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The past as key to the future: a new perspective on forest health

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1.1 Introduction

What exactly is forest health? How does one define it? Can it be defined? Is it something real, or is it just another "fuzzy concept?" (More 1996). Would you recognize a healthy forest if you saw one? These are among the questions with which forest ecologists and managers struggle. Many are surprised when they realize that these apparently simple questions do not have simple answers. In spite of the widespread use of the term "forest health," it means very different things to different people. While the notion of a healthy forest has universal appeal, different people have different reasons for needing to know if a given forest is healthy or not. To some, forest health means sustainable timber harvest; to others it means preserving biodiversity or restoring the forest to its condition prior to human disturbance.

1.2 Definitions of forest health

Forest health has been defined from a range of perspectives that can be categorized as either utilitarian or ecological (Kolb *et al*. 1994). Some of the key features of forest health that have been included by various authors include ecosystem "balance," "resilience" to change, plant and animal community "function," and sustainable productivity (Edmonds *et al*. 2000; Raffa *et al*. 2009). Given these diverse perspectives, and the disparate definitions arising from them, it is not surprising that many forest protection professionals find the concept

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confusing at best, and useless at worst. Is forest health or "ecosystem health" even a valid concept? Ehrenfeld (1992) concluded that it is not. We disagree. The term probably will continue to be used to formulate and to guide societal and landowner management objectives. Thus, a concise and useful definition of forest health is important. The term is used in government mandates regarding forest management goals. In the USA, the Forest Ecosystems and Research Act 1988 mandates surveys to monitor long-term trends in forest health. Furthermore, forest health and its maintenance are now central goals for the desired future condition of US forests (USDA Forest Service 1993a, b, 2003), to some extent replacing sustained commodity output as a management goal. Long-term health monitoring and assessment programs began about 20 years ago, and the data collected have been used to assess trends in forest condition, but how are the data being used to determine if a given forest is healthy or not? And is the approach valid?

From the utilitarian perspective, a forest is healthy if it satisfies management objectives, whatever they might be, and unhealthy if it does not. Consistency with management objectives is central to many such definitions of forest health (Monnig and Byler 1992). However, the utilitarian approach suffers from some obvious and debilitating inadequacies. First, if healthy forests meet management objectives, but creating and maintaining a healthy forest are the management objectives, then we have a case of circular logic where creating a healthy forest depends on the occurrence of a healthy forest. Second, a single forest may be viewed as healthy from one perspective, but unhealthy from another depending upon competing management objectives. This situation is especially problematic where multiple management objectives are mandated, as on most National Forest lands in the USA. The utilitarian approach is most appropriate on forestlands with unambiguous management objectives, e.g., private industrial forests managed for wood fiber or public wilderness areas managed to preserve biodiversity.

Problems with the utilitarian approach counsel the need for a definition of forest health based upon ecological principles. Such principles have included resilience, the ability of an ecosystem to recover from stress or disturbance; "stability," the ability of an ecosystem to resist change; "ecosystem diversity," "full functionality," and "a balanced ecosystem" to name a few. The problem with this approach is that many of these principles are difficult to define, measure, or apply. What do functionality, resilience, or balanced really mean? These are abstract concepts which may have merit, but they cannot be quantitatively assessed and applied, and certainly not across all forest types for comparative purposes.

The definition of forest health put forth by the Society of American Foresters attempts to bridge both the utilitarian and ecological concepts by defining forest health as the perceived condition of a forest derived from concerns about such factors as its age, structure, composition, function, vigor, presence of unusual levels of insects or disease, and resilience to disturbance – note that perception and interpretation of forest health are influenced by individual and cultural viewpoints, land management objectives, spatial and temporal scales, the relative health of the stands that comprise the forest, and the appearance of the forest at a point in time (Helms 1998).

