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Ecological Impacts of Southern Pine Beetle

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Abstract

The southern pine beetle (SPB) is the most important biotic disturbance in southern pine forests and causes extensive changes to the forest environment. In this chapter we provide an overview of the ecological impacts of the SPB on forest conditions (the state of the forest) and on forest resources (uses and values associated with the forest). We define ecological impact as the effects—positive or negative—of SPB activities on the forest ecosystem. The impact on forest conditions is the result of widespread tree mortality, which affects ecological processes such as: primary production, nutrient cycling, forest succession, and forest composition and configuration. We discuss how the SPB affects these ecological processes through modification of the physical environment and the temporal distribution of resources. For the ecological impact on forest resources, we emphasize the impacts of SPB on resources that are affected from an ecological point of view (e.g., hydrology and wildlife). Changes in forest structure resulting from SPB herbivory can modify key hydrologic processes that control the quantity and quality of water reaching a stream. The ecological impacts of the SPB on wildlife are the result of changes in the distribution and abundance of plant species and insect populations. Increases in SPB densities directly affect the food available for insectivore birds, mainly bark-foraging woodpeckers. The impacts on wildlife have been deduced from changes in wildlife habitat as a result of SPB infestations. An approach to estimate the impacts of SPB herbivory on wildlife habitat in a forest landscape is introduced.

15.1. INTRODUCTION

The structure, function, and processes of forest ecosystems have evolved with natural disturbances such as fire, windthrow, and pest epidemics (Crow and Perera 2004). In the Southeastern United States, southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) is the most important biotic disturbance and, along with fire, regulates the dynamics of nutrient cycling and succession of pine forests. Southern pine beetle outbreaks cause extensive change in forest conditions (the state of the forest environment) by modifying the processes of primary production, nutrient cycling, ecological succession, and the size, composition, and configuration of forest trees. The cumulative effects of SPB outbreaks can impact forest resources (uses and values associated with the forest environment) such as timber production, water quality and quantity, fish and wildlife populations, recreation, grazing capacity, real estate values, biodiversity, endangered species, and cultural resources (Coulson and Stephen 2006). It is obvious that the impact on forest resources results in economic losses to forest landowners (economic impact) and affects how humans perceive and use the forest environment (social impact); these topics are discussed in chapters 14 and 16 respectively.

For the purposes of this chapter, ecological impact of the SPB is defined as the effects of SPB herbivory on the forest ecosystem. The effects can be perceived as qualitative or quantitative changes in conditions and resources associated with the forest ecosystem, and can be positive or negative (Coulson and Stephen 2006). The most evident impact of SPB herbivory on pine forests ecosystems is the reduction or mortality of host tree species. Tree mortality by insect herbivory results in increased light penetration through the forest canopy, reduced competition among plants, changes in plant species composition and biomass, increased rates of water runoff and nutrient leaching, higher rates of litter decomposition, and redistribution of nutrients (Coulson and Witter 1984). One ecological effect of SPB outbreaks is the shift of forest structure from mature and overmature host trees to regenerating seedlings and competing vegetation species (Land and Rieske 2006). This shift is known to influence other ecological processes such as nutrient redistribution, ecosystem succession, and alteration of wildlife habitat (Coulson and Witter 1984).

Evaluating the ecological effects of the SPB has been a more difficult task than characterizing its social and economic impacts. Understanding of the natural role of the insect is essential for a true understanding of the impact (Stark 1987). Insufficient and inadequate historical data and lack of ecological theory have limited the efforts to evaluate the probable role of the SPB in forest ecosystems. In spite of this, considerable research has been made on the role of the beetle as a regulator of southern forest ecosystems at multiple scales (Coulson and Stephen 2006, Raffa and others 2008, Schowalter and others 1981a).

The goal of this chapter is to present a current overview of the existing information on the impacts of SPB herbivory on forest ecosystems. The specific objectives are: 1. to consider the effects of the SPB on forest conditions (the state of the forest) and 2. to examine the effects of SPB herbivory on forest resources (uses and values associated with the forest). Figure 15.1 outlines the organization of the topics covered in this chapter. Although forest resources are considered in this review, we place emphasis on the impacts of the SPB on resources that are affected from an ecological point of view (e.g., water quality and quantity, wildlife, endangered species).

15.2. SPB IMPACT ON FOREST CONDITIONS

Widespread tree mortality by SPB herbivory modifies the structure, composition, and function of southern pine ecosystems. This section examines how the SPB brings about change in the forest environment. It considers how SPB outbreaks influence the abundance, composition, and configuration of forest vegetation through modifications of the physical environment and the spatial and temporal distribution of resources. The ecological processes of primary production, nutrient cycling, ecological succession, and forest composition and configuration are addressed in further detail.

15.2.1. Primary Production and Nutrient Cycling

Little is known about the effects of SPB outbreaks on ecosystem processes such as primary production and nutrient cycling. Insect herbivory may stimulate forest productivity by

