Monitoring biodiversity in jarrah forest in south-west Western Australia: the Forestcheck initiative

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ABSTRACT

FORESTCHECK is a monitoring framework devised in 1999 to quantify, record, interpret and report on the status of key forest organisms, communities, and processes in response to both forest management activities and natural variation. Monitoring is treated in this initiative as a form of quality control, and not as a substitute for audit, compliance, survey or research. The most desirable attributes of a monitoring system were identified as simplicity, integrated sampling, efficient sampling, reliability, feasibility, credibility and affordability. It is recognized that it is not possible to optimise all of these traits simultaneously. FORESTCHECK has been designed to align with the Montreal Process Criteria and Indicators approach to achieving ecologically sustainable forest management (ESFM, agreed to jointly by the Commonwealth and State Governments in 1998). A concept plan was prepared and workshopped within the Department of Conservation and Land Management and with scientists from universities, CSIRO, and other agencies in the WA Government, as well as scientists privately employed. Sampling commenced in November 2001.

Key words: biodiversity, monitoring, eucalypt forest, Western Australia, *Eucalyptus marginata*

Introduction

Monitoring, audit, compliance and research are terms widely used at present in corporate governance in Australia. The first three concepts refer to the checking process in the sequence PLAN - ACT - CHECK. Audit until recently referred to the official examination and verification of (orally presented) financial accounts by an independent body. It is often used now to refer to independent verification of any matter, particularly the extent and quality of strategic and business planning processes. Compliance refers to the need to check how well an action adheres to stated policies, prescriptions, codes of practice etc. Monitoring is also a form of quality control, but includes the concept of testing at intervals in relation to achievement of nominated objectives. By contrast, research involves systematic and critical investigation to discover facts and reach novel conclusions and thereby create new knowledge or re-organize existing knowledge. Scientific research is generally pursued within a framework of formulating and testing a set of hypotheses. It is important to recognize that monitoring, while methodical, is neither scientific research nor a substitute for it. Nevertheless, monitoring is undergirded by scientific knowledge and its results may assist in the generation of hypotheses; these can then be addressed using scientific methodology.

Monitoring in jarrah forest commenced in 1916, with the establishment of plots to measure growth rates of trees. Other significant events in monitoring focused on mammals and fire impacts (1972). These and others are itemized in Table 1.

Compliance and monitoring are not new concepts, as evidenced by the venerable learning technique of trial-and-error (involving an action, then its assessment, followed by correction if an unwanted outcome resulted). The main difference between trial-and-error learning and more sophisticated versions lies in the degree of formality involved with the latter. Expected outcomes will be declared from the beginning in a written plan, there will be records of what actions were undertaken and when, where and how they were done. After implementation, there will be written records of how well the action was performed in relation to the declared expected outcome. If all proceeded 'according to plan' there is no need for corrective action and the principle of 'management by exception' is followed. If, however, there are 'surprises' (unexpected outcomes) or failure (the expected outcome was not produced), the planning process has to re-commence. The process is necessarily iterative.

This approach has become subsumed in the last 20 years under the concept of active adaptive management (Halbert 1993), in which management interventions are regarded as hypotheses to be tested by implementing the planned action and following up subsequent events ('learning from error, by doing').

Policy background

Since the 1920s forest management in Western Australia has comprised a mixture of adaptive and directed management. These elements have been based strongly on strategic planning, audit, compliance and scientific

Pp 947 - 958 in the *Conservation of Australia's Forest Fauna* (second edition) 2004, edited by Daniel Lunney. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

Table 1. Milestones in research and monitoring in jarrah forest.

1842	First vertebrate specimens collected for scientific study
1890	First publication on the forest avifauna
1916	First growth plots for trees established
1936	First paper published on predictability of fire behaviour from weather variables
1955	First fire impact study of soil/litter fauna published
1961	First thesis on jarrah silviculture
1964	First thesis on forest floor dynamics and soil properties in jarrah forest
1970	Commencement of first integrated biological survey
1972	Paper establishing the cause of dieback disease published
1972	Commencement of long-term studies of forest mammals - Perup forest
1972	First thesis on forest fire behaviour and fire danger rating system
1972	Commencement of long-term study of fire effects in southern forests
1975	Comprehensive review of fire impact studies on flora and vertebrate fauna published
1975	Site-vegetation types in northern jarrah forest described
1980	Hypothesis linking decline of native mammal species to fox predation published
1985	First logging impact study of soil/litter fauna published
1985	First logging impact study of avifauna published
1986	Comprehensive synthesis of knowledge about the ecology of jarrah published
1988	Site-vegetation types in southern jarrah forest described
1989	Comprehensive review of knowledge about dieback disease published
1989	Publication of multi-authored book on the ecology and management of the northern jarrah forest
1990	Publication of book on threatened flora
1991	Jarrah forest growth inventory completed
1992	Initiation of a four-year study of the impact of spring and autumn planned fire on surface-active species of litter invertebrates
1992	Initiation of multidisciplinary and integrated study of logging and fire impacts in jarrah forest ('Kingston project')
1994	Integrated study of the occurrence of hollows in standing trees commenced
1995	Monitoring commenced of the occurrence of a bio-indicator of large hollows in standing trees (Forest red-tailed black cockatoo)
1998	Comprehensive regional assessment published, containing a wealth of new information about forest ecosystems, vegetation complexes, floristic diversity etc.
1999	Planning for an integrated forest monitoring system commenced
1999	Comprehensive synthesis of knowledge about forest avifauna published

research but weakly on monitoring of outcomes. Senior managers saw monitoring as unnecessary in the context of effective planning, audit, compliance and research, as well as imposing a significant financial burden.

