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Seeing the forest for the trees: forest health monitoring

M. FIERKE, D. NOWAK AND R. HOFSTETTER

10.1 Introduction

A recent definition of forest health states that it is dependent on sustainability, productivity, and pest management (Raffa *et al.* 2009), which is similar to the central premise of this text (see Chapter 1). We suggest that one way to assess sustainability, as the first component of a healthy forest, is to determine if observed landscape-level tree mortality corresponds to baseline mortality (i.e., a stable size structure is maintained so that the number of trees dying within a size class does not exceed the number necessary to replace those in the next larger size class). Meanwhile, productivity, the second component of a healthy forest, involves meeting the management objectives of the landowner.

An understanding of the evolutionary history of the forest and all associated forest processes and components; e.g., fire, climate, insects, disease, etc., is critical when considering the spatial scale at which forest health is being assessed. For example, in the western USA and in Canadian lodgepole pine forests, the baseline mortality concept would need to be applied at the level of tens of thousands or hundreds of thousands of square kilometers. These forests experience repeated long-term cycles whereby forests become susceptible to the mountain pine beetle, die as a cohort, and burn so that seeds may germinate and the forest grow again (Peterman 1978; Berryman 1986). The conflagration that follows a mortality event occurs at large spatial scales and though forests can experience up to 100% mortality of all vegetation layers, they would still be considered "healthy" as this would be an essential renewal stage.

Forest Health: An Integrated Perspective, ed. John D. Castello and Stephen A. Teale. Published by Cambridge University Press.

Indicators of forest health, as with other indicators of ecosystem health, should be easily measured, sensitive to stressors, respond in a predictable manner to stress, and have a low variability in their response to stress (Dale and Beyeler 2001). Ecological indicators are used to assess the condition of ecosystems, provide early warnings of changes away from reference conditions, and facilitate identification of causes of deviations from reference conditions. Many processes and factors impact forest health, as identified in this text. Some of the most important of these factors, or those that best represent multiple facets have been selected as indicators of health, and a means to assess them established. Indicators commonly used in forest health monitoring include tree mortality, tree crown condition, growth of trees (as shown by basal area, height or volume changes through time), plant diversity, dominance of native species, soil morphology and chemistry, abundance of lichen communities, etc. Once forest health "indicators" are selected, they should be measured over time using designed experimentation or long-term monitoring programs to quantify trends and changes.

In addition to selecting indicators from a large number of possibilities, reference conditions (or standards) for each must be determined and agreed upon. The forest can be considered healthy when indicator values fall within a predetermined set of reference conditions. If one or more indicators do not fall within the standards, the forest is considered unhealthy. While this concept seems straight forward, it is not because it requires judgments and choices regarding the reference conditions against which to evaluate health and the spatial scales at which to apply them.

"Historical" or "natural" forest conditions often are preferred reference conditions. Unfortunately, numerous factors may have altered forest conditions in the recent past (e.g., climate change, air pollution, pest introductions, forest management), which makes identification of reference conditions difficult and oftentimes controversial. Long-term monitoring can provide data that contributes knowledge to an enhanced ecological synthesis thereby aiding refinement of reference conditions, as well as revealing deviations from reference conditions.

The spatial scale at which forest health is considered is critical. For example, a particular stand may not fall within the parameters of "health"; however, the stand is part of a larger whole; and if most of the trees/stands within a forest are healthy, then the forest as a whole is considered healthy. See Chapters 1 and 8 for a more in depth discussion of spatial scales within forested ecosystems. Inconsistencies in how forest health is viewed arise when scientists, land owners, and land managers apply their own concepts of health at different spatial scales. Seldom do landowners/managers consider how management of their forested properties fits into the larger forest ecosystem.

There are many other important considerations when monitoring forest health besides identifying indicators and reference conditions,. First, data collection must be standardized, and field crews well-trained to ensure comparable data are collected regionwide and during each measurement period. Furthermore, quality assurance protocols must be in place to ensure reliable and accurate data are collected. Documentation of data quality is essential for valid interpretation of forest health information. Forest health monitoring also should be conducted on permanent reference plots that are not destructively sampled so that re-measurements can be conducted to monitor changes in health within a time frame that allows changes to be detected. Monitoring plots should be explicitly located, either randomly or systematically, with an adequate number of plots to provide statistically reliable estimates for the forest of interest.

The terms "forest health" and "forest condition" frequently are used interchangeably (Percy and Ferretti 2004); however, these two visions of forest status will produce different monitoring systems. Forest health often denotes the degree to which normal tree processes have been disrupted (Percy 2002), while **forest condition** has been used in relation to the descriptive indicators used in routine forest assessments. Adopting a forest health or a forest condition viewpoint should not be undertaken lightly as selection of one or the other will ultimately drive the operational steps of the monitoring program (Ferretti 1997). For example, if one considers forest health to be defined only by the crown condition of trees, one will proceed to assess spatial and temporal variation of defoliation and foliar symptoms. On the other hand, if the ecosystem as a whole is considered, many different components and indicators will be taken into account, e.g., soil nutrients, soil biota, ecosystem productivity (Innes and Karnosky 2001).

10.1.2 The Montreal Process

The impetus behind many early forest health monitoring programs was the establishment of the **Montréal Process Working Group** and the subsequent development of a dynamic set of criteria and indicators for conservation and sustainable management of forests (Anon. 1995, Montreal Process Working Group 2009). This process was initiated in 1992, and in 1995 the Santiago Declaration was signed by 12 countries: Argentina, Australia, Canada, Chile, China, Japan, Republic of Korea, Mexico, New Zealand, Russian Federation, United States of America, and Uruguay. These countries account for ~ 90% of the world's temperate and boreal forests. Within the Declaration, seven criteria were adopted:

1. Conservation of biological diversity
2. Maintenance of productive capacity of forest ecosystems

3. Maintenance of forest ecosystem health and vitality
4. Conservation and maintenance of soil and water resources
5. Maintenance of forest contribution to global carbon cycles
6. Maintenance and enhancement of long-term multiple socioeconomic benefits to meet societal needs
7. Legal, institutional and economic framework for forest conservation and sustainable management

To assess trends in monitored forests, 67 associated indicators are used. Indicators are essentially repeated observations of natural or social phenomena that provide quantitative measures of systems (Montreal Process Working Group 2009). Indicators must be timely, reliable, and relevant to established criteria or management goals. Indicators specific to criterion no. 3, Maintenance of forest ecosystem health and vitality, are:

(a) Area and percent of forest affected by biotic processes and agents (e.g., disease, insects, invasive species) beyond reference conditions.
(b) Area and percent of forest affected by abiotic agents (e.g., fire, storm, land clearance) beyond reference conditions.

