Review of permanent plots for long-term monitoring of New Zealand's indigenous forests

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ABSTRACT

Monitoring status and trends in New Zealand's indigenous forests is required under domestic legislation and international agreements, and can assist the Department of Conservation to evaluate conservation performance and measure conservation achievement. We review a number of national permanent forest plots systems from overseas. We then present a three tier option for a national network of permanent plots in New Zealand. At the first tier, we propose a spatially extensive, unstratified representative network of permanent plots to sample forests nationally, incorporating existing permanent forest plots where possible. This will achieve an unbiased national coverage to report on domestic and international obligations, and will allow the Department to assess priority areas and issues for management. At the second tier, we propose use of existing local networks of permanent forest plots, especially those that combine unbiased local coverage with long histories of measurement, to yield finer-scale interpretation of national trends derived from the spatially extensive dataset. New local networks are needed to address current geographic deficiencies. At the third tier, we propose a small set of local permanent-plot networks with more detailed information, as investment sites for multidisciplinary long-term ecological research, to yield detailed interpretation of national and local-scale trends. Because of mutual interests among many agencies, we suggest a national permanent plot network can only be achieved by a consortium. Agreement needs to be reached by consensus about which parameters to measure in a national network, which will set the basis for sampling intensity.

Keywords: catchment-scale sampling, forest health, indigenous forest, international reporting requirements, long-term ecological research, monitoring, national forest inventory, National Vegetation Survey database, spatially extensive sampling, unstratified

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1. Introduction

This investigation considers options for a national network of permanent forest plots to report on current status of, and monitor change in New Zealand's indigenous forests. There is widespread concern that the condition of New Zealand's indigenous forests continues to deteriorate because of anthropogenic influences such as the introduction of weeds and pests. The need to protect and report on the status of these forests, both nationally and internationally, is encompassed in legislation (Conservation Act 1986) and international obligations (e.g. Convention on Biological Diversity). The study concentrates on forest plots in the National Vegetation Survey (NVS)* database, to which the Department of Conservation (DOC) is a major contributor. The investigation addresses the needs for widespread national coverage, while maximising the use of historical datasets that will better allow interpretation of trends. This investigation was carried out by staff of Landcare Research, Lincoln, for the Science & Research Unit, Department of Conservation, in April–June 1999.

2. Background

2.1 WHY MONITOR CHANGE?

In the opening months of the 21st century, very few people would dispute that our burgeoning human population is having detrimental influences on the climate and on ecosystems around the world. Yet many of the changes in natural ecosystems remain undetected or poorly understood, because we do not have monitoring systems in place to systematically record and analyse them. As Willig et al. (1998) point out: 'human activity has had a long and controversial history of causing or accelerating changes in natural communities and ecosystems'. The absence of long-term data from a variety of locations reduces effectiveness in detecting deleterious impacts early and contributes to the controversy surrounding the inability to distinguish between natural variation over time and space, and ecological aberrations induced by human activities.

Although environmental scientists extol the virtues of long-term monitoring, the political willingness to establish and maintain such systems has been, at best, lukewarm. Perhaps the very concept of maintaining long-term monitoring systems is anachronistic in a world where 'change' is thought synonymous with 'progress'. The need for permanent plots to monitor ecosystems is again on the national agenda, not least because the ratification of international agreements on climate change and biodiversity has obliged signatory nations to invest in systems to monitor man's influence on natural ecosystems. The requirements of national laws, and a desire for better accountability of the consequences of

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* For a list of acronyms used in this report see Appendix 1, p. 53.

management activities for biodiversity also provide renewed impetus to monitoring. New Zealand is certainly not alone in its current re-evaluation of monitoring practices, and our highly endemic flora and fauna strengthen the case for developing a robust national system for monitoring the impacts of invasive weeds, animals, and diseases. A national monitoring system that conforms with what is viewed as 'international best practice' would allow New Zealand to address international, national, and regional reporting requirements, simultaneously addressing the needs of the Department of Conservation and other central government agencies (e.g. Ministry for the Environment and Ministry of Agriculture and Forestry).

2.2 VALUE OF MONITORING TO THE DEPARTMENT OF CONSERVATION

A national monitoring capability is an essential tool to help achieve the Department of Conservation's mission statement (Department of Conservation 1998):

> 'To conserve New Zealand's natural and historic heritage for all to enjoy now and in the future'

This can only be achieved through benchmark information about our natural heritage, now and in the future, which can enable prioritising and apportioning effort for conservation management. The need for fundamental underpinning information is outlined in various policy documents, including the recently published 'New Zealand's Biodiversity Strategy' (Department of Conservation and Ministry for the Environment 2000), which lists among the desired outcomes for 2020, that 'decisions that affect New Zealand's biodiversity are based on sufficient and timely information, underpinned by a growing knowledge base' and that 'information about biodiversity at a national, bioregional and local level is accessible to resource managers and communities'. The strategy also recognises that to obtain information on 'status of, and trends in, indigenous biodiversity', consistent measures are required, and that currently a 'lack of consistent monitoring measures and methods means that information often cannot be compared or aggregated across different issues or administrative boundaries'. Our report presents options for a framework that could provide standardised national baseline information and allows determination of trends in a key component of New Zealand's natural heritage—its indigenous forests.

2.3 VALUE OF A NATIONAL PLOT NETWORK TO THE DEPARTMENT OF CONSERVATION

A framework for designing a national network of permanent forest plots is closely allied to development of methods to assess forest health as outlined by Allen (1999). To emphasise this, we adopt here a similar framework to consider the value of a national plot network. A national plot network is relevant for aspects of the Department's decision-making process, for the following reasons.

2.3.1 Evaluating conservation performance

A national plot network will allow the Department to report on the current status of indigenous forests (part of the Department's asset base *sensu* Stephens 1999). In contrast to the Department's man-made assets (e.g. visitor facilities) which are of known age and origin, assessing the current status of the Department's natural ecosystems must acknowledge that these 'assets' are dynamic. Thus we need to understand how these 'assets' came to be as they are, and to be able to predict how they may change in future. A dynamic view of the status of indigenous forests can be gained from measurements of permanent plots, and a perspective can be gained about which components of change can be ascribed to natural processes, and which to human influences. This can also be used to set priorities for active management of forests (Stephens 1999).

2.3.2 Measuring conservation achievement

Having set areas of priority for management, a national plot network can then be used to assess the effects of active management in indigenous forests. Stephens (1999) presented a method to evaluate a rate of return on investment that would be achieved by active management, particularly to mitigate the effects of human or human-related change. The method is predicated on an adequate knowledge base for an ecosystem (or asset base *sensu* Stephens 1999), and that ecosystems are sufficiently understood to be able to detect the difference that management intervention makes. In fact, baseline knowledge about indigenous forests is scant in many parts of New Zealand, while even in areas with a long history of measurement, it can be difficult to demonstrate a benefit from management intervention (e.g. no clear benefits were shown from animal control operations to populations of long-lived trees, Bellingham et al. 1999a). A consistent national method of collecting information will allow measurement of the achievements of active management, placed in context alongside areas that have not received active management.

A national monitoring system in New Zealand's indigenous forests will have the following additional benefit (alluded to above).

2.3.3 Increasing the knowledge base

Changes in the composition, structure, and functioning of forest ecosystems occur over a long time. For example, extensive dieback apparently induced by possum browsing is a process taking several decades in southern rata/kamahi forests (Bellingham et al. 1999a). Quantifying and understanding the changes driven by such human-related impacts, within a context of natural processes, requires improved data on patterns and rates of change. It is in the context of increased knowledge that the Department of Conservation's 'adaptive management' philosophy has developed, wherein research feeds directly back to operations, and allows scrutiny of accepted consequences of management actions, based on sufficient temporal and spatial data. This is the context for which major monitoring programmes overseas have been devised (Dallmeier & Comiskey 1998a).

Evaluating conservation achievement can be viewed as forming part of the Department's 'Achievement System'; evaluating conservation performance as

Figure 1. Indigenous forest assessment for decision-making purposes (boxes) and the nature of monitoring used to achieve these (Figure from Allen 1999).

part of a 'Status System' (Fig. 1), and, as outlined above, a national monitoring network can provide capacity to interpret and report on trends in indigenous forests. A national monitoring network can also be employed in 'surveillance monitoring', a term used by the Department of Conservation (1999) to describe the biological inventory component used for evaluating conservation performance, as well as for reporting on conservation assets and increasing baseline knowledge. Whereas 'outcome monitoring' considers what biological data are required to measure conservation achievement, 'surveillance monitoring' can contribute to evaluating conservation achievement by defining 'status' in the absence of active management, e.g. to provide background information from a wider area against which to assess local operations to control animal pests. Surveillance monitoring will thus reveal whether applied management accords with conservation goals (Bakker et al. 1996). Surveillance will also alert managers to new impacts, such as those brought about by the invasion of new exotic weeds.

2.4 SCOPE OF REPORT

This report presents options to the Department for using permanent plots to assess condition and trends and to report on the status of indigenous forests, at a national scale. The options we present should also have benefit in identifying 'hot spots' or 'trouble spots' for action at a local (regional or conservancy) scale.

For the present investigation we have considered the capacity of existing and possible future permanent plots to address national-scale issues according to methods of Allen (1992, 1993) that are commonly employed in indigenous forests. We regard these measurements as a minimum required to provide a baseline for assessment of either national or local trends in forest. These methods enable investigation of changes in vascular plant composition and diversity (in a structural description of vegetation), and of change with time of several life-history stages of trees (from seedlings to adult trees). In association with standard descriptions on reconnaissance plots (which describe vegetation in terms of cover and structure), it is possible to interpret how change in diversity and life histories of vascular plants may be related to some easily measured environmental variables. While a number of attributes are not typically measured in such plots, e.g. below-ground ecosystem properties and soils, invertebrate communities, cryptogams, etc., we believe the sampling regime we present should be capable of addressing change in many of these ecosystem attributes as well. It is beyond the scope of this investigation to consider methods useful for assessment of trends and condition, and of status of the forests that the Department administers. Development of appropriate methods is the subject of a separate investigation (Allen 1999).

3. Objectives

The project was developed to address the following four objectives:

- Give a national overview of agencies required to report on forest trends and conditions, and areas of mutual interest between other parties and DOC (section 5).
- Assess New Zealand's international obligations, and how existing permanent forest plots can meet reporting requirements (section 6).
- Present an international overview of the purpose and value of forest plots as sites against which to assess management activities, and long-term changes in biodiversity (including the effects of exotic invasions). This will include an assessment of methods in widespread international use, and an evaluation of their applicability to New Zealand's needs (specifically those of DOC) (section 7).
- Present a strategic range of options for a choice of permanent forest plots for onward measurement. This range of options will encompass current management needs (e.g. effects of wild animal control), wider needs (i.e. shared with DOC and other agencies), and will attempt to anticipate future management needs (section 8).

4. Sources of information

To obtain information about requirements of national agencies, we carried out literature reviews and interviewed staff of the Department and other agencies. To assess New Zealand's international reporting requirements, we carried out literature reviews, and relied on a recent report (Dunningham 1998). In gaining an overview of current international practice in forest monitoring we undertook literature searches, and searches of the world-wide web. In developing options for a network of permanent forest plots in New Zealand, we relied principally on the NVS database. Quantitative evaluation of reliability of parameters were derived from permanent plots in this database. Data were read from ASCII formats into a SAS database (SAS Institute 1989), and programs were written by one of us (SKW) to perform analyses (see section 8.2.3).

5. What needs might be addressed by a national network of permanent forest plots in New Zealand?

5.1 DEPARTMENT OF CONSERVATION'S MANAGEMENT

As outlined in section 2, a national network of permanent forest plots is an essential tool in: evaluating conservation performance; measuring conservation achievement; and in increasing the Department's knowledge base. A national network of permanent forest plots can provide a benchmark by sampling forest areas that are for the most part not actively managed, and thus can provide a standard against which to assess the effectiveness of intensive management at a local level. An unbiased national network can pinpoint 'hot spots' or priority areas for action. Current priority-setting nationally (e.g. deciding on which forests are most severely affected by weed invasion, or in which forests there is apparent regeneration failure by canopy tree species) is often dictated by the most vociferous argument made at a conservancy level, without some national means of assessment. It may be that such problems are most chronic in conservancies that do not even advance a case! As long as a broad range of parameters are measured, a national forest plot network can also identify new management priorities, such as the effects of new invasive biota.

5.2 DOMESTIC LEGISLATION

New Zealand's key conservation laws are summarised in 'The State of New Zealand's Environment' (Ministry for the Environment 1997). Of particular pertinence to New Zealand's indigenous forests are the:

- Conservation Act 1987
- National Parks Act 1980
- Resource Management Act 1991
- Environment Act 1986
- Forests Act 1949 (and 1993 amendments)

Of the legislation listed above, the Department of Conservation is the principal agency responsible for implementing provisions of the Conservation Act and the National Parks Act. Provisions of the Resource Management Act require policy formulation by the Ministry for the Environment and implementation by regional and territorial authorities. The Parliamentary Commissioner for the Environment and the Ministry for the Environment are charged with implementing the Environment Act, and the Ministry of Agriculture and Forestry oversees policy formulation and compliance with provisions of the Forest Act and its amendments.