In 1988 the Department of Conservation and Land Management (CALM) approved a formal monitoring policy. This proved unimplementable because of logistic reasons, resource limitations and lack of an agreed focus in the policy. It was subsequently formally withdrawn.

The current Forest Management Plan (LFC 1994) also committed to use of monitoring (pp. 51-52):

> *Implicit in the undertaking of management action is the need to monitor the implementation and impact of those operations. Monitoring is important across the full range of management actions, e.g. use of a recreation site or how closely a burn achieved its prescribed intensity, because through it the success of meeting forest management objectives is evaluated and the opportunity to upgrade prescriptions is presented.*
>
> *CALM's research programs also provide continuous input to the management process. The research programs are periodically adjusted to ensure they are providing information of the most important strategic value.*
>
> *At the most fundamental level CALM's forest management objective is to preserve biological diversity and the ecological processes which sustain that diversity. Monitoring to check if that is being achieved is difficult, because natural changes in ecosystems interact with those caused by management-related disturbance and because the large number of ecosystem components all react differently. A comprehensive*

monitoring program will encompass three components of ascending complexity, as follows:

(a) Monitoring the effectiveness of measures to protect the environment

Codes of practice are the guidelines used to control forest operations in the field. They set standards and measures of performance for activities and operations conducted by CALM, contractors and other users of public forests.

These codes aim to ensure that the people carrying out a forest operation such as road construction, tree planting, timber harvesting or recreation site maintenance complete it to the highest standard existing knowledge allows. They therefore constitute current best available practice.

"Codes of practice" collectively describe a range of documents including manuals, prescriptions, specifications, standards and Guidelines. The codes are one of the instruments used to set standards for forest operations. Acts of Parliament, regulations, policies and contracts are other instruments used for this purpose.

CALM uses codes of practice for each of the major activities and operations conducted in the forest regions. Codes are reviewed and re-issued annually to reflect the results of the year's monitoring, or new research information.

Responsibility for implementing the codes is assigned to CALM's regional and district staff, assisted as necessary by specialist branches. Specialists and regional staff also have a role in ensuring that prescriptions are correctly followed in the field.

(b) Monitoring the impact of disturbance-causing activities.

In CALM this is carried out primarily through the Department's research program. Clearly, all species of the biota cannot be studied, and research is concentrated on what are believed to be keystone species.

Species known to be rare or under threat are given special emphasis in research, and in operational planning procedures. Threatened flora management programs will be progressively developed and implemented.

(c) Monitoring ecosystem change through periodic measurement of an extensive system of permanent plots and selected vertebrate and invertebrate species.

This is the most sophisticated level of monitoring because, if done adequately, it measures baseline ecosystem health and can detect management-induced change or natural environmental changes. It is, however, very difficult because:

- *it requires considerable initial research to obtain a good dataset of regional biota;*
- *a large number of plots must be established and enough organisms sampled to ensure environmental diversity is covered.*

Within the forest regions (a) is implemented, (b) partly implemented and (c) yet to be initiated. As resources allow, the monitoring program will be steadily upgraded through sophistication of (b) and, finally, full implementation of detailed ecosystem monitoring.

In recent years impediments to commencing a monitoring program have been largely resolved because of significant advances in technology, information and concepts. First, the tool of Geographic Information Systems (GIS) has become more sophisticated and also more readily available as a result of increased computer capacity. Second, the information base for the south-west forests has greatly expanded, largely because of the Regional Forest Agreement (RFA) process (Commonwealth of Australia and the State of Western Australia 1999). All available fundamental data have been captured electronically (with one major exception, fire history from 1937 to 1990, currently being addressed). Third, the conceptual distinctions between strategic research, prescription, and monitoring have become clearer. The strong conclusions from soundly-based research when incorporated into prescriptions lessen the necessity for frequent or detailed monitoring. This permits better deployment of available resources so that time and money are not wasted on documenting the obvious or monitoring an action that already has sufficient safeguards built in.

Finally, nations with temperate forests have committed themselves to a process (the Montreal process) that uses agreed criteria and indicators to assess ESFM. This protocol developed from the 1992 Convention of Biological Diversity held in Rio de Janeiro and was agreed to by the Commonwealth of Australia and the States in August 1998 (Anon 1998). FORESTCHECK will contribute to indicators 3.1a, 1.2c, 3.1c and 4.1e. Some possible indicators of ESFM in jarrah and other south-west forests are tabulated in Attachment 3 of the FORESTCHECK Concept Plan at *http://www.naturebase.net/science/science.html*

When the Minister for the Environment approved the Forest Management Plan in 1992, he set a number of Ministerial Conditions that CALM had to address. Those relevant to monitoring are:

3-1 *The proponent shall manage karri and karri-marri forest in accordance with a precautionary approach. This approach requires that where there is a significant risk that a particular forest management measure could lead to an irreversible consequence, appropriate monitoring and subsequent adjustments to management within an acceptable time-frame be carried out.*

3-2 *The proponent shall manage the jarrah forest in accordance with the following general principles:…*

> (2) *adaptive and flexible management practices based on research and monitoring of environmental monitoring of operations…;*

5-3 *The proponent shall monitor the effectiveness of the travel route (road) river and stream reserves for nature conservation and protection of water quality to the requirements of the Minister for the Environment.*

11-1 The proponent shall implement the jarrah silvicultural prescription so that the monitoring of the environmental impacts on a representative range of treated sites and localities in the forest can be carried out to the requirements of the Minister for the Environment. This shall include long term monitoring which quantifies the impacts of silvicultural practices on environmental elements and values in the forest and provide bases to adjust management.

