Harmonisation of methods for the assessment and reporting of forest health in Australia — a starting point

A discussion paper prepared by a sub-committee of the Forest Research Working Group on Forest Health*

C. Stone1,2, T. Wardlaw3, R. Floyd4, A. Carnegie1, R. Wylie5 and D. de Little6

1Research and Development Division, State Forests of NSW, PO Box 100, Beecroft, NSW 2119, Australia
2Email: christines@sf.nsw.gov.au
3Forestry Tasmania, GPO Box 207, Hobart, Tasmania 7001, Australia
4CSIRO Entomology, GPO Box 1700, Canberra, ACT 2601, Australia
5Queensland Forestry Research Institute, PO Box 631, Indooroopilly, Queensland 4068, Australia
6Forest Health Consultant, 9 Three-mile-line Road, Burnie, Tasmania 7320, Australia

Revised manuscript received 6 January 2003

Summary

The harmonisation of a sub-set of forest health attributes suitable for aggregating, through scales ranging from individual trees to the operational forest management unit and up to the national level, has been achieved in countries such as the USA and Canada. In Australia, however, data collected on forest health is currently obtained on an ad hoc basis with only a small proportion of the national forest estate actually having been assessed. National guidelines are required for the objective assessment of a set of indices relating to forest health before Australia is in a position to report adequately on forest ecosystem health and vitality as recommended by the (Australian) Montreal Process Implementation Group. Obtaining these indices must be an affordable process that fulfills forest health reporting requirements for a range of national, state and regional reporting commitments such as the State of the Forests Reports and for the Regional Forest Agreements review process. In addition, it is envisaged that the indices will contribute to the verification process for the forest health and vitality criterion described in the Australian Forestry Standard for certification of sustainable forest management practices.

Tree crown condition is proposed as a key attribute of forest health and it is amenable to rapid standardised assessment. Four measures are proposed which have the potential to provide consistent core data on tree crown condition. Adoption of these indices will depend on the assessments being cost effective and consistent, and the results being meaningful for a range of applications. To facilitate this process an illustrated field manual has been published, providing guidance for standardised assessment methods. Initially the scope of the manual is limited, focusing on the assessment of eucalypt tree crown damage. If it proves successful, the number of indicators relating to forest health monitoring could be increased.

Keywords: plantations; forest trees; crown; foliage; damage; forest health; assessment; monitoring; data collection; Montreal Process; handbooks; Eucalyptus

Introduction

The harmonisation of a sub-set of forest health attributes suitable for aggregating, through scales ranging from individual trees to the operational forest management unit (FMU) and up to the national level, has been achieved in countries such as the USA and Canada. The purpose of the United States Department of Agriculture, Forest Service (USDA FS) Forest Health Monitoring (FHM) Program is to assess annually the condition of the nation’s forested ecosystems in a standardised way (Mangold 1998). This objective is achieved at a total cost of about US$50–80 million per year. In Australia, however, data collected on forest health are currently obtained on an ad hoc basis with only a small proportion of the national forest estate actually being assessed. At present, reporting on forest health tends to be narrative (e.g. National Forestry Inventory 2003). Unless a coordinated systematic model for assessing a core of valid forest health attributes is implemented, Australia will not be in a position to report on any of the Indicators (as defined by the Montreal Process Implementation Group: Commonwealth of Australia 1998) related to forest health and vitality in an adequate manner.

This paper presents the preliminary components of a harmonised approach to the collection of data on a small set of attributes suitable for reporting against Criterion 3 of the Montreal Process: forest health and vitality (Commonwealth of Australia 1998). The Montreal Process now forms the endorsed framework for most ecologically sustainable forest management (ESFM) systems and reporting in Australia. It is hoped that these recommendations will lead to the development of a set of voluntary assessment and reporting guidelines for forest health monitoring which, if adopted by state and private forestry organisations, environmental agencies, farmers and community groups, would expedite state and national-level reporting commitments on forest health.

A major driver for the adoption of these standardised guidelines will be their potential contribution to forest certification schemes, providing a mechanism for third-party audit. Forest certification schemes based on specifications in the Australian Forestry Standard (AFS) (Australian Forestry Standard Steering Committee 2003)
are now being promoted as a means of retaining competitiveness with countries with sustainable management schemes and standards in place. The AFS is intended for voluntary application to any forests being managed for wood production, whether native or planted forests, by individual forest owners or managers of multiple forest areas under a variety of land tenure arrangements. It recommends procedures for assessing and monitoring forest damage, and also that there be appropriate specification of acceptable levels of damage and its assessment. A field manual on assessment of crown condition would address both these requirements.

We recommend, at this preliminary stage, that the development and testing of protocols and methods should focus on the assessment of eucalypt trees, in particular tree crown damage and condition. It is assumed that the assessors will know the identity of the common damaging agents or that they will have access to diagnostic texts or seek expert advice. This paper concentrates on assessing the effects of insect pests and diseases. Many other agents and processes are known to affect forest health in Australia — for example, weeds, drought and fire — but they will not be addressed here.

Commercial eucalypt plantations will be used in the initial development of the crown condition indices because activities of most health surveillance teams are currently restricted to plantations, although mature non-plantation eucalypts will be included in some aspects of the proposed program. Other authors (Wicklum and Davies 1995; Ferretti et al. 1999a,b) have advocated a pragmatic stance focusing on a small achievable set of standardised attributes. The proposal not only takes into account the capacity of an agency to undertake such an assessment program (Stone et al. 2001) but also provides a mechanism for quality assurance needed for statistically sound comparisons through time and between sites (Ferretti et al. 1999b; Köhl et al. 2000). Nonetheless, it is essential that the development of more sophisticated methods be considered for future assessments of the health of native forest ecosystems.