A recurrent theme in all of these laws is that they should serve to preserve intrinsic qualities of ecosystems. All of these laws also concern either the protection and preservation of intrinsic values (Conservation Act and National Parks Act), or the sustainable use of natural resources (Resource Management Act, Environment Act, and Forests Act). A national monitoring system would provide the means to assess compliance with these laws. First, such a system would assist defining the 'intrinsic values' of New Zealand's indigenous forests. Second, by using consistent comparable methods to assess change in forests with time, a nation-wide assessment could be made of both the adequacy of their preservation, or the sustainability of their management.

5.3 VIEWS ON THE UTILITY OF A NATIONAL PLOT NETWORK

A range of staff of the Department of Conservation and other agencies (including research institutes and universities) were contacted to obtain views on the need for and attributes to be measured in a national network of forest plots. As in an earlier review of monitoring of vegetation within DOC (Bellingham 1996), most respondents believed long-term monitoring of forests is valuable, 'especially since the rate of change is often longer than an average working life' and because data provided by monitoring safeguards against loss of institutional memory. Some respondents considered that nation-wide long-term monitoring of forests should facilitate the ability to partition the various effects of successional, climatic, and pest-induced changes in forests, and others advocated either new investment in monitoring or using existing plots nationally to examine such phenomena as climate change. Others considered the chief strength of such a network might lie in its possible predictive value for determining future management priorities.

At the same time, many of the respondents could not see the benefit of a national-scale monitoring network of permanent forest plots; rather they focussed on what would be required at a regional or conservancy level. One respondent felt that a national monitoring programme for forests might develop best from conservancy-led initiatives. Another considered there may be more merit in monitoring change in non-forest systems that could be more sensitive indicators of environmental change.

Overall, respondents indicated that a forest monitoring system should cover these aspects:

- It should be comprehensive in areal coverage, and in representation of forest types and successional stages.
- Include managed and non-managed areas. Difficulties in finding truly comparable sites were acknowledged since all New Zealand forests have unique histories of past natural disturbances and invasion by introduced animals. Similarly, the desire for comparative data from forests more or less devoid of the influences of introduced organisms was recognised as difficult or impossible: equivalent unmodified ecosystems either do not exist, or are subject to influences that set them apart (e.g. maritime climate influences on offshore island forests). Furthermore, maintaining non-managed areas in such a state in perpetuity may be difficult to achieve because of conflicting policy demands.
- Include forest margins and fragments, which are perceived to be more vulnerable to weed invasion, and sensitive to climate change, e.g. at timberlines. However, it was acknowledged that issues of pseudo-replication can often arise in sampling such sites.

Suggestions made regarding sampling effort in a national monitoring strategy included:

- Choose a few major sites at a coarser scale than Ecological Regions, i.e. c. 13 areas for the whole country in which representative sites are chosen, covering vegetation classes, within which advice should be sought regarding an optimum number of plots to provide statistically reliable data.
- Choose a subset of existing sites with permanent forest plots within DOC Regions. One respondent considered that any appraisal based solely on the existing network of plots might be biased because northern New Zealand forest types might be unrepresented or poorly represented, and that the existing network might be biased toward beech (*Nothofagus*) forests. Another respondent considered there would be merit in biasing the sample toward forests where 'dieback' was prominent (e.g. Rogers & Leathwick 1997), so that management options could be developed as a response, if appropriate.

Other attributes that were seen by some respondents as desirable in a national sampling effort included:

- Some emphasis on urban sites, as these may include early foci of weed invasions.

- Some stratification of the country so that major recurrent disturbances on forests are likely to be sampled (e.g. to incorporate areas in which cyclone damage is frequent).

Whether sampling was nationally or conservancy-based, several respondents expressed the desire for nationally consistent methods and standards that:

- Were repeatable and reliable
- Minimised pseudo-replication
- Allowed sampling points to be relocated (acknowledged to be less problematic with increasing GPS access and reliability)
- Were easy to measure and remeasure by field staff
- Did not require frequent remeasurement
- Provided data comparable with that collected by other agencies, e.g. with those managing forests for timber production

Issues that arose included the need to stipulate the minimum number of sampling points (e.g. per area, Ecological District, forest type), and minimum time between remeasurements. One respondent observed that as long as data collection techniques and sampling are standardised, then sampling conducted primarily to answer questions at the local level (e.g. in relation to pest control) can be scaled up to a national level.

Concurrent with the need to use nationally standardised sampling and measuring methods, several respondents stressed that such an exercise could not be viewed in isolation from maintaining the resulting datasets in a timely and high-quality manner. For the data to be useful at a national level, the need for a centralised database for storage, retrieval and analysis of data was also believed to be important. One respondent considered that from any forest monitoring programme (nationally or conservancy-based), DOC needs procedures in place to:

- Analyse and interpret the data appropriately
- Communicate the management implications to the managers
- If immediate action cannot be taken, factor a response into the business planning process for the subsequent financial year

Inevitably, the issue of adequate resource levels to undertake national monitoring of forests arose, and one conservancy respondent considered that an adequately resourced national approach may be preferable to one conducted by conservancies where pressures for funding may see diversion of such resources.

5.4 BENEFITS OF A NATIONAL NETWORK OF PERMANENT FOREST PLOTS

A variety of national and local government agencies are charged with implementing conservation laws (section 5.2), and other agencies are involved under other conservation legislation. Because a national network of plots in indigenous forests is potentially of benefit to several organisations, and because benefits can accrue not only in terms of national assessments, but also as benchmarks against which to measure local performance, we envisage that a *consortium approach across central and local government agencies* would be the most appropriate means of developing and maintaining a national network. Support should also come from other agencies such as the Ministry for Research, Science and Technology, in ensuring that a research component is included in such a network. In this way, Public Good-funded research would directly benefit national and local government agencies.

A national monitoring network will provide more than the ability to meet the requirements of domestic legislation. Such a network could be used as a baseline from which to test new initiatives, e.g. the development of biodiversity indicators (Ministry for the Environment 1998). Among currently proposed biodiversity indicators in terrestrial habitats (including indigenous forests) is measurement of ‘the condition of selected ecosystem types compared to historic and current baselines’. A national network of permanent forest plots that includes plots with repeated historical measurements would allow objective national assessments of change in condition. A second proposed indicator is change in distribution of selected invasive weed species. A national permanent plot network could allow this indicator to be measured, as has already been demonstrated at a more local scale (Wiser et al. 1998a). This network could also serve the needs of central government agencies with reporting requirements under international protocols (Department of Conservation, Ministry for the Environment, Ministry of Agriculture and Forestry, see below).

The consortium contributing to, and deriving information from, a national network of plots should also include territorial local authorities. For example, many local authorities have recently prepared State of the Environment Reports that proposed monitoring be conducted to document changes in biodiversity in forests between initial and future reports (e.g. Manukau City Council 1999). Methods are not generally detailed, however, nor are methods necessarily comparable between even adjacent local authorities, let alone nationally. Private indigenous-forest owners, especially those attempting to manage forests for sustainable timber production (including iwi, and state-owned enterprises such as Timberlands West Coast) should also be involved in the establishment and maintenance of a national network of permanent plots, since both the Forests Act and Resource Management Act require long-term demonstration of sustainability of managed forests. If common methods are adopted (Allen 1999), this would enable comparable reporting between these organisations and territorial local authorities and central government agencies, including the Department of Conservation. A national network of permanent forest plots that is comprehensive would include forest areas administered by these non-governmental organisations and local authorities (e.g. parks and reserves, see section 7.4).

6. International reporting obligations

International reporting on the state of the New Zealand environment is likely to become increasingly important. For example, the OECD 'high-level advisory group on the environment' have intentions of putting sustainable development at the top of the organisation's policy list. It will recommend the redefinition of 'sustainable economic growth' in Article 1 of its convention to mean growth that sustains human, environmental, and economic capital. If the OECD does become a leader in harmonising policies on sustainable development (as its expert group recommends), we can expect more rigorous reviewing of international reports in the future, because the OECD has systems in place for peer review and systematic analyses.

New Zealand has ratified (or is in the process of ratifying) several pieces of international environmental legislation, and in coming years will become increasingly involved in supplying information on the state of our environment to various international bodies. One example is New Zealand's requirements to report on carbon emissions. The Ministry for the Environment (MfE) has contracted Landcare Research and Forest Research to design a national system for monitoring changes in carbon stock in native forests and scrublands (Allen et al. 1998; Coomes et al. 1999). As a part of this work, Dunningham (1998) has provided the MfE with a detailed review of the international agreements on the environment, compiling much of his information from websites.

In this section, we summarise Dunningham's (1998) report into a few pages, providing a brief description of each of the major international agreements and listing the environmental indicators on which agreement has been reached.

6.1 CONVENTION ON BIOLOGICAL DIVERSITY

The objectives of the Convention on Biological Diversity (CBD) are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources. The CBD was opened for signing at the United Nations Conference on Environment and Development, and was signed by New Zealand in 1993. The convention established a secretariat, the conference of parties (COP), and a scientific body to advise the COP (the Subsidiary Body on Scientific, Technical and Technological Advice, SBSTTA).

At the second meeting of COP, it was decided that the state of biological diversity would be assessed in the following ecosystems: forest and woodlands, montane systems, rangelands (arid and semi-arid lands), grasslands, wetlands and freshwater systems, and coastal and marine systems. The meeting identified the use of 'indicators' as the method by which biodiversity assessments would be made. Indicators are seen as information tools, summarising data on complex environmental issues to indicate the overall status and trends of biodiversity.

They can be used to assess national performance and to signal key issues to be rectified through policy interventions and other actions.

The CBD structures the assessment of biological diversity using a pressure-state-response framework:

- Pressures—the socio-economic factors that affect biological diversity
- State—the state of biological diversity (the extent and quality of ecosystems)
- Responses—measures taken to change the current or projected state (e.g. legislation)

In addition, it recognises the need to have indicators of the 'uses' made of components of biological diversity, and of the sustainability of usage. The second meeting of the COP endorsed the development of a core set of indicators in a two-track development process. The first track concentrates on developing indicators of the *state* ecosystems, the *pressures* acting on them, and of *uses* made of them. The second track will build upon the set of first track indicators, and will add indicators of 'fair and equitable sharing of benefits'. In the second track, response indicators for each indicator type will be developed.

Lists of the state, pressure, and use indicators are given in Appendix 2. Under the treaty, New Zealand is obliged to categorise land into land-use classes, and to develop indicators of forest biodiversity (and possibly that of other ecosystems) which are then used to monitor biodiversity changes. Understanding the 'state' of an ecosystem requires measuring its extent, and obtaining some indications about its quality. The notion of defining the spatial extent of ecosystems is not conceptually taxing, although it inevitably leads to debate about where the precise boundaries of adjoining ecosystems lie. On the other hand, indicators of ecosystem 'quality' are more problematic, because it is difficult to define simple and robust indicators capable of detecting changes within complex biological systems. For example, the structure and composition of forests depend upon: (a) abiotic factors (climate, soils, water, geological and geo-chemical processes); (b) biotic factors (competition, ecological succession, mutation, pollination); and (c) individual species patterns (feeding, reproduction, habitat). The SBSTTA recognised that human activity can modify forest structure and composition by modifying one or more of these factors. A second difficulty arises in the definition of a point of reference. Where changes over time in biodiversity are required, the SBSTTA has postulated a baseline for comparative purposes (i.e. not target purposes) of pre-industrial times, except for agricultural systems where the baseline is pre-industrial agriculture (i.e. not virgin cover). Allen (1999) discusses the issues involved in developing quality indicators for New Zealand.

6.1.1 CBD forest biological diversity

The SBSTTA liaison group on forest biological diversity met in May 1997, and recommended the following applications of the convention to forest:

- **Conservation of biological diversity**. Implies that the communities represented by forest ecosystems, their constituent populations of species, and the genetic diversity of those species, be maintained at levels and in conditions sufficient to preclude their loss or erosion—whilst recognising the dynamic state of each of these levels of organisation.

- **Sustainable use of the components of biological diversity**. Implies that harvesting regimes must operate within the constraints defined by conservation goals.
- **Fair and equitable sharing of the benefits arising out of the utilisation of genetic resources**. Implies both a recognition of the roles of people—individuals, communities and societies—in sustaining, shaping and harnessing forest biological diversity, and a distribution of benefits consistent with such recognition. Benefit-sharing regimes must acknowledge the spectrum of benefits and variety of roles which, together, conserve forest biological diversity and make its components available for use.