Forest health monitoring methods have been developed, and are used in many countries around the world. The remainder of this chapter provides details on how forest health monitoring evolved as a concept, and how forest health is being monitored and assessed in various countries.

10.2 Forest health monitoring

10.2.1 USA

Forest health monitoring is conducted on an annual basis by the US Department of Agriculture Forest Service, Forest Health Monitoring Program (FHM); with the plot component led by the US Forest Service Forest Inventory and Analysis (FIA) Program. This national program was initiated in 1990, and is designed to determine the status, changes, and trends in indicators of forest condition. The FHM Program uses data from ground plots, field surveys, aerial surveys, and other sources of biotic and abiotic data to develop analytical approaches to address forest health issues that affect the sustainability of forest ecosystems (US Forest Service FHM 2009a). FHM covers all forested lands through a partnership involving the USDA Forest Service, state foresters, other state and federal agencies, and academic institutions.

The FIA defines forest lands as being at least 10% stocked with forest trees of any size, including land that formerly had such tree cover and is being naturally or artificially regenerated (see Chapter 8 for definition of forest). Forest lands include transition zones, such as areas between heavily forested and non-forested lands that are at least 10% stocked with forest trees and forest areas adjacent to urban and suburban lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. Minimum area for classification of forest land is 1 acre (0.404 ha). Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet (36.5 m) to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide (Smith *et al.* 2004).

Within the FHM program, there are five major activities (US Forest Service FHM 2009b):

1. Detection monitoring – annual monitoring that uses nationally standardized aerial and ground surveys to evaluate status and change in condition of forest ecosystems.
2. Evaluation monitoring – projects that determine extent, severity, and causes of undesirable changes in forest health identified through Detection Monitoring.
3. Intensive Site Monitoring – enhances understanding of cause-effect relationships by linking detection monitoring to ecosystem process studies and assessing specific issues at multiple spatial scales, e.g., calcium depletion, carbon sequestration.
4. Research on monitoring techniques – develops or improves indicators, monitoring systems, and analytical techniques. Examples include urban and riparian forest health monitoring, early detection of invasive species, multivariate analyses of forest health indicators, and spatial scan statistics (see Chapters 2 and 5).
5. Analysis and Reporting – synthesis of information from various data sources within and external to the Forest Service to produce issue-driven reports on status and change in forest health at national, regional, and state levels.

Of these five activities, detection monitoring provides core long-term field plot measurements for monitoring forest health. In addition to permanent field plots, other sources of data include Forest Service' Forest Health Protection (FHP) aerial survey data, National Oceanic and Atmospheric Administration–Palmer Drought Severity Index, Moderate Resolution Imaging Spectroradiometer (MODIS) fire data, and National Interagency Coordination Center data on forest area burned (e.g., Ambrose and Conkling 2007).

10.2.2 FHM detection monitoring design

A major data source for forest health monitoring is the FIA national field plot network, which is based on the Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) hexagon grid (US EPA 2009; Moser 2008) (Figure 10.1). As a result of the 1998 "Farm Bill", the detection plot component of FHM has been integrated into the FIA Program plot network. (For detailed descriptions of the FIA program, see Bechtold and Patterson 2005).

FIA uses a three-phase systematic sampling approach for all US forested lands. In Phase 1 (P1), aerial photography and/or remote sensing are used to characterize size and locations of forest and non-forest land using interpreted "photo points" for every ~ 240 acres. In Phase 2 (P2), field crews visit accessible sample locations on forest land to collect data on forest type, land ownership, tree species, tree size, tree condition, and site attributes (e.g., land use, disturbance, slope). Plot density for P2 samples is approximately one plot per 6000 acres of forested land (or ~ 125 000 samples, nationally) (Burkman 2003; 2005). States can choose to increase the number of sample locations by contributing state funds.

Traditional forest inventory measures are collected annually on P2 sample locations with a fixed inventory-cycle length. Legislation mandates a 5-year inventory cycle in the eastern USA, and a 10-year cycle in the West. In states with a 5-year inventory cycle, 20% of the sample locations are measured each year. In states with a 10-year cycle, 10% of the samples are measured each year. Each set of annual samples are referred to as a "panel" (Burkman 2005). Sample locations are selected from a five- or ten-panel grid in a systematic manner with each sampling location assigned to a panel such that the overall design is that each panel represents an independent annual sample of forest conditions. Remeasurement consists of repeating the measurements starting with the first panel and proceeding through the remaining panels each year.

Phase 3 (P3) plots are established on a subset of P2 plots. A broader suite of forest health attributes related to ecosystem function, condition, and health is measured on every 16th P2 plot (one plot per 96 000 acres ~ 8000 forested P3 plots in the USA). P3 data generally are collected during June, July, and August when deciduous trees and other vegetation have leaves and are easily identified (Burkman 2003).