While acknowledging that a holistic perspective towards forest health monitoring is desirable (e.g. Hirvonen 2001), prevailing resource and budgetary constraints in Australia necessitate that we take a simpler but logical approach. This means concentrating initially on achieving acceptance of a small subset of standardised forest health measures which will be obtained over the long term, rather than being more ambitious and achieving only short-term success. More sophisticated indicators of forest health could be integrated into the assessment process once the simplistic approach has been successfully adopted.

Current situation in Australia on reporting of forest health

The Ministerial Council on Forestry, Fisheries and Aquaculture (MCFFA) endorsed the use of the Montreal Process criteria and indicators (C & I) as the basis for assessing sustainable forest management at the national level, and the development of a framework of indicators to be used at the regional level and in the Regional Forest Agreement (RFA) process (Commonwealth of Australia 1998). This universal framework is intended to promote consistency in reporting at all levels and to avoid duplication in data collection.

Currently there are three categories of agreed regional indicators: Category A, which is largely implementable now; Category B, which requires some development; and Category C, which requires longer-term research and development. Indicator 3.1.a (= area and per cent of forest affected by processes or agents that may change ecosystem health and vitality) has been classed as a Category A indicator.

The sub-national indicator A data (Commonwealth of Australia 1998) are compiled and analysed by the National Forestry Inventory (NFI), a group of the Bureau of Rural Sciences (BRS) within the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). Results have been presented in Australia’s State of the Forests Report 2003 (National Forest Inventory 2003) which serves as Australia’s country report to the Montreal Process. The Regional Forest Agreement Act 2002 included a requirement that there be ongoing commitment towards national and regional monitoring and reporting in relation to all of Australia’s forests. In addition, there is the Australian and New Zealand Environmental and Conservation Council (ANZECC) State of the Environment (SoE) Report (ANZECC State of the Environment Reporting Task Force 2000) which reports on the relative health, growth or decline of vegetation at intervals of five years.

The SoE core indicator ‘Extent and condition of native vegetation by type’ overlaps with Montreal Process Criterion 3, in particular, the component relating to the condition of forested vegetation. Also, the ANZECC indicator ‘The number (and identity) of native species outbreaks and location and area affected’ has requirements similar to those of Criterion 3 indicators: for example, the occurrence and extent of outbreaks of phasmatids, bell miners and Phytophthora cinnamomi in native forests.

In addition, the Commonwealth coordinates the implementation and management of the National Vegetation Information System (NVIS) framework (National Land and Water Resources Audit 2000). The NVIS framework provides an agreed set of guidelines for translating and compiling mapped vegetation data sets on all vegetation types into a standard set of attributes and a database. The NVIS vegetation dataset will become a major contributor to Australia’s national and international environmental and sustainable forest management reporting obligations (Richard Thackway, Bureau of Rural Science, Canberra, pers. comm. 2002). A report compiled by Thackway (2001) outlined a proposed Stage II of the NVIS to be led by BRS and supported by the Natural Heritage Trust. One of the funding priority areas for NVIS Stage II is the development of mechanisms that describe vegetation condition (deterioration or improvement) and, in particular, Activity 4: Development and testing of methods for regular assessment of change in condition to support sustainable landscape management.

The NVIS Stage II work plan states that DAFF is committed to the development of consistent standards and better integration with existing forest health monitoring, especially through the implementation of the framework of sub-national C & I, including indicators relating to the maintenance of ecosystem health and vitality (Commonwealth of Australia 1998). The eucalypt crown
condition attributes proposed in this paper may well contribute to this broad NVIS objective relating to natural resource management, in addition to sustainable management requirements associated with commercial production forests and plantations.

While the NFI is responsible for the compilation and analysis of information on Montreal Process indicators at the national level, it is the state-based forest management agencies that collect and collate this information. All State forestry agencies and some private forest companies employ staff with technical expertise relating to forest health (Stone et al. 2001). Because routine surveys are labour intensive and expensive to maintain, most surveillance programs are restricted to high-value plantations (or high-value conservation areas in some States). They tend to report only on agents that directly threaten tree growth, such as insect pests and diseases, mammal browsing, weed competition and nutrient deficiencies. Although the surveillance teams quantify both the extent and severity of damaging agents, methods have evolved from local conditions and requirements and there is little coordination between States (Stone et al. 2001). For commercial companies with the capacity to quickly implement effective control measures, their assessment teams focus on monitoring populations of known damaging agents during critical times of the year with the objective of preventing these agents reaching damaging levels. For these companies, assessment of crown damage would demonstrate the effectiveness of their protection programs. Companies without the capacity to intensively monitor and/or rapidly apply control measures could incorporate crown condition data into growth models to improve the accounting of potential productivity losses.

Environmental agencies conduct very few extensive, systematic insect pest or disease distribution surveys in native forests, and tend to concentrate on implementing regional abatement programs for feral animals and noxious weeds. An exception is the Phytophthora management program in Western Australia (Environment Australia 2001b). All threat abatement and recovery programs recommend some form of monitoring for evaluation purposes. For those damaging processes that affect eucalypts, the proposed crown condition index could be used as a standardised assessment tool.

At this stage, the request to the States for ESFM data by NFI is still evolving, in that the type and format of information requested has not yet been formalised, especially for the indicators relating to forest health. Information provided in the Annual Pest and Diseases Report compiled by Research Working Group 7 has been acknowledged by NFI, but due to its narrative form it is seen as difficult to quantify into a suitable tabular format. Consensus among the State-based forest management agencies, participating private companies and NFI is required to ensure that standardised, meaningful data are provided to the NFI. It is questionable whether the information presented in the 1998 State of the Forests Report could contribute towards any judgement on the health and vitality of Australia’s forests.

A national workshop, partially funded by DAFF, was held in Sydney in June 2002 to facilitate the development of a core set of standardised attributes and methods for the surveillance of health of eucalypts. This discussion paper is an outcome of that workshop. Without the harmonisation thus potentially ensuing, the value of any collated information greatly diminishes. Ferretti (1997) claims that — because of differing assessment protocols amongst countries and the lack of universal quality assurance — there is reasonable doubt whether the forest health survey data collected as Part I of the Economic Commission for Europe of the United Nations (UN-ECE) International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP — Forests) Strategy are comparable. This large-scale pan-European survey of forest condition was established in 1987 and a key objective was to be able to monitor forests across Europe.