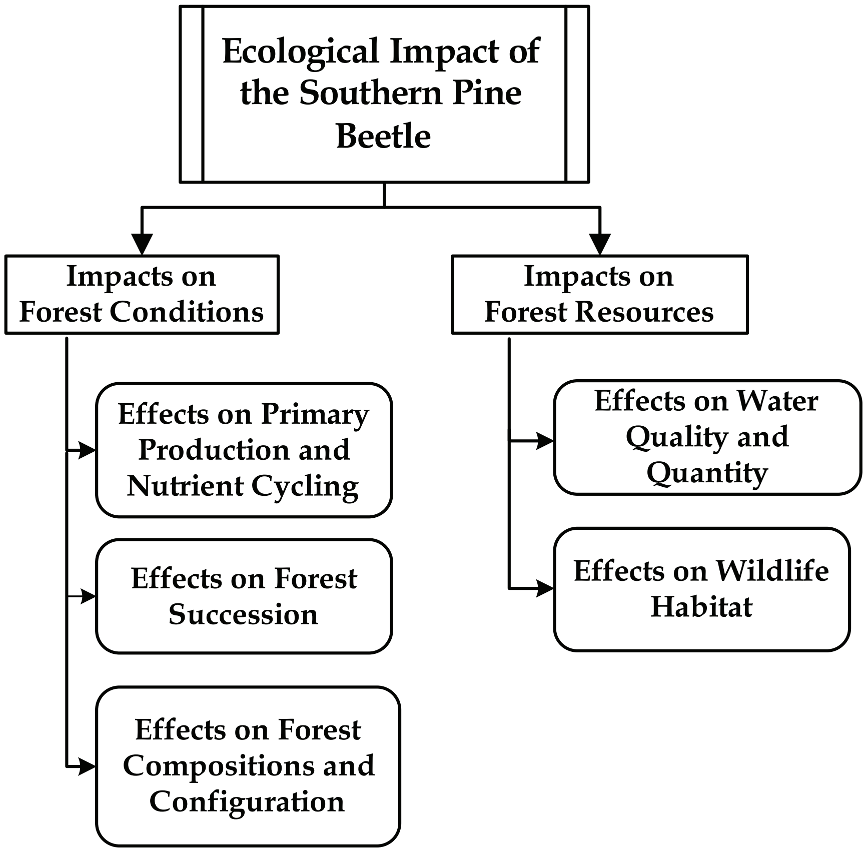

Figure 15.1—Diagram outlines the topics and organization of chapter 15. The probable impacts of the SPB on forest conditions and forest resources are examined.

selectively killing less productive plants or plant parts, therefore enhancing light, water, and nutrient availability for the survivor individuals (Mattson and Addy 1975). In general, nutrients become locked up in living biomass as mature ecosystems tend to have more closed nutrient cycles, with internal nutrient cycling exceeding nutrient input and output (Schowalter 1981). Insect herbivory accelerates the nutrient cycling by weakening/killing plants and increasing nutrient transfer from these nutrient-rich plants to the litter/soil complex. In addition, plant mortality releases resources such as space, nutrients, and light, increasing the establishment and vigor to other vegetation.

Successfully SPB-infested trees are usually dead within weeks of colonization. Resource distribution occurs as a result of leaf fall episodes lasting a few months and the falling of dead trees over a period of years (Romme and others 2006). The SPB selectively kills suitable mature host trees, and subsequent mortality increases nutrient release from pine biomass and increases growth of remaining trees (Schowalter 1981). A review of the literature revealed that no direct estimates on primary production and nutrient cycling following an SPB outbreak have been reported. In contrast, Romme and others (1986) reported that after a mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) outbreak, stand level primary productivity declines and leads to a more equitable distribution of biomass and resources. With time, individual surviving plants respond to the changes produced by the beetle outbreak and plant growth accelerates. The authors described growth increases of 20-70 percent in canopy lodgepole pines, and by 60-260 percent in understory vegetation for a period of 5-20 years after the outbreak.

15.2.2. Forest Succession

The SPB is the primary biotic agent affecting yellow pine forest ecosystems, and, in association with fire, determines the successional dynamics in these forests (Clarke and others 2000, Coleman and others 2008, Lafon and others 2007, Waldron and others 2007). Schowalter and others (1981a) suggested the interaction of SPB herbivory and fire disturbance as a mechanism to maintain early-successional southeastern coniferous forests, therefore preventing ecosystem development toward later-successional, shade-tolerant hardwood forest. These authors proposed that herbivory by the insect served to truncate ecosystem succession at a time when the forest had become stagnant or overconnected (Coulson and Stephen 2006).

Forest succession is a dynamic and cyclic process in which the normal conditional states of the forest change through time (Figure 15.2). In the Holling (1992) scheme of ecosystem succession (also known as adaptative cycle), the dynamics of the process include four stages: exploitation, conservation, release, and reorganization (Figure 15.3). These stages roughly correspond to birth (establishment), growth, death (disturbance), and renewal steps found in Figure 15.2. Each preceding stage of the cycle creates the conditions needed for the next stage. In the exploitation stage, establishment of early successional communities occurs. The transition from the exploitation to the conservation stage is slow; the system builds biomass (growth), connectedness, and potential for change. In the release stage (also known as "creative destruction") the accumulated and tightly bound biomass and nutrients are suddenly liberated by disturbances such as insect outbreaks, forest fires, or hurricanes. Rapid change and restructuring characterizes the transition from the release (disturbance) to the reorganization stage. The system collapses and begins to reorganize, and resources (e.g., light, nutrients, moisture) become available for the next phase of exploitation.

Within this scheme, the SPB serves as the agent of creative destruction, and its actions result in the release of biomass and nutrients (Coulson and Stephen 2006). The direction of ecological succession will be determined by the conditional state of the forest where the outbreak occurs and the severity of the attack. For example, Harrington and others (2000) observed that small patch mortality by the SPB increased structural complexity of late-successional pine-hardwood stands, and increased abundance of snags and dominance by late-successional hardwood species, indicating a hastening of succession towards the climax forest. In contrast, severely disturbed pine stands often resemble gaps containing early-successional vegetation; these conditions favor shade-intolerant species to get established and regenerate (Coleman and others 2008). Light, space, nutrients, soil, and moisture are released to early successional plants, which respond with greater gain in diameter, height, basal area, and volume (Coleman and others 2008).

Following an outbreak, overstory tree mortality by the SPB opens the canopy and changes the