10.2.3 Sample location layout

FIA plot design consists of a cluster of four circular 1/24 acre (subplots spaced out in a fixed pattern (Figure 10.2). Three subplot centers are established 120 feet (36.5 m) from the center subplot at directions of 120°, 240° and 360°. Annual plots (1/4 acre) are established around each subplot center for tree

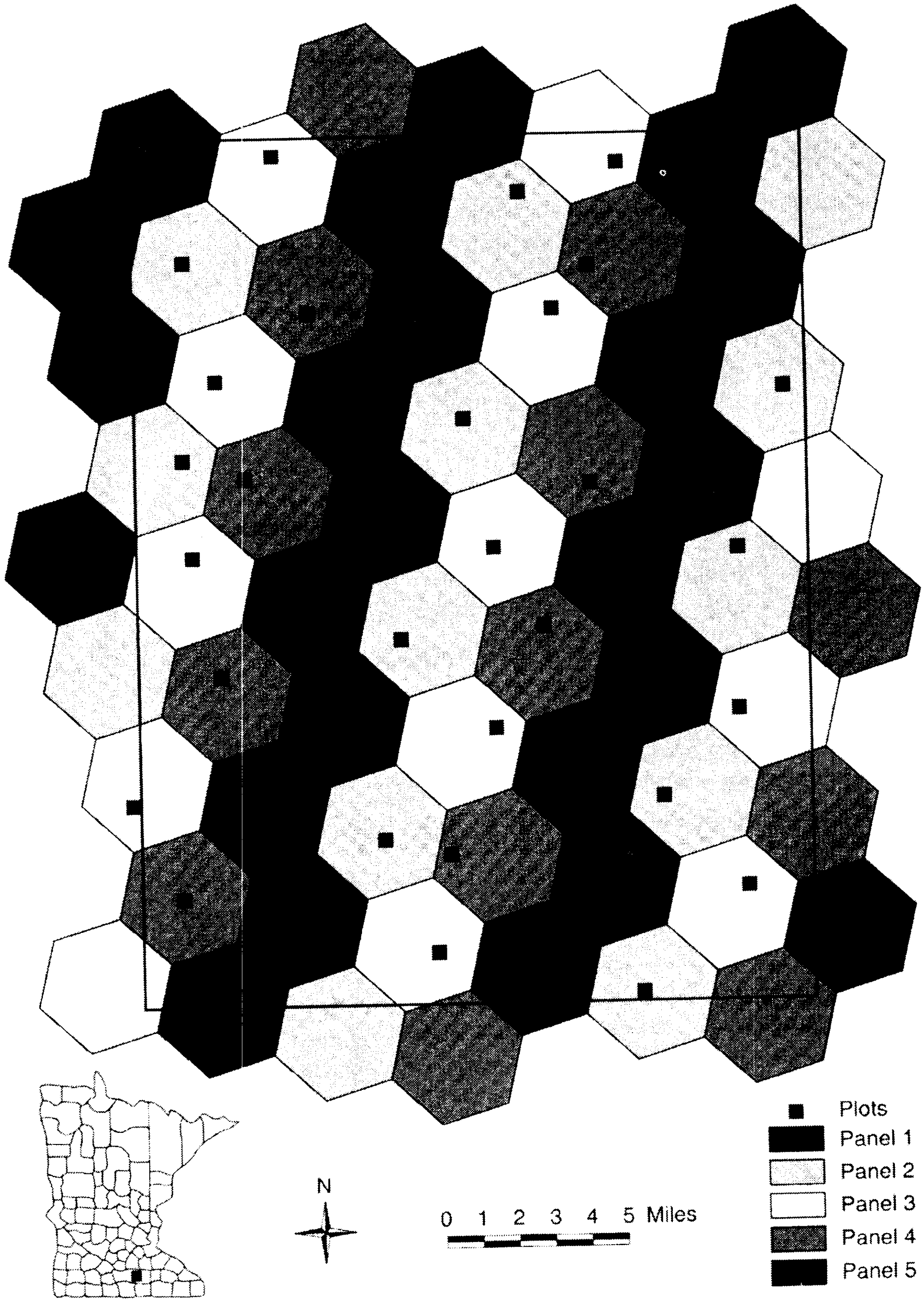

Figure 10.1 Five-panel grid showing Phase 2 hexagons from Waseca Co. Minnesota. Squares within each panel indicate sampling locations being evaluated every five years. (From Burkman 2005, with permission.)

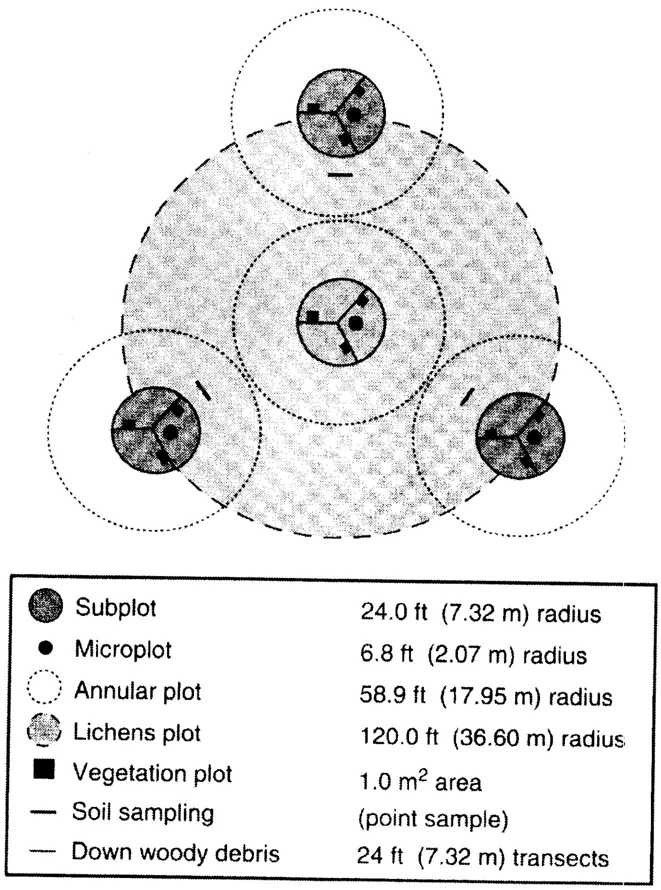

Figure 10.2 Plot layout for P2/P3 FIA sampling locations. (From Burkman 2005, with permission.)

measurements that require collecting a physical sample. Within each subplot, one 1/300 acre microplot is established 12 feet (3.6 m) 90° from subplot center. Most tree measurements occur within the subplot.

