11
Building and Using Habitat Models for Assessing Temporal Changes in Forest Ecosystems

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Abstract. Natural resources professionals face many long-term issues related to the use and management of forest resources including understanding: (1) the dynamic nature of forest ecosystems; (2) how management activities influence forest characteristics spatially and temporally; and (3) how wildlife respond to changes over time. One method used to assess the effects of long-term temporal changes in forest ecosystems involves the use of ecological classification systems, where ecosystems are classified and mapped according to specific biotic and abiotic properties, and facilitate assessment of distributions and movements of wildlife populations based on the identification of the spatial and temporal characteristics of the resources necessary for survival. Habitat type classification systems, provide a basis for predicting vegetation development and successional change. In this chapter, we describe how we constructed a habitat type ecological classification system using three case studies from Michigan to assess temporal changes in forests and wildlife habitat. In the first case study, we determined the potential of landscapes to provide white-tailed deer habitat components. The second case study addressed how managers and planners can understand the spatial and temporal effects of aspen management practices. The third case study integrated land-use, land-cover, and habitat classification to model temporal changes in locations and habitat suitability for the regionally threatened Canada lynx in the Upper Peninsula of Michigan. We argue that natural resource managers and planners can make more realistic predictions of changes in distributions of forest resources important for wildlife based on an understanding of the structural and compositional dynamics of specific vegetation types through time.

11.1. Introduction

Wildlife and forest biologists, planners, and managers face many long-term issues related to the use of forest resources, e.g., timber harvest sustainability, and understanding wildlife-habitat relationships. In the mid-1900s, forestland was managed primarily to yield specific crops (Kessler et al., 1992). Only within the past 35–40 years has a multiple use philosophy of forest management developed (Kessler et al., 1992). Sustaining forest ecosystems to meet diverse forest and wildlife objectives is a non-trivial challenge and involves understanding the ecological factors that influence vegetation change; how specific forest manipulations affect temporal and spatial changes in forest characteristics; and wildlife response.

The spatial and temporal distribution and availability of ecological resources in landscapes has important implications for wildlife and forest management. It is difficult, for example to understand the dynamic relationships between wildlife and their habitats without understanding the underlying regulatory mechanisms within landscapes and the processes by which habitats within landscapes change over time. This type of information is especially critical as agencies develop management plans within an ecosystem management framework to sustain forests for multiple purposes. Current land-cover classifications and maps are used widely by natural resource managers and planners to understand wildlife-habitat relationships and plan management activities (Box 11.1), but they do not identify vegetation structure, potential vegetation trends and successional dynamics, or vegetation types on distinctive soils that may have different wildlife values. Consequently, it is difficult to use only land cover to evaluate wildlife species responses to management or to ecosystem changes because assumptions about potential vegetation and successional dynamics can lead to unrealistic predictions.

Box 11.1. Using land-cover data to understand wildlife-habitat relationships.

Land-cover classifications and maps portray the spatial distribution of ground features (e.g., urban areas, bare soil, pasture) or vegetation types in an area at a specific time. Most land-cover maps are developed from remote sensing, which is the process of deriving information about the earth's surface from aerial photos, satellite imagery, or other images acquired at a distance (Campbell, 1987). Prior to using land cover maps, accuracy, spatial extent, and resolution should be assessed, and researchers should determine what is acceptable to investigate their specific questions. Accuracy, spatial extent, and resolution are all affected by the method used to collect spatial data. For wildlife habitat assessments, most land-cover maps based on satellite imagery have 15–100-m spatial resolution, but images with resolutions <1 m are becoming more accessible (Glenn and Ripple, 2004). Land-cover maps are widely used in wildlife-habitat assessments because they indicate composition, interspersion, and juxtaposition of vegetation types. For instance, researchers use land-cover maps to determine the composition of vegetation within home ranges of animals, or evaluate habitat suitability. Land cover also does not identify potential vegetation or distinguish between vegetation types on different soils that may have different wildlife values. Consequently, it is difficult to use only land cover to evaluate wildlife responses to management or ecosystem change.

Recently developed approaches using ecological classification systems (ECS) allow evaluations of land-use and land-cover based on biotic and abiotic properties of ecosystems. A useful approach is to use an ECS to describe potential and current ecological conditions that influence wildlife habitat quality as well as describe the spatial and temporal changes in habitat availability and distribution. However, because habitat is species specific (Box 11.2) and has a spatial extent determined by the ecology of a particular species during a particular time (Morrison, 2001), using only one ECS may not be appropriate to assess distributions and quality of habitat for all wildlife species. Nevertheless, ECSs are important tools for assessing spatial and temporal patterns in the potential distributions of wildlife.

Box 11.2. Explanations of terms.

Some terms frequently used in the ecological literature are often vague or misunderstood. Below are definitions and explanations of important terms and concepts that we use in this chapter.

Habitat: Habitat contains the abiotic and biotic factors in an area that interact and provide the minimum conditions for occupancy and reproduction of organisms (Daubenmire, 1968; Morrison, 2001). Vegetation types with specific structural and compositional attributes can provide habitat components for individuals within species, but habitat is the sum of all resources necessary for survival and reproduction.

Habitat classification: Habitat classification places vegetation types or other defined areas into categories to reflect habitat quality for a particular species or population.

Habitat type: Habitat types have "equivalent climax potentialities" if they occur in areas with the same ecological, geological, and climatic attributes (Daubenmire 1966:297). A habitat type has a predictable successional pathway.

Habitat-type classification: Classifications based on vegetation composition that "group communities and their environments into categories useful for management interpretation" (Kotar and Burger, 2000). Habitat type classifications allow an understanding of successional trajectories and distribution of ecological communities that reflect inherent site capabilities, and disturbance and management history.

Vegetation type: A vegetation type is an assemblage of plants that typically occur together in an area and have similar composition. Vegetation types are seral stages of habitat types.

Habitat type classifications, a type of ECS, can facilitate assessment of intraspecific distribution and movements based on a spatially and temporally informed identification of resources necessary for survival (Box 11.2). Abiotic ecological characteristics such as climate, landforms, and soil characteristics (e.g., nutrient content, moisture, texture) influence differences in vegetation structure, composition, and successional patterns within different habitat types (Crawford, 1950;

Daubenmire, 1966). Although the boundaries and dynamics of habitat types are not static, they define a relatively narrow range of environmental conditions (Kotar and Burger, 2000) that can provide a basis for predicting vegetation change over time within natural successional pathways or as a result of certain land-use and management practices. Linking these predictions with habitat suitability modeling can aid in evaluating the probability of species persistence during a given time frame and location in a landscape. This approach can be useful for identifying areas where management would benefit wildlife species. Understanding temporal changes in vegetation distribution, composition, and structure is critical for developing forest management models, which can be used for planning and evaluating effective practices to meet ecosystem management objectives.