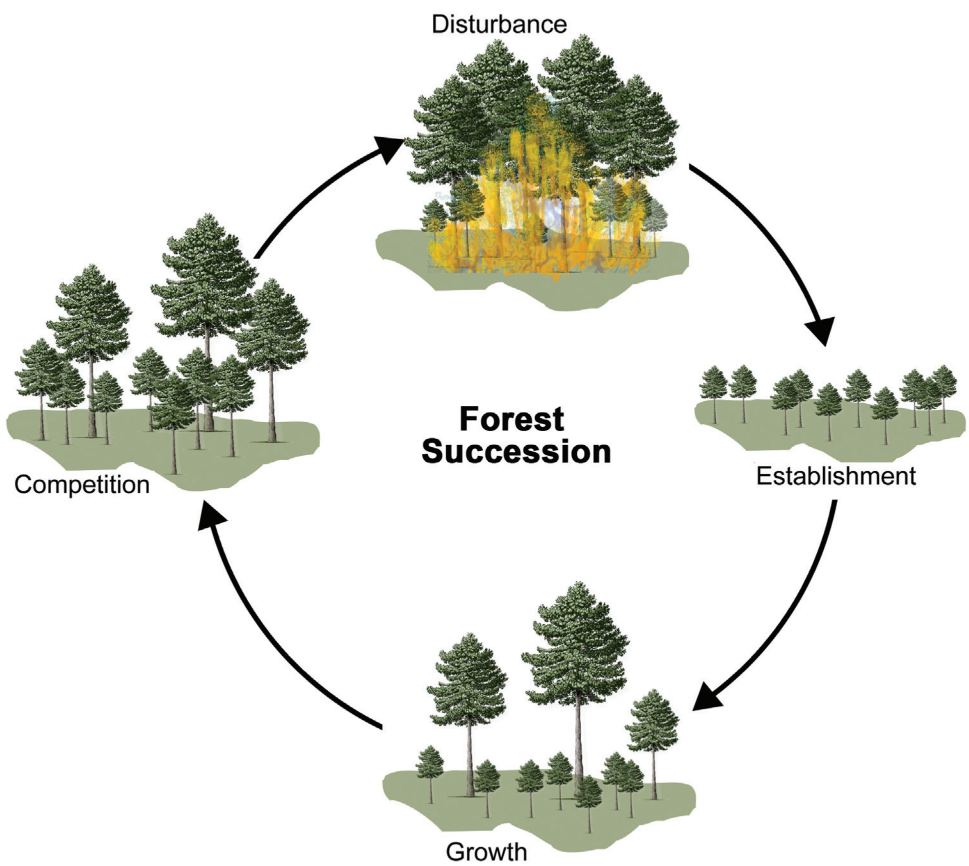

Figure 15.2—Forest succession dynamics. This figure depicts the conditional states of the forest changing through time. These states include: establishment, growth, competition, and disturbance. (modified from Bonnan 2008)

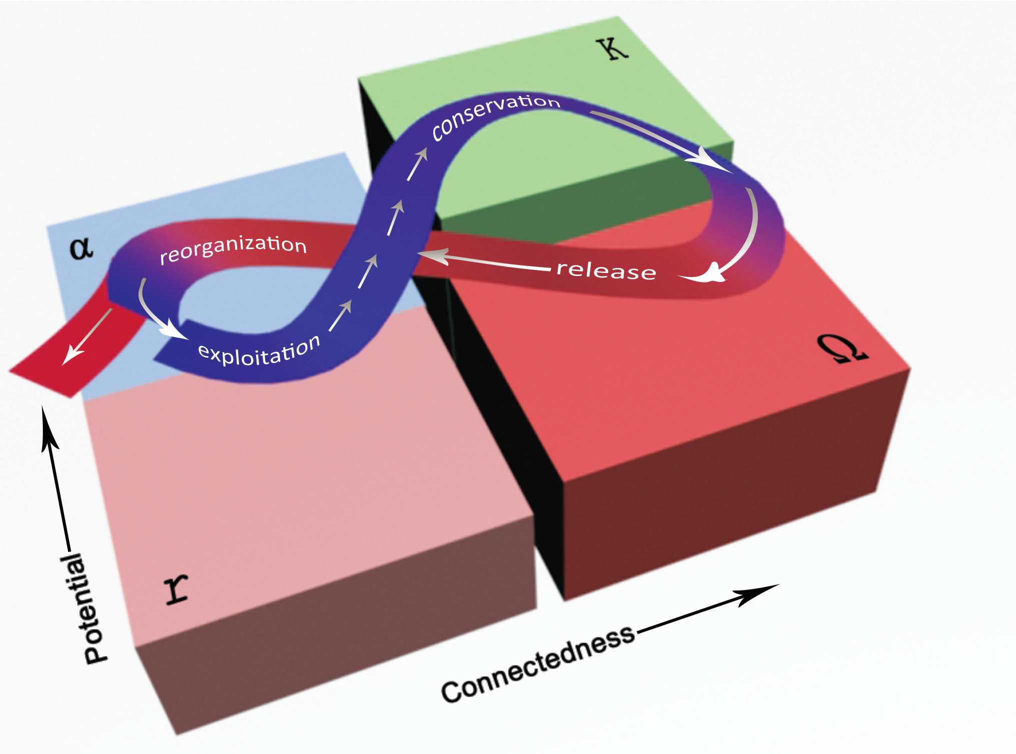

Figure 15.3—The general model of ecological succession. The stages of growth or exploitation [r], conservation [k], collapse or release [Ω], and reorganization [α] and the flow of events are illustrated in the figure. The speed of the flow in the cycle is shown by the arrows: short and closely spaced arrows indicate a slowly changing situation, and long arrows indicate a rapidly changing situation. (modified from Holling 1992)

pattern of light penetration to the understory. Abundance and composition of understory vegetation are significantly changed, favoring the establishment of shade-intolerant species and releasing competing vegetation. When the stands suffer extensive damage of canopy and subcanopy, ecological succession is reset to the herb, shrub, or sapling stage (Schowalter and others 1986). Leuschner and Maine (1980) estimated a 340-1700 kg/ha increase in herbage production beneath loblolly pine stands following mortality by the SPB. Similar results have been reported for the MPB. McCambridge and others (1982) documented increases of 555-962 kg/ha in understory vegetation beneath two ponderosa pine stands 3 years after a MPB infestation, and Kovacic and others (1985) described increases of 1,000-2,000 kg/ha of herbaceous biomass in ponderosa pines 5 years after MPB outbreaks. The increase in biomass following this type of disturbance is predictable based on a well-documented exponential inverse relationship between understory biomass and overstory canopy cover in many forest ecosystems (Stone and Wolfe 1996).