Measurements of seedlings, saplings, and other vegetation are measured on microplots (Burkman 2005). This plot design provides the basis for both the P2 and P3 samples. Additional P3 variables are collected within an approximately 1 acre (2.5 ha) plot established around the center subplot (lichens), on transects that run through each subplot (down woody material), and on three 1 m^2 quadrats established within each subplot (vascular plants) (US Forest Service FIA 2009).

10.2.4 Forest health monitoring variables

Phase 2 variables measured include (Burkman 2003):

- Tree diameter, length, damage, amount of rotten/missing wood, and tree quality
- Tree regeneration
- Site quality information

- Stocking
- General land use
- General stand characteristics, e.g., forest type, stand age, and disturbance
- Changes in land use and general stand characteristics
- Estimates of growth, mortality, and removals.

At each P3 plot, the following additional forest health measurements are made (Burkman 2003; US Forest Service FIA 2009):

- Crown condition – including foliage transparency, uncompacted live crown ratio, crown light exposure, crown position, crown vigor class, crown density, and crown dieback. Generally, it is assumed that trees with good crown condition are vigorous and healthy while trees with poor crown condition are typically under stress.
- Soil condition – soil erosion and compaction are measured, along with forest floor and litter layer thickness, and soil texture. Soil samples are collected for analysis of physical and chemical properties including estimates of site fertility and estimates of soil carbon in the litter and upper mineral soil layers.
- Lichen communities – lichen species richness and abundance are measured on the larger 1 acre (0.4 ha) P3 plot. Presence or absence of certain lichen species are indicators of air quality, climatic changes, and ecosystem biodiversity.
- Vegetation diversity and structure – vegetation composition, ground cover distribution, species abundance, and spatial arrangement of canopy layers in forested subplots are measured. In addition, presence/absence data are collected for vascular plants in the 1 m^2 quadrats. These data are used to assess vegetation diversity, presence and abundance of introduced plant species, fuel loading, wildlife habitat suitability, and carbon cycling.
- Down woody material – measurements of the amount of coarse and fine woody material, duff, litter and fuelbed depth, and fuel loading are used to estimate carbon storage, soil erosion potential, fire fuel loading and, combined with vegetation structure data, wildlife habitat.
- Ozone bioindicator data – on a separate grid, ozone-sensitive species (e.g., *Prunus serotina*, *Pinus ponderosa*) are evaluated for the presence of foliar ozone injury during the late summer.

Many of these forest health indicators, and other forest inventory measurements, serve to meet the Santiago Declaration and accompanying criteria and indicators (Anon. 1995; Montreal Process Working Group 2009) that were adopted by the Forest Service. National forest health monitoring reports address topics such as forest fragmentation, drought occurrence, fire occurrence, ozone damage to plants, insect and disease activity, down woody materials as an indicator of wildlife habitat, fuels and carbon stocks, and physical and chemical properties of soils (e.g., Ambrose and Conkling 2007).

In addition to using the plots and other data to link to these criteria and indicators and to conduct evaluation and intensive site monitoring, the FHM program works with FIA, FHP and state and Federal Agencies to monitor forest health conditions, including providing information on invasive species and forest insect and disease conditions in the USA (e.g., US Forest Service FHP 2007).

10.2.5 Non-forest health monitoring

As FHM currently focuses on forest areas, non-forest areas are not included in the national monitoring effort; however, a significant number of trees may be present in non-forest areas. In urban areas of the USA, which includes some forest stands, there are an estimated 3.8 billion trees (Nowak *et al.* 2001). To help address this issue, the Forest Health Monitoring Strategic Plan (US Forest Service 2003) calls for new monitoring approaches for under-represented forest ecosystems, e.g., urban and riparian forests.

Various researchers have investigated implementation of a riparian monitoring program (US Forest Service 2009). In addition, pilot-testing of baseline monitoring of trees in urban areas has been accomplished in Indiana (Nowak *et al.* 2007), Wisconsin (Cumming *et al.* 2007), and New Jersey (Cumming *et al.* 2008). More recently, urban plots have been established using the basic FIA P2 plot design and grid (5-year panel) in Tennessee and Colorado, with plots measured during the in-leaf season, and some P3 crown parameters to assess tree condition (Cumming *et al.* 2008). To date, though urban plots have been established, no repeat measurements of plots have been made to monitor changes in forests and trees through time.

The US Forest Service is an international leader in forest health monitoring with extensive amounts of data gathered to date. A yearly technical report is compiled to summarize trends across the landscape to highlight abiotic and biotic factors affecting forest conditions (e.g., Ambrose and Conkling 2007). The FHM Program provides important established baseline information for long-term monitoring along with repeated measures to monitor change. In addition, FIA reports include information regarding forest health and forest condition at the National (e.g., Smith *et al.* 2009), regional (e.g., Oswalt and Turner 2009), state (e.g., Conner *et al.* 2004), and sub-state (e.g., Oswalt 2005) levels. Standardized data collection protocols, including field crew training and quality assurance procedures, provide for quality long-term data. Annual plot data on a fixed national grid along with supplemental information from numerous sources provide the basis for annual forest health monitoring and detection of various forest issues essential for maintaining forest health at local, regional, and national scales. Other nations are implementing forest health monitoring based on FHM protocols (Hofstetter 2007). For example, Tanzania has established plots in the Eastern Arc Mountains taking data on crown condition, tree damage, and mensuration data (species density, diameters, heights, crown position). Indonesia has established plots to monitor sustainability and biodiversity of tropical rain forests using the FHM sampling design, and several eastern European countries (e.g., Belarus, Ukraine, Lithuania, Latvia, and Estonia) are using modified FHM plots.