**State-based reporting requirements**

Partly as a result of the Regional Forest Agreement Process, many State forestry agencies have developed environmental management systems (which are often compliant with a generic environmental management system standard such as ISO 14001), and an on-going information-gathering framework based on the Montreal Process. These systems provide the mechanism for fulfilling their reporting commitments (e.g. Environmental and Social Values reporting, Montreal Indicator reporting, RFA annual reports, State of the Forests and State of the Environment Reports). It is this information which is summarised and forwarded to the appropriate federal agency for aggregation to the national level (e.g. DAFF or Environment Australia).

While many of the reporting requirements relating directly to forests are federal requirements, they have also been enacted at the State level; for example, the New South Wales Forestry and National Park Estate Act 1998. Most forest management agencies are attempting to justify and support the costs associated with the collation of this information in a managerial context; for example, their individual environmental management systems are internally audited but could also be subjected to third-party auditing and hence ESFM certification. Therefore, the indicators selected need to be operationally valid for acceptance by agency managers as well as being scientifically meaningful within the context of the Montreal Process.

**Selection of indicator attributes**

Australia parallels North America in that forested areas are overlain by diverse and largely decentralised, jurisdictional, ownership and organisational patterns. The selection of indicators used for ESFM verification and reporting will be strongly influenced by the management requirements of the various agencies and organisations responsible for different aspects of land and resource management. However, unlike the North American countries, Australia does not have a large federal forestry agency providing significant financial support for regular collection of field data, and hence the NFI has less direct influence over the methods used and the quality assurance of the data collected.

Part of the difficulty associated with Montreal Process Criterion 3 lies in the multitude of definitions that have been proposed for forest health (e.g. Kimmins 1996; Stone et al. 2001 and references therein). Definitions relating to forest vitality are even more vague. The spectrum of perspectives range from utilitarian (commercial interests) to ecosystem (conservation interests) (Kolb et al. 1994). Because of these differences, the objectives of forest health survey programs can differ widely in both target and scale. For commercial forest entities, assessments tend to focus on the trees and stressful
agents that directly threaten tree growth or survival (related to tree and forest health), while conservation agencies attempt to monitor the biological integrity of forests (i.e. forest ecosystem health). The objectives of the first can be defined exactly and the results can be directly linked to both management operations and ESFM monitoring. The latter objective is much more difficult to achieve because of the increased structural and functional complexity of the target entity and hence the higher costs of these programs. In both cases, however, the attributes selected for inclusion in health assessment protocols must be practical, meaningful and repeatable. Repeated assessment of such attributes will enable the detection of changes and trends over time (i.e. monitoring).

**Tree crown condition**

Several overseas authors list desirable characteristics of attributes used for reporting on forest health (e.g. Innes 1993a; Ferretti 1997; Kneeshaw et al. 2000). They claim that these attributes not only need to satisfy stakeholders’ values and opinions but also should be scientifically valid and, very importantly, economically feasible to collate. Tree crown condition has become a universal indicator of forest health and is incorporated into the surveillance programs of many countries (e.g. Innes 1993a,b; Brand 1997; Ferretti 1997). One reason is that it can satisfy, to a varying extent, both commercial and ecological interests.

Assessment of tree crown condition is an integrative process based on a range of crown indices. Innes (1993a) discusses the merits of several dozen indices of tree condition that have been trialled in the British forest health assessment program. Indices listed include: foliage discoloration, density (or transparency) and damage; patterns of foliage flushing and senescence; patterns of branch growth and development; and leaf shape and size. The USDA FS Forest Health Monitoring (FHM) program argues that since tree crowns form the basic structure of the forest ecosystem, they directly affect the composition, processes and vigour of the understorey plant and animal components of the forest (US Department of Agriculture, Forest Service 2002a). The visual crown rating measurements are the cornerstone of FHM (Mangold 1998). The FHM program assesses crown condition through the following tree crown parameters: dieback, foliage transparency, crown density and tree damage. The aggregated data derived from standardised monitoring methods are then used in a variety of assessment reporting venues. In addition, Kneeshaw et al. (2000) claim that whether the goal is certification or to simply improve forest management, forest managers need standardised, acceptable indicators of sustainable forest management that are designed for use at the operational scale of an FMU. We argue that assessment of crown condition and damage will achieve these goals.

For the reasons outlined above, tree crowns will form the basic unit of all the attributes proposed in this paper. Our definition of **tree condition** incorporates shape and size of the crown (crown architecture) and foliage distribution and density, while **tree damage** takes into account the incidence and severity of missing, damaged and discoloured foliage. It is envisaged that the ground-based assessments of these crown-based attributes would be attained for individual trees, aggregated up to the FMU via appropriate sampling strategies, then to the forest level and finally to the regional level.

The four following four measures are recommended for the provision of consistent core data on crown condition.

**Crown condition (not related to causal agents):**

1a) A generic, ground-based crown damage index for use in young plantation eucalypts supported by a standardised visual rating system presented in a field guide manual.

1b) A generic, ground-based index of crown condition for non-plantation eucalypts and mature eucalypts supported by a standardised visual rating system also to be presented in the manual.

1c) A generic index of eucalypt canopy condition obtained from remotely-sensed multispectral imagery for integration into operational GIS systems and ground-based forest health surveillance programs.

**Crown condition by causal agents:**

2) The regional extent of key damaging agents in commercial eucalypt plantations attaining levels of damage that reach a reporting threshold.

The relationships between the four measures are illustrated in Figure 1.