12-3 The proponent shall monitor, to the requirements of the Minister for the Environment, and report by 2002 on the status and effectiveness of these measures to protect nature conservation values and water quality at the time of the next review of the Forest Management Plans and Timber Strategy.

In signing the RFA in 1999, the WA Government agreed to:

42. Within 5 years of the date of this Agreement, Western Australia will further improve its Forest Management System and processes through the development and implementation of environmental management systems in accordance with the principles specified in Attachment 13 and the actions identified in Attachment 5 and acknowledges that its objective for native forest management under the CALM Act is system certification comparable with ISO [International Standards Organization] 14000 series. The Parties note that such a system would include independent auditing of compliance with Codes of Practice and the Forest Management Plan.

46. Western Australia will report on the results of monitoring of sustainability indicators as part of each 5 year review and report in accordance with Clauses 36 and 37.

47. Comprehensive Regional Assessments, the development of criteria and indicators for sustainable forest management through the Montreal Process and the development of this Agreement have provided extensive opportunities for public participation and reporting. Parties note the range of reporting and consultative mechanisms that currently exist in Western Australia (see Attachment 4) and agree that Western Australia will further develop these by implementing the improvements specified in Attachment 4. (Attachment 4 is concerned with detailing public reporting and consultative mechanisms used during the RFA).

51. The Parties agree that the current Forest Management System will be enhanced by further developing appropriate mechanisms to monitor and review the sustainability of Forest management practices. To ensure that this occurs, in consultation with the Commonwealth, the State agrees to establish an appropriate set of sustainability indicators to monitor Forest changes. Any indicators established will be consistent with the Montreal Process Criteria (as amended from time to time), the current form of which is specified in Attachment 7, and will take into account the framework of regional indicators developed by the Montreal Process Implementation Group. Western Australia will implement those indicators, which are practical, measurable, cost-effective and capable of being implemented at the regional level and will monitor them at an appropriate frequency determined in consultation with the Commonwealth.

52. Development of indicators, and collection of results for those indicators, which can be readily implemented, will be completed in time to enable reporting during the first five-yearly review of this Agreement.

Other committees external to CALM, that reported in 1999, were also supportive of forest monitoring (Dell *et al.* 1999, Ferguson *et al.* 1999, EPA 1999). Corporate buy-in occurred in 2000 when the CALM Corporate Executive approved the FORESTCHECK Concept Plan. Its implementation was then stalled by insufficient resources and major legislative changes. ANZECC (2001) has also endorsed monitoring across all bioregions of Australia.

Jarrah forest environment, biodiversity and silviculture

Jarrah forest (Fig. 1) occurs in a Mediterranean climate, with reliably wet winters and hot, effectively, rainless summers 5-6 months long. The soil profile averages 20 m, is highly weathered, and the shallow topsoils are deficient in many nutrients and dominated by lateritic gravels. The original extent of the jarrah forest was nearly 3 M ha, but this has been halved because of clearing for agriculture. The forest is 20-30 m tall on average and is unusual for a eucalypt forest in that one tree species is numerically predominant over a relatively large area. Further information is available in Abbott and Loneragan (1986) and Dell *et al.* (1989). Photographs of jarrah forest can be viewed at the FORESTCHECK Report of Progress 2001-2002 at *http://www.naturebase.net/science/science.html*

The biodiversity of the jarrah forest is dominated by some 25 000 insect species, 15 000 species of fungi and 2 500 vascular plant species (Abbott and Christensen 1994). Species richness gradients are well understood for vascular flora and vertebrates (Abbott 1998, 1999; Gioia and Pigott 2000), less so for forest canopy arthropods (Abbott and Wills 2001, Majer *et al.* 2002), and not at all for fungi. Several hundred vegetation complexes have been described and mapped (Mattiske and Havel 1998). Because of the isolated nature of the south-west corner of Australia compared to the forests of south-east Australia and its climatic history, jarrah forest has an unparalleled mixture of Eyrean, Bassian and Gondwanan species. The forest is also notable for the persistence of many bird species and medium-sized mammal species that have become extinct elsewhere (Strahan 1995, Abbott 1999). Species endemism in jarrah forest is low, however, at c. 4% (Abbott and Burrows 1999).

Jarrah forest has been disturbed by humans for at least 50 millennia, when Aboriginal people colonized the region and are thought to have imposed frequent (triennial) burning in summer, a regime facilitated by the Mediterranean-type climate (Abbott 2003).