Surrogate measures are advocated for identification and monitoring. At the landscape level three categories are considered feasible:

- **Subset of species**. Some species are believed to act at some sites as indicators of forest biodiversity, but there is little evidence to suggest that a subset can adequately reflect biodiversity.
- **Ecological assemblages**. These are defined more loosely than species and incorporate a higher level of complexity but mask smaller variations. Community characteristics such as species richness, endemism, and abundance are relevant but are individually weak.
- **Environmental parameters**. These utilise the influence of the environment on diversity, i.e. vegetation can be classified based on the variation in the physical environment. Examples are the Australian and New Zealand 'environmental domain analyses' and the Canadian 'ecological land classification'. A list of the CBD forest indicators is provided in Appendix 3.

6.2 UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT

The UNCED ('the Earth Summit'), was held in Rio de Janeiro in June 1992, and the Commission on Sustainable Development (CSD) is now responsible for reviewing progress on implementing agreement made at the conference, and elaborating policy guidance to achieve sustainable development. The Convention on Biological Diversity and the Framework Convention on Climate Change were opened for signing at the conference, and in addition the conference produced three agreements.

6.2.1 Rio Declaration on Environment and Development

The declaration is the final ministerial statement from the conference, and as such it contains no specific reporting requirements, but its 27 principles govern state and inter-state behaviour for sustainable development, binding environmental protection into economic development. This declaration represents the highest level of political consensus of the conference.

6.2.2 Agenda 21

This is an ambitious statement of policy negotiated between nations, which identifies areas of work required to achieve sustainable development into the

21st century. Key chapters are listed with their associated work programme in Appendix 4. To assist monitoring progress towards implementation of the Agenda 21 themes, the CSD has started to develop indicators for sustainable development, based on the environmental Pressure–State–Response (PSR) framework. The term 'pressure' is replaced by the term 'driving force', which encompasses human activities having an impact on sustainable development; accommodating the social, economic and institutional dimensions; and allowing for both negative and positive impacts of development. Key indicators are given in Appendix 5.

6.2.3 Forest Principles

The 'Forest Principles' is the consensus result from discussions on sustainable development of the world's forests. The consensus is not legally binding, and progress following the discussions process has been marred by differences between countries of the North and South. The disagreement primarily involves individual country's rights to manage their forests without international interference. Therefore the principles enshrine these rights while 'noting' or 'recognising' the role of forests in the global environment, the concept of sustainable development of forest, and the need for forest conservation. A summary of the forest principles is given in Appendix 6.

The CSD created the Intergovernmental Panel on Forests (IPF) with a mandate to pursue a consensus on how the problems of global deforestation and forest degradation could be combated, by promoting management, conservation and sustainable development of all types of forests. Although no consensus was reached, over 130 recommendations for action were presented at the four IPF sessions. It was agreed that the dialogue should continue, and so the Intergovernmental Forum on Forests (IFF) was set up in 1997, with a mandate to continue working towards the international agreements; a negotiating panel will be set up in 2000.

6.3 INTER-AGENCY TASK FORCE ON FORESTS

The Inter-Agency Task Force on Forests (ITFF) is an informal task force chaired by the FAO with other international institutions to explore means for collaboration and coherent action at the international, regional, and country levels in support of any continuing intergovernmental dialogue on forests. It was recommended by the IPF and confirmed by CSD 5. The organisations involved are the FAO, CIFOR, ITTO, CBD, CSD, UNDP, UNEP and the World Bank. There are 10 programme elements that make up the implementation plan. These are expanded in the ITFF implementation plan, which details the work programmes of the individual ITFF parties in these areas.

6.4 THE MONTREAL PROCESS

The sustainable forests practices agreed upon in the 'Forest Principles' are being developed by eight 'regional processes', which are primarily aimed at developing indicators for sustainable forest management and related certification or accreditation schemes. New Zealand participates in the Montreal Process (initiated in Montreal in September 1993), which consists of 12 non-European countries with temperate and/or boreal forests (Australia, Canada Chile, China, Japan, Mexico, New Zealand, Korea, Russia, and the USA). The countries have endorsed seven criteria and 67 indicators of sustainable management in their forests through the Santiago Declaration. These indicators are more far-reaching than any of those endorsed by international agreements, and are listed in Appendix 7.

The Montreal Process reflects serious commitment by the participating countries. However, because it was developed at the 'expert' level, it is not legally binding and neither does it imply or convey legal or political obligations. An ad hoc technical advisory committee has been given the task of providing definitions to the working group for a specified list of terms. Country-specific protocols were used in the first approximation reports prepared for October 1997, in which member countries brought together existing information on the list of indicators.

For the moment, the Montreal Process provides the most complete set of indicators (Appendix 7). Timberlands West Coast has adopted these indicators in its recent draft management plan. Permanent plots could make a contribution towards the following indicators from the Montreal Process:

Criterion 1

Conservation of biological diversity. Extent of area by forest type, age class, and successional stage.

Criterion 2

Maintenance of productive capacity of forest ecosystems. Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production.

Criterion 3

Maintenance of forest ecosystem health and vitality. Area and percent of forest land:

- Affected by processes or agents beyond the range of historical variation, e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinisation, and domestic animals
- Subjected to levels of specific air pollutants (e.g. sulphates, nitrate, ozone) or ultra violet B that may cause negative impacts on the forest ecosystem
- With diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersion, pollination) and/or ecological continuity (monitoring of functionally important species such as nematodes, arboreal epiphytes, beetles, fungi, wasps, etc.)

Criterion 4

Conservation and maintenance of soil and water resources. Area and percent of forest land with significant soil erosion, or with significantly diminished soil organic matter and/or changes in other soil chemical properties.

Criterion 5

Maintenance of forest contribution to global carbon cycles. Total forest ecosystem biomass and carbon pool and, if appropriate, by forest type, age class, and successional stages, and contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon).

Many of these indicators are concerned with the extent of ecosystems, their degree of fragmentation, and so on. Satellite imagery is becoming the accepted norm for making these assessments, but these require extensive ground-truthing. Indeed, one problem with satellite imagery is that spectral reflectance signals do not just depend on one factor such as the height of vegetation, but also upon soil moisture, season, time of day—necessitating ground-truthing on a regional rather than a national scale. Permanent plot data are increasingly used to ground-truth remote sensing. For example Gerard et al. (1998) used data collected in four 1-ha permanent plots established by SI/MAB in Bolivia to refine the classification of rainforest types in the Amazon region. We believe that a greater synergism between satellite imagery and permanent-plot methods could be fostered in New Zealand. For instance, data from a South Island transect of permanent plots were recently used to test satellite imagery stored in the Land Cover Database, as a part of the MfE's programme to develop a carbon monitoring system (Coomes et al. 1999).

6.5 FOOD AND AGRICULTURE ORGANISATION FOREST RESOURCE ASSESSMENT 2000

One aspect of FAO's work is the Global Forest Resource Assessment, which is due for revision in the year 2000 ('GFRA2000 or FRA2000') in partnership with the United Nations Environmental Programme and the United Nations Economic Commission for Europe. New Zealand will be contributing to FRA2000, using the Temperate/Boreal (TBF) assessment approach recommended by experts at a meeting in Kotka, Finland in 1996. Appendix 8 lists the pertinent indicators of sustainable forest management recommended for assessment by FRA2000.

One of the recommendations made by the IFF (established under the 'Forest principles') was that the FAO should take a lead in:

- Developing indicators of sustainable forest management
- Developing suitable definitions of key terms used in forest assessment
- Implementing global forest assessments
- Encouraging better co-ordination and avoidance of overlaps between information systems and definition of data collection priorities

6.6 FRAMEWORK CONVENTION ON CLIMATE CHANGE

The objective of the Framework Convention on Climate Change (FCCC) is to stabilise the atmospheric concentrations of greenhouse gases at levels below which they detrimentally affect the global climatic system. Such levels should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable sustainable economic development to proceed. The principal goals of the framework are as follows:

- Report national inventories of anthropogenic emissions by sources (and removals by sinks) of all greenhouse gases, using internationally comparable methodologies.
- Implement programmes to mitigate the impacts of climate change.
- Promote sustainable management of sinks and reservoirs of all greenhouse gases.
- Limit anthropogenic emissions of greenhouse gases and enhance sinks and reservoirs, aiming to return to 1990 levels of CO_2 emissions.

The 'Kyoto Protocol' expanded the convention by setting quantified, legally binding commitments for developed countries to achieve, with the first commitment coming into effect in 2008–2012. The Protocol also enables emissions trading, joint implementation between developed countries, and a 'clean development mechanism' to encourage joint emissions reduction projects between developed and developing nations. Specifically, this means:

- New Zealand must ensure that the aggregate anthropogenic carbon dioxide equivalent emissions of greenhouse gases do not exceed the 1990-baseline figures in 2008, and must reduce their overall emissions to 5% below 1990 levels in the commitment period 2008–2012.
- Net changes in greenhouse gases resulting from direct human-induced land-use change and forestry activities that can be used towards meeting commitments, are limited to afforestation, reforestation, and deforestation since 1990, and must be reported in a transparent and verifiable manner.
- New Zealand must implement the protection and enhancement of sinks and reservoirs of greenhouse gases, taking into account other environmental agreements, promoting sustainable forest management, afforestation, and reforestation, and promoting sustainable forms of agriculture.

The FCCC was ratified by New Zealand in 1994, while the Kyoto Protocol was opened for signing on 16 March, 1998 and is yet to be ratified by all countries. The Intergovernmental Panel on Climate Change (IPCC) was created by UNEP and the World Meteorological Organization in 1988, and has the task of developing internationally agreed methodologies for the calculation and reporting of national greenhouse gas emissions/removals. The IPCC guidelines allow the reporting of national inventories of greenhouse gas emissions and removals that result directly from human activities, or are the result of natural processes that have been affected by human activities. Emissions are calculated by focussing primarily on major changes in land use that cause large changes in land cover and land-use activities (e.g. forestry), which in turn cause substantial fluxes of CO_2 into or out of the atmosphere. The land-use changes that require monitoring are listed in Appendix 9.

The IPCC recognises three categories of forest:

- Natural, undisturbed forests. These are defined to be in equilibrium and should not be considered either as an anthropogenic source or sink. They can be excluded from the national inventories.
- Forests regrowing naturally on abandoned lands. These are considered a net carbon sink. These are not subject to ongoing human intervention after abandonment, but are included as the carbon-uptake results from the withdrawal of human land management.
- All other types of forests. Any forest that experiences periodic or ongoing human interventions that affect carbon stocks should be included.

Therefore the IPCC does not recognise the need to monitor indigenous forest or established scrublands, in line with the FCCC and Kyoto protocols which make no references to non-anthropogenic sinks/removals. However, the majority of experts at a workshop in Rockhampton criticised these definitions as unworkable, pointing out that all but the remotest forests around the world are managed to some extent. They recommended that a more robust approach would be to report on all forests and wooded areas in national greenhouse-gas inventories, unless specific cases can be made for their exclusion. The workshop recommended the development of a framework for full-carbon accounting, which includes:

- Any anthropogenic processes that cause increased biomass densities should be accounted for within the guidelines through complete inventory of biomass changes. These processes include CO_2 fertilisation effects, if any, and woody plant encroachment.
- Sensitivity analysis is needed to identify and focus effort on key data that improve the precision and accuracy of greenhouse-gas inventories. In national inventories of greenhouse gases, estimates of uncertainty should be provided.
- To improve transparency in reporting, countries are encouraged to identify the total and anthropogenic emissions estimates for all forest fires, as far as possible. This recommendation could be extended to include all sources and sinks where it is difficult to decide whether the cause is natural or anthropogenic. In all cases, both emissions and uptake through regrowth should be consistently reported in national inventories.

6.7 ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The Organisation for Economic Co-operation and Development (OECD) is working toward integrating environmental matters with sustainable development, and is likely to become an increasingly important player in environmental accounting. The Group on Environmental Performance (GEP) is commissioned to review the performance of member countries in meeting domestic and international environmental commitments. Indicators based on the Pressure-State-Response framework are used to structure chapters on pollution, resource management, and the integration of environmental considerations into specific sectors of the economy. New Zealand's environmental performance review was started in June 1995, reviewed in May 1996, and published in November 1996.

The OECD recognises that governments should demonstrate an ability to achieve levels of environmental performance that equal, if not surpass, performances in the private sector and households. The OECD reviews whether the environmental information systems of member states are capable of supporting sustainable development. There is specific interest in whether systems are in place for developing and enforcing environmental polices and legislation, and supporting coherent sectoral and environmental polices, and providing information about environmental conditions and trends to the public and private sectors and NGOs.

Another focus of OECD environmental policy is the implementation of incentive measures for the conservation and the sustainable use of biodiversity (led by an expert group on economic aspects of biodiversity). This programme relates 'biodiversity ecosystems' with pressures from tourism, fishery, road transport, agriculture, forestry, land-use, shipping, and industry sectors. The framework identifies the causes and sources of pressures on ecosystems, and identifies what incentive measures are in place to conserve ecosystems.