We must ask ourselves if it is appropriate to apply the term "health" to a population of organisms or even to an entire ecosystem. An unhealthy or dead tree is comparatively easy to recognize. The health of a forest stand or an ecosystem, however, is not because it relates to proper functioning of the ecological processes that regulate that ecosystem, which are not so easily recognized and assessed. In fact, the intensity of effort and the amount of time that is required to adequately assess energy and nutrient flow, trophic level interactions, biodiversity, stability, and resilience to disturbance in an ecosystem is far beyond anything that could be considered practical to a forest manager. Furthermore, the methodologies involved are complex and would potentially vary from case to case yielding non-comparable results. People concerned with forest health (especially entomologists and pathologists) traditionally have focused on tree mortality. However, tree mortality in a forest does not necessarily indicate an unhealthy situation; in fact, some tree mortality is normal, if not essential. In stable populations of organisms, the capacity for reproduction is vastly greater than that which can be supported by the limited resources of the environment (Malthus 1798). Thus, a stable and presumably "healthy" population of trees (i.e., a forest) will have dead and dying trees. While this is readily apparent in a qualitative sense, the manner in which one can quantify acceptable or desirable levels of mortality is less apparent, but is nevertheless both attainable and of critical importance.

1.3 The concept of baseline mortality

Manion and Griffin (2001) viewed a healthy, sustainable, and mature forest ecosystem as one that maintains a stable size-structure relationship by balancing growth with mortality. This concept is based on the **Law of de Liocourt** (1898), which mathematically describes the size structure of forests, and has been applied to the development of a quantitative, ecologically based concept of forest health (Rubin *et al.* 2006). Simply put, it describes the relationship of the density of stems in a forest to their diameter. As a cohort of trees grows, it naturally progresses from many small stems to fewer larger stems. For many, if not most, forests this is represented by a negative exponential

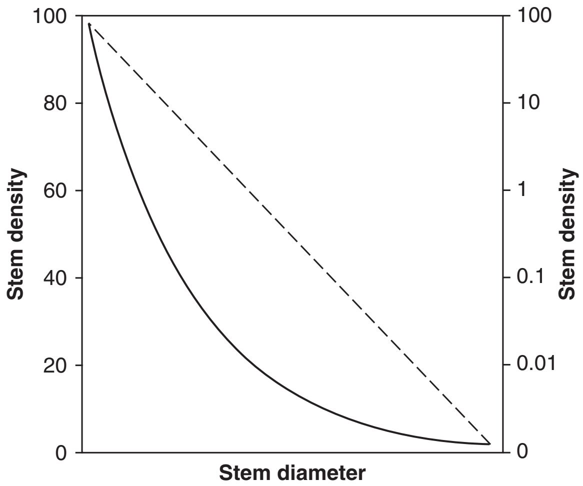

Figure 1.1 The relationship between stem density and stem diameter generally fits the negative exponential function. The line is a curve when plotted on linear axes (−) and straight when plotted on log-linear axes (- - -).

("reverse J") relationship, which when plotted on log-linear axes, becomes a linear relationship (Figure 1.1). It is important to note, however, that at the stand level, other mathematical functions usually describe the diameter distribution better than does the negative exponential (Chapter 2). This is due to high mortality of seedlings and old trees, which causes steep slopes at the tails of the diameter distribution function. If the smallest and largest size classes are omitted from the analysis (as they usually are at a practical level in forestry), then the negative exponential function has excellent predictive ability. Also, when many stands or several tree species are included in the analysis, the aggregate will tend to follow a negative exponential function. Other functions such as the rotated sigmoid, Weibull and modified Weibull generally yield better "fits" to diameter data, but at the cost of non-constant baseline mortality or negative mortality, problems which are avoided by using the negative exponential function, as long as the above caveats are kept in mind.

The slope of this line defines the number of stems of a given size class that must die in order for the population to maintain a stable size structure, i.e., **baseline mortality**. If the mortality of any size class is excessive, then there will be too few stems in the larger size classes as the stand grows, and the size structure will change. If the mortality is too low, then an unstable situation develops as too many trees survive and grow to the next size class and competition among trees intensifies. In the case of sugar maple, *Acer saccharum*, in northern New York State (Figure 1.2), the observed mortality approximates baseline mortality.