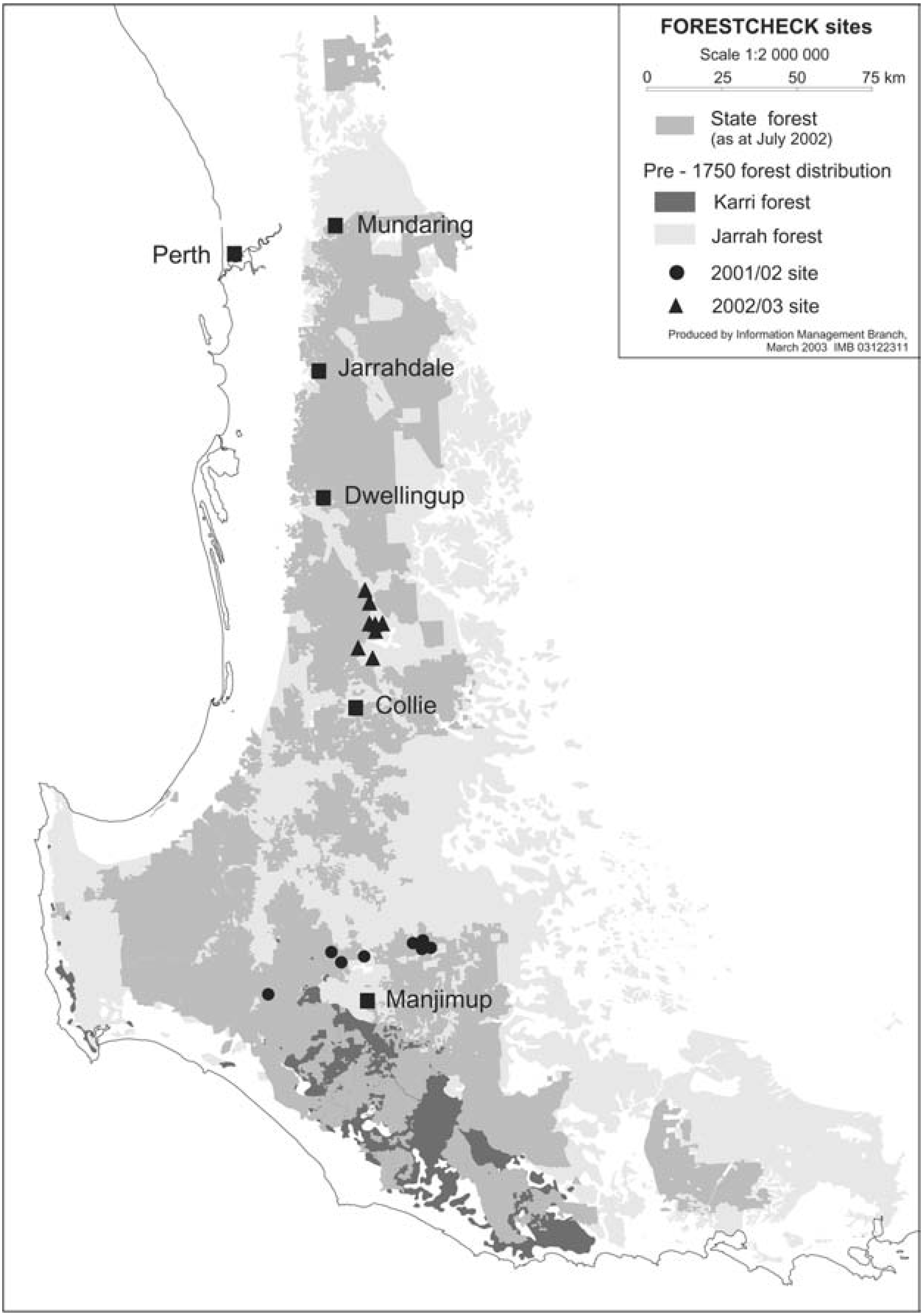

Figure 1. Map of south-west Western Australia showing the original extent of jarrah forest, the extent of forest currently available for logging (State Forest), and the location of FORESTCHECK sites established in 2001 and 2002.

Following settlement by the British, logging of the forest commenced but this industry was not regulated until the 1920s. Extraction of wood and burning of the forests has continued until the present, with many changes in the intensity, frequency and timing of these factors (McCaw and Burrows 1989, Bradshaw 1999).

Currently, in jarrah forest available for logging, one of three silvicultural systems (thinning, gap release and shelterwood) is usually applied to a patch of forest, based on existing stand structure and density of regeneration (Bradshaw 1999). Thinning serves to promote growth on retained crop trees. In gap release the overstorey is removed, except for habitat trees, in areas no larger than 10 ha in order to encourage the development of existing advance growth into saplings and poles. In shelterwood, the forest canopy is maintained to the extent that it is necessary to establish regeneration (seedling and ground coppice) from seed. Basal area of gaps is usually half that of shelterwood.

Proposed conservation objectives for forests

The maintenance of biodiversity and of the ecological processes upon which it depends is fundamental to the notion of ESFM. Setting forest biodiversity conservation objectives is not straightforward because of the complexity of biodiversity through space and time and because knowledge of biodiversity and disturbance ecology is incomplete. Therefore, having clear conservation objectives for forests is of key strategic importance, as these assist with setting silvicultural objectives and standards, with determining sustained yield, and with assessing the acceptability or otherwise of the environmental impacts of logging as they are understood from the research and monitoring.

The following proposed hierarchical set of conservation objectives for forests is intended to complement (rather than replace) existing codes of practice and silvicultural objectives. An important strategic issue is the degree of qualification with which conservation objectives are set. For example, should the objectives explicitly state that '*no species will become extinct as a result of management activities*', or should the objective be '*take all reasonable measures to ensure that no species become extinct*'? We adopt the latter here, as most species in jarrah forest (as is the case elsewhere in Western Australia) have not been collected and/or named.

