine forests in the US South, and severe drought has been implicated as a major factor to recent accelerated rates of pine tree mortality and decline (Kloeppel et al. 2003).

Insects and diseases have considerable impacts on the health of the southern pines (Walker and Oswald 2000; Wear and Greis 2002; Coulson et al. 2004; Coulson and Stephen 2006). They can kill pines, reduce their growth, degrade wood produces, and in a long-term, as well change the structure and composition of the pine forests. Bark beetles are the destructive insect pests of southern pine forests. Among common bark beetles (Ambrosia beetles, Black turpentine beetle, Ips engraver beetles, and southern pine beetle) in the US South, the SPB is the most destructive beetle of southern pine forests, which attack all the southern pines and can be the primary source of destroying pine stands in outbreaks (USDA Forest Service 1989; Wear and Greis 2002). Acting as invasive agents in susceptible host types, bark beetles may seriously affect the function and sustainability of southern pine forests (Coulson et al. 2004).

12.2.1.3 The Human Impacts

Along with physical and biological influences, human activities have affected pine forests in the southern United States since the first settlement at least 14,000 years ago (Williams et al. 2004). The distribution, composition, and structure of pine forests have been shaped by humans since then. The most important factors of human activities on pine forests include altered natural fire regimes, various harvesting activities, land clearance and abandonment, purposeful planting and other manipulations of natural forest ecosystems, alteration of biota, forest management, and more recently, introduction of exotic species (Richardson et al. 2007).

The human activities in the last 400–500 years have brought much more significant changes of the pine forests in the US South. The cumulative impact of burning by Native Americans profoundly altered the southern forests. During the pre-settlement period, Native Americans used fire to clean vegetation for farming and had strong local impacts on pine forests (Wear and Greis 2002). They burned parts of the forests in which they lived to promote a diversity of habitats, especially increasing the "edge effect," which gave them greater security and stability to their lives. As a result, fire frequency increased (Richardson et al. 2007). After European settlement, much of the natural vegetation in the US South has been greatly altered by human activities through intensive logging for timber and clearing the land for farming, while many southern Indian groups continued to use fire for farming and hunting during this period. All those altered natural and human-caused disturbances interact to each other and influence the distribution, composition and dynamics of southern pine forests (Platt et al. 2002).

Human activities in the past century in the region, mostly fire exclusion, forest fragmentation and urban development, introduction of exotic species, and forest management for goods and services, have introduced novel disturbances or altered the spatial and temporal nature of "natural" disturbances (Wear and Greis 2002; Richardson et al. 2007). Much of the forested landscape is heavily populated, and as growth precedes in the region this wildland-urban interface continues to grow. In addition, the range of pine plantations significantly increased in the Southern United States during the past few decades. By the year of 2006, there were about 12.95 million ha of southern pine plantations in the US South (Smith et al. 2009). The pines in plantations are usually dense and grow so fast that stands can become overstocked quickly to a degree that increasingly may be susceptible to the SPB and other bark beetles. Therefore while intensive pine plantation management practices have proven to greatly increase short-rotation pine productivity, in the context of SPB, those practices may have increased the susceptibility of pines to the SPB during outbreaks (Walker and Oswald 2000; Coulson et al. 2004).

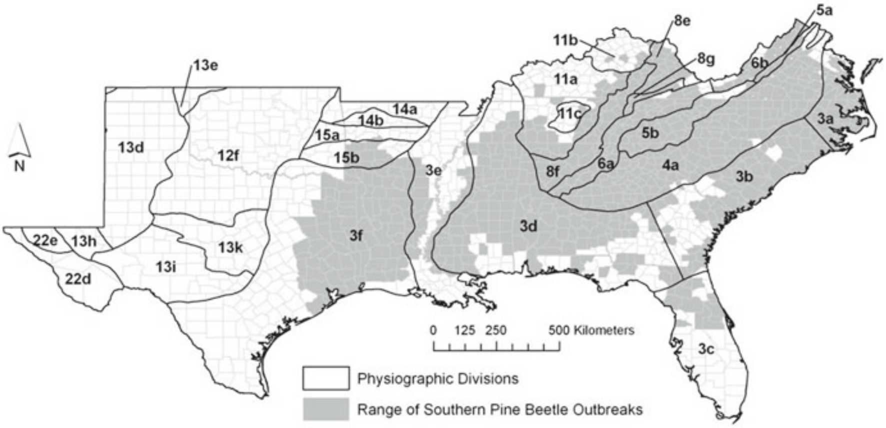

Fig. 12.1 Physiographic divisions of the southern United States and range of southern pine beetle outbreaks within the region from 1960 to 2004. The physiographic divisions are based on Fenneman and Johnson (1946) and include eight major divisions, 25 provinces, and 86 sections representing distinctive areas having common topography, rock types and structure, and geologic and geomorphic history. The codes in this map refers to physiographic provinces (numbers) and sections (letters): 3-Coastal Plain (3a-Embayed, 3b-Sea Island, 3c-Floridian, 3d-East Gulf Coastal Plain, 3e-Mississippi Alluvial Plain, 3f-West Gulf Coastal Plain); 4-Piedmont (4a-Piedmont Upland); 5-Blue Ridge (5a-Northern, 5b-Southern); 6-Valley Ridge (6a-Tennessee, 6b-Middle); 8-Appalachian Plateaus (8e-Kanawha, 8f-Cumberland Plateau, 8g-Cumberland Mountain); 11-Interior Low Plateaus (11a-Highland Rim, 11b-Lexington Plain); 12-Central Lowland (12f-Osage Plains); 13-Great Plains (13d-High Plains, 13e-Plains Border, 13h-Pecos Valley, 13i-Edwards Plateau, 13k-Central Texas); 14-Ozark Plateaus (14a-Springfield-Salem Plateaus, 14b-Boston "Mountains"); 15-Ouachita (15a-Arkansas Valley, 15b-Ouachita Mountains); 22-Basin and Range (22d-Mexican Highland, 22e-Sacramento). Historical southern pine beetle outbreak data were from the Forest Economics and Policy Research Work Units, USDA Forest Service

12.2.2 The Southern Pine Beetle

12.2.2.1 Biology and Ecology

The southern pine beetle (SPB) is a bark beetle indigenous to the southern United States. At endemic levels, bark beetles serve as natural agents of pine tree mortality, especially for lightning-struck or weakened pine trees. SPB mainly occurs in the southern and southeastern United States (Fig. 12.1), extending as far west as Arizona and as far south as Central America. The northern range extends from southern New Jersey and Pennsylvania, west to southern Missouri, south to east Texas, and east into Florida. The beetle has been reported to attack and kill all pine species in its range. Across the southern US, SPB has been known to infest loblolly pine, shortleaf pine, pitch pine, Virginia pine, Table Mountain pine, and occasionally eastern white pine (*Pinus strobus* L.), and eastern hemlock (*Tsuga canadensis* (L.) Carrière) (Payne 1980; Coulson et al. 1999a, b; Coulson and Wunneburger 2000). Multiple-tree infestations often develop in stands occurring on sites with poor nutrient and/or moisture content that contain mature host species with high basal area and stagnant radial growth (Fargo et al. 1985). Such stands are considered to be at high risk for infestation (Mason et al. 1985). Outbreaks are centered initially in high hazard stands, but when populations of the insect become large, less preferred hosts occurring on low hazard sites are also infested. Outbreaks of SPB occur periodically. In the Piedmont and Coastal Plain, outbreaks generally occur on a 7–10 year cycle (Price et al. 1998). However, in the southern Appalachians outbreaks occur less frequently. The factors that lead to SPB outbreaks are poorly understood, but when favorable environmental conditions coincide with optimal resource availability, populations increase in size, and outbreaks often follow (Rykiel et al. 1988).