6.8 WORLD TRADE ORGANISATION

The Word Trade Organisation (WTO) is the legal and institutional foundation of the multilateral trading system. The Committee on Trade and Environment (CTE) was established by the Marrakesh Ministerial Decision in April 1994 to examine the relationship between trade and the environment. It is charged with recommending modifications to the multilateral trading system that will ensure that trade and environmental issues are 'mutually supportive', which includes the promotion of sustainable development. One of the recommendations of the IPF was that the WTO should establish an international negotiating body to develop a legally binding instrument for trading in all types of forests.

6.9 SUMMARY

The following agencies have responsibilities for those international agreements listed above for which there are national reporting requirements:

- Department of Conservation—Convention on Biological Diversity
- Ministry for the Environment—Convention on Biological Diversity, Framework Convention on Climate Change; OECD
- Ministry of Agriculture and Forestry—Inter-agency task force on forests, Montreal Process, FAO Forest Resource Assessment 2000

Clearly within these agreements there is a diverse range of information requirements, with considerable overlap between agencies. We suggest that there are almost certainly efficiencies to be gained from basing the collection of much of the information on a single approach, rather than a disparate arrangement of single-purpose approaches. An additional benefit from a single approach is the interpretative advantages that derive from concurrent gathering of information from a site. Because all of these agreements require reporting at a national scale, a consortium approach among agencies will create efficiencies and economies, especially if agreed standard methods can be applied. This will become apparent as the discussion paper by Allen (1999) is modified to include other end-user needs.

7. Overseas examples of national networks of permanent forest plots

It will probably be some time before an international consensus is reached on standard methods. For example, there is much wrangling over systems to classify land cover and use. The FAO has aligned itself with a vegetation standard proposed by the U.S. Federal Geographic Data Committee, the Earth Cover Working Group, and its Vegetation Subcommittee, which in turn was largely derived from The Nature Conservancy (USA) system. However, there are plenty of other players, including the Institute for Terrestrial Ecology, the World Conservation Monitoring Centre, and the International Institute for Aerospace Survey and Earth Sciences. Contacts with the Joint Research Centre of the European Union and the IGBP-DIS (Data and Information Systems) and IGBP-LUCC (Land Use and Land Cover Change) were also developed to facilitate exchange of ideas and joint concept development. Lately the EU Working Party on Land Use Statistics and FAO's Statistical Analysis Service (ESSA) and Forest Resources Division (FOR) have provided additional input to these initiatives. Most countries conduct vegetation monitoring of one form or another. Only 3 of 41 countries submitting data to a UN-FAO Global Forest Assessment admitted to not having established plot networks for forest inventory (Lund et al. 1998). However, for other countries the degree of sophistication goes little beyond demarcating the boundaries of natural ecosystems on maps that are intended primarily for the development of the agricultural and urban landscape. Some international examples of national forest monitoring systems are detailed below.

7.1 US FOREST HEALTH MONITORING

The US Department of Agriculture Forest Service (USDA-FS) is required by law to report periodically on forest health, and its Forest Health Monitoring (FHM) programme is designed to monitor changes in vegetation and soils caused by natural and anthropogenic factors (Lund et al. 1998). The plots are largely financed and managed by the USDA-FS, but a number of other agencies provide additional monetary and personnel support.

The FHM system is projected to give coverage of all states by the year 2000 (Overton et al. 1990; USDA Forest Service 1998). The system is a triangular grid of 30 km^2 hexagons that span the entire USA, consisting of 12 600 hexagons in total ($^1/_{16}$ of land in the USA). Plots falling on forested lands (approximately 4000) are measured and maintained by the programme co-operators. A similar sampling strategy was recommended by Allen et al. (1998) and Coomes et al. (1999) to give unbiased assessments of carbon storage in New Zealand's native forests. The rationale is that sampling provides a *compositionally unbiased* sample of the forests, which can be stratified in any number of ways after collection. Examples of the uses of FHM plots include an assessment of the extent of invasion by exotic vascular plants of forests throughout the USA, and the relationship between invasions and human-related disturbance (Stapanian et al. 1998).

The plot consists of four circular subplots, each 7.32 m in radius. Three of the subplots are located at the apices of an equilateral triangle with sides of length 63.4 m, and the fourth circle is located at the centre of the triangle. So the total area sampled is 673 m^2, 50% greater than that sampling in standard National Vegetation Survey (NVS) plots in New Zealand, i.e. 20-m × 20-m plots (400 m^2). The manual also describes a 1-ha plot that is sometimes used for assessing timber volumes of large trees, but precisely when this method should be used is not clear. The following types of measurements are taken:

- Mensuration—information about rates of regeneration, survivor growth, and mortality.
- Soil samples—these are taken from the litter and mineral layers, and are sent for analyses of nutrient concentrations, carbon content, and so forth. An assessment of erosion is also made.
- Crown condition—used to assess the volume of crowns and intactness of tree crowns.
- Damage and mortality—types of serious damage to trees are classified, allowing catastrophic disturbance events to be monitored.
- Lichens—these are excellent indicators of air quality, climate change, and forest structure. Specimens are sampled from the plot and mailed to specialists. Field workers are expected to be able to distinguish lichens but not to identify them.
- Ozone bioindicators—measurements of damage (ostensibly resulting from ozone) on species with known sensitivity to ozone. These measurements are taken away from the main plots.

The mensuration data collected in FHM plots is essentially the same as that in New Zealand's NVS plots, except that (a) co-ordinates of trees are recorded, (b) the amount of crown exposed to full light is assessed, and (c) site productivity is assessed by recording the height-age relationship of a few selected trees, using increment cores to estimate age. However, non-woody vascular plants are not recorded on FHM plots, nor are any assessments made of browse-layer herbivory. The crown condition measurements have parallels with those developed by Payton et al. (1999), but these are not routinely used in NVS forest plots.

An experienced field crew can measure more than one NVS plot in a day (provided that the plots run along a single line and are in relatively simple forests, e.g. *Nothofagus* forests), while the FHM plots require many more measurements, and would probably take a whole day to complete. Thus the extra measurements taken in FHM plots (soils, crown conditions, lichens, damage) come at a cost. The national network design recommended by Allen et al. (1998), and Coomes et al. (1999) for carbon monitoring is a systematic grid of plots, too far apart to consider measuring more than one a day. If the network was extended to meet the needs of other end-users, then other FHM measurements could be included.

7.2 US FOREST INVENTORY AND ANALYSIS PLOTS

The Forest Inventory and Analysis (FIA) network consists of 400 000 sampling units across the USA, which are remeasured every 7 to 13 years. These data have been collected since the 1930s in the east, and were used traditionally to make periodic timber resource assessments (Powell et al. 1994). However, data from FIA plots have been used in a range of other applications, e.g. modelling the effects of climate change on different tree species (Iverson & Prasad 1998). The USDA-FS is currently considering ways of consolidating the FHM and FIA plot systems in a bid to increase efficiency and to standardise methods across regions (Dr C. Scott, pers. comm.).

7.3 SMITHSONIAN INSTITUTE/MAN AND THE BIOSPHERE FOREST PLOTS

In 1986, the UNESCO Man and the Biosphere (MAB) programme joined forces with the Smithsonian Institute (SI) to develop protocols for surveying and monitoring biodiversity in a global network of forested areas (Dallmeier & Comiskey 1998a); SI/MAB has established nearly 130, 1-hectare plots, mainly in the tropics. For each woody plant with a diameter greater than 10 cm, the species and genus is recorded, as well as its co-ordinates, its status (live, standing, broken, etc.), and its height and diameter. Also recorded are soil types, slope, geography, and descriptions of current/historical uses. Plots are remeasured at intervals of 1–5 years. The SI/MAB programme also oversees a network of 50-ha permanent forest plots, established at several sites in Bolivia, Guyana, Panama, Peru, Venezuela (Lund et al. 1998), Malaysia and India (Condit et al. 1996).

The programme has spawned several impressive ecological studies, most notably the 50-ha plot in Panama, which has contributed greatly to the field of rainforest ecology (Condit et al. 1998). Despite many successes at a local level, the SI/MAB system has inherent difficulties when it comes to making international comparisons. For reasons that remain obscure, protocols were adjusted to meet locally determined programme objectives, and were not standardised among the 23 countries using the SI/MAB framework—the data is ‘sectorial in nature rather than proceeding in a harmonized fashion’, as Nauber

(1998) puts it. Symptomatic of this problem is a notable lack of synthesis papers in two volumes emanating from a recent SI/MAB symposium (Dallmeier & Comiskey 1998b, c). In recognition of these difficulties, the European and North American sub-network (EUROMAB) established BRIM: the Biosphere Reserve Integrated Monitoring Programme, which is commissioned with facilitating the co-ordination of monitoring efforts within the 180 biosphere reserves found in the EUROMAB region. Hopefully it will help to overcome the system's shortcomings and set the stage for integrated environmental monitoring (Nauber 1998).

7.4 TROPIS

The Tree Growth and Permanent Plot Information System (TROPIS), under the aegis of the Centre for International Forestry Research (CIFOR), seeks to help forest scientists make better use of existing tree growth information. It is organised by Dr J. Vanclay, and concentrates mainly on tropical forests. The listing of permanent plots in TROPIS contains details about the objectives of experiments and plot systems; about the location, nature, and species composition of plots within these systems; and details about relevant contact people. It does not contain any raw data, growth data, or information likely to infringe intellectual property rights. It includes information on remeasured plots, including species/provenance trials; thinning, spacing and other silvicultural experiments; and continuous inventory systems.

7.5 SCANDINAVIAN FOREST INVENTORIES

The oldest consistently monitored national networks of forest plots are those of the Scandinavian countries, especially Finland and Sweden. In Finland, a systematic plot network is used to provide information on timber stocks and growth, forest health, and understorey composition (Tomppo 1998). Examples of the utility of long-term data from Scandinavian forest plots are apparent (e.g. Økland 1998). A detailed appraisal of design and parameters to measure in a national forest plot network in New Zealand should take account of methods used in these countries, where some aspects of biodiversity measurement (e.g. of bryophytes) is advanced.

8. Option for developing a national network of permanent forest plots in New Zealand

There are some basic requirements of a national plot-based monitoring network. First, it must provide adequate coverage of the entire country. Second, the plot measurements must allow unbiased estimates to be made of key parameters of interest (e.g. bioindicators, carbon storage, etc.). Third, it must be practical and cost-effective. We focus here on the sampling strategy, rather than on the attributes that should be measured on plots which are covered more completely in Allen (1999).

8.1 THREE-TIER APPROACH TO A NATIONAL PLOT NETWORK

We advocate a three-tier option for developing a national network of permanent forest plots. The *first tier* is aimed at achieving a spatially extensive national coverage of New Zealand's forests, for which we advocate an unstratified grid-based sampling regime. The *second tier* is local or regional (or conservancy) catchment-scale plot networks. Many such networks already exist in New Zealand's forests, and provide a history of measurement. The advantage of catchment-scale networks should lie principally in providing local interpretation of national trends, and providing confidence limits at a local level on trends such as invasions by exotic species. The *third tier*, nested within the second, is a set of detailed study areas, supported nationally, that are foci for research to understand the mechanisms behind trends observed nationally or regionally. While a national network of vegetation plots will need to meet international reporting requirements, its more direct use will be as a tool for conservation management. Monitoring programmes are essential for the long-term management of biodiversity (Margules et al. 1998), and New Zealand is fortunate to have an established network of plots monitored using a nationally accepted methodology. Some scientists seem to suffer from an irrepressible urge to tinker with methods and plot designs, but Vanclay (1995), a prominent forest modeller, warns against this, writing 'long-term studies are especially important for validation and to detect subtle trends, so 'old' plots and data should not be neglected but treasured'. Of course, the impression should not be given that the existing NVS network is perfect, but careful consideration is needed before changes are made.

A spatially extensive national network of plots will provide an unbiased assessment of where management issues lie, and thus enable rational targeting of resources. At the same time, the capacity for local resolution and interpretive ability will be provided by maintaining finer-scale local plot networks, especially those that allow both temporal and finer-scale spatial resolution of problems. For example, a national network of grids would reveal which forests have been invaded by the exotic herb *Hieracium lepidulum*, but a local plot network, such as that at Craigieburn Forest Park, can show the stage of invasion. Early in this invasion, predominantly plots close to forest margins were invaded (Wiser et al. 1998a). A local network can also identify determinants of invasions—soil nutrient properties, and local species composition (Wiser et al. 1998a) that might be used to predict and manage similar invasions elsewhere.