The whole-of-forest scale conservation objective: *To maintain biological diversity and ecological process in ecosystems within the forest region*. A comprehensive, adequate and representative (CAR) reserve system is an important strategy for achieving this.

At the landscape scale. A definition of a landscape:

'*A mosaic where the mix of local ecosystems and landforms is repeated in a similar form over a kilometres-wide area. Several attributes, including geology, soil types, vegetation types, local flora and fauna, climate and natural disturbance regimes tend to be similar and repeated across the whole area*' (adapted from Forman 1995). Scale is usually tens of thousands of hectares.

Forest landscape units have been recently described and mapped by Mattiske and Havel (2002), based on vegetation complexes (Mattiske and Havel 1998).

Landscape scale conservation objectives. Take all reasonable measures to:

- *Maintain viable populations of native species throughout their natural range.*
- *Ensure a diverse representation of forest structures, habitat elements and seral stages through time and space.*
- *Protect ecologically sensitive communities and niches such as riparian zones, aquatic ecosystems, wetlands, granite outcrops and other non-forested complexes.*
- *Ensure maintenance of water quality.*

At the forest management unit scale. A definition of a forest management unit (FMU):

A spatial or administrative element within a landscape. It could be a (sub) catchment or a logical administrative management unit such as a forest block [The State Forests of south-west Western Australia comprise 418 forest blocks, each of c. 3 000-5 000 ha]. It could contain a representation of landforms and ecosystems (or vegetation assemblages) common to the landscape unit. Scale is usually in the order of several thousand hectares.

Forest management unit scale conservation objectives. Take all reasonable measures to:

- *Ensure that no species declines to irretrievably low levels or to levels such that they are classified as threatened or vulnerable.*
- *Ensure that the capacity of the FMU to provide the range of habitat elements that it provided before timber harvesting is not permanently compromised due to timber harvesting.*
- *Ensure that an adequate proportion of the FMU retains mature or old growth overstorey structural characteristics or is within close proximity of a formal reserve that contains mature or old growth characteristics.*
- *Minimize soil damage and rehabilitate damaged areas such as landings [Areas where logs are temporarily held, awaiting transport to a sawmill].*
- *Prevent the introduction and spread of dieback.*
- *Minimize the introduction and spread of weeds and other alien species such as foxes and rabbits.*

At the forest patch scale. A definition of a patch:

A discrete area of forest to which a single silvicultural treatment has been applied, including gap release, shelterwood or thinning. Scale may vary from a few hectares to several hundred hectares.

Forest patch scale conservation objectives. Take all reasonable measures to:

- *Ensure that the capacity of the patch to provide the range of habitat elements that it provided before timber harvesting is not permanently compromised due to timber harvesting (or other management activity).*

- *Retain adequate habitat trees and potential habitat trees and other critical habitat elements.*
- *Prevent soil erosion*
- *Maintain the productive capacity of the soil by minimizing soil damage (compaction, profile-mixing, and puddling [The transformation of wet soil into mud]).*

Threatened, listed and vulnerable species and communities: These are defined according to various State and Federal legislation. Take all reasonable measures to:

- *Protect (retain at viable levels) all populations of threatened, listed and vulnerable species and communities.*

Purpose of FORESTCHECK

FORESTCHECK is intended to serve as a framework to quantify, record, interpret and report on the status of key forest organisms, communities and processes in response to both forest management activities and natural variation. Monitoring is an essential part of systematic best practice management in order to achieve the objective of ESFM. FORESTCHECK will provide relevant information to judge whether forest biological diversity is being sustained indefinitely, part of the overall objective of the 1994 Forest Management Plan (LFC 1994).

These objectives form the basis of more detailed monitoring objectives, involving all species of vertebrates (recorded as abundances), vascular flora (recorded as cover class and frequency class) and cryptogams (recorded as presence/absence), a selection of microbiota (invertebrates and macrofungi), and several practical measures of ecosystem processes relating to soil, water, vegetation growth, and foliage. Because microbiota are mostly unnamed and few species have been studied, it is necessary to focus on those groups for which some pertinent information is available. Similarly, ecosystem processes operate at many different spatial and time scales and have not yet been analysed comprehensively by scientists. Hence it is necessary to monitor those ecosystem attributes that are relevant but inexpensive to measure.

FORESTCHECK is a simple, practical, and integrated system that will satisfy (over time) a number of requirements; namely Ministerial Conditions, RFA, the biological subset of Montreal Process criteria and indicators of ESFM, a more generalized retrospective study, Western Shield monitoring in forests *(http://www.calm.wa.gov.au/projects/west_shield.html)*, and validation of previous vertebrate surveys in forest blocks (Christensen *et al.* 2001).

Phase I of FORESTCHECK is intended to satisfy Ministerial Conditions applied to the 1994 Forest Management Plan (jarrah silvicultural systems). Phase II is planned to provide a sophisticated retrospective analysis of historical disturbance information and assess the impact of disturbance across many taxa and a wider range of forest ecosystems. Phase II awaits the conversion of 50 years of fire records from microfiche to GIS and is not considered further.

FORESTCHECK deals only with monitoring. Compliance of Departmental operations with policies,, prescriptions, and codes of practice is addressed elsewhere in CALM through Management Audit Branch.

Structure of FORESTCHECK, Phase I (jarrah silvicultural systems)

FORESTCHECK is based on several fundamental environmental and disturbance themes:

a) Forest Landscape Units in the RFA area (Mattiske and Havel 2002). It is expected that only a few of the 29 units mapped will cover most logging operations pertaining to the Ministerial Condition.

b) Logging since 1990 under the two main silvicultural systems (gap release, shelterwood), of the seven systems currently in use.

c) Recent (1990 onwards) forest fire history. This information is already available in GIS.