During an outbreak year, newly emerged female adult pine beetles will fly from their natal tree to a new, potential host tree which they attempt to attack. Beetles attack trees by attempting to bore into the phloem triggering the release of host tree terpenes and SPB pheromones (Borden 1974; Payne 1980; Flamm et al. 1989). These attractants (particularly the pheromone frontalin and the host tree odor α–pinene) result in the subsequent immigration of large numbers of pine beetles, especially males, to the new host tree (Renwick and Vité 1969; Payne 1980; Flamm et al. 1989). The arriving males release their own attractant pheromone (endo-brevicomin). As the density of beetles increases, higher concentrations of pheromones create an inhibitory effect which instigates emigration to other host trees (Gara and Coster 1968; Payne 1980; Flamm et al. 1989). Mating occurs in the host tree and eggs are deposited in S-shaped egg galleries. Larvae hatch from the eggs within 2–9 days (Fronk 1947). Emergence of new adults is completed within ca. 28 days under optimal conditions (Wagner et al. 1984). Within a single year, 3–8 generations are possible depending on environmental factors (Coulson et al. 1980, 2004; Coulson and Witter 1984).

The geographical distribution of SPB is difficult to estimate exactly because of the periodic nature of outbreaks, year to year variations in climate and the possible influence of climate change (e.g., Ungerer et al. 1999). However, recently there has been evidence of range expansion in the South and changes in northern range limits (as was evident in the recent unprecedented large-scale outbreak in Kentucky and Ohio in 1999–2001, Williams and Liebhold 2002; USDA Forest Service 2003; Smid 2008). The northern range limit of SPB roughly corresponds with the isoline of the average minimum annual temperature representing a 90% probability of reaching the lower lethal temperature of the species (−16 °C) (Ungerer et al. 1999). Global climatic warming trends may be responsible for raising the northern limit of this isotherm (Gan 2004; Tran et al. 2007). It has been estimated that an increase of 3 °C in minimum temperature would result in an extension of the northern limits of SPB by 170 km (Ungerer et al. 1999).

12.2.2.2 Spatial Characteristics

The behavior of populations at the scale of the stand is fairly well understood. In non-outbreak years, small populations of beetles will colonize stressed or injured trees, particularly those that have been struck by lightning (Coulson et al. 1983, 1986; Flamm et al. 1993). As populations rise within injured trees, beetles begin to sequentially inhabit neighboring trees by degree of host attractiveness (Coulson et al. 1980). Thus, directionality of outbreak is largely determined by host suitability. If no suitable host trees are available, adult beetles will disperse and outbreaks will generally not occur. It is thought that wind may also influence directionality of infestations by affecting bark beetle dispersal (Byers 2000).

One factor contributing to attractiveness of potential hosts is tree density within stands. It has been repeatedly shown that densely planted or high basal area stands increase the likelihood of infestations (Gara and Coster 1968; Bennett 1968, 1971; Lorio and Bennett 1974; Leuscher et al. 1976; Hicks et al. 1978). Potential host trees become less likely to be attacked when spaced greater than about 6–7.5 m away from currently infested trees (Gara and Coster 1968). Similar research measured average movement distances of about 8 and 18 m for remerged and emerged beetles respectively (Schowalter et al. 1981). The planting distance in pine plantations typically is less than the beetle dispersal distance. This may explain why pine plantations are usually subject to higher hazard during SPB outbreaks (Wear and Greis 2002). Age is another factor that affects host preference with trees greater than 40 years old being most susceptible to pine beetle attack and mortality (Hicks et al. 1980).

Landscape-scale dynamics are much less understood than within stand dynamics. Landscape-scale studies deal with networks of habitats and population centers that occur in heterogeneous areas characterized by multiple interacting ecosystems (Coulson et al. 1986). The epidemiology of SPB involves a network of high hazard stands, lightning-struck hosts, and existing population centers that are connected through insect dispersal behavior (Coulson et al. 1983, 1986). Some general characteristics of regional (state) scale outbreaks include (1) host characteristics drive the risk of SPB outbreak, (2) outbreaks occur across multiple, adjoining states, (3) outbreaks are initiated simultaneously at multiple locations in adjoining states, and (4) outbreaks expand from multiple epicenters in multiple states (Pye 1993a, b). Three types or arrangements of host trees (acceptable species, susceptible habitat patches, and lightning-struck hosts) serve as targets for SPB (Coulson et al. 1999a, b). SPB outbreak probability is positively related to fall precipitation (the single strongest predictor), and summer and winter daily maximum temperature (Gumpertz et al. 2000).

Most recently, we used a modeling approach to show how landscape structure and herbivory interact to influence outbreaks of SPB in a landscape representative of the southern Appalachian Mountains (Xi et al. 2007, 2008a, 2009). We found that landscape composition was less important than host aggregation in determining the severity of SPB outbreaks. Also, simulated southern pine beetle outbreaks over time tend to decrease the aggregation of host species on the landscape by fragmenting large patches into smaller ones, thereby reducing the severity of future outbreaks. The results of this study indicate that when considering alternative restoration strategies for insect-affected landscapes, it is necessary to consider the patterns of hosts on the landscape as well as the landscape composition (Cairns et al. 2008a, b).

12.2.2.3 Ecological Impacts and Environmental Damage

Ecological impacts: In the most general terms, the direct ecological impact of SPB is that it kills pine trees (Fig. 12.2). In SPB damaged areas, stand density and basal area of pine trees decreases following a SPB outbreak. SPB-induced pine tree deaths may trigger a series of ecological changes (e.g., Conner et al. 1991, 1998). The SPB-related tree deaths cause openings in the forest canopy that permit increased light availability in the understory. Changes in light availability may alter overstory and understory species composition (Department of Agriculture (USDA) Forest Service 1989).

Acting as a disturbance agent for susceptible host types, SPB also affect the structure and diversity of the damaged forests. In the year 2000, the pine forests in two watersheds at USDA Forest Service Coweeta Hydrologic Lab were infested by SPB. In a comparative study on SPB and non-SPB impacted permanent plots, there was greater tree seedling species richness in beetle damaged plots than non-beetle damaged plots, while herb layers species richness tended to be greater in non-beetle plot (Kloeppel et al. 2004). In 2001, two of the beetle plots had 1 and 18% of their total basal area killed by beetles. By 2003, tree mortality due to SPB occurred in all plots ranging from 16 to 57% of total basal area. There was significantly more Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.) and violet species (*Viola* spp.) in non-beetle plots than in beetle plots, and there was significantly more low-bush blueberry (*Vaccinium vacillans* Torr.) in beetle plots than in non-beetle plots (Kloeppel et al. 2004).