In this chapter, we describe how we constructed a habitat type classification system (hereafter referred to as HCS). Using three case studies from Michigan, we demonstrate how we used models with a HCS to assess temporal changes in forest wildlife habitat. In the first case study, a HCS and habitat potential models were used to determine the potential of landscapes to provide white-tailed deer habitat components (viz., fall/winter food, winter thermal cover, spring/summer habitat). The second case study characterized how successional changes in structure and composition of aspen (*Populus* spp.) in different habitat types could be modeled and used by managers and planners for understanding cumulative effects of forest management practices on wildlife communities that depend on aspen. The third case integrated land-use, land-cover, and habitat classification data to model temporal changes in the location and suitability of habitat for the regionally threatened Canada lynx (*Lynx canadensis*) in the Upper Peninsula of Michigan over the last century.

11.2. Habitat Types: Ecological Classification Systems to Characterize Spatial and Temporal Variation

Ecological classification systems generally have three characteristics: (1) they provide maps of land units that have similarities in biotic and/or abiotic characteristics at multiple spatial scales (i.e., extent and resolution), (2) they provide data that can be used to help describe the ecological potential of geographic areas, and (3) they integrate biotic and/or abiotic information at multiple spatial scales to help understand the dynamics of ecosystem processes and wildlife-habitat relationships (Box 11.3). For example, classification systems that are based solely on abiotic attributes (e.g., Bailey, 1976, 1980) such as climate, geological characteristics, landforms, or soils are often used by management agencies to investigate ecological patterns over relatively large spatial extents (e.g., $>$10,000 ha). In contrast, classification systems that are based solely on biotic attributes, such as vegetation cover (e.g., presettlement vegetation for Michigan; Michigan Natural Features Inventory [MNFI] 1999) or land use, typically are based on a wider range of spatial extents (e.g., perhaps up to 250,000 ha or larger) and can be used by natural resource

Box 11.3. Ecological Classification Systems.

Ecological classification systems (ECS) are used to classify and map ecological units according to specific abiotic and biotic properties of ecosystems. ECS developed from a need for land-use planning assessments. One of the earliest uses of ECSs for natural resources planning and management was the National Hierarchical Framework of Ecological Units developed in the early 1990s by the US Forest Service (Bailey et al., 1994; McNab and Avers, 1994). By 1995, the US Forest Service also developed an additional ESC for aquatic ecosystems (viz., Hierarchical Framework of Aquatic Ecological Units; Maxwell et al., 1995) that was based on physical and biological criteria. Today, state and federal agencies, organizations, and industries are using variations of these ECSs to quantify availability and distribution of resources across a given landscape, and to model how temporal changes in ecological conditions throughout landscapes influence the abundance and population structure of species, the spatial structure of popultions, and temporal changes in wildlife habitat suitability (Morrison et al., 1992).

professionals to plan management activities in individual stands and across landscapes. Lastly, ECSs that have been developed by integrating biotic and abiotic characteristics (e.g., Cleland et al., 1985; Haufler et al., 1996; Kotar and Burger, 2000; Felix et al., 2004), can be used to describe the potential and current ecological conditions that may influence wildlife habitat suitability as well as describe the spatial and temporal scales at which wildlife select habitat components. For example, Kotar and Burger (2000, pp. 1–5) developed a HCS in the Great Lakes Region of the USA for "site classification that used floristic composition of plant community as an integrated indicator of environmental factors affecting species reproduction, growth, competition, and therefore, community development." For this HCS, the environmental factors used to distinguish habitat types were primarily combinations of soil properties such as moisture and nutrients. Abiotic properties like these are useful to help explain variations in ecosystems.

11.2.1. Methods of Constructing Habitat-Type Classification Systems

Several approaches have been used in constructing habitat type classification systems that include biotic and abiotic attributes of a specific geographic region. Felix et al. (2004) constructed a HCS for several regions in Michigan that included digital layers obtained from the Michigan Department of Natural Resources. At the broadest layer, Albert's (1995) eco-regions provided the basis for delineating and classifying habitat types because they defined climatic-physiographic boundaries that affected species composition and plant productivity at broad-scale extents (e.g., 1,000–40,000 ha; Albert, 1995). The next two layers included geological information such as land type associations (i.e., geomorphic features defined by parent material and superficial topography), and soil texture and drainage properties. The last layer included information on potential vegetation and boundaries of forest types from presettlement maps (Michigan Natural Features Inventory (MNFI), 1999). Felix et al. (2004) validated habitat types with current land-cover maps by determining if vegetation composition identified from the maps coincided or was congruent with the successional stage of the habitat type with which it intersected. Some areas were validated on the ground by assessing composition of understory vegetation. Essentially, the boundary of a habitat type was defined by the intersection of eco-regions, geological information, and vegetation layers (Fig. 11.1). Habitat types can potentially include several different vegetation types or successional stages (Fig. 11.1). Successional trajectories within habitat types were identified using information from the literature (Coffman et al., 1980; Burger and Kotar, 1999; Kotar and Burger, 2000). Understanding the potential successional trajectory within habitat types is the basis for understanding distributions and ranges of vegetation conditions caused by temporal changes and successional processes that occur within a geographic region.

11.3. Case Studies

11.3.1. Modeling Spatial and Temporal Distributions of White-Tailed Deer Habitat

One challenge that many state wildlife management agencies have been confronted with in recent decades has been the management of white-tailed deer populations and their habitat. For example, McShea et al. (1997, p. 1) commented that, "... deer populations have burgeoned and currently exist at densities exceeding historical levels ...." In an effort to meet the challenges of white-tailed deer management, researchers from the Michigan Department of Natural Resources and Michigan State University undertook a project with the goal of developing a process to quantify the ecological suitability of landscapes to support potentially different populations of deer throughout the state. The ability to quantify how deer habitat suitability varies spatially and temporally as a result of different abiotic conditions in landscapes is valuable for setting ecologically based harvest quotas and planning habitat management activities. A desirable outcome of this project was the development of a process to quantify the potential of landscapes to support deer using habitat type classifications and other existing data to generate a spatial and temporal representation of deer habitat suitability patterns statewide.