Therefore, a FORESTCHECK site will have attributes in relation to a forest landscape unit, a logging history, and recent prescribed burning history. Sample plots are located in various disturbance classes (shelterwood, gap release, coupe buffer not recently logged, external reference forest) within a FORESTCHECK site, which will be replicated.

Few existing sites for which adequate biological information is available (Water & Rivers Commission sample sites, existing growth plots, botanical sampling sites established for the RFA, Western Shield monitoring sites, experimental catchments) align with proposed FORESTCHECK sites. This reinforces the need for a more integrated system for monitoring the forests of south-west Western Australia.

Forest landscape units were selected as the appropriate framework for study. Forest ecosystems (Bradshaw *et al.* 1997) are too coarse and vegetation complexes (Mattiske and Havel 1998) are too fine a resolution (> 300 units).

The following principles have been adopted:

i) Because of the spatial and temporal scale involved and the vast number of invertebrate and fungal species present in forests, simplicity will be favoured over complexity e.g. ordinal data, counting only of indicator species, presence [=recorded]/absence [=not recorded]. Quantified measures of abundance will, however, be made of vertebrate species.

ii) Unlogged or lightly logged reference sites (controls) will be selected to serve to distinguish natural change from imposed change.

iii) The unit of study (a FORESTCHECK site) will be at the scale of 10-100 ha, consisting of several disturbance types in close proximity.

iv) Where there is sufficient information, indicator species will be selected to maximize contrasts in functional ecological traits (vital attributes). Relevant characteristics may include: mobility (dispersal capability); home range; time to first flowering/fruiting (obligate seeders with long juvenile periods, obligate seeders dependent on canopy-stored seed); slow-growing perennials subject to mechanical destruction; *Phytophthora*-vulnerable taxa; plants acting as substrates for cryptic and other epiphytes where the epiphyte requires mature hosts; summer/autumn flowering species; fecundity; trophic position; nesting substrate; feeding substrate; degree of specialization; taxonomic position (with reference to the Five Kingdom concept of Margulis & Schwartz 1988); and status (e.g. Declared Rare Flora). A balanced array of sensitive and robust species eventually will be selected.

v) Sampling will be at the patch level (up to 10 ha), so that data can be aggregated to the landscape level.

vi) Ecosystem processes such as nett primary productivity, nutrient and water cycling, and energy transfer cannot usually be monitored directly because of insufficient knowledge or logistic impediments. These processes will thus be approximated by key habitat attributes, e.g. litter depth (for soil organic matter), stand basal area (for tree growth and salinity), turbidity in higher order streams, compaction, and foliar nutrients.

vii) Biodiversity (here treated as species richness as a necessary simplification) will be calculated for all vertebrate and plant species present, but only for selected groups of invertebrates and fungi.

viii) Some groups or topics for which knowledge is deficient will need to be studied initially by way of special research effort, e.g. bats, locally endemic invertebrates, substrate-dwelling and other freshwater invertebrates, soil carbon.

ix) Sampling of as many attributes as possible will be co-located (on the same grids).

x) Landscape-scale surveys will continue to be used for larger animals, e.g. Forest red-tailed black cockatoo (Abbott 2002), chuditch (Morris *et al.* 2000), and owls (Liddelow *et al.* 2002).

Some attributes cannot at present be sampled directly because of inaccessibility, e.g. canopy arthropods, which occur 25-30 m above ground level.

Sampling design

The major elements of each monitoring site are as follows:

In addition, where there is a strong topographical contrast, such as close to the Darling Scarp, a ridge/valley comparison will be included. Most jarrah forest, however, occurs on relatively flat land.

1. Forest landscape unit	Initial emphasis will be placed on those units in which most logging in the 1990s has taken place.
2. Logging disturbance	2 timber harvesting methods, identified as % of stems retained, and 2 reference types, not logged in the 1990s [coupe buffer, in a road or stream reserve between 2 logged forests; the other in adjacent recently unlogged or lightly logged forest].
3. Time since logging	Areas logged in 1990, 1995 and 2000 will provide snapshots of forest 5 years apart.

It is envisaged that FORESTCHECK will eventually consist of about 30-40 monitoring sites.

Because FORESTCHECK is the monitoring component of an adaptive management approach, and is not a scientific experiment, no attempt is made to align the Department's prescribed burning program with FORESTCHECK sites. Prescribed burning usually follows within 2 years of logging, and then recurs some 5-10 years later, dependent on fuel accumulation rates, on burning days available and human resources. Records of all prescribed burning operations will be kept so that recovery of indicators following fire can be tracked. Over time the impact of fire will be able to be separated from the impact of logging. Phase II of FORESTCHECK will examine more systematically the effect of various fire regimes on biodiversity.

Harvesting treatments will be assessed as level of impact (tree cover, basal area retained) in the gap and shelterwood forests. Some sites may not have all treatment categories present.

Sampling frequency will need to be flexible. It is unlikely that sufficient resources will be available to re-sample monitoring sites more frequently than 5-10 years (longitudinal study). Sampling in the first few years will provide the necessary short-term retrospective focus of 1-10 years since logging.