15.2.3. Forest Composition and Configuration

SPB herbivory plays an important role in the abundance, composition, and configuration of tree stands in southern pine forests. Outbreaks have been associated with stand conditions and climatic factors that stress the forest at the landscape level. Coulson and others (1999b) defined three types of habitat targets required by the insect in a forest landscape mosaic: acceptable host species (loblolly pine [*Pinus taeda*], shortleaf pine [*Pinus echinata*], slash pine [*Pinus elliotí*], and longleaf pine [*Pinus palustris*]), susceptible habitat patches, and lightning-struck trees. The SPB often selects older age classes of their preferred host species with high basal area and stagnant radial growth; such stands are considered to be high hazard for infestation (see chapter 22). Herbivory occurs initially in high-hazard stands; however, when insect populations become large, less preferred host species are also infested. The occurrence of high-hazard stands with high adjacency and connectivity increases the severity of the bark beetle outbreaks (Raffa and others 2008).

Large tree mortality by the SPB creates both structural and age class diversity within forest landscapes; i.e., more and different kinds of patches. How the outbreaks alter and fragment the pine forest is very much a function of the initial structure of the landscape. Cairns and others (2008b) suggested that highly aggregated forest landscapes will be characterized by more extensive insect infestations, greater outbreak severity, and larger disturbed patches than less aggregated forests. Their simulation results revealed “that insect disturbances can restructure a landscape in ways that influence the continued impact of that disturbance agent", and are consistent with outbreak observations in actual landscapes. Coulson and Wunneburger (2000) described an instance of how the SPB introduced a new age structure and resulted in fragmentation in the Little Lake Creek Wilderness Area on the Sam Houston National Forest in Southeast Texas. The 1,495 ha wilderness area was a homogeneous landscape vegetated with uniform old-growth pines (Figure 15.4A). SPB infestations occurred in the pine forest and created disturbed patches of killed trees (Figure15.4B). Pine regeneration within the disturbed patches followed, introducing a new age structure to the forest landscape. Years later, another SPB outbreak killed the remaining old-growth pines (Figure 15.4C). Once more, pine regeneration occurred in the disturbed patches. As time progressed, the pines in the initial infestations grew into the oldest age class in the landscape (Figure 15.4D), creating a template for future SPB outbreaks. Herbivory by the SPB modified the initial structure of the wilderness area by introducing age class diversity, resulting in a fragmented and heterogeneous forest landscape. Infestations of the SPB will occur as the forest matures; however, the impact will be less significant because of the fragmented suitable habitat (e.g., large continuous areas of old-growth pine no longer exists).

15.3. IMPACT OF SPB ON FOREST RESOURCES

The uses and values of the forest environment (forest resources) are intrinsically linked to the utilization of the forests by humans. Forest management planning considers the manipulation of human activities to achieve the desired conditions of forest resources. In this section we examine how the cumulative effects of the SPB impact forest resources. Although effort has been directed to the evaluation of impact on forest goods and services (e.g., timber production, real state, recreation), we focus on the forest resources that have an ecological impact as a result of SPB activity. The potential effects of SPB on hydrology and wildlife are examined below.

15.3.1. Hydrologic Impacts

Changes in forest structure resulting from bark beetle activity can modify key hydrologic processes that control the quantity and quality of water reaching a stream within a forested watershed (Figure 15.5). Interception, evaporation, transpiration, and groundwater storage processes may be affected by bark beetle herbivory. The hydrologic impacts can be measured in terms of annual water yield, peak flows, low flows, soil moisture, groundwater levels, and water quality (Uunila and others 2006). In general, changes in water quantity and quality occur in response to beetle-induced tree mortality. Removal of forest canopy results in a temporary increase in water yield as a result of a substantial reduction of water loss

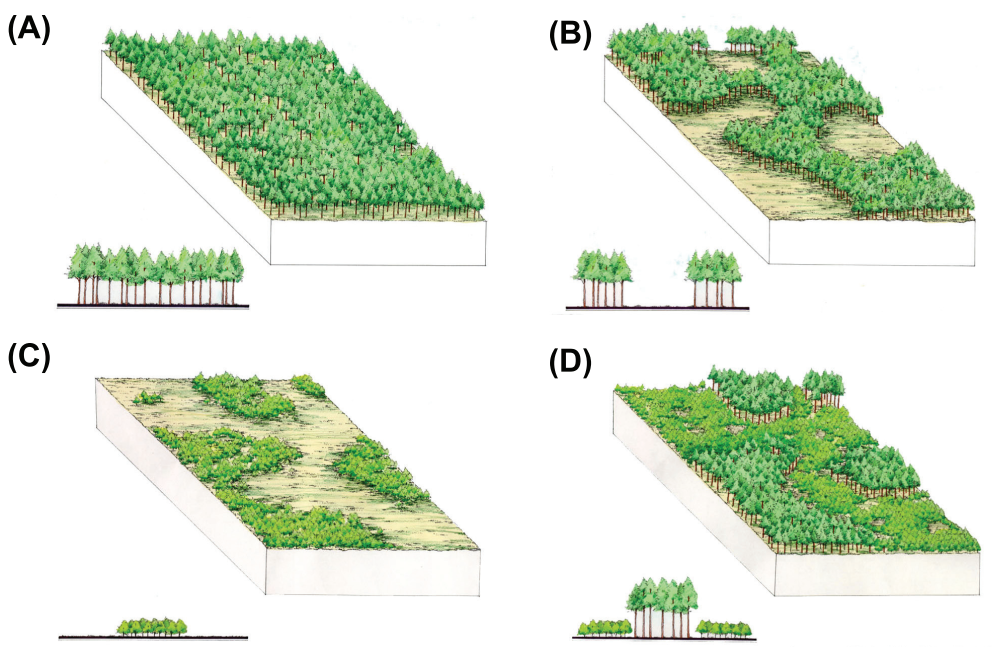

Figure 15.4—The effects of SPB herbivory on forest landscape structure and composition. (A) Homogeneous landscape with uniform old-growth pine optimal for SPB outbreaks. (B) Several infestation of SPB occurred and created disturbed patches of killed trees. (C) Another SPB outbreak killed the remaining old-growth pines. (D) Pine regeneration occurred. SPB herbivory introduced a new age structure and resulted in fragmentation of the forest. (KEL image)

via evaporation, transpiration, and the amount of precipitation intercepted by healthy trees. The magnitude of the responses is dependent on local climatology, forest age and species composition, understory response, and severity and location of the infestation (Elder and others 2008).