To gain a greater understanding of the potential of Michigan landscapes to provide suitable habitat over time, Felix et al. (2004) developed a landscape-scale deer habitat potential model, identified how vegetation structure and compositional characteristics within habitat types changed throughout succession, and then used habitat suitability index (HSI) models to quantify how suitability of three deer habitat components (viz., fall and winter food, winter thermal cover,

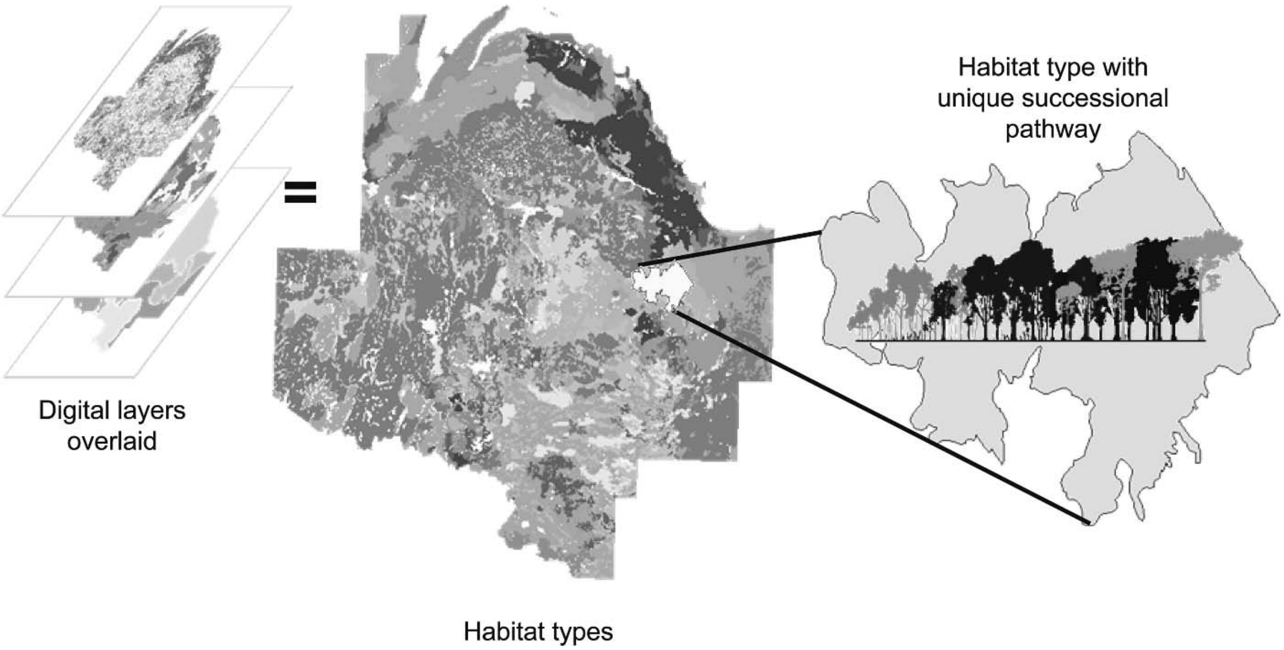

FIGURE 11.1. Building a habitat-type classification system. Boundaries of habitat types can be determined by overlaying digital spatial layers. These layers can include information about climate and broad regional differences, geological characteristics, and potential vegetation, or boundaries of forest types. Each habitat type contains a unique successional pathway that is determined from biotic and abiotic properties. Understanding the successional pathway of vegetation and the biotic and abiotic factors that affect succession can help managers plan forest management activities.

spring and summer habitat) would change throughout succession, given changing vegetation physiognomy within different habitat types. The results allowed managers to identify which successional stages of specific habitat types could provide deer life requisites. For instance, a common habitat type in the western Upper Peninsula of Michigan supports aspen in early successional stages (<30 yr old); sugar maple (*Acer saccharum*), red maple (*A. rubrum*), yellow birch (*Betula alleghaniensis*), and ironwood (*Ostrya virginiana*) in intermediate stages (30–100 yr); and is dominated by sugar maple and hemlock (*Tsuga canadensis*) in late stages (>100 yr). Intermediate successional stages provide high suitability for fall and winter food, whereas spring and summer habitat potential is highest in early stages (Fig. 11.2A,C). Because well-drained loamy soils are not conducive for growing lowland swamp conifers, this habitat type will likely not provide winter thermal cover for deer regardless of successional stage (Fig. 11.2B).

11.3.2. Understanding Temporal Variation in Aspen Forests To Assess Management: Effects on Timber Production and Wildlife Habitat

A major challenge facing natural resource professionals is to sustain natural systems and human commodities in the context of a growing human population and its associated demands on natural resources (Kessler et al., 1992). Aspen, for example, is a commercially valuable timber resource that is used to produce pallets, plywood, and pulpwood for paper, cardboard, and boxes. In the Lake States (Michigan, Minnesota, Wisconsin), aspen constitutes more than half of the industrial timber harvested annually, produces approximately four million cords of pulpwood (Piva, 2003), and with a value of more than $2 billion annually ($60 per cord delivered to the mill; Miller, 1998). In addition to economic demands on aspen, several wildlife species including ruffed grouse (*Bonasa umbellus*), white-tailed deer, many small mammals, and cavity-nesters also depend on it to meet their life requisites (Stelfox, 1995). As such, Michigan's aspen management goal includes maintaining a diversity of aspen age classes within the landscape to sustain wildlife habitat, ecosystem integrity, and social and economic values associated with aspen forests (B. Doepker, MDNR, unpublished data). The challenge associated with meeting this goal lies with multiple-use and ecological demands on the aspen resource. For example, aspen in Michigan may live past 100 years old, but begin to show signs of decline in commercial value after 60 years old (Graham et al., 1963). For maximum timber value, most aspen are harvested on a 45–50-year-old rotation depending on site quality (Brinkman and Roe, 1975). As a result, certain aspen age classes are not well represented in the landscape. Approximately 10% of all aspen in the western Upper Peninsula of Michigan, for instance, is 40–60 years old, whereas 42% is 10–30 years old (B. Doepker, MDNR, unpublished data). When certain vegetation types are not represented in landscapes (e.g., 40–60-year-old aspen), wildlife habitat components provided by those vegetation types are also not present. Thompson and Stewart (1998) argued that attempts to manage wildlife