**Crown Damage Index for young eucalypts**

In the USDA FS FHM program, visual symptoms of crown damage have been identified as providing valuable information about a tree’s condition. The assessment has three components: type of damage; location of damage on the tree; and severity of damage, with each component recorded separately (US Department of Agriculture, Forest Service 2002b). The proposed Crown Damage Index (CDI) is more specific in its application, being restricted to young eucalypts before they reach canopy closure. It is designed to be a simple, comparable, generic measure that will enable comparisons irrespective of eucalypt species, plantation location or causal agents.

The CDI is based on the product of crown incidence and leaf severity for three types of damage commonly observed in eucalypt crowns (Stone et al. 2003). The three types of damage are:

i) **defoliation** = entire leaves missing or leaf tissue missing per leaf (including leaf holes, edge scalloping and total leaves missing which would have a value of 100% for severity at the leaf scale);

ii) **necrosis** = dead leaf tissue (= necrotic leaf spots, leaf blisters and entire dead leaves still in the crown recorded as 100% affected at the leaf scale);

iii) **discolouration** = nongreen leaf tissue (= yellowing or reddish-purple discolouration, chlorotic spots or margins).

Therefore, the CDI is based on a visual estimate of the incidence (extent) of damage over the entire tree crown (as a percentage) multiplied by the average level of severity at the leaf scale (as a percentage) for each of the three types of damage (if present). The three products are summed to produce the CDI. To produce a continuous variable between 0 and 100, each product of incidence and severity is divided by 100 before summing. The CDI can then be placed in one of nine categories:
No crown damage (= a score of 0);
1–5 (= a score of 1);
6–12 (= a score of 2);
13–25 (= a score of 3);
26–50 (= a score of 4);
51–75 (= a score of 5);
76–88 (= a score of 6);
89–94 (= a score 7); and
greater than 96 (= a score of 8).

For example, a young eucalypt tree crown with the top half of the foliage missing (50% of crown and 100% severity at the leaf scale) (= 50 x 100/100) and no damage on the remaining leaves would have the same CDI (i.e. 50), as a crown with the upper 25% of foliage missing and 50% of the crown having, on average, leaves with 50% of their area damaged by fungal leaf spot (CDI = (25 x 100)/100 + (50 x 50)/100).

The assessment of leaf discolouration is more problematic because leaf colour is influenced by both biotic and abiotic damaging agents, and often there are confounding effects (Dell et al. 2001). In order to uphold the desirable features of the CDI, that is, simplicity, ease of assessment and consistency, it has been decided to treat all leaf tissue whose colour is outside the normal range of variation for that host species, irrespective of possible causes, as discoloured, and to give it weighting equal to that of missing or necrotic leaf tissue. For example, where leaves on the top half of a young eucalypt are totally purple, and those on the lower half are healthy, the CDI would be 50 (= 50 x 100/100). A similar CDI would be given to a tree which had all its leaves half yellow with inter-veinal chlorosis (= 100 x 50/100).

While identification of the agents responsible for the observed damage is desirable from a management perspective, it is not required for the CDI assessment. Several damaging agents may affect the tree simultaneously and many individual damaging agents produce a range of symptoms that can change over time. Therefore, the assessment date must be recorded. For example, in Tasmania, defoliation of young E. globulus following infection by Mycosphaerella nubilosa proceeds from the outside of the crown inwards (approximately a top-down spread in vigorously growing trees, see Appendix 1). If the same trees are examined after several months of post-defoliation growth, the damage appears to have spread upwards from the bottom of the crown.
A prerequisite for CDI assessment is an appreciation of the range of normal (healthy) variation in the crowns being assessed, especially in terms of leaf distribution, density and colour. An example would be the change in normal colouration as the leaves mature and age. The CDI should be assessed in terms of any deviation from this healthy phenotypic expression of crown condition, especially when estimating the loss of entire leaves and discoloration.

Several forest health surveillance units including those within State Forests of NSW, Forestry Tasmania and the Queensland Forestry Research Institute now routinely use this scheme for assessing eucalypt crown damage. Calculation of the CDI can be done either manually on paper (or rather, intuitively by experienced assessors) or derived from the individual tree-scale and leaf-scale estimates using palm computers. A field manual (Stone et al. 2003) is now published that provides guidelines for visual assessments for the CDI (refer to relevant section below). Once collated, the CDI could be reported independently or linked to our proposed table of reporting thresholds of damage (see below) which summarises damage by specific insect pests or fungal pathogens.

Crown Condition Index for mature eucalypts

Innes (1993b) claimed that tree condition is often used in a non-specific sense, referring to the overall appearance of the trees within a forest (irrespective of the damaging causal agents or processes and type of damage). Development of a single, generic measure of eucalypt crown condition will be challenging, partly because of differences in crown form between eucalypt species and the crown maturation process within species (e.g. Florence 1996).

Parameters often included in visual assessment of crown condition include crown size and shape, branching, crown density (or transparency) and colouration. With respect to eucalypts, the extent of epicormic growth is also included (e.g. Kile transparency) and colouration. With respect to eucalypts, the extent of epicormic growth is also included (e.g. Kile transparency) and colouration. The proportion of the current tree crown which is of epicormic origin. These variables should be derived from direct measurement (e.g. the Live Crown Height Ratio, as used in the USDA FS FHM program), or with the assistance of a standard reference such as a foliage crown grid (USDA FS FHM program). Research is needed to determine the optimal combination of crown indices for a Crown Condition Index of mature eucalypts.

It is envisaged that a ground-based Crown Condition Index for mature eucalypts would be more commonly applied in native forests, rural woodlots and older eucalypt plantations while the Crown Damage Index would be used in young commercial plantations. It is proposed that assessment methods for both crown indices would eventually be presented in a single field guide manual.

Field guide manual

The national forest health monitoring programs of both the USA and Canada have comprehensive field guides on methods (e.g. US Department of Agriculture, Forest Service 2002b). The ready availability of a manual documenting definitions of terms, descriptions of visual scoring categories, sampling, recording and reporting protocols reduces assessor variance and enables the implementation of a quality assurance system as well as facilitating training for surveillance.