There are very few studies on the effects of bark beetle outbreaks on the hydrologic cycle of forested watersheds. A review of literature on large-scale beetle epidemics and their possible impact on hydrology was compiled by Hélie and others (2005) and Uunila and others (2006). The authors agreed that the published research on the topic is very limited and suggested that the effects of bark beetles on forest hydrology may be similar to those experienced after forest harvesting. In contrast to the bark beetle impact on the hydrologic cycle, the impacts of forest harvesting on hydrologic processes have been widely documented in the literature. These studies may contribute considerable knowledge on forest hydrology useful for understanding the potential impact of bark beetle infestations.

For the SPB, even less published research exists on the effects of herbivory on hydrologic processes. In one of such studies, Leuschner and others (1979) used a hydrologic simulation model to estimate changes in water yield after an SPB outbreak. They examined changes in water yields as stand basal area decreased at three different sites with high, average, and low precipitation. The authors reported a yield increase between 0.3-9.0 acre-inches per year for an acre of SPB spot, depending on the site, original basal area, and the amount of basal area reduction. Using these estimates on data from a real infestation in the Sam Houston National Forest, Leuschner (1980) concluded that the impact of the SPB on water yield is small and its impact on water quality is null. However, the author acknowledged that this conclusion was based on an infestation with small and dispersed spots and contended that the conclusions could change if the infestation configuration is large and contiguous. Uncertainty about the effects of SPB outbreaks on hydrologic processes leads to the following key research questions:

- How do small infestations compare in their hydrologic impact with larger infestations?
- How do density, type, and extent of forest understory affect hydrologic response?
- How do location, elevation, aspect, and weather control the hydrologic impacts of the SPB?
- What is the impact of standing dead timber on key hydrologic processes?

Despite the lack of reported research on the effect of SPB herbivory on water quantity and quality, insight could be gained from the extensive existing literature on harvesting and its effects on the hydrologic cycle in forested areas of the South (for a good review on this topic see Grace 2005).

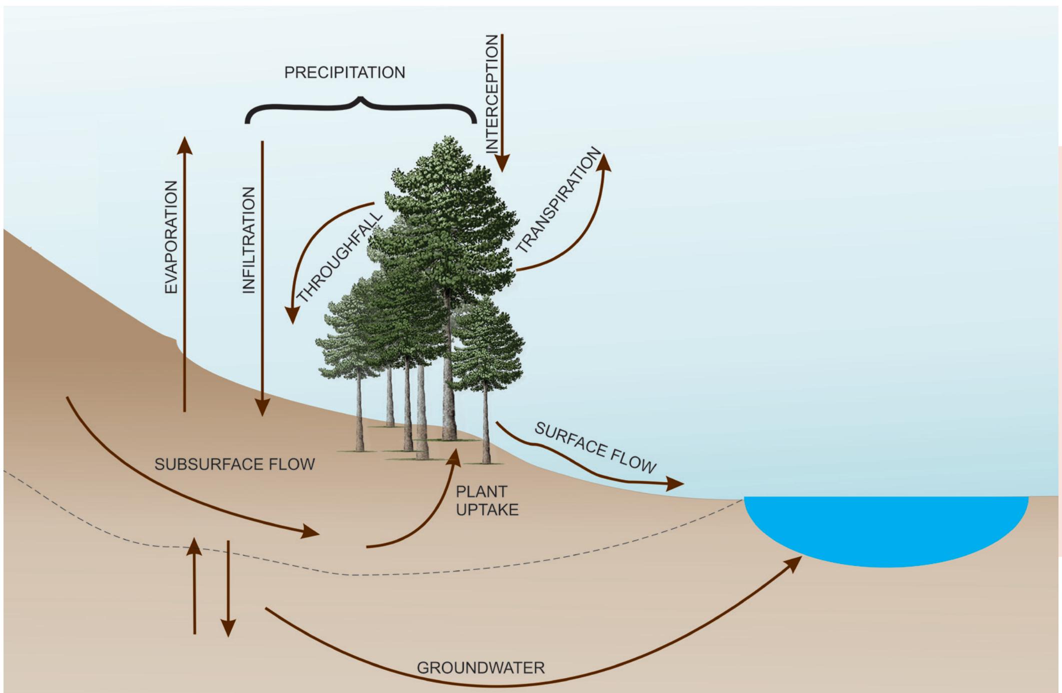

Figure 15.5—The forest hydrological cycle provides a model for understanding the movement of water in a forest landscape. Large tree mortality by SPB herbivory can alter key ecological processes that control the quantity and quality of water reaching the stream. (modified from Hélie and others 2005)

15.3.2. Wildlife Impacts

The impacts of the SPB on wildlife are the result of changes in the distribution and abundance of forest plant species and insect populations. During outbreaks, modifications in vegetation density, species composition, and age structure are likely to have cascading effects on wildlife food resources and habitat structure. Leuschner (1980) indicated that the primary or direct impact of the SPB occurs when it is a food for some species; i.e., outbreaks of the SPB may benefit populations of bark-foraging woodpeckers. The secondary or indirect impacts occur when SPB activities modify the structure and composition of the forest, causing changes in shelter, cover, and food available for the wildlife species inhabiting the forest.

Measuring the impacts of SPB herbivory on wildlife has a number of challenges. First, long-term studies of wildlife populations are needed to permit comparison of unimpacted and impacted populations during epidemic and post-epidemic conditions. Second, direct measurements of wildlife populations are difficult due to the labor-intensive censusing techniques and the associated costs. And third, more attention is given to the impact of the SPB on economic resources (e.g., timber production) during beetle epidemics. As a consequence, a limited number of studies have measured the impact of the SPB on wildlife. The few attempts have been focused on changes in habitat as a result of altered forest conditions caused by SPB herbivory.

In the following section we summarize information on how SPB outbreaks affect wildlife. We first consider the direct impacts of the SPB as a source of food to insectivores, primarily woodpeckers. We then examine the indirect effects of the SPB as it modifies habitat suitability for wildlife (e.g., birds and mammals).