By killing trees and decreasing crown cover, SPB may also impact the habitat of other ecologically important species (USDA Forest Service 1989). Red-cockaded woodpecker (*Picoides borealis* Vieill.), for example, is a federally endangered species dependent upon mature pines for nesting, roosting and foraging for insects. Reduction of the population in Daniel Boone National Forest in eastern Kentucky has been attributed to the destruction of suitable pine habitat following SPB outbreaks (USDA Forest Service Forest Health Protection 2005). Similarly, using the Bankhead National Forest as a study area, Tchakerian et al. found a reduction in the habitat suitability of stands for pine warbler (*Dendroica pinus* Wilson) following SPB infestations (Tchakerian et al. 2008).

SPB outbreaks increase fuel loading and thereby increase fire intensity and subsequent losses. For example, one study found that wood debris weights were four times higher in former SPB hot spots than in uninfested stands, with total volumes of wood debris up to three times higher in infested versus uninfested stands (Nicholas and White 1984).

SPB outbreaks may also have positive ecological impacts by shaping southeastern pine ecosystem structure and function. It is suggested that at low population densities, lightning-struck or weakened pine trees are removed by SPB thereby enhancing the resistance of pine forests to further SPB infestations. Past studies have also shown that SPB and fire play an important role in maintenance of structure and function of the southeastern pine forests (Schowalter et al. 1981; Williams 1998). A combination of fire and SPB may create sustainable pine forests with complex patterns of succession supporting diverse flora and fauna (Waldron et al. 2007; Xi et al. 2008a, 2009).

Economic damage: The SPB is the most destructive forest insect pest in the southeastern U.S. and the economic damage associated with outbreaks is of national importance (Coulson et al. 2004). According to the USDA Forest Service, ‘Forest Economics and Policy’ working unit’s research, the total value of damage caused by SPB from 1973 to 2004 was $3.57 billion, and from 1991 to 2004 the SPB has been responsible for over $1 billion in damage (Pye et al. 2005). During the more recent 1999–2003 SPB outbreak in the southern Appalachian Mountains and on the Cumberland Plateau, over 0.4 million ha of pine forests were damaged or lost in five states (Alabama, Kentucky, Tennessee, South Carolina, and North Carolina) with an estimated economic impact of $1.5 billion. Over 54,630 ha of pine forest in North Carolina were damaged and the destroyed timber valued at more than $156 million. During the same outbreak period, Tennessee experienced the destruction of approximately 121,406 ha of pine timber valued at $500 million. Alabama lost 80,937 ha of pine forest valued at $250 million (USDA Forest Service, Forest Health Protection 2004).

In the core range of the beetle, damage estimates have been even more dramatic. For example, the Bankhead National Forest in Alabama alone experienced over $20 million in damage between 1986 and 2001, and during the same period, total economic losses in the Homochitto National Forest in Mississippi was $9.3 million (Addor and Birkhoff 2003; Tchakerian et al. 2003).

In addition to decreased timber products, the deterioration of impacted pine stands causes significant negative recreational and esthetic impacts. Although these types of impacts are difficult to measure directly, one study revealed that campground recreation at the Rayburn and Steinhagen Reservoirs in east Texas was impacted by SPB (Leuschner and Young 1978).

12.3 Restoration of Southern Pine Beetle Damaged Pine Forests

12.3.1 Defining Ecological Restoration

Forest restoration generally is accepted as the reestablishment of natural ecological processes that produce certain dynamic ecosystem properties of structure and function (Stanturf and Madsen 2005). It also has been defined as the process of restoring a forest to its original state before degradation (FAO 2002). We broadly define forest restoration as the reestablishment of natural ecological processes that promote specific, historically relevant properties of forest structure and function, after and/or despite the effects of deleterious anthropogenic influences (Xi et al. 2007, 2008a, Fig. 12.2).

Generally, ecological restoration involves some transition from a damaged state to a desired natural condition. Restoration requires understanding of the physical,

Fig. 12.2 Infestation of the SPB illustrating the damage caused by this pest species on forest resources. Infestation of southern pine beetle in the Little Lake Creek Wilderness, southeast Texas on the Sam Houston National Forest, illustrating the damage caused by this pest species on forest resources. The Little Lake Creek Wilderness consists is a 1,796 ha forested landscape and a massive outbreak of the southern pine beetle occurred in 1990. The large contiguous areas of mature host species coupled with favorable weather conditions triggered the southern pine beetle outbreak. As the southern pine beetle can have six to eight overlapping generations per year, the effect of the insect on the forest environment was quick and dramatic. The result was widespread mortality to the mature loblolly and shortleaf pine present on the landscape (Photo by R.N. Coulson, June 1990)

chemical, and biological processes that affect forest growth. Restoration may involve facilitating or speeding up the transition from a damaged to a restored state that would otherwise occur naturally, but more slowly, because of the resilience of natural ecosystem function. However in some cases disturbance may have been so severe that these natural restorative abilities are impaired and significant human intervention is required to drive the recovery of the forest (Heaton et al. 2002).

In our case of restoration southern pine forests following SPB, specific restoration goals need to be set based on damage severity of the pine forests and their desired ecosystem conditions. The damaged forests need to be restored in a way that will prevent or reduce damage from future outbreaks while maintaining the multiple forest management purposes (timber production, wildlife habitat enhancement, biodiversity and rare species preservation, carbon sequestration, and forest sustainability). Thus, it is important to know forest restoration goals, reference vegetation conditions prior to SPB outbreaks, and desired future forest conditions. To achieve a diverse purpose of forest restoration, it is sometimes necessary to use human intervention and restore damaged pine stands towards more diversified mixed pine and hardwood forests.

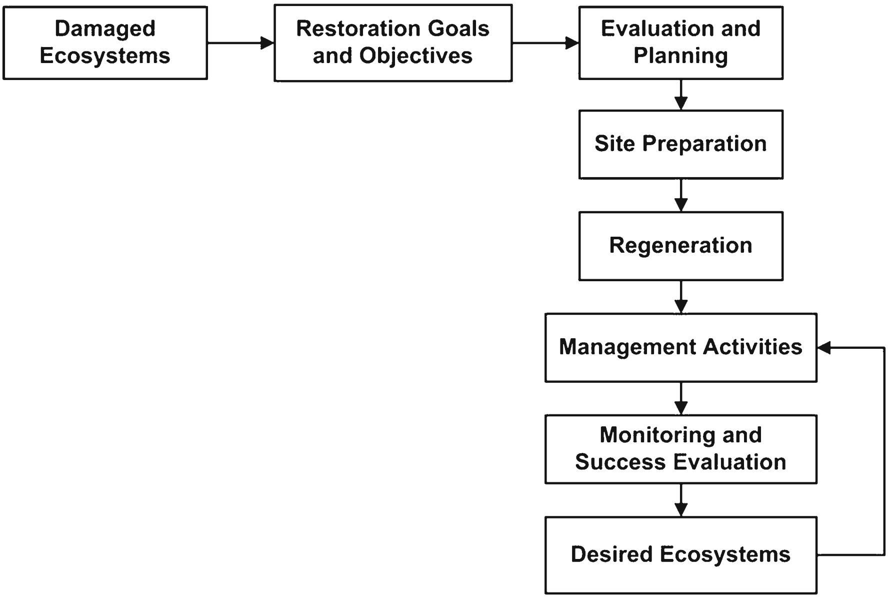

Fig. 12.3 A conceptual model of the process of ecological restoration. Generally, ecological restoration involves some transition from a damaged state to a former natural condition. The establishment of restoration goals and objectives is essential in that, without goals and objectives, there can be no determination of restorative success