Hypothesis testing, false positives, false negatives, and statistical power

Hypotheses cannot logically be proven true, as inability to invalidate a hypothesis does not necessarily prove it to be true. However, incorrect hypotheses can be demonstrated to be false. For most of the period since the rise of physical science as a discipline of rigorous inquiry, the least preferred outcome has been that of the false positive, where an untrue connection between two factors as cause and effect has been accepted as correct (Type I error). In environmental science, however, the false negative (where a lack of an impact is wrongly accepted as correct, Type II error) potentially has irreversible consequences through the continuance of the threatening process.

In any monitoring study, it is important to consider statistical power. In simple terms, statistical power encapsulates the obvious notion that a study must be sufficiently replicated to give reasonably precise estimates of the measured parameters. In monitoring, where comparisons are often made between a 'control' and 'impact' treatment, this precision must be sufficient to detect any biologically important differences. If a variety of organisms are to be monitored, different levels of replication may be needed for each in order to accommodate the different levels of variability of each organism.

An important aspect of power analysis is that it enforces an explicit consideration of effect sizes and specification of null and alternate hypotheses. In monitoring, these hypotheses are:

H_o: The mean for the disturbed site is equal to the mean of the reference site.

H_a: The mean for the disturbed site is greater than or less than the mean of the reference site.

In H_a, the one-sided alternatives may be appropriate for some organisms where the form of the response to disturbance is known. The effect sizes are the degree to which differences between the treated and reference sites are deemed of biological importance. Thus, for one species, the criterion may be that its abundance be > 90% of that at the reference site. For another, it may be that it is present at the same proportion (within 5%) of disturbed, as at reference, sites.

However, determining what constitutes 'sufficient' replication prior to commencing a study is difficult. Many studies have found that *a priori* power analysis is so inaccurate as to be almost worthless, leading some to argue that power analysis itself is irrelevant (Green 1994). Research conducted on forest birds (Craig 1999, Williams *et al.* 2001) and invertebrates (Abbott *et al.* 2003) indicates that the analysis of variance approach for individual taxa fails because the large number of replicates required is far beyond the resources available. However, with ongoing collection of data, replication will increase over time. Initially, therefore, analytical techniques that do not depend on power will be favoured. These are multivariate techniques that examine changes in community structure rather than in individual taxa.

Sampling methodology

The major constraint in designing sampling protocols is the 10 ha maximum size of forest logged to gaps. If plots or grids are too large, the buffer area will be compromised and any effects due to gap treatment will thus be confounded with edge effects.

Burbidge *et al.* (2000) deployed pitfalls continuously for a period of several months in order to maximize sampling of frogs and reptiles, which have episodic pulses in activity related to particular weather conditions. These pulses are unlikely to be detected with sporadic sampling. This protocol was not adopted because of concerns about the ethics of unnecessarily killing large numbers of animals. Additionally, such a procedure may have compromised future monitoring. FORESTCHECK sampling in contrast is based on short-term operation of pitfall traps (10 days for invertebrates; 4 days for small mammals, frogs and reptiles).

Treatments are defined as forest that is either shelterwood, gap release, coupe buffer or unlogged controls. It is intended that each FORESTCHECK site will be re-assessed at 5-10 yearly intervals, depending on availability of resources and time since disturbance, with more regular assessments soon after disturbance. Outputs and estimates of the time taken to complete fieldwork at a FORESTCHECK site are provided in the Operating Plan (*http://www.naturebase.net/science/science.html*).

Data management

Standardized corporate databases will be set up prior to fieldwork. These will determine the recording sheet for each taxon/attribute. Once data are collected, they will require processing, management, maintenance, integration and distribution. These processes are critical to the success of FORESTCHECK. Science Division staff will be responsible for vouchering of specimens and the co-ordination, analysis, interpretation and initial reporting of the data collected. One officer has been assigned responsibility for metadatabasing and archiving of the data collected.

Public consultation and community involvement

A workshop involving CALM personnel was held in 1999 to discuss the framework of a forest monitoring system. A CALM Implementation Group was then established. The role of this group has been to guide the development of a monitoring protocol (FORESTCHECK). The resulting draft concept plan served as the basis of an external workshop held in 1999. This was attended by 22 scientists not employed by CALM. They were asked to address several issues, particularly to consider the strengths and weaknesses of FORESTCHECK, to suggest improvements to sampling design and methodology, and to provide advice on the interpretation and presentation of monitoring data. A second workshop was convened in 2000 to address monitoring protocols and interpretation of outputs, issues that were not resolved at the first workshop. Twenty-six invitees participated in the workshop. Their suggestions were used to revise the concept plan. A summary of advice not adopted was sent to all participants in these workshops.

It is proposed that field days will be held periodically in each CALM District. Interested stakeholders (e.g. local community groups, university students, academics) can then participate in data collection; this may also lead to corps of volunteers willing to commit to the ongoing collection of data.

Interpreting and reporting the results

FORESTCHECK concentrates on only some aspects of ESFM and as such cannot be expected by itself to guide changes to forest management consistent with ESFM. In addition, the relative importance of specific forest values depends on community expectations that vary. Hence, what constitutes sustainable forest management will vary depending on the nature of the forest and community expectations, as indicated in each edition of the Forest Management Plan.