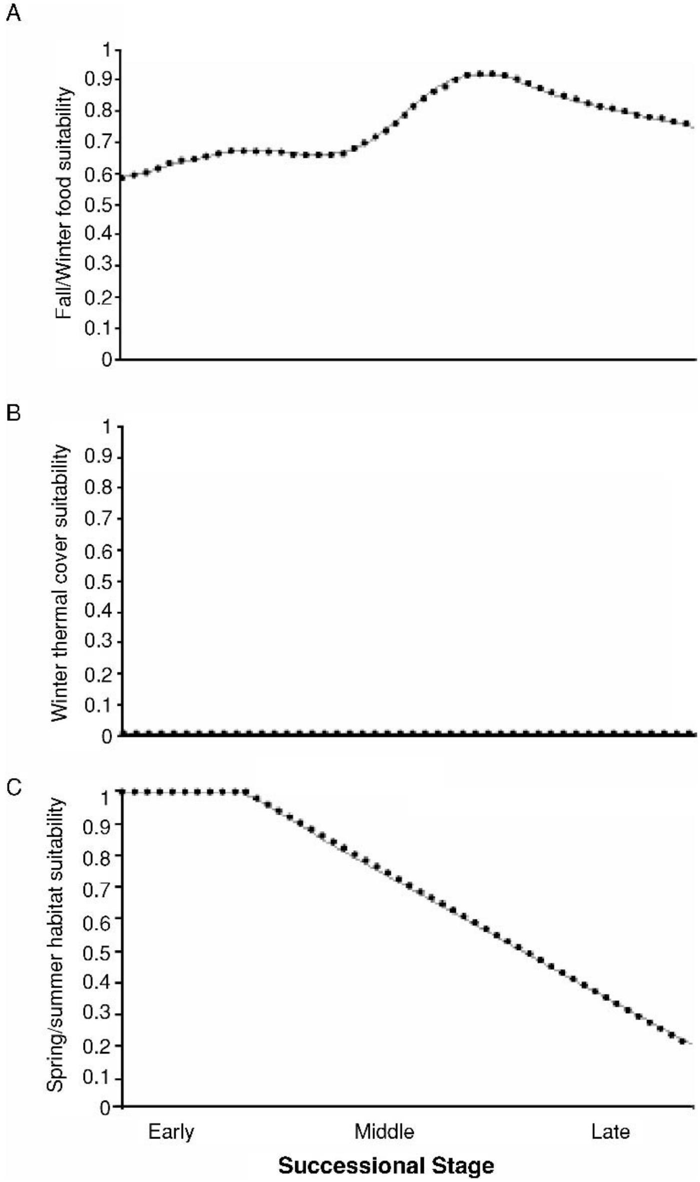

FIGURE 11.2. Suitability of an upland deciduous habitat type (*Acer-Tsuga-Dryopteris*) in the western Upper Peninsula of Michigan that supports aspen in early successional stages (aged <30 yr), sugar maple–red maple–yellow birch–ironwood in middle stages (aged 30–100 yr), and sugar maple–hemlock in late stages (ages >100 years) to provide 3 white-tailed deer habitat requirements throughout succession: fall and winter food (A), winter thermal cover (B), and spring and summer habitat (C). Suitability ranged from 0 to 1; 1 represents optimal conditions. Fall and winter food potential for this habitat type was 0.92 (i.e., 0.92 was the highest suitability to provide deer fall and winter food that this habitat type can attain throughout succession). Thermal cover potential was 0.0, and spring and summer habitat potential was 1.0.

populations without knowing the relationships between the capability of an area to support a population and population productivity is costly and ineffective, wastes time and resources, and may jeopardize wildlife populations. In response to a need to understand how aspen forests are affected by patterns of resource use as well as the cumulative effects of tree harvesting (Kessler et al., 1992; Davis et al., 2001), we recently initiated a study to assess what timber values and wildlife habitat components are provided by different successional stages of aspen, and to assess how harvesting activities influenced the structure and composition of vegetation within aspen stands as well as the spatial arrangement of vegetation types across the landscape. In this case study, a modeling process was developed that allowed managers to understand the critical times when areas are capable of supporting deer during succession (Fig. 11.2) and allowed them to plan management activities that maintained deer habitat components across the landscape and to plan harvest quotas based on the potential of specific areas to support deer populations.

11.3.2.1. Determining Differences in Aspen within Different Age Classes and Habitat Types

The study area was located in the western Upper Peninsula of Michigan and included Baraga, Dickinson, Iron, Marquette, and Menominee counties. Biologists knew the current spatial distribution of aspen in the study area from land-cover data sets (e.g., IFMAP [Integrated Forest Monitoring and Assessment Prescription; Michigan Department of Natural Resources (MDNR), 2003]) and also knew the current distribution of aspen age classes in the landscape from forest records kept by the MDNR.

Using an ECS developed by Coffman et al. (1980), habitat types were identified in the study area (Felix, 2003). By overlaying the current distribution of aspen on the habitat type data layer using a Geographic Information System (GIS), Felix (2003) determined within which habitat type each aspen stand was associated. According to Coffman et al. (1980), aspen occurs as an early successional vegetation type in 14 of 21 habitat types in northeast Wisconsin and in the Upper Peninsula of Michigan. These habitat types have soils ranging from very wet and poorly drained to dry and nutrient rich. Within the habitat types that supported aspen, quaking aspen (*P. tremuloides*) occurred in all 14, whereas bigtooth aspen (*P. grandidentata*) occurred only in half, most of which were characterized by dry-mesic to mesic soil conditions. Because aspen can occur over a wide range of ecological conditions, the successional trajectories of the vegetation type may differ.

To investigate differences in aspen structure and composition throughout succession, three age classes in three distinct upland habitat types were selected to assess forest attributes and their associated wildlife habitat characteristics. The selected habitat types were named for the tree species (genus) that showed the strongest tendency to dominate a community on that site in the absence of disturbance, and the genus of characteristic understory species (Coffman et al., 1980). Aspen stands were selected within the 20–29-, 50–59-, and $\geq$70-year age classes. Selected habitat types included *Tsuga-Maianthemum* (hemlock-Canadian mayflower), *Acer-Tsuga-Dryopteris* (maple-hemlock-fern), and *Acer-Viola-Osmorhiza* (maple-violet-sweet cicely; Coffman et al., 1980). By determining the habitat type in which each aspen stand was located, managers were able to predict which vegetation types were likely to succeed aspen.