Impact of the SPB on Woodpeckers

Pulses of food caused by SPB outbreaks increase the food available to insectivore birds, mainly bark-foraging woodpeckers. Southern pine beetle-infested trees represent a concentrated food source that is prized by the birds. Kroll and Fleet (1979) studied the impact of four woodpecker species (Downy [*Picoides pubescens*], Hairy [*P. villosus*], Pilaeted [*Dryocopus pileatus*], and Red-cockaded woodpeckers [*P. borealis*]) on populations of the SPB in East Texas. Their results showed that all four species preyed heavily on the beetles and had a significant impact on the densities of SPB pupae and adults. As a consequence of food availability, woodpeckers were found in higher numbers in infested SPB stands than when compared to uninfested SPB stands. According to Conner and others (2001a), woodpeckers show a "boom and bust" relationship with the SPB. Woodpecker densities initially increase with beetle abundance and then decline sharply as beetles run out of susceptible trees. Fayt and others (2005) identified the functional responses of woodpeckers associated with spruce bark beetles outbreaks. They suggest that the increase in woodpecker densities represents a combination of responses, in which the birds respond to higher prey densities by increasing the proportion of spruce bark beetle in the diet (i.e., predatory impact), and true numerical responses, in which the local woodpecker numbers increase as a result of aggregation or population growth to increases in beetle densities. These functional responses may apply in other woodpecker-bark beetle interactions; e.g., outbreaks of the SPB.

Red-cockaded woodpecker

Within the woodpecker guild, the relationship between the SPB and the red-cockaded woodpecker (RCW) is more complex and deserves special attention. The RCW (Figure 15.6) is an endemic species to the South that requires a constant supply of living, old pines with decayed heartwood (Conner and Rudolph 1991). Red-cockaded woodpecker populations declined dramatically as a result of logging, fragmentation, and suppression of fire in southern pine forests. Its preference for old-growth pines, particularly longleaf pine, and the loss of that habitat have resulted in the woodpecker becoming an endangered species (Jackson 1994). Southern pine forests, primarily longleaf, shortleaf, loblolly, and slash pine, are a critical resource to the RCW for cavity excavation and a key element for its recovery (Conner and others 1998).

Red-cockaded woodpeckers look actively for living old pines for cavity excavation, and these are the same trees susceptible to SPB attack. The cavity trees they create are essential for reproduction and roosting (Conner and others 1997). Red-cockaded woodpeckers peck shallow excavations, termed resin wells, around the entrance to the cavity. The resin exuded from the trees serves as a barrier against climbing rat snakes (*Elaphe* spp.) (Rudolph and others 1990).The volatile terpenes associated with the resin appear to increase the preference/vulnerability of such cavity trees to SPB attack. Conner and Rudolph (1991) reported that SPB infestations are the major cause of RCW cavity tree mortality in loblolly and shortleaf pines. The SPB can eliminate active single cavity trees, cavity tree clusters, and foraging habitat of the RCW, creating a potential problem to the conservation and recovery of the bird (Conner and others 1998).

Coulson and others (1999a) examined the nature of the interaction of the SPB and the RCW based on how the organisms perceive and respond to the elements of the forest landscape. They concluded that the interaction can be explained by the fact that there is spatial and temporal coincidence of the insect and the bird within the landscape; namely, the organisms respond to the same structural elements of the forest (i.e., similar habitat preferences). One important observation made by the authors is that the degree of the interaction is subject to the composition of tree species in the forest landscape. For instance, SPB outbreaks occur much less frequently in longleaf pine forests. Longleaf pine produces greater resin yield than any of the other southern pines. Resin yield production by the host trees is considered to be the primary defense mechanism against colonization by bark beetles. In contrast, nest site selection by male RCWs is directed to pines having high yield resin (Conner and others 1998). Given a preference, the RCW selects forests containing longleaf pine for nesting, roosting, and foraging. Therefore, longleaf pine-dominated forest landscapes minimize the interaction between the bird and the beetle (Coulson and others 1999a). The loss of longleaf pine forests and the replacement of this species with loblolly pine over large areas of the South have greatly increased the potential for a negative impact of the SPB on the RCW.

Figure 15.6—The red-cockaded woodpecker (*Picoides borealis*). This endangered species looks actively for living old pines for cavity excavation, and these are the same trees susceptible to SPB attack. (USDI FWS photograph taken by Eric Spadgenske)

Impact of the SPB on Wildlife Habitat

Following an SPB outbreak, stand parameters such as vegetation density, species composition, and age structure are quite different from those that dominated before the infestation. These changes in vegetation have an effect on habitat structure and food resources to wildlife species living in the forest. The magnitude of the impact on wildlife species composition, distribution, and abundance depends on the degree to which resultant modifications in vegetation increase or decrease the resources necessary for reproduction and survival. The responses of individual species may differ significantly based on the ecological requirements of the species, the differences among the stands, and the ability of the species to exploit modified habitat (Matsuoka and others 2001).

Published research on the probable impacts of the SPB on wildlife habitat is very limited. Most of the information available has been inferred by integrating published data on known biological associations (e.g., preferred habitat, food requirements, natural history) in terms of the altered forest conditions caused by the SPB. These studies have been qualitative because of the challenges associated with measuring wildlife populations. Maine and others (1980) conducted a qualitative study on the impact of SPB infestations on wildlife. They estimated the impact on amount and kind of food due to changing overstory and understory vegetation for several wildlife species (e.g., woodpeckers, turkey, quail, other birds, squirrels, deer, small mammals). The authors concluded that SPB outbreaks have a positive impact on wildlife, mainly due to increased food and habitat diversity. Other information has been the result of direct observations made after bark beetle outbreaks. For example, Stone and Wolf (1996) indicated that epidemics of bark beetle in pine forests increase the availability of forage and browse to livestock and wildlife, and offer nesting and foraging cover to small mammals and birds.