Nevertheless a key challenge is to interpret change in measured variables after imposed disturbance and to decide when the trajectory of recovery during a particular period warrants consideration of change to management practices. FORESTCHECK will provide information relevant to determining recovery periods, recovery patterns and patterns in variation through time. For invertebrates and fungi, knowledge of recovery of biodiversity is minimal. There will be an ongoing need for research scientists to provide advice, training, and to assist with the interpretation of outputs. Each team will provide annual reports on progress and data to the Program Team Leader (ESFM) in the Science Division. As data accrue, small taxa/attribute-based working groups will be convened so that interim results can be interpreted by experts in CALM, CSIRO and universities. Results from FORESTCHECK will continue to be posted on

CALM's website (http://www.naturebase.net/science/science.html). This should increase the visibility and credibility of FORESTCHECK with the public and build community confidence and trust.

The recolonization by birds of the forest regenerating on a clearfelled karri coupe in Gray forest block (Williams *et al.* 2001) serves as an example of the type of data that will be collected by FORESTCHECK. These data show that the avifauna is 'on track' in terms of the recovery trajectory.

Three broad types of output are envisaged. Trajectory graphs with standard errors of the means calculated as data accrue will show the extent and rate that biodiversity, indicator species, and other attributes return to levels comparable to reference sites. Calculation of 95% confidence intervals will permit valid statistical comparisons. Where there are regular monotonic trajectories it may be practical to fit equations (as in Williams *et al.* 2001). The second output will be ordination analysis of assemblage data (species composition), using non-metrical dimensional scaling (based on abundance data) or similarity coefficients (based on presence/absence of species). For an example of the former, see Abbott *et al.* (2003). The third output is a profile diagram, showing the proportion of treatment sites at which species have been recorded. When the species are sorted in order of their frequency of occurrence in reference sites, it is straightforward to determine which species have recovered in treated sites (Alford and Richards 1999).

It is intended that correction of management practices will take place formally. The Director of Science Division will initially communicate in writing to the Director of Sustainable Forest Management (a senior officer in CALM) and to the Chair of the Conservation Commission (a committee independent of CALM and reporting directly to the Minister for the Environment).

Outcomes from FORESTCHECK

In addition to making a significant contribution to forest science and to ecologically sustainable forest management in Western Australia, FORESTCHECK will provide a framework for meaningful public participation in forest management and will deliver relevant information to satisfy the following obligations:

Ministerial Condition 11.1:	Vertebrate, invertebrates, plants, fungi indicators, litter depth, soil organic matter, soil bulk density.
Ministerial Condition 12.3:	Vertebrate, invertebrates, plants, fungi indicators, litter depth, soil organic matter, soil bulk density.
RFA 42.	Vertebrate, invertebrates, plants, fungi indicators, litter depth, soil organic matter, soil bulk density.
RFA 46.	Vertebrate, invertebrates, plants, fungi indicators, litter depth, soil organic matter, soil bulk density.
RFA 47.	Consultative mechanisms and public reporting.
RFA 51.	Montreal process criteria/indicators.
RFA 52.	Montreal process criteria/indicators.

As data accrue, modelling of the distribution of some species will become possible.

Discussion

ESFM includes delivery of economic, social and environmental outcomes. Environmental monitoring via FORESTCHECK is just one aspect of the ESFM process. Collectively, these three components will facilitate changes to forest management practices so that the community obtains from forests what it seeks. Although ESFM is well defined at a policy level, it remains an ill-defined scientific concept.

Because knowledge about disturbance ecology is incomplete, monitoring is likely to generate some data open to interpretation. Expert scientists can contribute to the interpretation of the data acquired. Small, taxon-based, working groups of experts from CALM, CSIRO, and universities will be set up so that interim results can be objectively interpreted. Ultimately, it is most important that the forest owners, the Western Australian community, understand and accept the consensus of expert opinion, and take this into account when making social and political decisions about ESFM.

It is important to remember that monitoring is not experimental research. Monitoring is intended to track management performance over large space and time scales in relation to stated goals, whereas experimental research is to discover the causes of observed phenomena. Monitoring serves management by demonstrating long-term trends in the performance of measured attributes. If such trends are downwards or slow to improve, management is then alerted to the need to conduct investigations, which may include experimental research.

One possible limitation of FORESTCHECK is that it initially sacrifices geographical replication in favour of taxonomic comprehensiveness. However, the rate and scale of spatial replacement of invertebrate and fungal species across landscapes (α diversity) and subregions (β diversity) in the jarrah forest is uncertain. A biological survey organized along the lines of Burbidge *et al.* (2001) is necessary to clarify this issue. Several colleagues have suggested an alternative approach to the one adopted here for vertebrates and vascular flora. This would involve targeting a smaller number of species, with emphasis given to threatened taxa and those species whose life histories and reproductive biology suggest low resilience to imposed disturbance, on many more sites. We believe that the current approach is more cautious. Otherwise, there is a risk that present biological knowledge is insufficient to identify relevant taxa. Furthermore, the public is interested in biodiversity *per se* and needs re-assurance that species are not being subject to increased risk of extinction through anthropogenic disturbances. The strategy adopted for FORESTCHECK will be reviewed regularly and does allow for subsequent selection of indicator vertebrate and plant species without compromising the relevance of the data collected in the early years of implementation.

The monitoring initiative outlined here does not address water quality and stream ecology. The Australian River Assessment Scheme is available (Smith *et al.* 1999), but cannot readily be applied at the scale of FORESTCHECK and is based on macro-invertebrates identified only to family level. Any streams present on FORESTCHECK sites are likely to be of 1st or 2nd order and consequently ephemeral.

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