The current field manual for the CDI (Stone et al. 2003) presents common patterns of foliar damage at both the leaf scale and tree crown scale. In addition, a sampling procedure is presented for collecting and summarising CDI data in an objective, rigorous and repeatable way. This helps reduce variability arising from the subjective evaluation of visual estimates and from inconsistent recording methods.

Other issues addressed in the manual include the seasonal timing and frequency of assessments. The manual provides access to a Microsoft Excel worksheet for recording CDI data and for preparing a summary that can be downloaded from the National Forest Inventory web site (www.affu.gov.au/nfi ). The manual will evolve over time through the addition of new information. It will not only benefit forest managers seeking advice on readily standardised data on tree crown damage but will also assist audit teams with their compliance assessments. Other groups of potential users of the manual include researchers such as silviculturalists and tree improvement officers who need to make a rapid visual assessment of tree damage. Farm forestry extension officers and Landcare groups may also wish for access to standardised methods. Perhaps all or part of this specific manual might be incorporated into more general silvicultural manuals, such as those developed for individual forestry agencies, or assessment guidelines for the NVIS.

Reporting thresholds of damage

In Canada only moderate and severe defoliation categories are selected for analysis and illustration in maps, graphs and tables prepared for reporting purposes (Simpson and Coy 1999). Moderate
Table 1. Proposed reporting thresholds for key pests and pathogens of young eucalypts

<table>
<thead>
<tr>
<th>Species</th>
<th>Reporting damage threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>25%</td>
</tr>
<tr>
<td>Autumn gum moth (<em>Mnesampela privata</em>)</td>
<td>25%</td>
</tr>
<tr>
<td>Christmas beetles (<em>Anoplognathus</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Chrysomelid leaf beetles (e.g. <em>Chrysophtharta</em> spp., <em>Paropsis</em> spp., <em>Cadmus</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Leafblister sawfly (<em>Phylacteophaga</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Gumleaf skeletoniser (<em>Uraba lugens</em>)</td>
<td>25%</td>
</tr>
<tr>
<td>Sawfly (<em>Perga, Pergagrapta</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Psyllids (e.g. <em>Cardiaspina</em> spp., <em>Creis</em> spp., <em>Glycaspis</em> spp., <em>Crenarytaina</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Gumtree scale (<em>Eriococcus</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Weevils (e.g. <em>Gonipterus scutellatus</em>)</td>
<td>25%</td>
</tr>
<tr>
<td>Spring beetle (swarming scarabs) (e.g. <em>Heteronyx</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td>Wingless grasshopper (<em>Phaulacridium vittatum</em>)</td>
<td>2% mortality of seedlings</td>
</tr>
<tr>
<td>Cerambicid / longicorn beetles (e.g. <em>Tryphocaria</em> spp., <em>Phoracantha</em> spp.)</td>
<td>5% presence</td>
</tr>
<tr>
<td>Wood moths (e.g. <em>Endoxyla cinerea</em>, xyloricittids)</td>
<td>5% presence</td>
</tr>
<tr>
<td><em>Phytophthora</em> spp.</td>
<td>1% mortality</td>
</tr>
<tr>
<td>Eucalypt leaf spot (<em>Mycosphaerella</em> spp.)</td>
<td>25%</td>
</tr>
<tr>
<td><em>Quambalaria</em> (Ramularia) piterka</td>
<td>25%</td>
</tr>
<tr>
<td>Eucalypt target spot (<em>Aulographina eucalypti</em>)</td>
<td>25%</td>
</tr>
<tr>
<td><em>Cylindrocladium</em> spp.</td>
<td>25%</td>
</tr>
<tr>
<td>Wallabies / kangaroos</td>
<td>25%</td>
</tr>
<tr>
<td>Possums</td>
<td>25%</td>
</tr>
<tr>
<td>Rabbits / hares</td>
<td>25%</td>
</tr>
<tr>
<td>Parrots</td>
<td>25%</td>
</tr>
</tbody>
</table>

For some agents, for example stem damaging agents or those that attack seedlings, it is more appropriate to have a threshold based on presence/absence or tree mortality.

damage is defined as 30–69% and severe damage is defined as 70% or greater defoliation to a tree or stand. One reason for this is that it is quite normal for trees to incur some crown damage, with low to moderate levels of damage having little impact on tree health, depending on the specific circumstances. Several Australian studies have examined the influence of crown damage on young eucalypt growth, either through direct insect herbivory (e.g. Carne *et al.*, 1974; Elliott *et al.*, 1993), or artificial defoliation studies (e.g. Candy *et al.*, 1992; Abbott *et al.*, 1993; Abbott and Wills 1996; Collett and Neuman 2002). Collett and Neuman (2002) reported that repeated defoliation had an adverse impact only where young *E. globulus* are threatened with total crown defoliation by mid- to late summer. Alternatively, Pinkard and Beadle (2000) examined the effect on growth of defoliation through pruning, and found that while tree responses to pruning are influenced by site fertility, water availability and climate, the level of defoliation that significantly affects eucalypt growth lies between 40% and 50%. The damage threshold levels recommended in Table 1 are not impact or action thresholds, such as those defined in the above studies, but are recommended as reporting thresholds for specific key insect pests and diseases and might be viewed as moderate damage. Some companies might use these thresholds as triggers for identifying plantations requiring more intensive monitoring.

It is envisaged that the CDI data would be collected at an intensity appropriate for internal management needs of individual agencies or companies. The actual CDI values could then be applied to action (reporting or action) thresholds developed within management programs for specific insect pests or pathogens. Damage threshold values selected for national reporting purposes would be based on a consensus of Australian forest health experts and presented in the proposed field guide manual. These thresholds would then be used to determine the reportable area of affected plantation.