Next, forest attributes of each stand were sampled to determine differences in vegetation structure and composition of stands within different age classes and habitat types. Attributes including stem density, tree diameter, basal area, tree height, canopy cover, species composition, and density and size of down woody debris were measured within each stand. These attributes can be used with habitat models to determine habitat quality for various wildlife species. Wildlife surveys, including breeding and winter bird surveys, were conducted to determine differences in wildlife composition between age classes and habitat types. With this information, a database was compiled that included for each aspen stand sampled, its location, age class, vegetation structural and compositional characteristics, its associated habitat type and successional trajectory, and its wildlife community associations.

11.3.2.2. Modeling Temporal Changes in Aspen Communities

The utility of having a database that included structural attributes of specific forest stands, wildlife associations, and successional trajectories was evident when developing a modeling process to predict the effects of timber harvesting on timber production and wildlife communities over time. Once information is compiled on vegetation structure, composition, and wildlife associations of different aspen age classes within different habitat types, it can be linked to a spatial dataset (Fig. 11.3). Structural and compositional characteristics of stands that were not sampled can be added to the dataset under the assumption that the structure and composition of stands will occur within the range of conditions identified for the sampled stands of the same age, habitat type, and management history. In this manner, forest managers and planners can understand spatial and temporal variation in forest structure and composition.

Forest management models such as HARVEST (Gustafson and Rasmussen, 2002) can then be used to evaluate how different harvesting alternatives affect landscape structure parameters such as age distribution, distribution of edge, and interior patches (Gustafson and Rasmussen, 2002). Harvest simulation provides information on interspersion and juxtaposition of vegetation types and age classes following harvest, but does not indicate how vegetation types, stand structure, composition, and wildlife associations may subsequently change throughout time following harvest. Those attributes, however, can be determined with data on habitat type and successional dynamics. If aspen stands are not harvested, we can predict how structure, composition, and wildlife associations will likely change as stands within different habitat types age between 20 and 70+ years (Fig. 11.3). For example, aspen basal area is one descriptive metric of ecological differences among age classes and habitat types. Forest managers and planners can associate aspen basal area measurements with age classes and habitat types and then simulate how basal area may change spatially and temporally following a harvest or over time (Fig. 11.3). Once management alternatives are simulated, each alternative

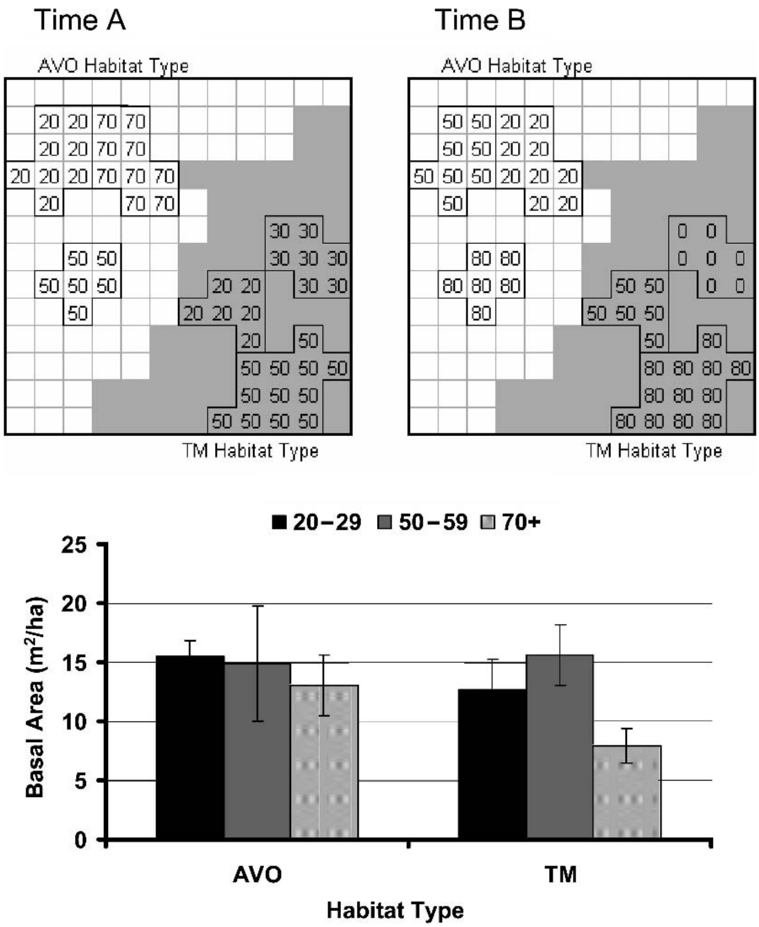

FIGURE 11.3. Spatial and temporal representation of aspen and age distributions within two habitat types (*Acer-Viola-Osmorhiza* [AVO] and *Tsuga-Maianthemum* [TM]) in the western Upper Peninsula of Michigan. Aspen basal area will vary over time and within different habitat types. By understanding variations within habitat types, managers and planners can simulate how age and distribution of aspen will change over time and link structural and compositional characteristics (such as basal area) to those distributions. Spatial and temporal distributions of timber production potential and wildlife habitat suitability can also be simulated following management or throughout natural successional trajectories.

can be analyzed to determine which management decisions would maintain long-term sustained timber yield, enhance wildlife habitat suitability, or evaluate how to meet different wildlife or biodiversity objectives. For example, managers might use habitat types and models of successional changes within forests to understand temporal changes in bird community distribution or timber production potential (Fig.11.4). Changes in habitat suitability for different wildlife species or groups of species can be modeled throughout time from data collected on structural and compositional changes in aspen growing on different habitat types (Fig. 11.3).