12.3.2 Forest Restoration Goals

The objectives of restoration of SPB damaged southern pine forests encompass recovering natural functions and processes within the context of natural and human disturbances (National Association of State Foresters 2001; Coulson et al. 2004; Xi et al. 2007). The goal is to restore ecological processes to promote the reestablishment of native natural vegetation and to return it to a desired state via removal of the cause of degradation (Stanturf and Madsen 2005; Xi et al. 2008a). However, because many restoration projects are situated on both multiple-use public and private forest lands, any restoration efforts must address forest sustainability and wildlife habitat to attain long-term desired future conditions (USDA Forest Service 2004).

The goals for restoration of southern pine forests after SPB in the National Forest System lands are highly variable depending on the overall forest management goals identified in the Land and Resource Management Plan of a National Forest, the nature of damaged ecosystems, the complexity of restoration processes, and the cost of proposed restoration actions. It is essential to clarify appropriate restoration goals and identify project objectives to allow some determination of restorative success (Fig. 12.3). Three major themes/levels that are currently

Table 12.1 Three major themes that currently are used to develop restoration goals: species – ecosystem function – ecosystem service

Restoration goals	Description	Strengths	Weaknesses
Species conservation	Endangered species High interest species Game species Critical habitats	Rescue endangered species Increase biodiversity	Lack of recognition of ecosystem and landscape-level processes Attention to one may divert attention from others
Ecosystem function	MATERIAL FLOW Nutrient cycles Carbon storage Productivity Water flow PHYSICAL ELEMENTS Disturbance regimes Soil formation BIOLOGICAL STRUCTURE Trophic structure Succession Diversity	Ecosystem approach recognizes interaction of large and small-scale processes	Definitions of ecosystem and ecosystem function are not clear Ecosystem processes may be poorly correlated The public may not value ecosystem functions
Ecosystem service	Maintain: hydrologic cycles Regulate climate Clean air and water Pollination of crops Maintain soils Cycle nutrients Detoxify pollutants Provide beauty and inspiration	Generate public support Identify specific actions	Definitions of ecosystem service can be unclear Difficult task of understanding what the public wants Stability of preferences under varying economic conditions local versus non-local preferences

This summary could serve as a starting point for developing restoration goals and objectives for the SPB damaged forests (Modified from Ehrenfeld 2000)

used among foresters and land owners: species conservation, ecosystem function, and ecosystem service, could serve as starting points to develop restoration goals and objectives (Ehrenfeld 2000) (Table 12.1). Essentially, restoration goals should meet the goals and objectives in the Land and Resources Management Plan of the specific National Forests or in a private land, the overall management goals in the damaged area. In addition, the goals and objectives should help restore damaged forests to conditions less susceptible to SPB outbreaks and set the stage for attaining long-term desired future conditions (National Association of State Foresters 2001).

Restoring forest sustainability should be one of the concerns of the restoration efforts in SPB damaged forest landscapes in the southern US (USDA Forest Service 2004). A sustainable forest landscape is one that through a period of time and in the face of management practices: (1) retains the basic elements of its structure; (2) the processes, which define how the system functions, operate within normal or expected ranges; and (3) the system can withstand disturbance and return to the normal condition (Coulson and Witter 1984; Coulson et al. 2004). Sustainability also has a temporal component, which is generally defined by a number of human generations (usually three) (Forman 1995). This time-frame is a practical boundary that attempts to set a realistic planning horizon.

For management purposes, sustainability of a forest landscape is normally defined by a set of criteria (e.g., plant and animal biodiversity) and indicators (e.g., numbers and kinds of soil arthropods) and evaluated in the context of the set of processes that control ecological succession (Lindenmayer et al. 2000). "Sustainability as applied to forestry is the enhancement of human wellbeing by using, developing, and protecting resources at a rate and in a manner that enables people to meet their current needs while also providing future generations with the means to meet their needs as well; it requires simultaneously meeting environmental, economic, and community aspirations." (The Society of American Foresters Council 2001). Sustainable forest management practices are place-based activities that influence the mosaic pattern of landscape element types present through space and time (USDA Forest Service 2004). Both natural (SPB herbivory) and cultural (harvesting) disturbances are expected events associated with the process of ecological succession of forest landscapes (Xi et al. 2007, 2008a).

Realistically a total return to an 'ideal' ecosystem with the same species, composition and structure is impossible to attain since the former ecosystem was the result of the thousands of years of natural processes. As there can be no one paradigm for setting such goals, restoration goals need to be developed appropriately for each project, relative to scope and reasons for the restoration. In addition, a variety of factors (funding, workforce etc.) will require a flexible approach for implementing the proposed actions. Expectations should be clearly communicated (to ecologists, restorationists, and the public) as to what restoration can realistically accomplish. In addition, many other factors (natural, historical, social culture activities, political, aesthetic and moral) need be considered.

Defining restoration goals for non-industrial private forest lands and timber industrial lands are more complex than that for the National Forest System lands because private landowners and commercial forestry tend to maintain a balanced perspective of economic return from restoration of pine forests. Their general goal is the maximization of profit by planting large, even-aged, densely-spaced, monoculture of high-yield pines (usually loblolly pine in the southern United States). In most cases, those returns do not account for ecosystem benefits such as biological diversity and habitat quality as private landowners generally perceive them as public goods and do not consider them in their property goals (e.g., timber production goal, agricultural goal) and their land-use decisions. For the private non-industrial forest lands and timber industrial lands, the restoration goals for SPB damaged pine forest landscapes should be more realistic and needs to consider the landowners' property goals (Molnar et al. 2007).

12.3.3 Benefits of Restored Southern Pine Ecosystems

The material and intangible benefits of restoring southern pine forests, in many areas mixed pine-oak forests, are substantial. Restored southern pine and pine-oak forests can provide local communities with economic and ecological benefits or ecosystem service. Major southern pines are among the most versatile of all the southern pines and provide a variety of highly valued products. High productive southern pine forests are important as the largest source of wood fiber internationally and for some wood processing facilities, such as paper manufacturing and log home building. Restored forests that are maintained in a healthy condition, also bring a premium in recreation-related services to landowners. Moreover, southern pines are an important species that provides high habitat value for many wildlife species.

In one example, pine-grassland restoration for red-cockaded woodpeckers created vegetation composition and structure at the stand and landscape scales that may benefit numerous endangered avian species of regional conservation concern. Mature restored pine-grassland stands had greater avian species richness, total bird abundance, and avian conservation value than traditionally managed pine sawtimber stands (Wood et al. 2004).