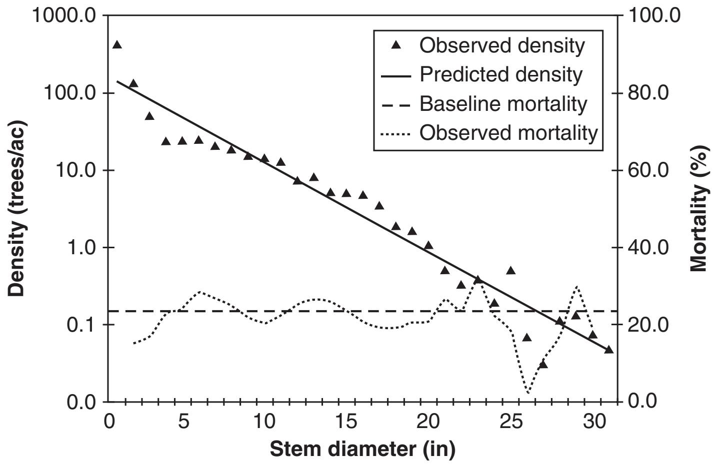

Figure 1.2 Observed and predicted density, baseline mortality, and observed mortality in the sugar maple northern hardwood forest type of northern New York State. The slope of the predicted density is constant and determines the baseline mortality. (From P.D. Manion with permission.)

This indicates that the diameter distribution of sugar maple is stable, or sustainable, in this region. Whether or not the existing structure is desirable is equally as important, but what is deemed desirable depends on the landowner's objectives, and is a separate, but related, issue to be taken up later in this chapter. Using baseline and observed mortalities as measures of sustainability allows one to determine quantitatively if a perceived threat such as a pathogen or insect outbreak is endangering the sustainability of the forest or if it is merely acting as a natural thinning agent. An example of an unstable forest structure is white pine (*Pinus strobus*) in the same region (Figure 1.3). In this case, the observed mortality in the smaller size classes is substantially (two to over three times) greater than baseline mortality. As the forest grows, the deficit of small diameter trees (saplings) becomes a deficit in mid-sized (pole-sized) trees and the diameter distribution at that time will be different than it was initially; thus the structure of this forest is unstable, or unsustainable. At this point, a forest manager may wish to determine the cause of the mortality in the small diameter classes to determine if management action can remedy the problem if the expected change in forest structure is inconsistent with management objectives. This represents a departure from the traditional approach of reacting to apparent forest health threats without first quantifying the severity of the "problem" in the broader context of the growth of the forest.

Our last example, American beech (*Fagus grandifolia*), presents an interesting situation (Figure 1.4 and Chapter 3). The observed mortality in the smaller

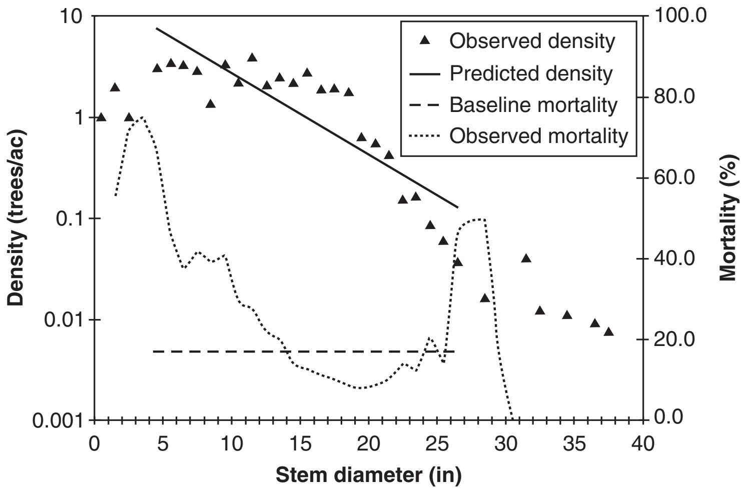

Figure 1.3 Observed and predicted density and mortality of white pine in the forest lands of northern New York State. Excessive mortality in the smaller size classes indicates that the density of the mid-size classes will decline in the future, i.e., the current diameter distribution is unsustainable. (From P.D. Manion with permission.)