10.3 Canada

Almost 40% of Canada is forested, ~400 million ha (NRC 2001), which comprises ~10% of the world's forests (CCFM 2003). Natural Resources Canada recently implemented a National Forest Inventory that will provide information on the current state of forests and how they are changing through time (Gillis *et al.* 2005). This inventory and monitoring system is a plot-based system (Figure 10.3) (Canadian Forest Service 2008) using a national grid to cover the entire landmass (Gillis *et al.* 2005). There are ~1150 ground plots established in forested areas. Plots are grouped into 10-unit panels with one panel measured annually (i.e., a 10-year measurement cycle). Data measurements include:

- Two 30-m line transects for small and coarse woody debris and surface substrate
- Four 1-m^2 microplots for shrub, herb, grasses, mosses, lichen biomass, and fine woody debris
- One soil pit for soil classification, coarse fragments, organic and bulk density soil samples
- Two ecology plots for recording a list of all species and percent cover
- 50 m^2 small tree plot for small tree data and stumps
- 400 m^2 large tree plot for tree data (age, height, dbh) and plot parameters (successional stage, disturbance, plot origin, management treatments, defect or pathological indicators).

Canada is a world leader in **third-party certification standards** for sustainable forestry management (CCFM 2007). The Forest Stewardship Council (FSC) was established in 1993 (*www.fsccanada.org*), and is one of three voluntary systems in place to achieve third-party certified status. The Canadian Standards Association's Forest Management Standard (CSA) is another means of certification as well as the Sustainable Forestry Initiative (SFI), both of which are

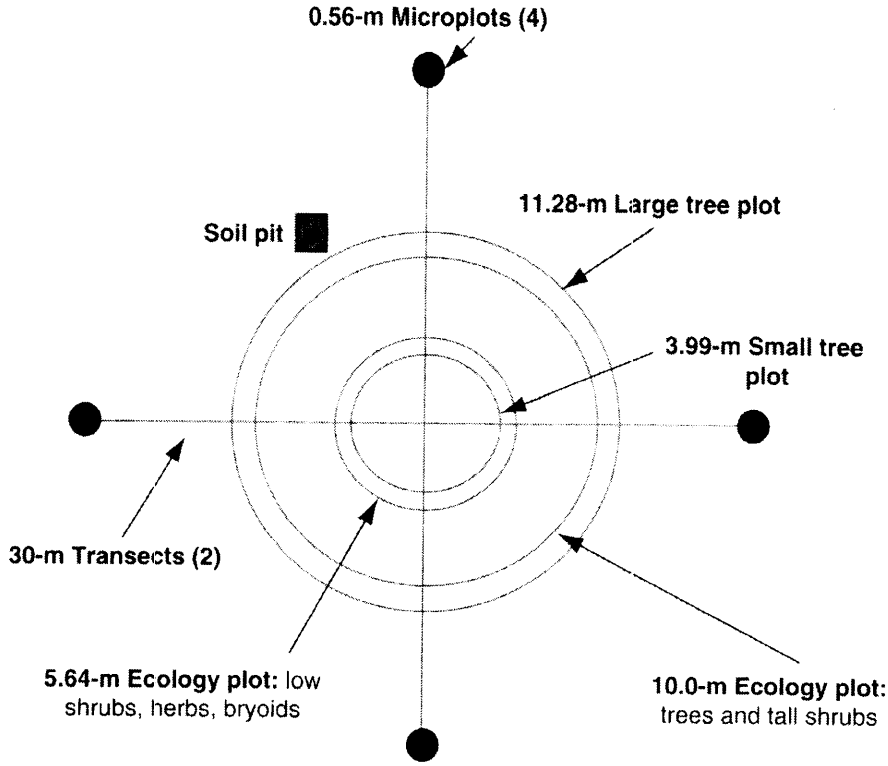

Figure 10.3 Natural Forest Inventory of Canada ground plot design. (Canadian Forest Service 2008.) Circular plot measurements are radii, e.g., the Large Tree Plot has a radius of 11.28 m.

endorsed by the Programme for the Endorsement of Forest Certification (PEFC). A goal of these systems is to maintain and enhance long-term health of forest ecosystems in Canada, while providing ecological, economic, cultural, and social opportunities. All three certification systems ensure conservation of biological diversity, wildlife habitat, soil and water resources, and sustainable timber harvest, and all require annual monitoring and public disclosure of findings (see Chapter 8 for discussion of forest certification).

10.4 Europe

Monitoring of forest conditions was initiated in the early 1980s in response to a suspected occurrence of a widespread forest decline event (Vanguelova *et al.* 2007; IWF 2008). A coordinated effort across Europe was initiated in 1985 by the United Nations Economic Commission for Europe, and implemented by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) to improve understanding of factors affecting forest ecosystems (UNEC-ICP 2006). Intensive forest health monitoring is implemented at two levels: Level I and Level II (EFMP).