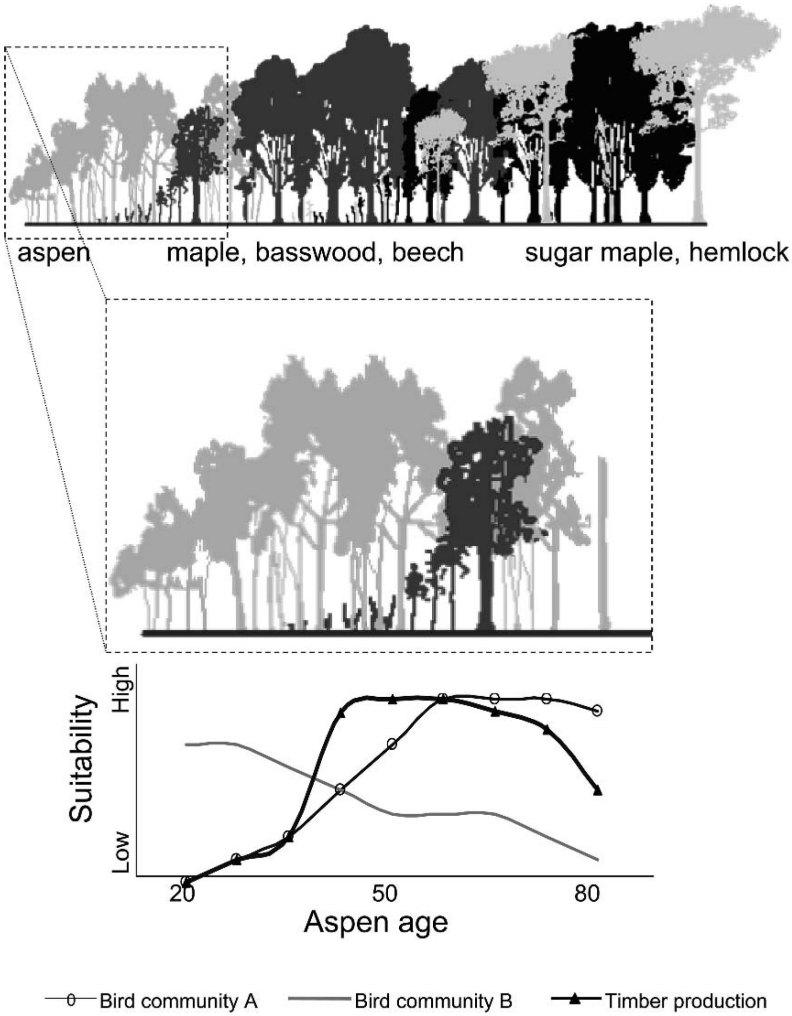

FIGURE 11.4. Hypothetical example of how managers might use habitat types and modeling of habitat and timber production potentials to understand changes in wildlife community distribution and timber harvesting potentials. Output from habitat potential models developed for each wildlife species or community could produce suitability curves that would indicate which seral stages provide habitat for different forest wildlife. For example, throughout aspen succession in certain habitat types, habitat suitability for cavity-nesting birds would likely increase as the availability of large snags increases. Habitat suitability for ground-nesters may follow a different curve. Timber production potential may also have a certain threshold, which may differ among habitat types.

Timber production potential can also be modeled throughout aspen succession (Fig. 11.4). In a dry upland hardwood habitat type, habitat suitability for bird community A (e.g., cavity nesters) increases as aspen ages and the diameter and density of snags increases (Fig. 11.4). Habitat suitability for bird community B (e.g., ground nesters) decreases. Timber production potential is highest when aspen is 40–60 years old, but then decreases with aspen age (Fig. 11.4).

Managing forests for long-term silvicultural and wildlife objectives is challenging. Davis et al. (2001) noted that the key to managing land scientifically lies in the ability to predict the outcomes of current management practices. We argue that combining habitat type classification systems with successional models will help wildlife and forest managers understand the consequences of forest management decisions before they are made and allow them to meet other management objectives; e.g., mature oaks [*Quercus* spp.] for mast production, lowland conifers to provide winter thermal cover for ungulates, or northern hardwoods for timber products. Managers also may wish to know how individual stand treatment might affect wildlife, given the landscape in which the stand is located. For example, when planning aspen management practices, managers may be confronted with the decision to harvest aspen potentially on three sites: a mesic site, a poorly drained site, and a well drained xeric site. The three stands in all probability have vastly different successional trajectories that influence their composition and structure. Within each site, different types of ecological and economic objectives can be met by deciding whether or not to harvest aspen. Aspen stands on the mesic site may be primarily influenced by disturbances such as blow downs or herbivory, since mesic soils likely contain greater nitrogen concentrations that attract herbivores. High water levels may influence aspen on poorly drained soils. Lastly, aspen on xeric sites may be more frequently subjected to wildfires and those stands on south facing slopes may face a greater risk of developing sunscald and/or infusion by pathogenic fungi (e.g., *Cystospora chrysosperma*; Hart et al., 1986). Harvesting each of the three mature stands would likely result in regenerating aspen but with potentially different species and stocking densities. The decision to avoid cutting stands will also create different forest conditions. By considering the diversity of site conditions as well as the temporal dynamics associated with the site conditions, managers can ask "what-if" questions in order to realize a greater range of management options associated with wildlife habitat or timber harvesting planning.

11.3.3. Determining Spatial and Temporal Changes in Lynx Habitat

In 2000, the Canada lynx was listed as a federally threatened species in the contiguous United States in accordance with the Endangered Species Act of 1973, and following an investigation regarding its status (US Fish and Wildlife Service, 2000). The USFWS determined that some current land management practices had the potential to negatively affect lynx and lynx habitat. In light of the final ruling, government agencies have been faced with developing and implementing management strategies that facilitate lynx populations on public lands. The Hiawatha and Ottawa National Forests, located in the Upper Peninsula of Michigan, represent areas where lynx habitat management has become a concern.

Lynx historically inhabited Michigan (Wood and Dice, 1924), but population numbers had dwindled to near extirpation by the first half of the 20th century (Michigan Department of Conservation, 1938). A sharp increase in the number of individuals trapped in the 1960s led to the impression that the species was making a "comeback" (Harger, 1965, p. 152), but McKelvey et al. (2000) attributed the increase to an irruption of lynx populations in Canada, leading to migration of individuals. Biologists have found no recent evidence of a resident population in the state (Beyer et al., 2001). It is possible that individuals dispersing from Canada may enter the state occasionally. A number of factors, including inadequate prey densities, interspecific competition from bobcat (*Lynx rufus*) and coyote (*Canis latrans*), and increased forest fragmentation due to anthropogenic land uses (Koehler and Aubry, 1994) may be inhibiting lynx from persisting in the Upper Peninsula, similar to other areas in the southern part of their range. An examination of the changes in forest conditions and land cover throughout the Upper Peninsula over the last 150+ years may help us understand if these changes have affected lynx habitat suitability. This case study describes how the current amount and distribution of lynx habitat in the Upper Peninsula of Michigan was determined, and how suitability may have changed from presettlement times. The use of a habitat type classification system to assess lynx habitat suitability and temporal changes in suitability facilitated this large-scale analysis.