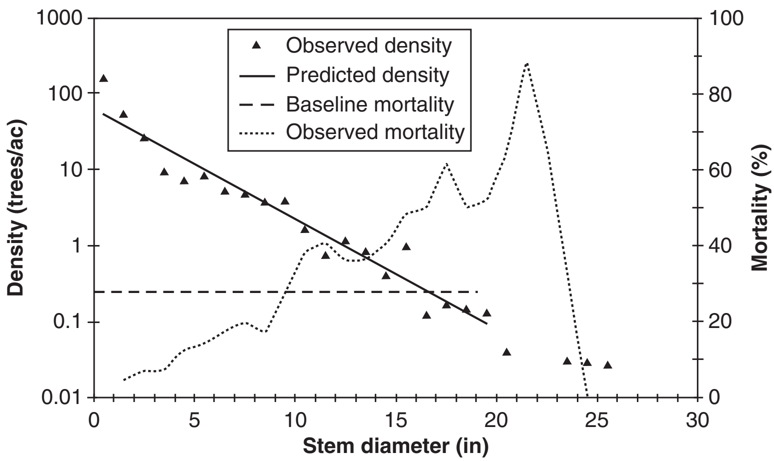

Figure 1.4 Observed and predicted density, mortality, and cutting of American beech in the state forest land in northern New York State. (From P.D. Manion with permission.)

diameter classes is well below baseline mortality, while the observed mortality in the larger diameter classes is substantially higher than baseline mortality. In this case, we can see that the structure of the forest is stable because the surplus of surviving smaller trees is balanced by excessive mortality in the larger size classes. This is due to a non-native, invasive insect and disease complex called beech bark disease (BBD) that has been present in the region for approximately four decades (see Chapter 3). Stands affected by BBD for such long periods are characterized by high mortality of trees over 25 cm diameter at breast height (dbh), and the presence of dense stands of small diameter trees of root sprout and seedling origin. Thus, a long-recognized forest health problem is clearly reflected in a discrepancy between observed mortality and baseline mortality, yet the structure is sustainable.

To label a forest so dramatically altered by an invasive disease healthy would serve no useful purpose, even though the forest has adapted and reached a stable state. Virtually every forest has been disturbed by both natural and/or anthropogenic agents, but the presence of disturbance does not mean that the forest is necessarily unhealthy. The baseline mortality approach gives us an ecologically based method to assess the sustainability of any forest by determining if the mortality caused by any agent of disturbance is causing instability in the system. Yet, many disturbed forested systems have adapted to the disturbance (e.g., elimination of tree species by invasive diseases, introduction of non-native trees) and have reached a stable, sustainable condition. Are these forests forever to be labeled unhealthy because they are not pristine? Or, do we consider them healthy because they are sustainable? The answers to this question will always depend on the perspectives of the individual. A person who places the greatest emphasis on a pristine condition (no human disturbance) may not consider healthy any forest that does not meet that criterion, which excludes from healthy virtually all secondary forests. This would not be a practical definition of forest health for the vast majority of forest landowners and managers. A person who only values resource extraction may consider highly disturbed forests as healthy with little regard to its ecological condition. Similarly, this approach would not have universal appeal. We can solve this dilemma with a two-component definition of forest health. First, a healthy forest must be sustainable with respect to its size structure (i.e., a correspondence between baseline and observed mortality). Second, a healthy forest must meet the landowner's objectives, provided that those objectives do not conflict with sustainability. Management objectives range from ecological (intrinsic) to economic (utilitarian) but these are extremes of a continuous spectrum, not discrete categories. For example, managing a forest for wildlife may have both ecological and utilitarian value. Whether the animals are to be hunted or photographed, or merely seen, the management of the forest is essentially the same. Each component of forest health thus has two possibilities resulting in four combinations (Table 1.1). We propose that forests meeting the landowner's management objectives, whatever they may be, are "productive" forests. Forests that do not are non-productive. In order to be truly productive in the long term, forests must be ecologically **sustainable**.