8.1.1 Tier 1. A spatially extensive national plot network

A national network of permanent forest plots will achieve an unbiased national coverage, to allow reporting on domestic and international obligations (see sections 5.2 and 6). In collaboration with other agencies (in particular MfE), DOC could use a national network of permanent plots to report on a range of attributes, including biodiversity and carbon, using an agreed common sampling framework. Through co-ordination of effort among interested agencies, there would be economies of cost and effort if a range of attributes were measured on a national network of plots to meet a range of reporting requirements. This was demonstrated during a pilot exercise to determine above-ground carbon in indigenous forests and shrublands (Coomes et al. 1999). With little additional cost and effort for trained field staff, not only was carbon measured, but also coarse woody debris—an indicator of habitat availability for some indigenous biota (Allen 1999)—and total vascular plant diversity, including exotic plants—an indicator of intactness (Allen 1999). As a result, a good deal more useful data were gathered than would have been the case if only a single attribute, carbon (the chief purpose for the field survey), had been measured (Coomes et al. 1999). The second important contribution that can be gained from a national network of permanent forest plots is that this will allow the Department to assess, in a truly unbiased way, where are the priority areas and issues for management. At present, it is not possible to judge whether, for example, issues of forest health are more important in one Conservancy than another because of uneven national coverage and parochial concerns. Comparable data from throughout New Zealand could mitigate against these problems. For example, Bellingham et al. (1999b) demonstrated that imbalances between mortality and recruitment in populations of Halls' totara (*Podocarpus hallii*) were much greater in montane forests in Westland than in other parts of New Zealand. On the basis of information derived from a national network of plots, it should be possible to ensure resources are apportioned appropriately to ensure the long-term conservation of these populations.

To achieve national coverage of New Zealand's indigenous forests, we recommend sampling forests according to a regularly spaced grid. The intensity of the sampling grid will depend on the level of precision required to estimate parameters, and exactly which parameters best assess indigenous forest health are still under debate (Allen 1999). We chose two likely examples—invasion by an exotic species, and basal area of a widespread forest tree—to demonstrate how the required sampling intensities can be determined (section 8.2.3). This grid-based option would employ existing forest plots as much as possible, but recognises that there are some major forested areas of New Zealand (e.g. forests of Northland and eastern Taranaki) where existing coverage is very poor, and new plots would need to be established.

8.1.2 Tier 2. Local or regional plot networks contributing to a national coverage

There are strategic reasons why the Department should support maintenance of local or regional networks of plots established in specific localities. Most local plot networks sample catchments representatively and in an unbiased fashion. Their chief value lies in interpreting long-term trends and capitalising on the investment the Department (and its predecessor organisations) have made to collecting data; a point reiterated by some respondents within the Department (section 5.3). In so doing, the Department can incorporate into its management the knowledge that derives from determining trends in forests for which, in some instances several decades of data exist. National support for some key existing networks of permanent plots will also achieve the goal advocated by Allen (1999). This goal was that changes in forests in which trees, in particular, have long life spans, can be best understood using comparable data over the longest possible time. 'An over-riding principle ... is to always build on the past' in the choice of long-term monitoring methods, and sites to be monitored.

We suggest that maintenance of a selection of local catchment-scale plots will be especially useful in assisting finer-scale interpretation of trends detected through a national-grid plot network. As one respondent stated of a coarse-scale national grid of plots: 'this would reveal general trends at a few sites [which are] not particularly useful for management at a conservancy level.' Maintaining a system of high-quality local sites concurrent with a national network of plots will allow detailed evaluation of apparent national trends at a local (conservancy) level. In conjunction with past (decades-level) data it will also provide a time scale for some aspects of national trends.

8.1.3 Tier 3. Intensive long-term study areas

Within the second tier of local or regional plot networks, we suggest that prominence be given to some intensive local study areas (the equivalent of the USA's Long-term Ecological Research (LTER) sites). Such sites should already have a major history of research and measurement, and should preferably have a history of multidisciplinary research. Examples in New Zealand include study sites in the Orongorongo Valley near Wellington and the Craigieburn Range of inland Canterbury. The expected benefits from maintenance and support of these sites is fine-scale resolution of ecological problems based on long histories of scientific study, supported in part by the Public Good Science Fund. Strengths of LTER sites are usually that many different types of research are carried out at a single locality. This is in contrast to many of the local or regional plot networks, which may have a history of measurement of vegetation in permanent plots, but which are seldom sites for multidisciplinary research.

8.2 DESIGNING A SPATIALLY EXTENSIVE NATIONAL PLOT NETWORK FOR NEW ZEALAND

The spatially extensive national network we describe will allow assessments of change in the dominant or more common species, communities, and combinations of environmental conditions. However, the grid-based approach we outline will tend to miss rare species, uncommon or sparse communities and unique combinations of environmental conditions. Specific targeting of these situations is required to monitor them adequately, although standard monitoring methods can be applied to allow the trends observed to fit into a wider context. Similarly, capacity for a grid of national plots to effectively deal with issues such as fragmentation (including urban forests), as desired by some respondents within the Department (section 5.3), will largely be a function of choice of sampling intensity. That is, the coarser the resolution of a grid, the less likely it is that it will intercept fragmented forests and the more likely it is to favour contiguous tracts.

Two of the most important decisions regarding the sampling strategy for a monitoring system are determining how plot locations will be selected, and how many plots are required. These decisions will influence the type and quality of conclusions that can be drawn and generalities that can be made from the plot measurement data.

8.2.1 How should plots be located?

Plots can be located randomly, systematically, or subjectively. These locations may be in pre-selected strata (e.g. forest types, environmental domains), or may be unstratified. Both randomly and systematically located plots allow unbiased estimates of key parameters to be made. However, systematically located plots have several advantages over randomly located ones. They provide better coverage of an area with the least number of sample points and they are better for understanding spatial patterns and responses to large-scale environmental gradients (Gauch 1982).

Stratification by forest types or by environmental parameters is often suggested to reduce the amount of sampling effort required to cover the range of conditions present. We advise against stratification of plot locations in a nation-wide monitoring system, such as this one, that must serve multiple goals over a long period. One set of strata may be relevant to one type of bioindicator while another set of strata may be more relevant to another type. The importance of particular sets of strata may also change with time. Prior stratification of plot locations can thus lock in place a set-up that is not flexible enough to meet future needs (Overton & Stehman 1996). Two potential strata that have been promoted in New Zealand are forest types and disturbance regimes, but we recommend against these. Forest types are somewhat arbitrary entities and can change with time. With very few exceptions, we know too little about disturbance regimes to use them as strata (cf. comments of one respondent, section 5.3). Furthermore, systems with characteristic, recurrent disturbances are likely to be more resistant to their effects than those where the same disturbance type is rare (e.g. the rare instances where strong tropical cyclones go to high latitudes). However, stratification after sampling is an option with an unstratified sampling scheme. For example, stratification after sampling allows us to monitor how different vegetation types are changing over time, which is not only answering specific questions, but also reducing some known sources of variation.

8.2.2 How many plots are required?

The plot density in the monitoring system will be crucial: too few plots will not allow conclusions to be drawn about changes in attributes of interest, while too many plots will increase the expense of monitoring. Because some ecosystem attributes or bioindicators are more variable than others, different numbers of plots may be required to estimate them accurately. In a report to the Ministry for the Environment on a national network for monitoring carbon storage in New Zealand forests, Hall et al. (1998) determined that approximately 500 plots are required nationally to calculate a plot-level estimate of mean biomass carbon to within 5% (at a 95% probability level). Examining plot remeasurement data from a test area of plots on a 9-km grid in the South Island, Coomes et al. (1999) determined that only 210 of 500 plots nationally would be required to estimate change in plot-level mean biomass carbon to within 5% over a period of 10 years. This number is lower than the number of plots required to develop the original national estimate because repeated-measures statistics can be used on plot remeasurement data. Thus while an initial investment in a spatially extensive monitoring system is large, future estimation of change is likely to be more cost-effective.

8.2.3 Two examples of nation-wide indicator estimates

The Department of Conservation will have an interest in measuring a range of ecosystem attributes and bioindicators that are currently being defined (e.g. Ministry for the Environment 1998; Allen 1999). Here we provide an example of how data from existing plots can be used to determine values of such attributes or indicators and how the number of plots required to estimate two different types of parameters nationally can be determined. The parameters we estimate are the frequency of the exotic plant species wall lettuce (*Mycelis muralis*) and the basal area (per hectare basis) of the common endemic tree, kamahi (*Weinmannia racemosa*), across the entire forest area of New Zealand. Our approach builds on that used by Hall et al. (1998) and Allen et al. (1998). This is meant to serve as an example only; decisions on final plot density of the national monitoring system can only be made after similar analyses have been done with the bioindicators and ecosystem attributes for which DOC will monitor.

We used the Vegetation Cover Map of New Zealand (VCM) to define the forested area of New Zealand. The VCM was compiled at the coarse scale of 1:1 000 000 (Newsome 1987). It manages to resolve vegetation communities with a reasonable degree of accuracy, but can only delineate map units greater than 500 ha in area. The New Zealand Land Cover Database (LCDB) would be superior for this exercise as the minimum mapping unit is 1 ha, target classification accuracy is 90%, and positional accuracy is ±25 m. However, it has yet to be completed for the entire country.

To provide plot-based measurements for these estimates, we used data from National Vegetation Survey (NVS) plots (Allen 1992, 1993). Plots that fell within the area mapped as forest provided the potential universe of data from which to calculate the frequency of wall lettuce and basal area of kamahi. Mapping the geographical distribution of plots measured at different times showed that to provide coverage of the country it was necessary to include plots quantified from 1975 to 1999. We chose the most recent measurement of individual plots for our calculations.

These plots have been located in two ways: representative of a specified survey area, or subjectively (Allen 1993). Because it is not possible to establish random plots in mountainous terrain and, in particular, relocate them, a representative sample has usually been achieved by establishing plots at fixed distances along compass lines that traverse from valley bottoms to ridge tops, or tree line. The origins of compass lines are selected randomly. We included both representative, catchment-scale and subjectively located plots, but excluded special-purpose (e.g. exclosures) plots from our analysis.

For the wall lettuce calculations we used RECCE plots that assess total plant species composition (Allen 1992). RECCE plots have been measured at permanently marked sites and in 'one-off' surveys. We used only those RECCE plots that were measured in survey areas that also have permanent plots. In the area mapped as forest by the VCM, these RECCE plots totalled 6440.

For kamahi, basal area we used plots based on two main types of measurement systems:

- **20 m × 20 m (Allen 1993)**. The 20 m × 20 m plots make up 98% of the 5057 permanent plots in the area mapped as forest by VCM. On each plot all trees (usually stems >2.5 cm diameter at breast height (dbh)) are identified by species, permanently tagged, and measured for dbh at 1.4 m.
- **Cruciform (Holloway & Wendelken 1957)**. Cruciform plots (90 plots) are composed of a belt transect of 200 × 25 links (40.24 m × 5.03 m) with two wings, each 100 × 25 links (20.12 m × 5.03 m) having their origins at the mid-point of the transect. Total plot area is $^1/_{10}$ acre (405 m^2). Measurements are similar to plots of 20 m × 20 m, except that number of trees are counted in 1 inch (2.5 cm) dbh size classes.

Note that we used only stems that were determined as *Weinmannia racemosa*, and did not include stems of *W. silvicola*, which is sometimes synonymised with *W. racemosa*, nor putative hybrids between the two.

The distribution across New Zealand of plots used for both our attribute estimates is provided in Table 1. Although there is extensive coverage of the country, there are also areas lacking plots (e.g. inland Taranaki and North Westland).

Only a subset of these NVS plots should be required to achieve a given level of precision for estimates of wall lettuce frequency or kamahi basal area. To establish a systematic sampling design we superimposed a grid of 1 km × 1 km over the area mapped as forest on the VCM. This grid was used as a basis for forming grids of varying size and, based on grid intersections, resulted in varying numbers of potential sampling points (Table 2).

TABLE 1. NUMBERS OF NVS PLOTS LOCATED IN AREAS MAPPED AS FOREST BY THE VCM FOR VARIOUS PARTS OF NEW ZEALAND.

LOCALITY	RECCE PLOTS FOR WALL LETTUCE ESTIMATE	TREE DIAM. PLOTS FOR KAMAHI BASAL AREA ESTIMATE
North Island	1297	1295
South Island	4819	3601
Stewart Island	324	161
New Zealand	6440	5057

TABLE 2. NUMBER OF PLOTS SELECTED BASED ON GRIDS OF DIFFERENT SIZES BEING SUPERIMPOSED ON FOREST AS DEFINED BY THE VEGETATION COVER MAP OF NEW ZEALAND. A RANDOM PLOT FROM THE CLOSEST LINE TO A GRID INTERSECTION WAS CHOSEN. CALCULATIONS OF FREQUENCY OF WALL LETTUCE (*Mycelis muralis*) AND BASAL AREA OF KAMAHI (*Weinmannia racemosa*) ARE PROVIDED.