12.4 Restoration Framework

12.4.1 Determining Desired Ecosystems and Reference Conditions

Three major steps are key to planning forest restoration: (1) understanding current forest conditions (including SPB damage severity and SPB population dynamics) and reference forest ecosystems (including disturbance regime) as a starting point; (2) clarifying objectives and identifying appropriate goals, and (3) defining feasible actions likely to attain the desired condition. In most cases, foresters may choose among multiple silvicultural pathways toward the desired future conditions (Stanturf et al. 1998). In the restoration planning stage, it is relatively easy to understand current forest conditions. The task of determining desired ecosystems, reference conditions, and assessing 'restorability' is more challenging.

Understanding the structure and function of natural forested ecosystems forms the necessary basis for all forest restoration activities (Landres et al. 1999; Kuuluvainen 2002). Knowledge of the composition, structure and function of natural forests (i.e., the average values) is needed to set goals for restoration and to evaluate the success of particular restoration actions. The ranges of these variations could be critical as well. For a restoration project, a considerable amount of reconnaissance and assessment is needed (Lake 2001). For example between 2000 and 2003 after very high level of SPB infestations, the Bankhead National Forest began a forest restoration initiative to improve and maintain overall forest health and to restore native upland hardwood forests and pine-oak woodlands (Addor and Birkhoff 2003). They identified ‘the desired future condition’ for major forest types and assessed the historical reference conditions in the area. They also conducted analyses of the actual forests in relation to the desired future condition of their natural vegetation and the restoration benefits. In their overall restoration plan, several alternatives were proposed to the forest managers. For each of the proposed alternative, desired future condition and a 5-year priority treatment plan were also proposed in order to achieve the desired future conditions and to prioritize restoration activities.

12.4.2 Restoration of Ecosystem Functions and Processes

Restoration of pine stands killed by SPB is necessary to retain the important ecological functions of the ecosystem (National Association of State Foresters 2001). These damaged pine forest ecosystems need to be restored in a way that reduces future susceptibility to SPB damage. Within a National Forest, all restoration activities should to be undertaken in a manner consistent with the objectives of its ‘National Forest Land Management Plans’. Restoration plans after SPB should include specific recommendations for: (1) what are the desired future conditions, (2) how forest landscapes can be structured to minimize the magnitude of any future SPB outbreaks, (3) which tree species minimize future outbreaks of the SPB, while maintaining other forest management objectives, and (4) what management practices (prescribed fire, thinning or others) should be used to foster forest health.

In the US South, re-introduction fire is important for successful restoration of southern pine forest as fire is an integral part of the natural process to shape the southern pine forests. In the context of SPB, fire may prevent SPB outbreaks by thinning the forests; fire also helps regeneration of young pines. Past research have found that in the absence of fire, a major transformation occurred leading to the loss of pine itself as well as the numerous fire-dependent ground layer species (e.g., Zobel 1969; Buckner and Turrill 1999; Waldron et al. 2007; Lafon et al. 2007; Xi et al. 2009). Since it is impractical to allow wildfire to burn in public or forest lands, prescribed burning is a practical alternative that has been found to be effective to promote regeneration of pines (Vose et al. 1993, 1995, 1999; Waldrop and Brose 1999; Waldrop et al. 2000; Boyle et al. 2004). This issue will be addressed in more detail in the following sections.

12.5 Conducting Restoration Practices

Before conducting any restoration practices, certain recommended direct control practices, including cut-and-remove, cut-and-leave, cut-and-hand-spray, and pile-and-burn, can be applied to the SPB infestation spots, in order to stop further spot growth and reduce tree loss (Swain and Remion 1981). The purpose of these silvicultural treatments is to remove infested and high-risk trees, and to produce environment and biological conditions unfavorable to the attack, spread, and population growth of this forest pest (Thatcher et al. 1980). Certain chemical treatments such as verbenone, which interferes with the pheromone and pine attractants (verbenone-only tactic, or verbenone-plus-felling tactic), can also be used for treating individual trees and SPB spots (Swain and Remion 1981; Clarke et al. 1999).

Ideally, forest landowners and managers should act before the SPB becomes a problem since SPB outbreaks limit management options (Moorhead et al. 2007). Over 70% of the pine stands in the South are at moderate to high risk for SPB (National Association of State Foresters 2001). These stands are typically overstocked, overmature, or are planted with tree species not matched to the site (i.e., off-site). The condition of these stands results in periodic outbreaks from SPB. Proper management of such stands, including pre-commercial thinning and prescribed burning, can significantly lower the risk category (Thatcher et al. 1980; Swain and Remion 1981).

12.5.1 Practical Prevention Concerns

12.5.1.1 Pre-commercial Thinning

Pre-commercial thinning is an important silvicultural technique in long term prevention of SPB. It represents the predominant strategy of prevention efforts in the South (Belanger and Malac 1980; Brown et al. 1987). The main purpose of thinning practice is to reduce stand density, improve the growth and form of the remaining trees, and increase pine vigor and resistance to SPB, thereby increasing economic gains (Belanger et al. 1993). Thinning is preferred before SPB outbreak for reducing susceptibility of a forest stand to SPB (Swain and Remion 1981). Generally, thinning stands to a threshold of about 18 m^2/ha of basal area decreases the frequency and severity of SPB infestations (Thatcher et al. 1980).

Pre-commercial thinning is one of the major practices of the SPB Prevention and Restoration Initiative (i.e., SPB Cost-Share program) administered through the USDA Forest Service since 2003 (Nowak et al. 2008). The objective of this program is to encourage eligible non-industrial private forest landowners in the US South to improve forest health and reduce the threat and severity of SPB attacks through technical assistance and cost-sharing of recommended prevention practices (Nowak et al. 2008). An eligible landowner may receive funds sufficient to complete needed practices at the prevailing rate and cost share rate of 50–70%. Landowners who accept the Program funding are required to maintain those areas in forestland for a period of 10 years and to comply with the provisions in the approved forest management plan (Nowak et al. 2008). During 1999–2008, more than 162,400 ha were thinned in the southeastern US, and the program is an effective approach to prevent SPB damage and promote restoration of southern pine forests after SPB and to involve National Forests, state agencies, and non-industrial private forest landowners (Nowak et al. 2008).

Several southern states, including Florida, North Carolina, South Carolina, Tennessee, Georgia and Texas, have issued related policies and detailed thinning guides. Most of the state-level SPB Cost-Share Program guidelines set targets to thin down to a basal area of 18 m^2/ha (±15%) for first thinning to loblolly pine stands (USDA Forest Service 2005). For example in South Carolina, for pine stands less than 10 years old with more than 1,750 pine stems per ha (if the stand is mixed pine and hardwood, then >70% of stems must be pine) should be considered for thinning to 750–1,600 stems per ha (South Carolina Department of Agriculture Division of Forestry 2006).

The thinning is best accomplished during periods when SPB populations are low (USDA Forest Service 2005). The first thinning should be performed as soon as the seedlings are well established, usually between ages 2 and 5 before they have experienced severe intra-specific competition (Moorhead et al. 2007).