Table 1 presents an example of proposed reporting damage thresholds for known insect pests and diseases of plantation eucalypts, and Table 2 an example of how the areas of plantation attaining these thresholds might be reported. The actual data collected may well be much more comprehensive and analysed for specific internal needs. However, the extent to which information on areas affected would be reported in Table 2 would be up to the discretion of individual agencies and companies. For example, some private companies may wish not to identify the region or district in which significant damage from a particular insect pest occurred, and provide information only on a statewide basis.

Development of standardised reporting thresholds will simplify both national collation and interpretation of the impact of various damaging agents. Over time they will support the identification of plantations affected beyond the range of historic variation. Although it will probably take several decades of monitoring to obtain an appreciation of the levels of ‘natural’ variation, these standards will assist in monitoring national trends.
Permanent plot systems

The validity of the CDI is not only reliant on the assessor’s interpretation of crown damage but also on the sampling strategy used. Initially it is likely that the data will be collected from extensive surveys using a sampling protocol such as that presented in the CDI field manual rather than permanent plots, although the CDI could be applied to either system.

In the near future, the major source of data on crown damage will be forest health surveillance teams undertaking extensive systematic surveys for their agencies. This type of surveillance, based on temporary, independent surveys, is efficient for estimating current values. Change is estimated as the difference between the current and previous estimates, and the variance of change is estimated as the sum of the variance of the current and previous values. Unfortunately statisticians claim that such change estimators can be inefficient (Schreuder et al. 1993). Permanent-plot surveys result in more precise estimates of change. Therefore there is compromise between the more detailed monitoring resulting from a permanent plot system and the cost-efficiencies associated with stratified surveillance surveys.

Most overseas forest health assessment programs are based on the monitoring of permanent plots. A permanent plot system has many advantages, including potential integration with other indicators such as biodiversity (e.g. Hirvonen 2001; Working Group on Criteria and Indicators 2001). However, while the advantages of a uniform grid system are acknowledged, such an approach has also been criticised (Innes 1993a). Only two States currently maintain native forest monitoring programs based on a permanent plot system, and they include forest health (e.g. the Warra long-term ecological research site in southern Tasmania and FOREST-CHECK established in jarrah forest, south-western Western Australia). A network of forest monitoring plots had been initiated in Queensland but collapsed following withdrawal of financial support by the State agencies. The establishment of a continental framework to monitor Australia’s forests is currently being considered by the NFI (Melissa Wood, NFI, Canberra, pers. comm. 2002). In addition, most Australian forestry agencies maintain a system of permanent inventory plots although they vary greatly in extent and density between regions.

Inclusion of a tree-based health attribute for mature eucalypts such as the Crown Condition Index might serve as a generic measure for a range of plot-based monitoring systems. The responsibility for the health assessments in these plot-based systems will extend across a range of Commonwealth and State agencies. The State-based forestry health surveillance teams are likely to continue to rely on broad-scale surveys.

North American forest health monitoring programs

Both Canada and the USA are in the process of establishing a national grid system of multi-functional permanent forest plots. The Canadians are able to take a holistic perspective of forest health through their national Forest Health and Biodiversity Network, which relies on their National Forest Inventory program to gather the appropriate forest health and biodiversity attributes. The Canadian Forest Service (CFS) coordinates this new National Forest Inventory and provided start-up funding (about Can$10 million) while the provinces carry out the inventory. The Canadian NFI will be based on 25 000 randomly selected permanent plots. It is expected that the plots will cost about Can$1 million per year to maintain and assess (10% of plots per year) and this is to be funded by the provinces. The CFS is working actively with other federal agencies such as Environment Canada and Parks Canada on developing common assessment protocols.

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service now encompasses the Forest Health Monitoring program and receives federal legislative financial support. The legislative mandate calls for a single inventory program to include all forested lands in the US, regardless of ownership or availability for forest harvesting. The program has been initiated and is maintained through a formal federal–state partnership. Federal funding available for the FIA program in 2001 totalled US$49 156 950, with a further US$8 020 651 received from the State-based partners (US Department of Agriculture, Forest Service 2001). The federal funding has enabled national coordination and standardisation of all aspects of information gathering, analysis and reporting. The FIA has a nationally uniform cell grid of permanent plots of which a subset of 7861 plots are assessed for forest health attributes. While tree crown condition is assessed in these plots it is just one of twelve indicators measured in the FIA plots. The ground-based health attributes include tree crown condition, tree crown damage, tree mortality, tree growth, tree regeneration, lichen communities, vegetation structure and diversity, and ozone bioindicators. The plot monitoring component is supported by an extensive survey component, currently based on aerial-sketch mapping, but alternate remote sensing technologies are being investigated. The survey component focuses on the distribution and severity of a group of key insect pests and diseases as well as some abiotic stressful agents (fire, storms, flooding and salinity).

Use of remote sensing technologies

A common challenge for all forest health-surveillance programs in Australia is to secure sufficient resources to cover all forests of

### Table 2. Example of possible presentation format for national reporting based on reporting damage thresholds for key pests and pathogens

<table>
<thead>
<tr>
<th>Damaging agent</th>
<th>Area of eucalypt plantation affected to a degree greater than the reporting threshold of crown damage (ha)</th>
<th>Total area assessed (ha)</th>
<th>Total area treated (ha)</th>
<th>Host tree species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn gum moth</td>
<td>&lt;10</td>
<td>15 000</td>
<td>350</td>
<td>E. globulus</td>
</tr>
<tr>
<td></td>
<td>10–100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100–500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>500–1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;1000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
interest within an appropriate time frame. Broad-scale assessment of forest health has traditionally relied on aerial surveys. This approach requires technical expertise and is subjective, qualitative and labour intensive. Traditional aerial photographic interpretation principally relies on high structural and hence textural resolution, whereas high resolution, hyperspectral reflectance imagery captures information pertaining to the physiological status of vegetation as well as textural differences. Another advantage of hyperspectral imagery is that it is acquired in a digitised format, making it suitable for classification modelling. The integration of a digitised canopy condition coverage with other physical and environmental GIS layers presents the real possibility of spatial modelling of site-specific classification and health risk ratings.