FREQUENCY OF WALL LETTUCE				BASAL AREA OF KAMAHI		
GRID SIZE (km)	NO. OF SAMPLE POINTS	NO. OF PLOTS SELECTED	FREQUENCY OF WALL LETTUCE	NO. OF PLOTS SELECTED	MEAN ±S.D. (m^2/ha)	UPPER RANGE (ZERO TO:)
2	12774	1320	4.9			
3	5716	874	4.5	801	7.32±14.28	98.43
4	3207	616	5.2	572	7.81±17.87	271.50
5	2032	448	5.8	421	7.45±13.46	81.73
6	1384	345	5.5	330	7.22±13.88	94.28
7	1057	289	7.3	284	6.19±11.21	58.50
8	803	243	6.8	232	7.13±13.69	80.64
9	621	207	7.7	203	10.14±24.57	271.55
10	490	173	7.5	168	5.49±11.46	67.88
12	352	144	7.6	140	6.75±12.78	63.24
15	229	96	4.2	92	7.67±14.92	72.68
20	136	70	7.1	67	6.20±13.15	72.06
25	87	55	10.9	58	5.08±11.18	60.09
30	64	46	4.3	43	6.52±13.61	47.07
35	35	25	4	27	11.22±12.87	41.56
40	34	26	11.5	28	4.13±7.65	27.00
45	23	19	5.3	17	10.20±14.96	38.89
50	15	13	7.7	15	10.87±15.09	54.04

For the 1990 estimate of carbon storage Hall et al. (1998) selected the closest NVS plot to each grid intersection. Hall et al. (1998) showed that this approach allowed the final carbon storage estimated to be based on plots that were as geographically dispersed as possible and had minimal bias in terms of regional sampling intensity, elevation, and mean annual precipitation. Later examination of the plots selected showed that this tended to favour plots that were at the bottom or the top of a sampling line (Coomes et al. 1999). Here, we modified the plot selection method to select a random plot from the sampling line closest to the grid intersection. This method associates a plot with a grid intersection only if the plot is found in the square region (size determined by grid density) around each grid intersection. As grid density increases, proportionately fewer grid intersections have associated plots, although the total number of plots associated with sampling points increases (Table 2).

At grid densities between 12 km and 7 km (between 144 and 287 selected plots respectively), our estimate of the frequency of wall lettuce began to stabilise at around 7.5% (Table 2, Fig. 2). With higher grid densities, 6 km to 2 km grids or between 345 and 1320 plots, the estimate dropped to about 5% frequency. This could represent better accuracy at higher grid densities, or the introduction of geographical bias at higher grid densities. A low density of grid points may select plots with less geographic bias because they will be more evenly distributed across the country. As grid point density increases, more plots will be selected from high-plot-density areas rather than low-plot-density areas. If plot densities were, for example, higher at low elevations than high elevations, there would be a lowering of the mean elevation of selected plots with increasing grid point density. At a grid density of 8 km (232 plots selected), our estimate of basal area of kamahi began to stabilise at 7.13 m^2/ha (Table 2, Fig. 3).

If a grid-based national monitoring system is developed, our estimates of the frequency of wall lettuce and kamahi basal area provide some guidelines for the number of plots needed to estimate these parameters. Assuming that the stabilisation at 5% frequency for wall lettuce is not due to bias, we suggest about 600 plots located in forest nationally should be adequate to estimate this parameter. A 9-km grid will furnish 621 sample points in the area mapped as forest by the VCM (Table 2, Figs 4 and 5). Because basal area of kamahi is calculated as an average across a number of plots, estimates at different grid densities have both a mean and standard deviation. This allowed us to determine the size of sample required to estimate the mean within an acceptable error limit. For basal area of kamahi the number of plots required for a nation-wide estimate would be higher than for wall lettuce frequency. This is because kamahi basal area varies widely across different stands in New Zealand. In many stands it is absent (3067 of the 5057 plots in our initial universe, Figs 6–9). Where kamahi is present, its basal area ranges from <1 m^2/ha to 316 m^2/ha. Thus, 4160 plots nationally would be required to estimate kamahi basal area to within 5% of the mean with 95% probability; and 1040 plots would be required to provide an estimate within 10% of the mean with 95% probability. These most closely match a 4-km grid (Table 2, Figs 6 and 7; produces 3207 sample locations) and 7-km grid (Table 2, Figs 8 and 9; produces 1057 sample locations), respectively.

Figure 2. Percent frequency of wall lettuce (*Mycelis muralis*) in plots in indigenous forests, for various plot densities nationally.

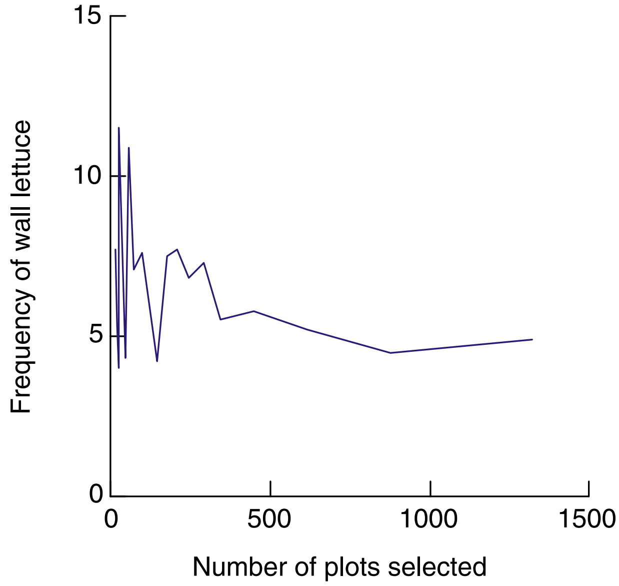
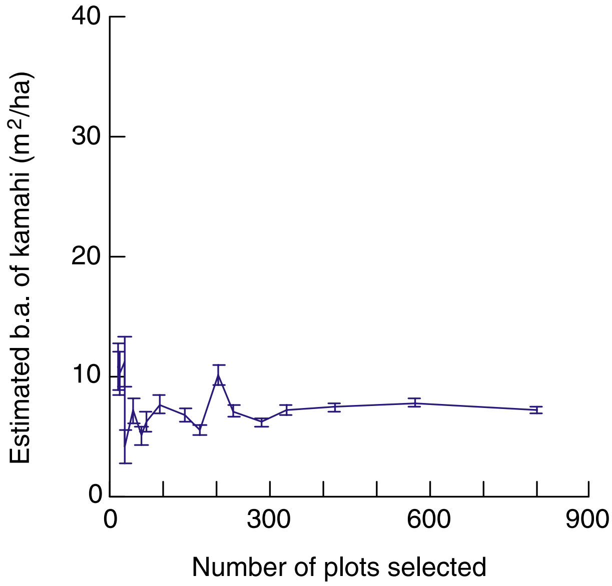


Figure 3. Basal area of kamahi (*Weinmannia racemosa*) in plots, and associated standard error, for various plot densities nationally.



While this exercise is valuable for illustrating how national-level estimates of indicators can be made, and the plot numbers required to obtain precise estimates, we note that the forest area as mapped by the VCM is unsuitable for providing the framework in which to further develop a national monitoring system for forest. If the national monitoring system for forest is to be conducted within areas mapped as forest, the Land Cover Data Base, which is much more precise, must be completed to provide this framework. Because of the lack of precision of the VCM, no forest at all is mapped in areas where we know forest to occur (e.g. the Kaikoura Range, South Island). The Kaikoura Range happens to be the area of the country where wall lettuce is most frequent in forest

Figure 4. Presence or absence of existing permanent forest plots on a 9 km × 9 km grid superimposed on North Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of wall lettuce (*Mycelis muralis*) is shown.

Figure 5. Presence or absence of existing permanent forest plots on a 9 km × 9 km grid superimposed on South Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of wall lettuce (*Mycelis muralis*) is shown.

Figure 6. Presence or absence of existing permanent forest plots on a 7 km × 7 km grid superimposed on North Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of kamahi (*Weinmannia racemosa*) is shown, and where present, its basal area is shown in two categories, i.e. less than and greater than 30 m^2/ha.

Figure 7. Presence or absence of existing permanent forest plots on a 7 km × 7 km grid superimposed on South Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of kamahi (*Weinmannia racemosa*) is shown, and where present, its basal area is shown in two categories, i.e. less than and greater than 30 m^2/ha.

Figure 8. Presence or absence of existing permanent forest plots on a 4 km × 4 km grid superimposed on the eastern North Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of kamahi (*Weinmannia racemosa*) is shown, and where present, its basal area is shown in two categories, i.e. less than and greater than 30 m^2/ha.

Figure 9. Presence or absence of existing permanent forest plots on a 4 km × 4 km grid superimposed on the south-western South Island forest area from the Vegetation Cover Map of New Zealand (Newsome 1987). For those grid points for which there is an existing permanent plot, presence and absence of kamahi (*Weinmannia racemosa*) is shown, and where present, its basal area is shown in two categories, i.e. less than and greater than 30 m^2/ha.

permanent plots and where it is increasing at the most rapid rate (Wiser et al. 1998b). Because this area was not mapped as forest by the VCM, however, the plots that occur there were completely ignored in our estimate. Nationally, 1523 permanent plots with tagged trees were not in areas mapped as forest and so were excluded from our estimate of kamahi basal area. However, they all contain tagged trees and clearly are forested. Kamahi is present on 357 (23%) of these plots.

8.2.4 Incorporating existing permanent plots into a spatially extensive national monitoring system

To maximise the benefit of New Zealand's existing permanent forest plots, NVS plots should, where possible, be incorporated into a national, grid-based monitoring system. Allen et al. (1998) showed that selecting the nearest NVS plot that falls within 4.5 km of 9-km-grid intersections results in accepting 206 existing NVS forest plots nationally as representing these grid intersections. Grid points with existing plots give nearly complete coverage for several major mountain ranges (e.g. Tararua, Ruahine, Kaimanawa), partial coverage for some (e.g. Urewera, Fiordland), and little coverage for other areas (e.g. North Westland). Maintaining many of these plots is the responsibility of the Department of Conservation. Also, additional existing plots that are not currently part of NVS will likely represent grid points and form part of the national monitoring network, e.g. those maintained by Timberlands West Coast in North Westland.

Allen et al. (1998) conducted a range of analyses to determine whether the nearby NVS plots adequately represented the conditions of the grid intersection that they were meant to represent. This was done in terms of a variety of attributes that were mapped for these 9-km-grid intersections. The NVS plots sampled VCM forest classes and soil-climate classes in very similar proportions to grid points. For each of three continuous mapped environmental variables, the mean, standard deviation, and range calculated for plots were remarkably similar to those generated for the systematically located grid points with which the plots were associated (Table 3). The only difference of note was that the maximum mean annual precipitation for plots was somewhat higher than the maximum for grid points. Allen et al. (1998) argued that the similarity of plot and grid point strata and environments demonstrated that the 206 existing plots are representative of the indigenous forest area they sample. New plots will be required to sample the geographic and environmental space that is under-represented nationally.

8.2.5 Integration with other nation-wide monitoring efforts

The Ministry of the Environment has jointly contracted Landcare Research and Forest Research to design a system capable of monitoring changes in carbon stock within New Zealand's indigenous forests and scrublands. The proposed system is based on a combination of satellite imagery and permanent-plot inventories. The Land Cover Database (LCDB) would be used to produce estimates of groundcover of forest and scrub, while a grid-based network of permanent plots would be used to provide a representative sample of the carbon storage per unit area (Hall et al. 1998).

TABLE 3. MEAN, STANDARD DEVIATION (S.D.), AND RANGE OF ENVIRONMENTAL VARIABLES GENERATED BY A GEOGRAPHIC INFORMATION SYSTEM FOR A 9-km-GRID POINTS THAT HAVE AN ASSOCIATED PLOT (GRID); AND FOR THE 206 INDIVIDUAL PLOTS ASSOCIATED WITH EACH 9-km-GRID POINT (PLOT). REPRINTED FROM ALLEN ET AL. (1998).

	GRID			PLOTS		
VARIABLE	MEAN	S.D.	RANGE	MEAN	S.D.	RANGE
Elevation (m)	700	354	6–1499	701	355	7–1590
Mean annual precipitation (mm)	2006	612	0–3050	2004	626	0–3815
Mean annual temperature (°C)	8.72	2.24	0–13.2	8.64	2.45	0–12.8

The proposed system of forest plots is based largely on NVS methodology (i.e. Allen 1993), with some additional measurements designed specifically for carbon storage assessment (measures of tree heights, and volumes of coarse woody debris). The scrub plots have comparability with the forest plots, but in other respects are substantially different in design from any of their predecessors, and still require further refinement. Coomes et al. (1999) trialed the carbon monitoring system along an east–west transect of the South Island covering half a degree of latitude (42° 45' S to 43° 15' S), enumerating a total of 61 plots on a 9-km grid. Whenever an existing NVS plot was located within 4.5 km of the sampling point, it was remeasured in preference to establishing a new plot, thereby maximising the historical value of data.