Table 1.1 *Healthy forests are both productive and sustainable. A sustainable forest is one in which there is a close correspondence between observed mortality and baseline mortality. A productive forest is one that meets long-term ecological and/or economic management objectives*

Forest Structure / Management objectives	Sustainable	Unsustainable
Productive	Healthy	Unhealthy
Nonproductive	Unhealthy	Unhealthy

Does this concept of forest health address the breadth of organismal diversity and trophic interactions in the ecosystem? Or, is this a narrow concept that only applies to populations of trees? Single or multi-species populations of trees are generally the **foundation species** (Dayton 1972; Ellison *et al*. 2005) of forested ecosystems, i.e., they are the primary producers that dominate the system in both abundance and influence. It follows, then, that if the population structure of the foundation species of an ecosystem is stable, then populations of the other species in that ecosystem are likely to be stable and to interact with each other in a manner that is typical of that community. The baseline mortality concept of forest health is based on a demographic model (the negative exponential function, see Chapters 2 and 3), which is based on size-class structure. The sustainability of populations of organisms is often assessed using life tables and transition matrix models (Caswell 1989). These approaches enable estimation of future population structure (i.e., stability) based on the reproduction and survival of specific age classes (Harcombe 1987). An alternative approach is the use of size classes rather than age classes, which are often difficult to measure in trees (Werner 1975; Hughes 1984); this has been applied to hardwood forests of northeastern North America (Buchman *et al*. 1983). All of these approaches attempt to include the multitude of interacting biotic and abiotic factors that shape the structure and composition of forests (Figure 1.5).

An advantage of the baseline mortality approach to forest health is that it is not necessary to identify the agent that is reducing the health of the forest (although it may be desirable); one only needs to appropriately assess the trees in the forest to determine if the diameter distribution is sustainable. As new invasive insects and diseases appear, some, such as BBD, may diminish the health of the forest, while others will become innocuous components of the ecosystem. Native insects and diseases have been the concern of forest entomologists and