The application of (low-resolution) satellites has already improved our ability to detect land-cover and land-use changes over large areas in a cost-effective manner (e.g. the Australian Greenhouse Office national monitoring program and the National Land and Water Resources Audit). Whether the remote sensing platforms currently being used (e.g. LANDSAT, 30 m spatial resolution) can detect and monitor physiological condition within a specific vegetation type is debatable (e.g. Royle and Lathrop 1997). Current attributes used to assess environmental health at the landscape scale include vegetation extent and clearing; land use; fragmentation of native vegetation; hydrological change; weeds; feral animals and threatened ecosystems and species (Environment Australia 2001a). A quantified, high-resolution assessment of vegetation condition could provide baseline information for interpreting these broader ecosystem monitoring programs.

A common surrogate for vegetation stress and condition is the use of reflectance indices to estimate stand parameters such as canopy leaf area index and canopy chlorophyll content. These simple indices may be suitable for application to uniform canopies (e.g. agricultural crops or forestry plantations), but may not be appropriate for canopies that have complex structure and composition. We argue that a more sophisticated approach that takes into account the potential range of structural and functional symptoms of stressed or damaged trees and forest stands is required when applying reflectance-based monitoring technology. The rapid advances in resolution capacities of remote sensing platforms make this approach a viable option.

A recently-completed CSIRO–SFNSW project (Coops et al. 2001) demonstrated that high-resolution hyperspectral imagery can identify and categorise canopy unhealthiness in native eucalypt forests. The spatial algorithm used, termed the Eucalypt Canopy Condition Index (ECCI), is derived from an assumed hierarchy of crown decline symptoms, both physiological and structural (Stone et al. 2000) across a forest canopy. The ECCI algorithm comprises a series of spectral and spatial variables extracted from the high-resolution imagery. The ECCI was successfully applied to 0.8 m hyperspectral imagery acquired using an airborne Compact Airborne Spectrographic Imager 2 (CASI-2) over a site affected by Bell miner dieback (Stone 1999), south-west of Newcastle. It is not a diagnostic tool but rather a generic indicator of eucalypt canopy condition. Forest health experts are still required to identify the damaging agents or processes.

The next major task is to test the potential for ‘scaling up’ from this high spatial resolution, hyperspectral imagery to less expensive, lower resolution multispectral imagery. If this is feasible, the latter would provide the option of using readily-available, local airborne imagery or satellite imagery. Apart from examining the appropriate trade-off between scale or resolution and cost of acquisition, other issues that need to be examined include image ownership and disclosure.

**Integration of ground-based data with airborne surveillance**

A major challenge for forest health monitoring systems is the integration of data collected from ground-based plots with information from airborne surveillance. This is essential because while airborne technologies provide information on spatial distribution of the symptoms of canopy condition, identification of the causal agents and processes requires ground-based assessment. Spatial statistics and modelling are advancing rapidly, but point data are, and will continue to be for some time, the basis for complex numerical examination. The Canadians are developing methods that link their cartographic products and textural database information on key damaging agents (e.g. defoliating insects, atmospheric pollution) in a statistically useful manner. As a first step they have produced a national ecozone classification system consisting of a nested hierarchy of ecological units for their environmental reporting needs (Forest Health Network 1999; Hirvonen 2001). Both the aerial surveillance and permanent plot programs operate within this framework.

In New Zealand, a national monitoring system for providing verifiable estimates of carbon stocks in forests and shrublands has been proposed by Coomes et al. (2002). It is based on a combination of measurements obtained from a network of permanent plots and land-cover area estimates from satellite imagery. It has been deliberately designed to provide a framework for other environmental reporting obligations.

Within the context of our proposal there exists the possibility of linking the common features of the two generic ground-based eucalypt crown measures (i.e. the Crown Damage Index and the Crown Condition Index) with the remotely-sensed Eucalypt Canopy Condition Index. Improvements in and increasing availability of integrated GPS and GIS systems will assist this process.

**Assessment of native forest ecosystem health and vitality**

The recommendations in this discussion paper have been pragmatic and should be viewed as an initial phase. To develop methods and reporting systems capable of monitoring the biological integrity of a forest ecosystem will be much more technically and financially challenging. In Australia, the range of natural variation in the patterns and processes of native forest ecosystems is generally unknown. Linkages between long-term sustainability and management practices should therefore be treated cautiously. Re-examination of studies on specific examples of forest ‘unhealthiness’ (e.g. regrowth stand stagnation; crown dieback) might help to identify attributes most appropriate for inclusion into future EFSM monitoring programs (e.g. Podger et al. 1980; Kile et al. 1981; Florence 1996; Stone 1999). Identification and long-term assessment of such indicators is essential for a true audit of
management practices. In North America and some European countries an integrated approach, using information from a wide range of sources, is being developed to tackle the complex issue of assessing ecosystem health and vitality (e.g. Rapport et al. 1998).

DAFF and Environment Australia acknowledge the merit of such an approach and planning is proceeding, but the actual collection of these desirable data may not proceed without federal support.

The only feasible approach for monitoring extensive non-commercial native forests in Australia is to use remote sensing technologies. Any reliable assessment of forest ecosystem health, however, will require that these techniques be supported by both comprehensive regional permanent plot programs (e.g. the Warra long-term ecological site and FOREST-CHECK), and an extensive continental plot system, as well as sufficient resources to enable post-detection diagnostic ground-truthing by forest health experts.