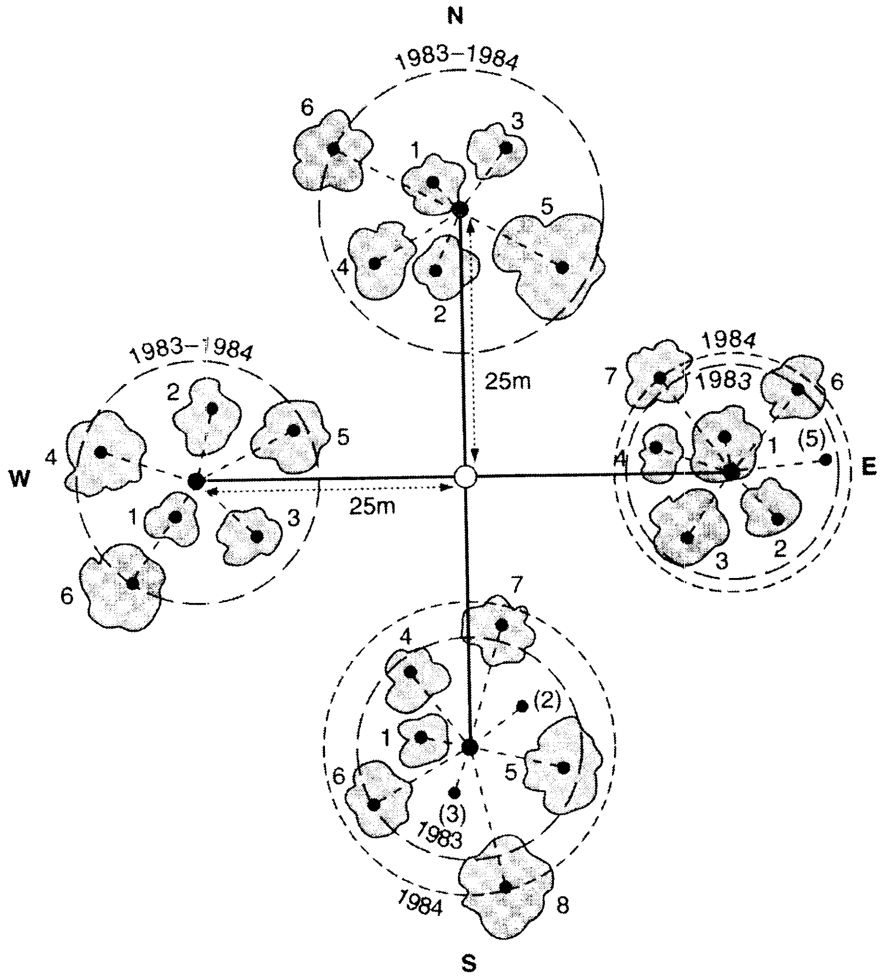

Figure 10.4 Four-point cross cluster plot for selection of trees to monitor in Level I European ICP forest sample plots. (Source: http://www.icp-forests.org/pdf/Chapt2_compl06.pdf.)

Approximately 6200 Level I plots have been established across Europe in 33 countries on a 16 × 16 km grid. Data taken in Level I plots include annual crown defoliation and discoloration estimates, and damage visible on a total of 10–24 trees. Sample plots and trees are selected using a statistically sound procedure, an example of which is the four-point cross cluster with six trees measured in each of four subplots (Figure 10.4).

Approximately 800 Level II plots are located in managed forests representing the most important forest ecosystems (Figure 10.5). Plots are 0.25 ha, and data collected in these plots represent both stressor and response indicators including: crown condition, foliar chemistry, tree growth, ground vegetation composition, stand structure (including deadwood), epiphytic lichens, soil chemistry, soil solution chemistry, atmospheric deposition, ambient air quality, meteorology, phenology, litterfall, and remote-sensing data (Figure 10.6) (IWF 2008).

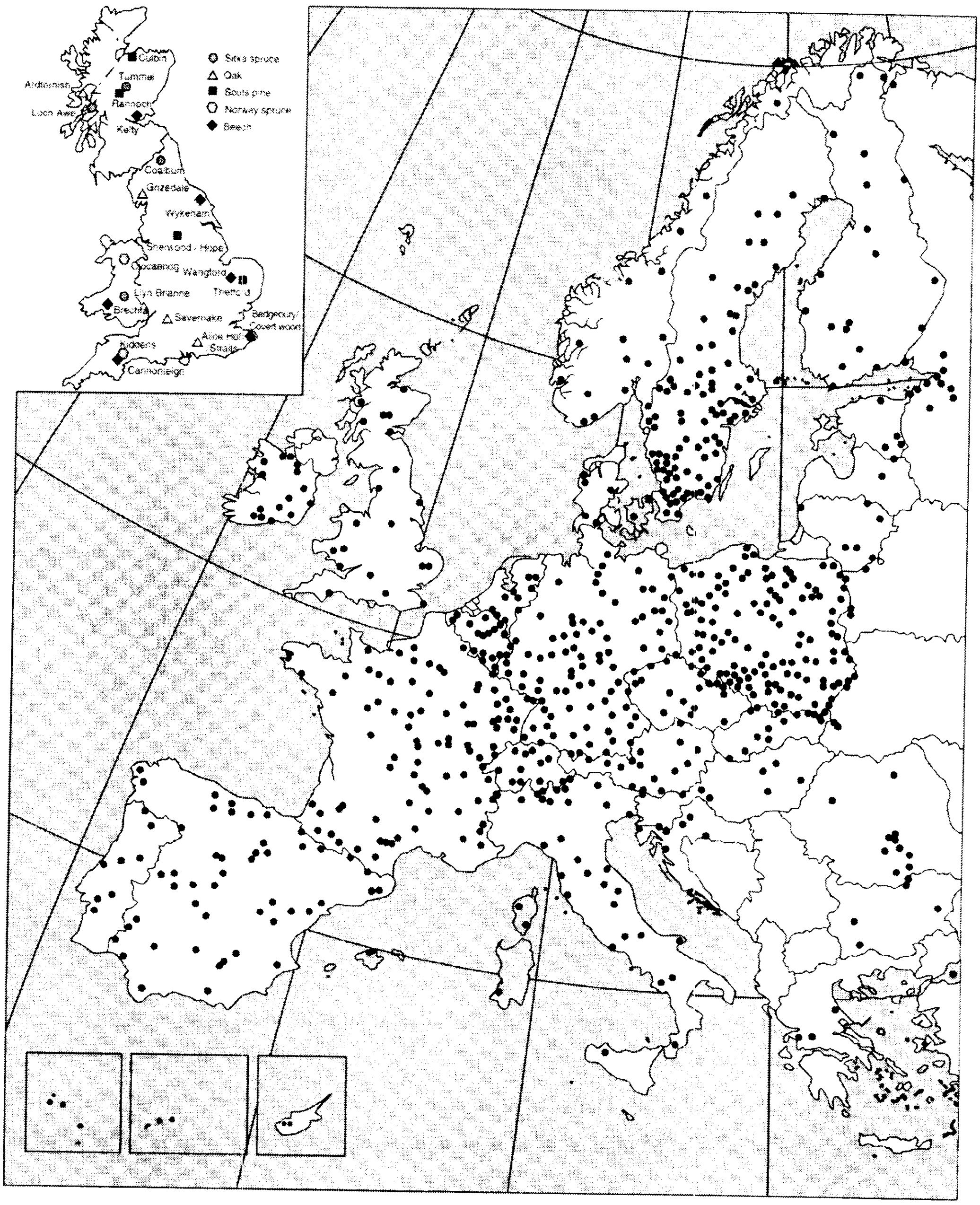

Figure 10.5 European Level II monitoring plots. (Source: http://www.forestresearch.gov.uk/images/imfe.gif/$file/imfe.gif.)