Because the Department of Conservation was involved on the steering committee for this project, measurements pertinent to the Department's concerns were measured at the same time as measurements of carbon in the 61 plots (i.e. issues of biodiversity, exotic invasions, and regeneration success), and a section of Coomes et al. (1999) discusses these aspects within the transect. Data from these plots on the South Island east–west transect are stored in the NVS database. As such these are amongst the first permanent plots in the NVS database to provide a large-scale unbiased sample of forest and scrub, which is precisely what DOC will require if they are to monitor objectively the changes in diversity, exotics, and stand structure at a large scale. It is not yet certain whether the method of using permanent plots on a 9-km grid as used in the trial by Coomes et al. (1999) will serve as a template for the whole country, but if it does, the Department should stand to capitalise by deriving information nationally on issues that are its concern. However, to derive greatest benefits and synergies from a national carbon inventory, a consensus is required by the Department (and potentially other agencies, see section 5) on what parameters to measure (see also Allen 1999). Then (as shown in section 8.2.3), it will be necessary to determine whether the same sampling intensity of a 9-km grid is appropriate to achieve the precision required to estimate these parameters.

8.3 CHOOSING LOCAL FOREST PLOT NETWORKS TO CONTRIBUTE TO A NATIONAL COVERAGE

There is already a large network of permanent forest plots (9792 nationally in the NVS database). Most existing local networks of permanent forest plots were established at a catchment level. The catchments or sites were chosen intentionally, often reflecting management concerns of the time, many of which remain relevant today (including sampling forests where 'dieback' is prevalent, seen by a respondent as a necessary feature of any national network, section 5.3). However, within most catchments or sites, plot placement is usually representative, especially those that involve networks of permanent 20 m × 20 m plots (6383 such plots nationally, Table 4), so catchments are sampled in an unbiased way. A smaller proportion of local networks of forest plots have been sited selectively or determined by ease of access, and others have been stratified to sample particular types of vegetation.

TABLE 4. NUMBER OF STANDARD NVS 20 m × 20 m PLOTS NATIONALLY AND THEIR HISTORY OF REMEASUREMENT.

	n	% OF TOTAL
Number of plots	6383	
Number of plots remeasured	2152	33.7
Number of plots remeasured within the last decade	1020	16.0

The consistent sampling method used in the existing local plot networks is one of its greatest strengths; as such they provide an invaluable base upon which to contribute to a national network. This consistency was applied nationally in the design, establishment, and remeasurement of plots throughout New Zealand (Allen 1992, 1993), initially by the New Zealand Forest Service and, over the last 12 years, by the Department of Conservation. Over the last 12 years, the majority of new permanent forest plots established by DOC have also conformed to the same sampling and plot methods. Because of this, existing plots can be useful at both a conservancy scale (in addressing local management concerns), and in allowing national-scale forest monitoring. For example, while catchment-scale systems of plots can be used to determine deer impacts on forest regeneration at a local scale (e.g. Allen & Allan 1997), the data from these plots can be combined with those of similar plot systems across the country to answer questions concerning a particular forest type (e.g. Bellingham et al. 1999a), or across forest types (e.g. Bellingham et al. 1999b).

The existing local networks of permanent forest plots provide an invaluable window to the past. A history of measurements of plots (Table 4) gives the ability to determine temporal change and the effects of natural disturbance and human-induced change (including the effects of introduced animals). Therefore we present a listing of the most frequently measured local networks of forest plots in the NVS database (Table 5, Figs 10 and 11), and those with notably long periods of measurement (Table 6, Figs 12 and 13). The strengths in the existing local plot networks lie principally in the long periods over which data have been collected: up to 45 years' data in the case of some central North Island

TABLE 5. LOCAL FOREST-PLOT NETWORKS IN NVS (AND SOME OTHERS) MEASURED AT LEAST THREE TIMES. NOT ALL SAMPLE CATCHMENTS REPRESENTATIVELY, AND SOME HAVE NOT BEEN MEASURED WITHIN THE LAST DECADE. NETWORKS ARE ORDERED FROM NORTH TO SOUTH.

CONSERVANCY	LOCALITY	LAT. & LONG.	NO. AND PLOT TYPE(S)	YEARS MEASURED
Auckland	Hunua[1]	37º 07' S, 175º 12' E	4 transects of variable size (0.284–0.012 ha)	1963–66, 1968–69, 1974, 1988, 1999–2000
Bay of Plenty	Mamaku Plateau	37º 56' S, 176º 02' E	10 transects: (20 m × 210 m)	1960, 1963, 1982–83
Waikato	Pirongia	37º 59' S, 175º 02' E	20 plots: (20 m × 20 m)	1979, 1987, 1999
Bay of Plenty	Rotoma Forest	38º 06' S, 176º 36' E	2 transects: (20 m × 210 m)	1959–60, 1963, 1983
Bay of Plenty	Okataina	38º 08' S, 176º 27' E	36 plots: (20 m × 20 m)	1983, 1989, 1992, 1999
East Coast–Hawke's Bay	Northern Urewera (Waioeka)	38º 13' S, 177º 13' E	3 transects: (20 m × 210 m)	1962, 1984
Bay of Plenty	Whirinaki	38º 38' S, 176º 41' E	2 transects: (20 m × 210 m)	1957, 1963, 1982
Waikato	Pureora (Waihaha)	38º 41' S, 175º 36' E	4 transects: (20 m x 210 m)	1957, 1962, 1982, 1999
Tongariro–Taupo	Northern Kaimanawa	39º 01' S, 176º 11' E	8 transects: (20 m × 210 m)	1960, 1963, 1983
East Coast–Hawke's Bay	Ruahine (Pohangina Valley)	40º 03' S, 176º 02' E	10 plots: (20 m × 20 m)	1975, 1983, 1996
Wellington	Lower Tararua[3]	41º 00' S, 175º 13' E	36 plots: (20 m × 20 m)	1975, 1985, 1996
Wellington	Orongorongo[2]	41º 20' S, 174º 58' E	1 plot: (150 m × 150 m, or 2.25 ha)	1969, 1978, 1985, 1994
West Coast	Maruia[4]	42º 16' S, 172º 15' E	4 plots: (1 ha)	1986, 1992, 1995
West Coast	Taramakau (Hut Creek)	42º 44' S, 171º 35' E	8 plots: (20 m × 20 m, subjectively located)	1978, 1984, 1992
Canterbury	Hurunui (South Branch)	42º 45' S, 172º 02' E	30 plots: (20 m × 20 m)	1976, 1986, scheduled 2000
West Coast	Taramakau	42º 47' S, 171º 42' E	20 plots: (20 m × 20 m)	1969, 1975, 1979 (11 also remeasured in 1978)
West Coast	Kokatahi	42º 57' S, 171º 12' E	22 plots: (20 m × 20 m)	1972, 1980, 1995
Canterbury	Ashley	42º 59' S, 172º 15' E	9 plots: (20 m × 20 m)	1973, 1979, 1984
West Coast	Whitcombe[2]	43º 05' S, 171º 01' E	23 plots: (20 m × 20 m) and 2 plots: (10 m × 20 m)	1972, 1980, 1999
Canterbury	Craigieburn[2]	43º 10' S, 171º 35' E	250 plots: (20 m × 20 m)	1970, 1974, 1976, 1978, 1980, 1982, 1984, 1987, 1994, 2000
West Coast	Copland	43º 36' S, 169º 54' E	46 plots: (20 m × 20 m, subjectively located)	1978, 1984, 1992
Otago	Caples–Greenstone	44º 55' S, 168º 14' E	32 plots: (20 m × 20 m)	1976, 1982, 1989, 1997–98
Southland	North Fiordland	45º 12' S, 167º 30' E	9 plots: (20 m × 20 m)	1969, 1975, 1984 (4 plots), 1998 (5 different plots)
Southland	Blue Mountains	45º 58' S, 169º 21' E	27 plots: (20 m × 20 m)	1976 (data lost), 1982, 1984, scheduled 2000
Southland	North Stewart Island	46º 47' S, 168º 00' E	24 plots: (20 m × 20 m)	1976, 1981, 1985
Southland	Bench Island	46º 54' S, 168º 15' E	5 plots: (20 m × 20 m)	1979, 1985, 1999
Southland	Chew Tobacco Bay	47º 01' S, 168º 12' E	2 plots: (020 ha) and 2 plots (0.24 ha)	1982, 1985, 1989

Remeasurements were most recently conducted by the Department of Conservation (or its contractors, or by its predecessor organisations) except where indicated by:

[1] Auckland Regional Council
[2] Landcare Research (funded by FRST)
[3] Wellington Regional Council
[4] Lincoln University (funded by Lincoln University and FRST).

Figure 10. Areas of forest in the North Island defined by the Vegetation Cover Map of New Zealand (Newsome 1987) showing localities with permanent forest plots in the National Vegetation Survey database which have been measured at least three times.

Figure 11. Areas of forest in the South Island defined by the Vegetation Cover Map of New Zealand (Newsome 1987) showing localities with permanent forest plots in the National Vegetation Survey database and other sources which have been measured at least three times.

Figure 12. Areas of forest in the North Island defined by the Vegetation Cover Map of New Zealand (Newsome 1987) showing localities with catchment-scale sampling by permanent forest plots of 20 m × 20 m in the National Vegetation Survey database with at least14 years' data.

Figure 13. Areas of forest in the South Island defined by the Vegetation Cover Map of New Zealand (Newsome 1987) showing localities with catchment-scale sampling by permanent forest plots of 20 m × 20 m in the National Vegetation Survey database with at least14 years' data.

TABLE 6. LOCAL NETWORKS OF 20 m × 20 m PLOTS SAMPLING CATCHMENTS, WITH AT LEAST 14 YEARS' DATA, AND THE MOST RECENT MEASUREMENT WITHIN THE LAST 10 YEARS, OR MEASUREMENTS SCHEDULED WITHIN THE NEXT YEAR. NETWORKS ARE ORDERED FROM NORTH TO SOUTH.

CONSERVANCY	LOCALITY	LAT. & LONG.	NO. OF PLOTS	DURATION
Waikato	Pirongia	37º 59' S, 175º 02' E	20	20 years 1979–1999
Bay of Plenty	Okataina	38º 08' S, 176º 27' E	36	16 years 1983–1999
Waikato	North Pureora	38º 23' S, 175º 35' E	28	18 years 1975–1993
East Coast–Hawke's Bay	Kaweka	39º 15' S, 176º 25' E	140	>14 years 1981–(1995–99)
East Coast–Hawke's Bay	Ruahine (Pohangina Valley)	40º 03' S, 176º 02' E	10	21 years 1975–1996
Wellington	Lower Tararua[1]	41º 00' S, 175º 13' E	10	21 years 1975–1996
Canterbury	Hurunui	42º 43' S, 172º 01' E	126	25 years 1975/76–2000/01
West Coast	Kokatahi	42º 57' S, 171º 12' E	22	23 years 1972–1995
West Coast	Whitcombe[2]	43º 05' S, 171º 01' E	23	27 years 1972–1999
Canterbury	Craigieburn[2]	43º 10' S, 171º 35' E	250	30 years 1970–2000
West Coast	Okarito[3*]	43º 13' S, 170º 16' E	32	14 years 1983–1997
West Coast	Arawata (Waipara)	44º 15' S, 168º 41' E	4	29 years 1971–2000
Otago	Caples–Greenstone	44º 55' S, 168º 14' E	32	22 years 1976–1997/98
Southland	Murchison	45º 18' S, 167º 38' E	39	29 years 1969–1998 23 years 1975–1998
Southland	Waitutu	46º 12' S, 167º 04' E	107	19 years 1978–1997/98
Southland	Longwood[4]	46º 13' S, 167º 50' E	42	20 years 1977–1997/98
Southland	Blue Mountains	45º 58'S, 169º 21' E	27	24 or 18 years (1976 [data lost] or 1982–2000)
Southland	North Stewart Island	46º 47' S, 168º 00' E	47	18 years 1981–1999
Southland	Bench Island	46º 54' S, 168º 15' E	5	20 years 1979–1999
			Σ = 1000	Average = 21 years

Remeasurements most recently conducted by the Department of Conservation (or its contractors, or by its predecessor organisations) except where indicated by:

[1] Wellington Regional Council

[2] Landcare Research (funded by FRST)

[3] Timberlands West Coast

[4] Waikato University

* Plots located on a grid within the catchment rather than along randomly located transects.

Note: The Ruahine and Tararua datasets are small subsets remeasured in the 1990s of very large (>100 plot) surveys established in the 1970s and 1980s. Likewise the Murchison dataset is a subset of a much larger North Fiordland original dataset comprising several of the ranges of northern Fiordland.

forest 0.42 ha transects, and an average of 21 years data in the case of extensive catchment-based networks of 20 m × 20 m plots (Table 6). The value of plots listed in Table 5 is that trends can be examined, providing these data sets with some predictive capability. Those local plot networks that sample catchments in an unbiased way over long time periods of census (Table 6), have the additional strength of a common sampling method as well as long durations of census. Common attributes such as demographic data, or rate of invasion by exotic species with time, could be determined already, and these data could be contrasted with results gathered from a nation-wide spatially extensive plot network (section 8.2). The attributes of a long history of measurement of local plot networks and the consequent predictive power that may derive from their repeated measurement were recognised by several respondents as strengths (section 5.3). Those local networks with the greatest utility will be those that combine both the attributes of several measurements and a long period of census. An additional benefit provided by existing local networks of permanent plots is that they can provide local detailed resolution of trends detected in a nation-wide spatially-extensive-plot network, e.g. of finer-scale determinants of weed invasion (Wiser et al. 1998a).