12.5.1.2 Prescribed Thinning

While prescribed burning is most often used to control hazardous fuel accumulation in the US South, it is also commonly used in naturally regenerated pine forests to thin the forests and to reduce understory competition, and can be used to treat a large number of areas at a low cost relative to other treatments (USDA Forest Service Fire and Aviation Management 2006). The USDA Forest Service defines prescribed burning as ‘fire applied in a knowledgeable manner to forest fuels on a specific land area under selected weather conditions to accomplish predetermined, well-defined management objectives’ (USDA Forest Service 1989). Prescribed burning has been used to control fast-growing understory, and promote pine tree regeneration. In Great Smoky Mountain National Park, for example, the forest managers have been using prescribed burning (plus allowing lightning ignited fires in certain zones to burn) to restore declined Table Mountain pine (National Park Service Great Smoky Mountains National Park 2007). Prescribed burning is especially effective for establishing and propagating longleaf pine, which is a fire-dependent species (Brockway et al. 2005).

Prescribed burning is an optional treatment in the SPB Prevention and Restoration Program for SPB damaged pine forests in the South (U.S. Department of Agriculture and Forest 2005, 2007; Nowak et al. 2008). During the SPB Prevention and Restoration Program’s first 5 years (2003–2007), about 48,500 ha were prescribe burned on state and private lands. Prescribed burning is also used for site preparation because it increases natural pine regeneration and seedling growth (Vose et al. 1993), releases nutrients into the soil (Stark and Steele 1997), alters the canopy structure and light environment (Zobel 1969; Coleman and Rieske 2006), and reduces vegetative competition (Vose et al. 1995; Waldrop 1997). However, limited literature currently exists on the relationships between the prescribed burning and bark beetles in the southern United States. Because the value of prescribed burning for directly reducing the SPB hazard remains unclear, some of the southern states do not include this practice among the cost-share eligible treatments (Nowak et al. 2008).

Such management, however, is a long-term process requiring a number of integrated steps. The Integrated Pest Management (IPM) concept and methodology (Thatcher et al. 1986; Saarenmaa 1992; Coulson et al. 2004) is useful as a means to this end. Certain management plans need to be made for treatment priority. For this, survey data (e.g., Forest Inventory and Analysis, Forest Health Monitoring) can identify areas at higher risk. More detailed surveys may be needed to identify specific stands at risk of SPB damage (Coulson et al. 2004). Management plans can be developed to use appropriate available technology, and consider the need for various prevention techniques (thinning, moving to pine/hardwood mix, restoring proper species, managing age structure, and managing hazardous fuels). Where appropriate, assistance programs can be utilized to help landowners with activities that do not generate offsetting income (Coulson et al. 2004). This encourages proper stand treatments. The end result should be a healthy ecosystem and viable communities with minimal SPB problems (National Association of State Foresters 2001). Finally, a conservation education and landowner outreach program can be used to reach potentially affected landowners (Clarke 2001; Molnar et al. 2007).

12.5.2 Restoration Methods

Restoration is an effective and aggressive forest management practice to restore damaged forests (Stanturf and Madsen 2005). Restoration efforts, including (but not limited to) site clean-up, site preparation, natural regeneration, and replanting less susceptible pine species or hardwood trees should be conducted soon after SPB outbreaks (Nowak et al. 2008).

Restoration practices can return damaged areas back to healthy forests by creating stands which are less susceptible stands to future SPB outbreaks (Swain and Remion 1981; Rabaglia 1994; Moorhead et al. 2007; Nowak et al. 2008). This is also the major goal of the national level SPB Prevention and Restoration Program (USDA Forest Service 2005). The emphasis of restoration has been placed on low density planting of suitable pine trees to create pine stands, and in some areas, suitable pine and hardwoods to create mixed pine-oak forests. During the program's first 4 years (2003–2006), nearly 30,000 ha of damaged pine forests were restored according to the program's guideline (Nowak et al. 2008).

12.5.2.1 Site Clean-Up to Minimize Logging Damage

After SPB outbreak, removal of offsite, high-risk stands, and dead trees is a necessity (Thatcher et al. 1980, 1986; Billings and Bryant 1987). Pine trees damaged by recent logging (within the past year) favor SPB infestations (Hyland 2008). Careless cutting, skidding, and hauling often cause severe mechanical injury to above and below-ground portions of residual trees. Those moderately to severely damaged trees are of high-hazard to their neighboring trees and should be removed from the stand as soon as possible (Thatcher et al. 1980). It is critical that damaged trees created by SPB activity along roads, in recreation sites and in other high use areas be treated. In most cases, this means prompt removal, due to the risk these trees pose to human health and safety, as well as the potential of beetles coming from these trees to infest other trees in the stands (Billings and Bryant 1987).

12.5.2.2 Site Preparation for Restoration

Site preparation may include a combination of prescribed burning, mechanical, and chemical treatment of competing vegetation. Site preparation has been found to improve southern Appalachian pine-hardwood stands (Knoepp and Swank 1993). Prescribed burning is perhaps the least expensive method for site preparation, but should be used with caution since pine stands following SPB are relatively dry with large volumes of dead materials (Ganz et al. 2003). The impact of mechanical vegetation removal on the soil is substantial and should also be used with caution because the disturbed soil layers are often critical to site productivity (Thatcher et al. 1980). Herbicidal treatment could be used in restoration areas to prepare SPB damaged sites for regeneration of pines (Forest Service Chattahoochee-Oconee National Forest 2005). The treatment methods include (1) basal stem spraying, (2) hack and squirt method, and (3) cutting trees and then treating the cut stumps with an herbicide. The objective of this treatment is to control competing vegetation to allow pine species to re-establish (USDA Forest Service Chattahoochee-Oconee National Forest 2005).

12.5.2.3 Natural Regeneration of SPB Damage Areas

Natural regeneration has low restoration costs and can satisfy a number of forest management goals. Natural regeneration of pine after SPB occurs at some locations in the South, and ‘replanting’ may not be the best option for some private landowners (The Southern Appalachian Man and Biosphere 2004). This natural regeneration often is a result of (1) pine seeds that fell prior to the death of their parent tree or (2) the few remaining green pine trees that are providing a nearby seed source. In these cases, efforts should be made to promote natural regeneration of pines (i.e., through forest succession).

Certain management practices may still be needed to reduce competition from understory hardwoods under this ‘natural regeneration’ option, otherwise natural regeneration will take its course and most likely the damaged pine stands will be replaced by hardwoods. Data from the Coweeta Hydrologic Lab near Franklin, NC show that once the pine is gone from sites, if there is no human intervention, the pines probably will not come back. At Coweeta, most of these sites where nothing was done are now dominated by low-quality hardwoods with a dense mountain laurel understory (Southern Appalachian Man and Biosphere 2004).