Results from Level I and Level II forest surveys are summarized annually in ICP Forest technical reports (e.g., Lorenz *et al.* 2008).

10.5 Australia

The Australian Department of Agriculture, Fisheries and Forestry have issued criteria and indicators that closely follow those outlined by the Montreal Process. Indicators specific to monitoring forest ecosystem health are

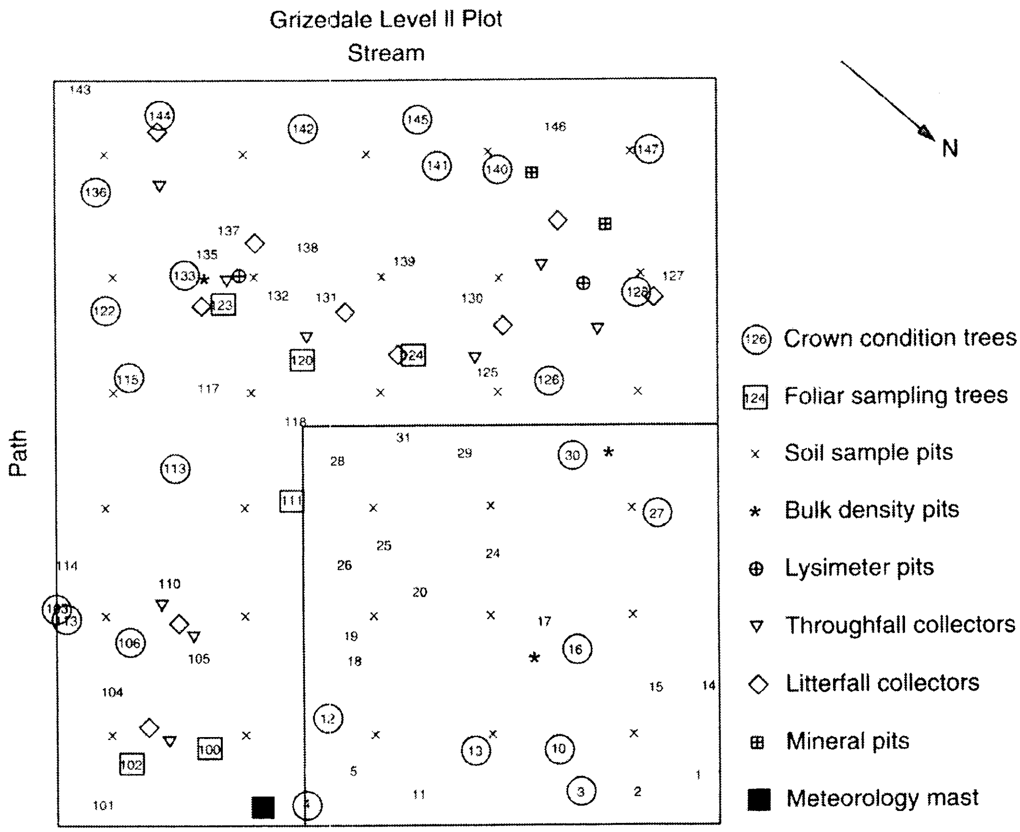

Figure 10.6 A typical Level II plot used in European forest monitoring plots. (Source: http://www.forestresearch.gov.uk/images/level2plotgrize.gif/$FILE/level2plotgrize.gif; http://www.forestresearch.gov.uk/images/level2plotgrize.gif/$FILE/level2plotgrize.gif.)

to quantify scale and impact of agents and processes affecting forest health and vitality as well as fire data (Australian Government 2008). Australia consists of eight states, and each has developed specific monitoring protocols established through Ecologically Sustainable Forest Management (ESFM) plans. The state governments will facilitate research and long-term monitoring to detect adverse impacts and develop practice and management plans to ameliorate identified adverse impacts in keeping with the "precautionary principle" (Commonwealth of Australia 1995). In general, objectives for ESFM plans are to maintain ecosystem health and vitality, and to control outbreaks of disease, pests or other agents affecting ecosystem health and vitality, through cooperative planning and management (Commonwealth of Australia 1995). Data requirements and monitoring methodology include identifying and quantifying factors (processes and agents) that may change ecosystem functioning. Factors may include interactions between natural events and management actions in the following areas: fire, climatic events, river regulation, salinization, grazing, introduction of exotic biota, logging, clearing, roading, bell-miner dieback, insects, and diseases. Relevant factors are identified and monitored on a regional basis.

Four main health surveillance and monitoring activities are implemented by forest managers: (1) Forest health surveillance focused on detecting and quantifying damage; (2) Health/condition monitoring that is tree/forest-focused and optimized to describe condition of trees and detect change; (3) Pest population monitoring optimized to measure populations of target pests; and (4) ad hoc detection that is damage-focused on specific pests and disease issues (Australian Government 2008). Most states use aerial surveillance, drive-through surveys, and ground inspections in plantations with very little monitoring occurring in native forests. Two states, however, have established plot-based monitoring systems (Wardlaw *et al.* 2007; Carnegie 2008). Victoria has established surveillance methodology based on the US FHM plot system and western Australia monitors forest health using intensive measurements in permanent "Forestcheck" sites where plant species and cover are documented in four 1000-m plots and twenty 1-m plots) within different forest types.