A major limitation of these studies is that they do not consider the spatial arrangement (configuration) of the SPB-infested stands within the forest landscape. The habitat requirements of wildlife are related not only to the structure of the habitat but also to the landscape surrounding the habitat (Store and Jokimaki 2003). Therefore, quantifying the impacts of the SPB on wildlife habitat requires consideration of infested stand adjacency and spatial configuration within the forest landscape. In the next section, we present an alternative approach for measuring the SPB impacts on wildlife habitat within a spatial context in a forest landscape.

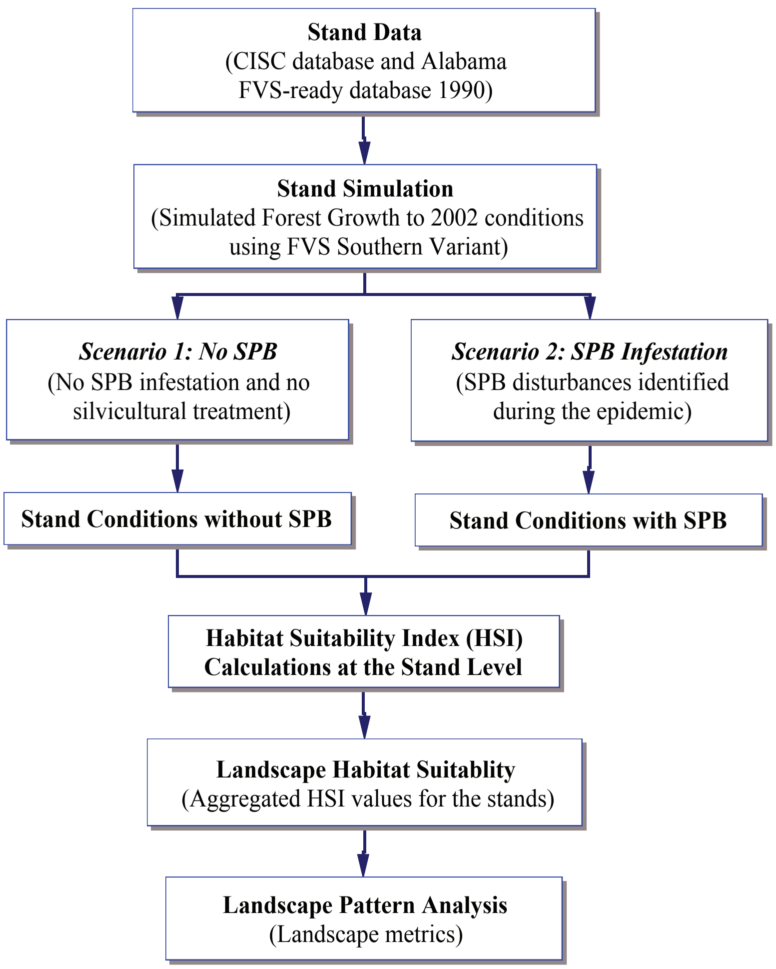

Figure 15.7—Diagram illustrating the methodology in assessing the impact of SPB herbivory on wildlife habitat suitability at the Bankhead National Forest, Alabama. (KEL image)

Estimating SPB impacts on wildlife habitat suitability in forest landscapes, a case study

Approach description. We evaluated how changes in forest landscape composition and configuration resulting from SPB herbivory impact the wildlife habitat suitability in the William B. Bankhead National Forest, AL. From 1998 to 2001, this national forest experienced SPB infestations at epidemic levels, primarily in loblolly pine forests. We used a spatially explicit approach that integrates forest inventory information (FIADB–Forest Inventory and Analysis Database), vegetation growth models (FVS – Forest Vegetation Simulator Southern Variant), SPB infestation data, geographic information systems (GIS) data, and published wildlife habitat suitability indices (HSI) developed by the USDI Fish and Wildlife Service.

To assess the SPB impact on wildlife habitat at the stand and landscape level, we implemented the Habitat Evaluation Procedure (HEP) developed by the USDI Fish and Wildlife Service. Integral to HEP is the use of habitat suitability indices (HSI). These single-species models are based on the premise that habitat suitability can be linked to habitat attributes (i.e., measurements of specific habitat features and environmental variables) by some quantitative functional relationship (Morrison and others 2006). The relationship is represented as HSI value ranging from 0.0, no habitat value, to 1.0, optimal value (USDI Fish and Wildlife Service 1981).

The steps used in the methodology are illustrated in Figure 15.7. Landscape level data included forest stand inventory information (i.e., tree-based measurements) and spatial location and size of SPB spots. The Southern Variant of the FVS was used to simulate forest growth and to project stand conditions under two different scenarios. One of the scenarios allowed the forest stands to grow without SPB herbivory and with no silvicultural treatment. The other scenario included the SPB disturbance identified in the SPB damage stand using the GIS coverage. The projected stand conditions (i.e., habitat variables) were evaluated using published habitat suitability models for four wildlife species: pine warbler (*Dendorica pinus*) (Schroeder 1982), gray squirrel (*Sciurus carolinensis*) (Allen 1982), eastern wild turkey (*Meleagris gallopavo sylvestris*) (Schroeder 1985a), and northern bobwhite (*Colinus virginianus*) (Schroeder 1985b). These species were selected because they are considered management indicator species.

Landscape habitat suitability was defined by preparing maps of aggregated HSI values of the stands within the national forest. Landscape habitat suitability maps were created for each species under the two different scenarios. The resultant HSI values were classified in five categories (Table 15.1), where classes 3 and 4 represent the areas suitable for optimal habitat. The spatial pattern of suitable/optimal habitat areas was analyzed for each map based on landscape metrics calculated with FRAGSTATS version 3.3 (McGarigal and others 2002)

Results and Discussion. The results of the analysis are summarized in Table 15.2; the calculated landscape metrics include: total habitat area (AREA), number of habitat patches (NP), patch density (PD), mean patch size (MPS), and mean core area (MCA). The results from each scenario fluctuate for pine warbler, eastern wild turkey summer food/brood habitat (SFB) and fall/winter/spring food habitat (FWSF), and northern bobwhite, but show no significant change for gray squirrel and eastern wild turkey cover habitat.