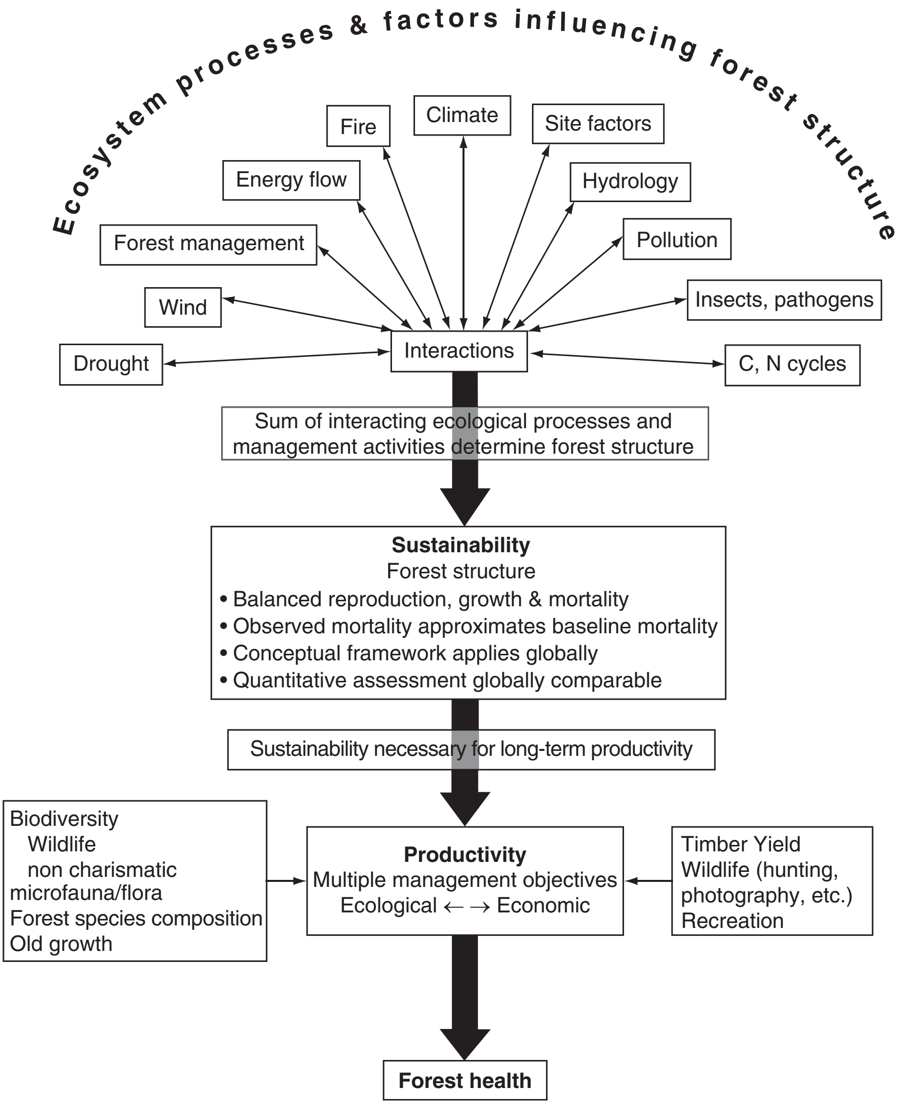

Figure 1.5 Relationships among interacting ecological factors, management, forest structure and sustainability, and productivity.

pathologists for many decades, yet so many of these organisms are essential components of the ecosystem because they are agents of mortality that is essential to maintain stable forest structure. Insect or disease outbreaks are often nothing more than an episode of mortality resulting from an accumulation of insufficient mortality that has produced an unstable forest structure. If the mortality is less than the baseline level, then an agent of mortality will emerge and return the forest to a stable age and size class, and thus health.

If actual mortality is greater than baseline mortality, then the forest cannot sustain its age and size class structure, and is therefore unhealthy.

1.4 Baseline mortality and silviculture

In managed forests under ideal conditions, the principal cause of mortality is the chainsaw. The silvicultural systems employed by foresters have been designed to produce forests that variously fit the negative exponential curve (see Chapter 8). In a managed forest with the sustainable production of wood fiber as a management objective, losses caused by insects and diseases are usually viewed as undesirable. Silvicultural systems are categorized as either even-aged or uneven-aged, yet both types of systems are based on the negative exponential function. Naturally reproducing, uneven-aged stands have a range of tree sizes and ages and generally fit the reverse-J distribution at a single point in time. Even-aged stands do not fit the reverse-J distribution at any one point in time, but generally follow the distribution as they grow and develop. At the landscape level, even-aged forests may be composed of a mosaic of stands of varying age, and at this broader spatial scale may fit the reverse-J distribution even at a single point in time. In both systems, the number of stems must be periodically or continually reduced to allow for subsequent growth. If a forest manager fails to reduce the number of stems in a stand through periodic thinning, eventually another agent will exploit the over-crowded situation and thin the stand naturally. This causes economic loss to the landowner and generates concern over the agent (insect, disease, etc.) that killed the trees, when in reality there was an underlying silvicultural problem. These agents of mortality often are quite imprecise in their thinning measures and cause excessive levels of tree mortality. Insects, diseases, and other disturbances become problematic when they confound management objectives or otherwise alter management plans (Castello *et al.* 1995), or if they induce mortality greater than the baseline for that forest type.

1.5 Biodiversity and forest health

The relationship between biodiversity and forest health is not well understood, but does not appear to be a simple one (see Chapter 9). In general, habitat heterogeneity favors greater biodiversity (Vanbergen *et al.* 2007), suggesting that a mosaic of varying stand structures may be a desirable management strategy. In fact, some of these stand structures may have excessive mortality and could be considered unhealthy from a baseline mortality perspective, but may have higher biodiversity (Kraus 2003, and Chapter 9). In this scenario, forest health almost seems to be at odds with biodiversity, but only at the level of the individual stand. At the landscape level, both forest health and biodiversity can be compatible (Vanbergen *et al.* 2007). If enhanced biodiversity does not necessarily result from the maintenance of sustainability, then perhaps it is most appropriate to view biodiversity as a management objective, rather than as part of an ecological definition of forest health.