Fig. 12.4 Replanting less susceptible species, such as longleaf pine, to SPB is recommended by USDA Forest Service SPB Prevention and Restoration Program. The photo shows seedlings after 5 growing seasons (Photo by David Stephens, Bugwood.org)

12.5.2.4 Tree Replanting

Planting offers the best opportunities to control seedling quality, species composition, stocking for the future stands. The USDA Forest Service has recommended replanting less susceptible pines, including certain hardwood species, on appropriate sites when conducting post-SPB forest restoration (USDA Forest Service 2005). In general, longleaf pine and eastern white pine are less susceptible pine species to SPB (Thatcher et al. 1980). However, the suitable pines may have considerable regional variability. Longleaf pine is the most resistant pine to SPB attack, and should be considered for planting in its range, especially in Georgia, Alabama, and Florida (Thatcher et al. 1980; USDA Forest Service 2005, Fig. 12.4). Eastern white pine is considered resistant to SPB infestation and has been recommended in Tennessee and North Carolina (North Carolina Division of Forest Resources 2009; Tennessee Department of Agriculture 2009). Shortleaf pine can be considered for most of the southern States (Thatcher et al. 1980). Loblolly and shortleaf pines, although susceptible to SPB, are still recommended by some states (e.g., South Carolina and Tennessee).

Landowners should avoid planting pines off-site or outside its natural range, especially loblolly and shortleaf pines, which are more susceptible to SPB than longleaf (Florida Department of Agriculture and Consumer Services Division of Forestry 2009). Even if a site is a pine site, there are differences in soil types, geographic location, and moisture which make sites more suited to some species of pine than others (Thatcher et al. 1980). The relative resistance of longleaf pine to SPB (and some major pathogens) has led to pressures to plant these species on less than ideal sites. Since many sites in the southern US are well suited to loblolly pine, it is also recommended as a replanting species for most southern states (e.g., Tennessee Department of Agriculture 2009; South Carolina Forestry Commission 2009). As a possible alternative, research plantings of seedlings from SPB resistant loblolly pine trees are beginning on experimental forests for long-term evaluation (Nowak et al. 2008). In some places, hardwood species such as red oak also can be considered to create mixed pine-oak forests and to promote a diversity of tree species and ages in a forest landscape that improve wildlife habitat (Addor and Birkhoff 2003; USDA Forest Service Chattahoochee-Oconee National Forest 2005).

Restored sites should be re-planted at low densities and stocking regulated for reducing SPB damage (Thatcher et al. 1980). Starting with the planting process, a landowner need consider SPB in the determination of the planting density (spacing). With modern planting techniques and site preparation methods pines grow, and thus gain crown closure faster. This leads to quicker onset of competition stress (Billings and Bryant 1987). Stands planted at high densities reach "high hazard" for SPB at an early age (sometimes before the stand has an average diameter large enough for commercial thinning) (USDA Forest Service 2005). The easiest and best way to avoid this is to plant fewer than ca. 1,340 seedlings per ha. When replanting, plant to a maximum of 1,375 stems per ha for all pine species (Florida Department of Agriculture and Consumer Services Division of Forestry 2009; North Carolina Division of Forest Resources 2009; South Carolina Department of Agriculture Division of Forestry 2009; Texas Forest Service 2009; Nowak et al. 2008). Lower initial planting densities should reduce overcrowding in later years, which will delay or alleviate the need for future forest health treatments (Hyland 2008).

In areas where endemic pine species abundance has been lowered due to SPB activity (e.g., Table Mountain pine on southern Appalachian xeric ridges and peaks) it is naturally preferable to restore endemic pines (Xi et al. 2007). Promoting natural regeneration of the pines by prescribed fire or other management practice is helpful for restoring endemic pine species (Vose et al. 1993). For example, one review recommends intense, small-scale prescribed burning to clear the forest floor down to mineral soil, eliminate hardwood competition, and allow Table Mountain pine regeneration (Buckner and Turrill 1999).

12.5.2.5 Post-restoration Care

Good post-restoration management could ensure high level of establishment of planted pine seedlings. Once seedlings are established, the principal factors affecting seedling development are vegetative competition and the environmental factors. Prescribed fire is the most common cultural treatment used to reduce competition (USDA Forest Service 2005). Other practices, such as fertilization, pre-commercial thinning of young pine stands also are important. Additional management techniques include use of herbicides to reduce competition (USDA Forest Service Chattahoochee-Oconee National Forest 2005). Use of herbicides increases stem growth over areas where no herbaceous vegetative control is used (Creighton et al. 1987).

Table 12.2 Cost ranges for prevention and restoration related activities of damaged southern pine forest in five southern states of the United States

	Tennessee	Florida	North Carolina	Texas	Georgia
Site preparation	280–750	125–500	250–850		155–310
Release	280				250
Pre-commercial thinning	280	250		375–525	440
Prescribed burning		75			30
Replanting pines and hardwoods	200–270	200	350–450		125–185

The data were compiled based on the information in the guidelines of the Southern Pine Beetle Prevention Cost-Share Programs (Florida Department of Agriculture and Consumer Services Division of Forestry 2009; North Carolina Division of Forest Resources 2009; Tennessee Department of Agriculture Division of Forestry 2009; Texas Forest Service 2009; Georgia Forestry Commission 2009). The costs are US dollars per hectare. Actual costs may vary based on forest types and treatments

Mechanical measures such as hand tools and bulldozers can be used for understory vegetation control (Balmer and Little 1978; Thatcher et al. 1980). Using bulldozers, although expensive, may effectively help to clear-up the undesired understory, reduce competition and promote forest heath in SPB damaged areas (Nowak et al. 2008).

12.5.3 Estimating Restoration Costs

The on-going SPB Prevention and Restoration program and the state-level cost-share guidelines provide general cost ranges. Since 2003, USDA Forest Service has allocated nearly $70 million to state forestry agencies and national forests during federal fiscal years 2003–2008 through the SPB Prevention and Restoration Program (USDA Forest Service 2005, 2007; Nowak et al. 2008). A landowner, under the program, can receive up to about $10,000–$20,000 annually in cost share payments in a federal fiscal year (Florida Department of Agriculture and Consumer Services Division of Forestry 2009; North Carolina Division of Forest Resources 2009; South Carolina Department of Agriculture Division of Forestry 2009; Texas Forest Service 2009; Nowak et al. 2008). Actual costs vary across the southern states based on forest types and treatments (Table 12.2).

12.6 Social and Political Context

12.6.1 Improving Understanding and Knowledge

Since 1970s, the USDA Forest Service has supported a series of research programs to improve understanding and knowledge of SPB biology, stand susceptibility, and measures for suppressing SPB and outbreak prevention (Clarke 2001; Coulson et al. 2004). Recommended suppression and prevention practices have been in existence for some time (e.g., Thatcher et al. 1980; Swain and Remion

1981; Billings and Bryant. 1987; Belanger et al. 1993; Clarke et al. 1999; National Association of State Foresters 2001; Clarke and Billings 2003). However, knowledge of practices for effective restoration of stands after SPB outbreaks is relatively limited (Coulson et al. 2004; USDA Forest Service 2005; Xi et al. 2007, 2008a, b, c). From 1999 to 2003, SPB caused unprecedented damage to pine forests in the southern Appalachian Mountains (Pye et al. 2005). These losses severely impacted the natural resource base that supports the South's tourism and wood-based manufacturing industries and also destroyed the habitat of threatened and endangered species. Since then, Forest Health Protection and the Southern Research Station provided funding through SPB initiative funds to cooperatively focus more resources on SPB prevention work and restoration efforts (Nowak et al. 2008).