11.3.3.1. Quantifying Lynx Habitat Suitability

The resource most important to lynx survival is its primary prey, the snowshoe hare (*Lepus americanus*). The patterns of habitat use exhibited by lynx are likely to be strongly correlated with those of hare (e.g., Keith, 1963; Nellis et al., 1972; Brand et al., 1976). The synchronous fluctuation between the two species' populations has been well documented, though there is some debate as to whether southern populations show the same pattern (see review in Hodges, 2000). An adequate amount of early successional vegetation types with dense understory is required to sustain hare populations, and for lynx an interspersion of relatively mature forest is needed (O'Donoghue et al., 1998; Mowat et al., 2000). Lynx use mature forest stands for denning and the amount of down woody debris is the most common characteristic found to be an indicator of good denning conditions (Mowat et al., 2000). Old growth forests with a conifer-dominant climax stage have the potential to provide a mosaic of dense understory beneath the sparse canopy and an adequate array of woody debris, thus containing the structural attributes important to lynx and hare (Buskirk et al., 2000). Some forest types may, therefore, provide a bimodal distribution of suitability for snowshoe hare. Identifying suitable habitat for snowshoe hare and lynx depends upon the ability to locate forest stands throughout the landscape that contain adequate understory cover.

A habitat suitability model for Canada lynx, developed by Roloff and Haufler (1997), integrated the concepts of a habitat suitability index (HSI) with that of population viability at multiple spatial scales through use of a GIS. The model determined the number of viable and marginal lynx home ranges within the landscape based on three components (foraging, denning, and interspersion of non-habitat). The foraging component, considered the most limiting factor, was modeled by a HSI for snowshoe hare, in which horizontal understory cover was the predominant variable. The estimation of lynx home ranges was based on thresholds of habitat quantity and quality that described the minimum requirements of a given area to support a lynx (Roloff and Haufler, 1997). The habitat quantity threshold was determined by calculating the minimum allometric home range for lynx (i.e., 250 ha); the habitat quality threshold was arbitrarily chosen based on relationships between viability indicators (e.g., survival, pregnancy rate) and home range estimates from previous lynx studies. The key to this methodology was the input of an ecological land classification in the form of a GIS grid that stratified the spatial variation in attributes measured by the HSI model (Roloff and Haufler, 1997).

11.3.3.2. Estimation of Current Forest Conditions

Multiple spatial layers (eco-regions, land-type associations, soils, vegetation) were combined to create the HCS which contained compositional attributes and successional trajectories of forest stands. Quantifying the structural attributes to assess current distribution of lynx habitat, however, required the collection of additional information.

Box 11.4. Forest Inventory and Analysis Program.

The USDA Forest Service has been tracking changes in the nation's forests since Congress mandated a national inventory of all timberland in 1928. The Forest Inventory and Analysis (FIA) program was implemented mainly for the assessment of timber resources. A new emphasis on ecosystem monitoring within the last 20 years has resulted in an expanded set of collected data providing greater information on temporal trends in forested ecosystems (Smith, 2002). Historically, surveys were conducted periodically within a state on 10–12-year rotations. New legislation in 1998 requires that a portion of plots within each state (10–20% depending on the state) be sampled annually on continuous cycles. In Michigan, 20% of all plots are sampled each year, resulting in a completed cycle every 5 years. The temporal and spatial scales of this data collection make it useful for assessing both short-term and long-term ecological issues over large areas. The FIA program is considered "a powerful tool for providing statistically sound and scientifically reliable data and information for monitoring the sustainability of the nation's natural resources" (Smith, 2002:S235). More information about the program can be found on the FIA website: www.fia.fs.fed.us.

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service collects tree-level plot surveys located systematically throughout forested land in each state, including Michigan (Box 11.4). These stand level data were input to forest modeling software, including the Forest Vegetation Simulator (FVS) and the Stand Visualization System (SVS). Structural variables (e.g., basal area, stem density, canopy cover) necessary for the lynx model were computed. Understory cover was an important variable not directly measured in the plot surveys, so it was estimated by examining simulated diagrams generated by SVS. FIA plot locations were overlaid with a grid of the habitat type classification in a GIS, allowing plot information to be attributed to each spatial class. The sampling protocol for the sixth cycle (2000–2004) of the FIA program (Box 11.4) resulted in data from nearly 4,000 plots in the Upper Peninsula (with 80% of the survey goal complete) being available for the overlay. This sample size of plot data was adequate for describing the current range of forest conditions in the Upper Peninsula, but the grid classes were too coarse to adequately account for the spatial variation in forest structure. Another spatial layer was required to account for structural differences across large tracts of compositionally similar forest types (i.e., within a grid class).

The final spatial layer was created through predictive modeling of forest structure using spectral satellite imagery, which provided a way to map variation at a resolution of 30 m. The methodology used was k-nearest neighbors (KNN) classification, which assigns values to non-sampled pixels based on their feature space distance from sampled pixels (i.e., those associated with FIA plots). Multidimensional feature space is defined by the spectral values measured for each of the band wavelengths at each pixel in the image. A summary of this process and its prior application was described by Franco-Lopez et al. (2001), who utilized FIA plot surveys from Minnesota for KNN classification of stand density, volume, and cover type in multi-temporal satellite imagery. Heterogeneity in forest composition across the landscape can hinder the ability to model relationships between spectral values and forest parameters (Mallinis et al., 2004), so the application of this modeling to large-scale analyses is limited. A balance between the intensity of the ground truth sampling and the extent of the landscape being modeled is needed for accurate predictions. Understory horizontal cover was predicted throughout the Upper Peninsula using a KNN classification of Landsat 7 imagery with limited success (root mean square error equaling 30% of the mean cover). An enhanced capability to predict forest structure using satellite imagery would allow natural resource managers to assess changes across time in an efficient manner, and examine large scale relationships between habitat suitability and species' distributions. Determining the current suitability of the Upper Peninsula to sustain lynx will help guide contemporary management policies; examining the condition of the forests before European influence and the temporal changes in forest conditions will provide additional insight to factors that have contributed to the species' subsequent absence.