Issues relating to private ownership of forests

A basic premise of the Montreal Process C&I framework is that it is intended to apply to all forest tenures, including private and leasehold forest lands. To ensure voluntary adoption of any health assessment protocols, the significant issue of disclosure must be addressed. Safeguards that minimise interference with investor confidence will have to be in place to ensure the satisfaction of forest growers. At present the NFI does not have a generic policy statement covering confidentiality, but agreements regarding data have been negotiated with specific companies (Andrew Wilson, Coordinator, State of the Forests Report, Bureau of Rural Sciences, Canberra, pers. comm. 2002).

Public reporting would occur only on a regional or state-level basis. Whether and how private companies release information to their own investors would be a policy matter for each company. However, full details could be made available to bona fide researchers on negotiation of a confidentiality agreement with the company concerned.

This issue is currently being tackled in North America. For example, in Canada, commercial forestry companies lease about 20% of the forests from the provinces, and the national representative association for commercial forestry appears to be committed to monitoring the NFI plots on the land of members, using approved protocols, and providing results to the appropriate provincial agency in agreed format (Harry Hirvonen, Canadian Forest Service, Ottawa, pers. comm. 2002). In the USA the issue of disclosure is covered by FIA legislation. Ownership information is not available to the general public and exact location details are never published.

Conclusions

Because of the broad spectrum of values relating to definitions of forest health, the attributes selected for national harmonisation need to possess both environmental and commercial values. There will, however, always be trade-offs in attempting to appease all stakeholders, and hence data collected will always appear incomplete. Integration with other Montreal Process indicators (e.g. indicators of biodiversity and productivity) will minimise some deficiencies.

The long-term maintenance of programs for monitoring forest health is likely to remain a regional responsibility. To ensure long-term adoption of these proposed assessment protocols, the end product must have operational value at the FMU level. However, the data also need to be suitable for aggregation up to the national level, and to have the capacity to be linked to other sets of spatial information. We believe that the small set of attributes proposed in this paper has the potential to fulfill these objectives.

This is a simplistic but pragmatic approach. While the comprehensive, holistic concept of forest health advocated by Yazvenko and Rapport (1996), Rapport et al. (1998) and Hirvonen (2001) has scientific merit, Australia is not yet in a position to measure, on an extensive scale, process-based indicators that relate to forest ecosystem functioning. We do recommend, however, progressive development of national capability through a series of phases, commencing with the initial phase outlined in this paper.

Acknowledgements

This discussion paper is an outcome of two workshops, the first held in Brisbane in February 2001 and the second in Sydney in May 2002. Members of the Primary Industries Ministerial Council Research Working Group on Forest Health convened both workshops, and contributions were received from forest health experts throughout Australia. The second workshop received financial support from the Australian Government Department of Agriculture, Fisheries and Forestry, Barton, ACT. We thank Ross Florence (Managing Editor, Australian Forestry), Andrew Wilson (BRS, AFFA), Richard Thackway (BRS, AFFA) and Mellissa Wood (BRS, AFFA) for their constructive comments on the paper.

References


Coops, N.C., Stone, C., Culvenor, D.S. and Old, K. (2001) Forest vitality and health: Indicators of changes in fundamental ecological processes in forests based on eucalypt crown condition index (ECCI), Report to Forestry and Wood Products Research and Development Corporation PN99.814. CSIRO Forestry and Forest Products, Canberra, ACT.


Appendix 1

Visual standards for top-down defoliation by *Mycosphaerella* leaf blight in young *Eucalyptus globulus* grown in Tasmania
Appendix 2

Example of a eucalypt crown condition scoring system used to assess bell-miner-associated dieback in moist forests on the east coast of NSW (Stone 1999, adapted from Grimes 1978)

<table>
<thead>
<tr>
<th>Overall canopy size and shape</th>
<th>5 Large, vigorous smaller branches</th>
<th>Large, well balanced canopy, shaped by several large branches containing a healthy ‘hierarchy’ of smaller branches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 Moderate</td>
<td>Moderate-size canopy, often co-dominant, non-uniform in shape. Few major branches present.</td>
</tr>
<tr>
<td></td>
<td>1 Contracted</td>
<td>Canopy contracted, unbalanced or somewhat cylindrical in shape, foliage on only minor branches or stem arising from epicormic growth</td>
</tr>
</tbody>
</table>

| Crown density | 9 Very dense | Very dense leaf clumps with even distribution of clumps over the crown. Very little light penetrating the leaf clumps. |
|               | 7 Dense      | Dense leaf clumps distributed unevenly over the crown.                                                      |
|               | 5 Average    | Clumps of average density with reasonable distribution or dense clumps very unevenly spread                  |
|               | 3 Sparse     | Clumps are sparse and poorly spread                                                                          |
|               | 1 Very sparse| Very few leaves anywhere in the crown                                                                          |

| Dead branches | 5 Nil          | No visible dead branches or branchlets/shoots in the crown                                                   |
|               | 4 Dead terminal shoots | On close inspection some dead terminal branches are evident but not over all the crown                     |
|               | 3 Dead small branches | Some small branches are dead but not over all the crown. These are easily observed but do not give the impression of seriously affecting the crown |
|               | 2 Dead main branches | Some large and/or small branches dead over part of the crown with the obvious impression of serious branch death |
|               | 1 Dead main branches | Large and small branches dead over most of the crown which is obviously dying                               |

| Crown epicormic growth | 3 Nil | Limbs clean, growth concentrated at branch extremities |
|                        | 2.5 Slight | Slight epicormic growth can be seen in part of the crown |
|                        | 2 Moderate | Moderate epicormic growth is present over most of the crown |
|                        | 1.5 Severe on crown or stem | Epicormic growth is evident over most of the crown |

| Foliar damage | 5 Low | No insect or fungal damage visible in the crown from the ground, no reddish-purple or brown discoloration present or only a small amount on old foliage |
|               | 3 Moderate | Obvious reddish-purple or brown discoloration on some of the foliage; insect or fungal damage may be visible from the ground |
|               | 1 High | Insect or fungal damage severe enough to be visible from the ground, foliage may have a ‘tatty’ appearance. Crown has an overall reddish-purple or brown coloration. |