Pine warbler habitat area showed a decline of 37 percent for class 3 and 15 percent for class 4 under the SPB infestation scenario. The number of patches and patch density increased, whereas the mean patch size and mean core area decreased, resulting in a more fragmented habitat. The decline in habitat area resulted from reduction in standing volume of late successional pine trees killed by SPB.

The SFB habitat for eastern wild turkey had a considerable increase in all of the landscape metrics in the SPB infestation scenario (Table 15.2). Habitat area for class 3 increased by 1,280 percent as a result of the openings caused by SPB-killed stands. SPB creates openings that promote increased cover, understory growth, and edge that are favorable for SFB eastern wild turkey habitat.

The eastern wild turkey FWSF component showed a decreased in habitat area of 27 percent for class 3 and 8 percent for class 4. Patch number and density increased and mean patch size and mean core area decreased, resulting in a fragmented habitat. The FWSF habitat loss was a consequence of the reduction of pine canopy cover under the SPB outbreak scenario.

The habitat area for northern bobwhite quail increased by 56 percent for class 3. Larger numbers of patches and mean patch size resulted in a more connected habitat under the SPB outbreak scenario. The habitat gain was a result of the reduction of canopy cover, increased edge, and increased understory vegetation created by SPB spots.

Table 15.1—Habitat suitability classes

Classes	HSI Values
0	HSI = 0
1	0.01 ≤ HSI<0.25
2	0.25 ≤ HSI<0.5
3	0.50 ≤ HSI<0.75
4	0.75 ≤ HSI ≤ 1

Table 15.2—Landscape metrics calculated from the aggregated HSI value maps

		Scenario 1(No SPB)					Scenario 2 (With SPB spots)				
Species	Class	AREA	PN	PD	MPS	MCA	AREA	PN	PD	MPS	MCA
Pine Warbler	3	22,822	606	1.47	37.66	6.92	14,464	794	2.57	18.22	2.51
(General Habitat)	4	7,732	372	0.91	20.78	2.76	6,548	404	1.31	16.21	1.96
Gray Squirrel	3	18,624	419	1.37	44.45	9.00	18,293	424	1.95	43.14	8.70
(General Habitat)	4	3,511	99	0.32	35.46	1.63	3,394	101	0.47	33.60	1.44
Eastern Wild Turkey -SFB	2	37,063	356	0.94	104.11	36.23	37,063	356	0.73	104.11	36.23
(Summer Food and Brood Habitat)	3	824	65	0.17	12.68	0.94	11,378	658	1.36	17.29	2.28
Eastern Wild Turkey -FWSF	3	29,875	618	0.87	48.34	12.64	21,572	813	1.37	26.53	5.29
(Fall, Winter, and Spring Food Habitat)	4	41,092	371	0.52	110.76	44.37	37,672	443	0.75	85.04	29.83
Eastern Wild Turkey	3	7,407	259	0.37	28.60	4.30	6,959	272	0.85	25.59	3.52
(*Cover Habitat)*	4	25,519	397	0.56	64.28	14.05	24,937	408	1.28	61.12	13.04
Northern Bob White	3	18,550	419	0.59	44.27	9.29	28,924	626	1.88	46.20	15.15
(Winter Food Habitat)	4	4,402	228	0.32	19.31	2.43	4,401	228	0.68	19.31	2.43

Note: AREA, total area (*ha*); PN, number of patches; PD, patch density (*Patch#/100ha*); MPS, mean patch size (*ha*); MCA, mean core area (*ha*).

Gray squirrel habitat was not affected under the SPB outbreak scenario, mainly because this is a species that inhabits hardwood forests. The winter food HSI model used to evaluate the habitat did not consider pure pine stands which are the most affected by SPB.

The cover habitat for eastern wild turkey did not show a significant change among the SPB scenarios. Although turkeys utilize both hardwood and pine forests, hardwood forest types are preferred for cover. Pure pine stands are not considered suitable/optimal cover habitat for eastern wild turkey

Conclusions. The methodology used in this study facilitates the description of SPB impacts at the stand level of resolution and at the forest landscape level. The integration of stand data, vegetation growth models, and habitat evaluation procedures allowed us to define the suitable/optimal habitat in a forest landscape. Using data from actual SPB infestations, we simulated the effects of SPB outbreaks on the habitat suitability of four wildlife species. The analysis of two different SPB scenarios permits comparison of unimpacted (no SPB) and impacted habitat (with SPB infestations). From this comparison we can draw the following conclusions: The impact of the SPB varied in predictable ways depending on the ecological requirement of the species. Pine warbler habitat was destroyed, grey squirrel habitat was not affected, eastern wild turkey habitat was affected both negatively and positively, and northern bobwhite quail habitat was enhanced. The effect of the insect outbreak was to perforate the landscape, which generally decreased the habitat patch size, increased habitat patch density, increased habitat patch number, and reduced the core of habitat patches for species using pine stands as preferred habitat. One positive aspect of the infestations is that the infested stands provide wildlife habitat components that include early successional vegetation, open canopies, hardwood introduction, and the presence of standing pine snags. These habitat components create conditions for a more diverse wildlife.

15.4. SUMMARY

Large tree mortality by SPB outbreaks causes extensive changes in the forest environment. In this chapter, we examined the ecological impacts of the SPB on forest conditions (state of the forest environment) and forest resources (uses and values of the forest environment). We defined SPB ecological impact as the effects, positive or negative, of SPB herbivory on forest ecosystems. Some of the ecological impacts we investigated are summarized as follows:

- The activities of the SPB may stimulate the ecological processes of primary production and nutrient cycling, having a positive effect on survival vegetation.
- Southern pine beetle herbivory regulates the dynamics of southern pine forests and affects the direction of forest succession, depending on the severity of the epidemic.
- Forest structure is greatly affected by SPB activities. The heterogeneous landscape resulting from repeated SPB infestations is likely critical to maintaining forest diversity.
- The studies of the impacts of the beetle on water quantity and quality have been limited, and more research is needed in this area.
- The SPB affects wildlife directly as a food source and indirectly through changes and modifications of wildlife habitat. Bark-foraging vertebrates are positively affected by the SPB.
- The ecological impact of the SPB on wildlife habitat varies depending on the ecological requirements of individual species.