1.6 The importance of spatial scale

The concept of a healthy forest also must incorporate the spatial scale. At the scale of the individual tree or small groups of trees of high amenity value (e.g., a homeowner's front yard) no mortality is acceptable, and thus the concept of baseline mortality does not apply because it is based on populations of trees. But it applies equally well to even-aged as well as uneven-aged forests, natural as well as managed forests, plantations as well as virgin forests, and native as well as urban forests. For example, at first blush even-aged stands do not appear to conform to the reverse-J distribution, but they do if considered as a landscape mosaic at a single point in time, or over the lifespan of the stand. Conceptually, the idea of a healthy forest (i.e., baseline mortality) is appropriate at the stand, landscape, and regional levels; however, at levels below the landscape level adequate sampling of the larger diameter classes becomes problematic (Rubin *et al.* 2006). Examples of the landscape level include national forest lands, industrial timber lands, forest preserves, etc., that represent diverse and multiple stands and management objectives.

1.7 Equilibrium vs. non-equilibrium concepts

The baseline mortality approach is an equilibrium model that tells us how the forest will be structured in the future in the absence of environmental change (i.e., non-equilibrium factors). Because the world is "non-equilibrium," a forest may or may not develop as the negative exponential model predicts. However, the baseline mortality approach to assessing forest sustainability enables us to evaluate the impacts of non-equilibrium factors on the size class structure of the forest in a simplified fashion.

1.8 Assumptions for appropriate use of the concept

The use of the baseline mortality approach to assess forest health is dependent upon some important underlying assumptions that must be considered for appropriate use of the method and interpretation of results, and which include the following: (1) The method generally is applicable only at the landscape scale to minimize the influence of individual stand peculiarities. It may, however, be appropriate at the stand level if the stand is fully stocked, and is appropriately sampled (i.e., sample plots are large enough or sufficiently numerous to provide an adequate representation of all diameter/size classes and species of trees in the forest. The plots also should be randomly selected to remove sampling bias). (2) The method used to quantify observed mortality assumes that dead trees remain identifiable to species for about the same time that it takes for the living trees to grow into the next diameter class. Therefore, the decay rate and the growth rate must be taken into account when determining the optimum width of the diameter classes. (3) Observed mortality includes all mortality regardless of cause including cutting, fires, landslides, diseases, and insect pests, etc. (4) The management and disease/pest history of the forest are known, and the silvics and ecology of the species comprising that forest are understood.

1.9 Human activities, forest health, and the outline of the book

All forests are undeniably affected by human activity, and all forest health problems are induced by human activity (though not all human activity causes forest health problems). Some human-impacted forests are sustainable, and some are not. Similarly, some are productive and some are not. Examples of human factors that have caused problems include past land use or harvest practices, fire suppression, overuse of fire, global climate change, pollution, desertification, introduction of invasive species, and recreational activities.

How exactly does one calculate baseline mortality? What are some of the problems that might be encountered when attempting to calculate it? When, where, and under what conditions is its use appropriate? Is it a universally applicable concept? These issues will be addressed in Chapter 2.

If all forest health problems are induced by the activities of man, then what precisely are the roles of the traditional big five disturbance factors (i.e., insects, diseases, fire, drought, and invasive species) in this new concept of forest health? When are these factors problematic, and when are they not? Can we predict when forests are likely to experience health problems, and respond proactively to avert them? How will forests respond to mortality greater or lower than baseline? We provide case studies to illustrate some possibilities in Chapter 3.

Forest health is influenced by many complex and interacting factors. We will examine how biotic agents of mortality including insects and pathogens (Chapter 4) native as well as invasive species (Chapter 5), and abiotic agents such as soils, climate change, and fire (Chapters 6 and 7) interact directly and indirectly to alter forest structure. Invasive species present new and growing challenges to forest management, and their impact on forest health is among the greatest threats to contemporary forested ecosystems.

Assuming that we can recognize an unhealthy forest, or anticipate a potential problem due to mortality levels above or below baseline, what management options are available to the forester and the landowner? We provide examples to illustrate some of the available options in Chapter 8.

Because forests are ecosystems that include many kinds of organisms it is essential to consider the relationship between forest health and biodiversity conservation (Chapter 9).

How are we currently monitoring trends in forest health worldwide? How can we incorporate this new concept into national forest health monitoring programs with the aim of developing a global forest health monitoring network based upon this concept? Such a network would permit a comparison of long-term trends in the health of the world's forests. These questions will be addressed in Chapter 10. Finally, we attempt to integrate the various chapters into one unified concept of forest health in Chapter 11.

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