11.3.3.3. Estimation of Past Forest Conditions

A major difference between northern forests of the contiguous United States, where lynx populations have existed, and the boreal forests of Canada and Alaska, where populations presently thrive, is the high frequency and intensity of fire disturbance that occurs in the boreal region. This disturbance regime creates widespread areas of early successional vegetation types important to hares, interspersed with a mosaic of mature forest patches (Keith et al., 1993; Agee, 2000). The periodic occurrence of intense fires in the boreal forest has been hypothesized as a driving force behind the lynx-hare cycle (Fox, 1978). The combination of fire suppression practices and naturally longer fire return intervals in the mesic hardwood forests of the Upper Peninsula results in less frequent disturbances of a lower intensity. An examination of the disturbance regimes, and resulting forest conditions during the presettlement era could reveal the inherent capacity of the region to support lynx.

Historical fire regimes in northern Michigan have been examined previously by classifying ecologically similar areas based on abiotic components only, without considering vegetation attributes (Cleland et al., 2004). These components (landform, lake density, soil texture, soil drainage) influence a landscape's susceptibility to fire (Cleland et al., 2004). A similar approach to that in the northern Lower Peninsula of Michigan was applied to the Upper Peninsula (D. Cleland, USDA Forest Service, personal communication), producing a map of estimated fire rotations that occurred prior to European settlement in the 1800s. By combining the spatial layer of presettlement vegetation and that of fire rotations, we simulated different proportions of seral stages that may have existed among the habitat types, based on the frequency of disturbance. For example, mesic northern hardwood habitat types contained mostly mature stands, while xeric upland conifer types had a mosaic of seral stages. The inherent capacities of these two habitat types to support lynx were different, since early successional vegetation necessary for hares was provided more frequently on one than the other, given the disturbance regimes. It is obvious that the temporal dynamics of forest succession were not static in the Upper Peninsula, so an understanding of the cycles that naturally occurred within habitat types allows a better estimation of potential forest conditions during that era. With the pre-settlement spatial layer created, the stand attribute data necessary for the lynx HSI model can be obtained by linking the seral stages and habitat types delineated in the map with those of corresponding FIA plots. Thus, lynx habitat during presettlement times can be projected and compared with current habitat distributions. The inferences that can be made using these data are limited, given the amount of uncertainty in formulating the pre-settlement information. Even so, the ecology of yesterday's landscape can have important implications for the present, and as such, any historical information will be deemed useful in the context of resource management (see Chapter 3, this volume).

11.3.3.4. Importance of Understanding Spatial and Temporal Changes in Lynx Habitat

Habitat is one of many factors influencing the presence of a species, and in the case of Canada lynx in the Upper Peninsula, suitable habitat alone may not result in the persistence of a resident population. Changes in climate which affect snow accumulation in northern temperate regions, coupled with human facilitated range expansions by interspecific predators (e.g., bobcat, coyote) have increased the pressures of possible competition on lynx in their southern range (Koehler and Aubry, 1994). In addition, if dispersing individuals from Canada are to migrate to the Upper Peninsula, they will likely encounter barriers of human development (viz., urban areas, agriculture). We are currently assessing where potential barriers may exist in the Upper Peninsula, to estimate the probability that an individual would be able to move across the landscape. Digital maps describing the location of other factors influencing lynx populations become increasingly important once the resources vital to their survival have been mapped. This methodology can be used to assess the suitability of a landscape for numerous species for which habitat requirements have been quantified. It is important that the resolution at which the habitat is analyzed matches that of the species' resource selection (Roloff and Haufler, 1997). The use of FIA survey data is most applicable to large-scale analyses due to the sampling protocol. Spatial considerations aside, an advantage to this methodology is that the temporal resolutions of data collection for the forest inventory (5 years) and satellite imagery (16 days) allow continuous evaluations at a reasonable time interval (i.e., one that corresponds with forest successional dynamics). Natural resource agencies can use habitat type classifications, which remain static barring a major geologic event, and efficiently keep track of changes in forest structure over time.

11.4. Implications of Understanding Temporal Changes in Forest Ecosystems

Habitat-type classification systems contain structural and compositional characteristics of vegetation within different habitat types that managers can use to predict temporal changes across large spatial extents. This has important implications for meeting multiple-use and ecological objectives. For example, natural resource managers can make more realistic predictions of timber production potential or the availability and distributions of resources important for different wildlife species or communities based on an understanding of the potential availability of specific vegetation types throughout time and an understanding of how structure and composition of those vegetation types change temporally. Knowing those spatial and temporal distributions, managers can then plan forest management activities within landscapes more effectively. State and federal agencies, and some private organizations and corporations are striving toward implementing ecosystem management to conserve, protect, and manage natural resources for current and future generations. The use of ECSs such as habitat type classification systems will help aid managers in accomplishing economically viable and socially acceptable management goals that sustain functional ecological systems. The three case studies described in this chapter describe how those goals might be accomplished, but there is still work to do.

Davis et al. (2001, p. 77) wrote, "The empirical core of our professional claim to manage land scientifically and to ensure that owner objectives are met lies in our ability to predict the conditions and outcomes of current and future stands and stand types when managed under a specified prescription." In essence, if managers cannot predict with acceptable accuracy the conditions and outcomes associated with implementing specific management activities, it will be difficult to determine if ecosystem management goals are being met. Classifying forests into ecological units (e.g., habitat types), compiling vegetation structural and compositional changes within habitat types, and quantifying changes in wildlife habitat suitability or timber production potential throughout time is important for planning forest management activities, accurately predicting management outcomes, and sustaining functional forest ecosystems while meeting human demands for resources.

Acknowledgments. The Michigan Department of Natural Resources-Wildlife Division, Michigan State University, Department of Fisheries and Wildlife, United States Forest Service, and the Michigan Agriculture Experiment Station provided funding to support projects associated with this chapter. Collaborators on these associated projects included D. E. Beyer, Jr., K. F. Millenbah, W. E. Moritz, G. Roloff, and S. R. Winterstein. T. Hiller reviewed earlier drafts of this chapter.

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