The need for coordination and compatibility of assessment and reporting systems at the state-level is recognized in order to link these efforts at the national level (Stone *et al.* 2001; Stone and Coops 2004). Unfortunately, divergent management priorities for forests and plantations have resulted in differing interpretations of what is meant by forest health, as well as how it is assessed and monitored at the state level. Individual state priorities and available resources and funding are limitations that greatly influence these processes.

10.6 Indonesia

The Indonesian Forest Health Monitoring (INDO FHM) program is charged with delineating current conditions of Indonesian tropical rain forests with respect to sustainability and biodiversity (Soekotjo *et al.* 1997). The program is a collaborative research effort with the US FHM Program, and is supported by the International Tropical Timber Organization (ITTO). INDO FHM is initiating a plot system and using indicators similar to those of the US FHM program. Data from these efforts will provide an assessment of forest conditions as to the proportions of forests in poor, sub-nominal, nominal, and optimal condition. Long-term monitoring will subsequently quantify changes and trends through time.

10.7 China

Recognizing that forest resources are a critical issue, the Chinese Academy of Forestry, and the Chinese Ecosystem Research Network established the Chinese Forest Ecosystem Research Network (CFERN) (Wang *et al.* 2003). CFERN is comprised of 15 stations that conduct research in forested areas throughout the country where water quality, pest abundances, tree conditions, and composition are continuously monitored. These stations also collect data on forest fires, disease/pest outbreaks, and forest resources that can be used in evaluations of forest health (Xiao *et al.* 2004).

10.8 Food and Agriculture Organization (FAO) of the United Nations

Fifty-nine countries, representing 75% of the world's tropical forests and 90% of the global tropical timber trade, operate under the guidelines of the International Tropical Timber Organization (ITTO 2005). ITTO encourages member countries to strive for export of timber products from sustainably managed sources. To facilitate sustainability, ITTO provides criteria for management of tropical forests as well as tools for monitoring, assessing, and reporting changes and trends in forest conditions and management. ITTO considers seven criteria essential to sustainable forest management. Of these, the first three are relevant to forest health, and the last four concern various goods and services provided by forests (Forest production, Biological diversity, Soil and water protection, and Economic, social, and cultural aspects). Criterion 1 (Enabling conditions for sustainable forest management) outlines general legal, economic, and institutional frameworks that facilitate success of the other criteria. Criteria 2 (Extent and condition of forests) and 3 (Forest ecosystem health) are concerned with quantity, security, and quality of forest resources.

Many other countries operate under the umbrella of the FAO (Castaneda 2000). Nine countries participate under the Asian Dry Forests Process. Seven countries operate under the Leparterique Process of Central America, 13 participate under the African Timber Organization, 30 under the Near East Process, and 30 under the Dry-zone Africa Process. Forest health under the last criterion include such factors as area modified by humans, fire, storms, insects, diseases, animals, drought, invasives, percent of forest without regeneration, changes in nutrient balance and soil acidity, percent of population employed in farming, bush encroachment, and trends in crop yields. The Tarapoto process is part of the Amazon Cooperation Treaty; which includes eight countries representing a substantial proportion of tropical forests. This process includes 8 criteria and 15 indicators including: existence of policies and legal framework for land-use planning, rate of conversion of forests to other uses, and prevention measures to protect water courses from forest extraction activities.

10.9 Other countries

Many countries not specifically addressed above have forest health monitoring programs, or are in the process of establishing programs. Some focus efforts on plant pests and diseases, others on conservation, and still others on environmental services provided by forest ecosystems. Adaptations often are necessary in order to use existing indicators from temperate regions of the world. The list of indicators used within each country should necessarily be adapted to the specific forest type, and the social and economic needs of citizens of that country.

10.10 Conclusions

As indicated in Chapter 1, forest health monitoring began some time ago, but there remain questions to be addressed. Some of the most pressing include assessing if all monitoring approaches are statistically valid. If so, are they comparable? Would a healthy forest under one system be deemed unhealthy under another? Do the indicators currently being used provide the data necessary to assess forest health in a meaningful manner? Has this been rigorously evaluated for the different monitoring programs? Are there other indicators that we could monitor or calculate (e.g., baseline mortality) that would be better? Answering these questions and moving toward implementation of a global forest health monitoring network is ideal, but would need to have a common definition of "health", as well as a common system of monitoring that is statistically sound at known spatial scales across all forest ecosystems.

The most widely used indicator of biophysical forest health is probably visual estimations of crown condition of trees (Alexander and Palmer 1997). Use of this indicator is predicated on the assumption that if a majority of trees are exhibiting crown dieback, then the forest is experiencing some deleterious process, and so, is unhealthy. US forest conditions are primarily summarized based on crown condition using a combination of measurements for crown dieback and crown transparency. Observer bias and objectivity often is a problem in assessing this variable (Innes 1988). A similar variable estimating crown condition in European forest health monitoring plots has been questioned and criticized (Ferretti 1997; Ferretti and Chiarucci 2003; Seidling 2004). Crown dieback may be a good indicator of tree stress, but measuring it accurately requires extensive training of field personnel. Estimates still can vary considerably, especially if measurements are taken during different months (Seidling 2004). In addition, crown dieback often is reversible, i.e., not all trees that show crown dieback are necessarily unhealthy (see Chapter 4). Trees under stress often exhibit dieback that is reversed when the stress abates. Use of crown discoloration and assignment of causal agents is apparently even more variable (Ferretti 1998, Ferretti and Chiarucci 2002).

Calculations of baseline mortality (stable age and size class discussed in Chapters 1 through 3) from mortality data already being collected may be a strong candidate to incorporate into forest health monitoring programs considering its simplicity, and in recognition of the limitations of measuring crown condition. Information derived from it also may facilitate establishment or refinement of reference conditions critical to monitoring indicators of forest ecosystem health and vitality.

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