The leading unit for research and development on SPB control and prevention, SRS-4552: Insects, Diseases, and Invasive Plants, has funded millions of dollars in cooperative research to increase understanding of the insect and to enhance the ability to reduce its negative impacts. Projects funded addressed a number of high priority areas including (but not limited to): (1) determining risks and costs, (2) preventing and controlling outbreaks, and (3) recovering from outbreaks. These collaborative efforts have included studies conducted by research scientists at universities, private companies, and state forestry agencies.

12.6.2 National, State Policy Implications

Existing laws in the US provide a legal framework for, and have positive impacts on, forest restoration efforts. For example, on December 3, 2003, President Bush signed into law the Healthy Forest Restoration Act of 2003 to reduce the threat of destructive wildfires while upholding environmental standards and encouraging early public input during review and planning processes. The bill directs the USDA to conduct an accelerated program of study of certain insect pests that have caused large-scale damage to forest ecosystems. It also directs the USDA to assist land managers in the development of treatments and strategies to improve forest health and reduce susceptibility to future infestations (The bill is available online at http://rpc.senate.gov/_files/L46ev102903.pdf).

In addition, existing policies focus specifically on SPB prevention and encourage forest landscape restoration. In 2000, after severe SPB outbreaks in the southern Appalachians, National Association of State Foresters issued a policy statement (National Association of State Foresters 2001: Southern Pine Beetle: A Time for Action to Protect the South's Forests) and provided a strategy for action. The statement emphasized actions to reduce both immediate and long-term threats to forest resources and associated impacts to forests. The strategy consists of seven components:

1. Continued suppression of pine beetle epidemics using time-tested and effective control strategies.
2. Reduction of future epidemics by making existing forests more beetle resistant.

3. Prevention of loss of the southern yellow pine ecosystem through restoration of forests destroyed by the beetle, but in a form less susceptible to future beetle attack. This includes removal of beetle-killed trees that pose imminent hazards to people in high public use areas.
4. Assistance to communities affected by beetle epidemics to protect jobs and to develop the infrastructure necessary to employ effective beetle control and prevention techniques.
5. Funding necessary for full compliance with all laws, planning, implementation, monitoring, accountability, and coordination among federal and state agencies.
6. Funding for educating the public and landowners about the SPB and the need for suppression and prevention activities.
7. Conducting research to support suppression, prevention, and restoration activities.

In 2003, the USDA Forest Service supported a meeting that identified SPB research, development and application and has provided a framework for action (Coulson et al. 2004). In 2004, the SPB Prevention and Restoration Program was authorized and funded by grants from the USDA Forest Service FHP. FHP developed the SPB Prevention and Restoration Program and is working with 12 national forests and all 13 States in the Southern Region (USDA Forest Service 2005). The SPB Prevention Initiative Funding has allocated approximately $60 million to state forestry agencies and national forests since 2003, making it one of the larger federal bark beetle prevention programs in the U.S. history of forest health management (Nowak et al. 2008).

12.6.3 Engaging Public Involvement in Restoration and Prevention Practices

Restoration is a long-term investment that many landowners cannot undertake without financial assistance (National Association of State Foresters 2001; Coulson et al. 2004). The federal interest is in the maintenance of a healthy, diverse forest ecosystem that is available to serve a variety of needs, including economic and environmental needs. The success of a restoration program hinges on available funds to accomplish work on both public and private lands (USDA Forest Service 2005, 2007). Work includes restoration and thinning in areas considered high priority from a forest health perspective. Considerable effort is underway to integrate SPB prevention work with other national forest objectives; including fire hazard reduction, red-cockaded woodpecker habitat protection, and timber stand improvement (Nowak et al. 2008).

The SPB initiative has positively impacted southern states. Forest management tools and strategies associated with the SPB program have encouraged thinning and hazard fuel reduction on more than 161,880 ha across the South (Nowak et al. 2008). For National Forests nearly 38,445 ha of SPB prevention practices will be completed on national forests by the end of 2007, in addition to practices being completed on state and private forests. SPB management approaches are now more proactive, and current accomplishments will have long lasting impacts on forest health (Nowak et al. 2008).

In addition, the USDA Forest Service regulations require public input and involvement during review and planning processes. The purpose of the public input is to determine the issues and concerns related to the proposed plans (Clarke 2001).

12.6.4 Educating Landowners for Forest Health and Sustainability

Many landowners in the Southern US are unaware that SPB is a source of timber loss or they have little interest in limiting SPB impact (Mayfield et al. 2006). This lack of awareness creates an opportunity to educate landowners about the benefits of healthy management, SPB prevention and forest restoration (Clarke 2001; Nowak et al. 2008). Several states have well-developed landowner education programs incorporated in their SPB prevention and restoration programs (e.g., North Carolina Division of Forest Resources 2009; Texas Forest Service 2009). Educational materials include online publications, posters, and brochures. The SPB initiative program educated thousands of landowners about SPB challenges (Nowak et al. 2008). In addition to an internet clearinghouse (http://whizlab.isis.vt.edu/servlet/sf/spbicc/index.html) for SPB information, control strategies, and on-going research, knowledge gained from decades of SPB research is being synthesized into an online encyclopedia (Coulson and Klepzig 2008) to make it more accessible to managers, researchers, and the public. Special efforts are progressing in several states in the South to reach traditionally underserved and minority landowners (Nowak et al. 2008).

12.7 Conclusion and Future Research Needs

Restoring pine forests damaged by SPB requires a proper understanding of the components of the host forests: composition, pattern, functions, process, resilience, and continuity in time and space. Ongoing cooperative research and program support will better prepare the forestry community to identify and address future SPB outbreaks throughout the South. Prevention and restoration should be conducted in concert with one another. Recently SPB activity has increased in the southern US, including North Carolina, Southern Carolina, Georgia, Alabama, and Mississippi; therefore continued cooperation among Federal, State, and private partners is critical.

12.7.1 Implications for Practice

- In the southern United States, the old-growth southern pine forests are under periodic threats from the outbreaks of southern pine beetle and have resulted in substantial timber losses and devastating social and ecological impacts.

- The successful restoration of the pine forests requires a proper understanding of the pine ecology, beetle biology and landscape restoration through a combined government and grass root efforts.
- Understanding reference forest conditions, clarifying restoration objectives and identifying appropriate goals, defining feasible actions likely to attain the desired condition, are three key steps for planning pine forest restoration.
- Restoration efforts, including (but not limited to) site clean-up, site preparation, natural regeneration and replanting certain pines and hardwood trees, should be conducted soon after SPB outbreaks.
- Certain silvicultural practices, including cut-and-remove, cut-and-leave, cut-and-hand-spray, and pile-and-burn, can be applied to the SPB infestation spots, in order to stop further spot growth and reducing tree loss.
- Certain issues need to be considered include improving understanding and knowledge, engaging public involvement in restoration and prevention practices, educating landowners for forest health and sustainability.

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