It is not surprising that the Department of Conservation is the chief agency to have remeasured many of the local plot networks (listed in Tables 5 and 6). Hall et al. (1991) provided a listing of local NVS plot networks for each conservancy. Recent reviews of local plot networks have been conducted for Southland and West Coast Conservancies (Bellingham 1996, 1997) that have drawn attention to strengths and weaknesses in the available local networks of NVS plots. As a consequence, there has been a reinvigoration of plot remeasurements or establishment in both of these conservancies. There has also been a major increase in remeasurement of plots in some other conservancies, notably East Coast–Hawke's Bay, Waikato, and Otago Conservancies. Other agencies, including regional councils, have also remeasured permanent forest plots (e.g. Auckland Regional Council, assessing changes in vascular plant diversity and the effects of goat control). Others have been measured for research purposes (e.g. by Landcare Research as part of PGSF-funded forest research, and by universities as in Mark et al. 1991). While most of the plot re-measurements have focused on local management issues, because of common methods and sampling strategies, it is possible to synthesise results of these studies nationally. Co-ordination of data in a central database (i.e. NVS) using common data standards (e.g. format, taxonomic nomenclature, etc.) allows national-scale interrogation of the database.

Maintenance of local plot networks is also strategically wise since many of the issues that prompted establishment of plots initially are still topical, and are likely to remain so in the future. Local plot networks established to determine the effects of browse by introduced animals on forest biodiversity and maintenance, are in areas that are controversial, such as the Kaweka Range (Allen & Allan 1997), southern Ruahine Range (Rogers & Leathwick 1997), the Murchison Mountains (Burrows et al. 1999), the wapiti habitat in Fiordland National Park (Stewart et al. 1987), and on Stewart Island (Stewart & Burrows 1989).

The inclusion of some local plot networks should be a matter of urgency in cases where they have not been remeasured for over 15 years. Although it is possible to relocate and remeasure plots that have not been measured in over twenty years (Burrows et al. 1999), the longer the time between measurements the more difficult it becomes to relocate individual plots. This is especially so when transects are inadequately marked. Within plots, the longer the interval between measurements, the more likely that there will be difficulties in identifying individuals if, for example, radial growth of trunks results in tree tags being grown over (Wiser et al. 1999). In some Conservancies many of the local plot networks that could contribute to a national network have not been measured in at least 15 years (Tables 5 and 7).

A major deficiency of the existing local plot networks, either with several measurements, or with a long history of measurements (Tables 5 and 6), is that they are geographically unrepresentative (Figs 10–13). This is a concern also expressed by some respondents from DOC. In particular, of the local

TABLE 7. LOCAL NETWORKS OF PLOTS (20 m × 20 m) SAMPLING CATCHMENTS THAT COULD EXTEND GEOGRAPHIC COVERAGE IN ADDITION TO PLOTS LISTED IN TABLES 5 AND 6. NETWORKS ARE ORDERED FROM NORTH TO SOUTH.

CONSERVANCY	LOCALITY	LAT. & LONG.	NO. OF PLOTS	DURATION
Auckland	Great Barrier Island (northern)	36° 05' S, 175° 23' E	38	Established 1987, not remeasured
Bay of Plenty	Kaimai (Wharawhara catchment)	37° 33' S, 175° 49' E	11	10 years 1974–1984
			26	Established in 1974 or 1984, not remeasured
East Coast–Hawke's Bay	Raukumara	37° 59' S, 177° 45' E	34	Established 1983/84, not remeasured
East Coast–Hawke's Bay	Northern Urewera (Whakatane catchment)	38° 27' S, 177° 00' E	59	5 years 1980–1985
Tongariro–Taupo	Kaimanawa	39° 03' S, 175° 58' E	40	9 years 1979–1988
East Coast–Hawke's Bay	Boundary Stream	39° 06' S, 176° 47' E	20	Established 1997, not remeasured
Wanganui	Kaitaki	39° 10' S, 173° 58' E	8	4 years 1982–1986
Wanganui	Taranaki	39° 12' S, 174° 02' E	38	9 years (1977–79) –1986
Nelson–Marlborough	Cobb	41° 03' S, 172° 03' E	70	8 years 1978–1986
Nelson–Marlborough	Mt Arthur Tablelands	41° 11' S, 172° 38' E	34	9 years 1978–1987
Nelson–Marlborough	Kahurangi National Park	41° 10' S, 172° 34' E	278	Established 1981, not remeasured
Nelson–Marlborough	Wairau (northern)	41° 30' E, 173° 21' E	134	10 years 1973–1983
Nelson–Marlborough	Isolated Hill	41° 54' S, 173° 57' E	29	8 years 1985–1993
Nelson–Marlborough	Cupola	41° 58' S, 172° 44' E	23	10 years 1976–1986
Nelson–Marlborough	Clarence	42° 02' S, 173° 50' E	39	Established 1982, not remeasured
Canterbury	Kaikoura	42° 20' S, 173° 32' E	43	Established 1980, not remeasured
Otago	Waipori	45° 56' S, 170° 02' E	8	6 years 1978–1984
			Σ = 932	

catchment-scale networks plots of 20 m × 20 m with recent measurements (Table 6), only 6 of the 19 datasets are from the North Island (Fig. 12), and these constitute only 234 plots (23.4% of the total) with ≥14 years of census data. For local plots with long histories of repeated measurements (Table 5) the North Island is slightly better represented (Fig. 10). Thus there is a bias in the best available plots towards New Zealand's cool temperate forests (*sensu* Meurk 1984) and warm temperate forests are under-represented; the latter includes forests of the North Island and the northern tip of the South Island, which also lacks recently measured plots (Figs 11 and 13). Entire DOC Conservancies entirely lack local forest plot networks that provide either histories of repeated measurements or which have long census intervals (Tables 5 and 6), these include Conservancies (Northland and Nelson–Marlborough) within which are areas of high floristic richness and endemism (Wardle 1991). There are local plot networks that have not been measured within the last decade that could redress some of the most obvious geographic deficiencies (examples are given in Table 7), including substantial existing networks in Nelson-Marlborough Conservancy. Other recently established local plot networks are included in Table 7, such as those in Boundary Stream (East Coast–Hawke's Bay Conservancy) that can serve to strengthen national coverage. Some non-standard NVS plots such as those listed by Meurk & Buxton (1991) might address some geographic deficiencies. A glaring deficiency in the existing national network of plots is in Northland Conservancy, where, other than the two plots on the Three Kings Islands (see below), only four permanent plots of 20 m × 20 m are in the NVS database (these are in Waipoua Forest where they serve as controls for adjacent exclosure plots). The near absence of existing plots in Northland reduces latitudinal coverage nationally and, given that Northland is an area of high floristic diversity with endemic tree taxa (Wardle 1991), the current capacity to interpret the consequences of management activities in Northland forests is extremely poor. There may be strategic reasons for establishing a local catchment-scale plot network in at least one Northland forest tract to contribute to a national network of plots.

Beyond the main islands of New Zealand, a national-level network of plots might also encompass other local plot networks in forests in New Zealand's other bioclimatic zones (not listed in Tables 5 and 6). There are permanent forest plots of 30 m × 30 m, established in 1993 in subtropical forests on Raoul Island (Kermadec Islands), that have been remeasured twice since (a total of 6 years' data, C.J. West, DOC, pers. comm.). However there are no existing permanent forest plots in New Zealand's subantarctic forests (e.g. on Auckland Islands). The Department may wish to consider long-term national support for existing local forest-plot networks on the Chatham Islands because they sample a unique forest flora of high endemism. These are 13 plots established on Rekohu (Chatham Island) in 1990 and remeasured in 1996, and eight plots established on Rangiauria (Pitt Island) in 1995. There are also two permanent forest plots (0.16 ha and 0.23 ha) on Great Island, Three Kings Islands, established in 1946 and remeasured in 1951, 1963, and 1983 (Turbott 1948; Cameron et al. 1987); these are among the oldest forest plots in New Zealand. For these reasons, and because of the endemic forest flora of Great Island, the Department may wish to support their onward measurement as a contribution to a national plot network.

We have not included in Tables 5–7 a number of plots that serve as controls alongside adjacent exclosure plots, mostly because they are usually small in number and are not often spatially extensive for any given site, but these should certainly be included in any national coverage. We estimate 51 of a total of 143 exclosures and adjacent controls in the NVS database have been established and remeasured nationally, and it would be appropriate for a national assessment to be conducted of their utility and coverage.

8.4 LONG-TERM ECOLOGICAL RESEARCH SITES TO CONTRIBUTE TO A NATIONAL MONITORING NETWORK

A research component will be required to better understand patterns detected in an extensive spatial plot network or from a series of local plot networks. We believe this can best be achieved through maintenance of a few key sites distributed throughout New Zealand, which capitalise on histories of multidisciplinary research. New Zealand has maintained such areas in the past (e.g. Orongorongo Valley and Craigieburn Ranges) but these research efforts have faltered as the organisations that supported them have been restructured during the last 15 years. Even so, these areas have continued to provide multidisciplinary research that, for example, ties together plant and animal ecology (in the case of Orongorongo, Brockie 1992), although in recent times this has been achieved largely through the efforts of individual scientists, without an overall supporting framework. In Tables 5 and 6 we indicate some areas with outstanding histories of measurement of indigenous forests, but recommend that this be only one factor to be considered in assessing which sites might be supported by the Department as sites for long-term ecological research.

9. Conclusions

A growing number of imperatives, brought about by domestic legislation and international agreements, mean that New Zealand must report on status and trends in its indigenous forests. The Department of Conservation's own philosophy of 'Quality Conservation Management' also means that better capacity to report on operations and to set a context for priorities for management is required. For all of these reasons an objective, unbiased method is required to sample forests nationally.

We propose a three-tier option for a national network of permanent forest plots:

- **A spatially extensive, unstratified grid network** to sample forests nationally, incorporating existing permanent forest plots where possible. This will achieve an unbiased national coverage, which will allow reporting on domestic and international obligations, but will also allow the Department to assess, in a truly unbiased way, where are the priority areas and issues for management.
- **Use of existing local networks of permanent forest plots**, especially those that combine unbiased local coverage with long histories of measurement, to yield finer-scale interpretation of national trends derived from the spatially extensive dataset. This will allow the Department to capitalise on its and its predecessor organisations' investment in forest monitoring. New Zealand is very fortunate, internationally, not only to have an enviable historical record of change that can be provided by permanent plots (some yielding over

40 years' data), but also to have most existing plots sample catchments in an unbiased fashion, using a consistent method that has been applied nationally. New local networks will be needed to redress some key geographic deficiencies in present plot networks.

- **A small set of high-quality local permanent-plot networks** as investment sites for multidisciplinary long-term ecological research, to yield detailed interpretation of national and local-scale trends. These sites can be recommended by the Department as key areas to co-ordinate research funded by the Department, and by the Public Good Science Fund.

Achievement of national coverage by an unstratified grid approach will require some decisions to be made by the Department, three of which are:

- **The choice of the sampling universe**. We advocate use of the Land Cover Data Base (LCDB) to define forest boundaries as superior to other options, but even this approach may not include some key areas of interest to the Department (e.g. forests on some remote islands). Alternatively, the Department might choose not to stratify the landscape by predetermined boundaries. In this instance the sampling grid might cover the entire landscape of New Zealand, so that biodiversity might be estimated over the whole New Zealand landscape.
- **The choice of parameters to estimate**. This debate has already begun within the Department with the publication of a discussion document 'Forest Health Assessment for Conservation Performance' (Allen 1999).
- **The choice of acceptable confidence limits within which to estimate chosen parameters**. We used two examples of possible parameters to demonstrate that sampling intensity nationally would differ for different parameters. To estimate some parameters desired by some respondents within the Department (e.g. variables within small fragments nationally) may entail a large sampling effort.

We believe that there are opportunities for synergies with other national monitoring efforts in forests. Principally these lie with the national reporting system for carbon inventories in forests and shrublands being undertaken by the Ministry for the Environment which presently uses a grid-sampling approach. We advocate a consortium approach among as many agencies as possible besides the Department of Conservation (those with reporting requirements under both domestic and international auspices) to achieve consensus on desirable parameters to be estimated and to achieve a compromise on a national sampling intensity. If the wider sampling universe of the entire New Zealand landscape were considered, the consortium would need to be broadened to include major representatives of the primary production sector. It is also noteworthy that detection of change in parameters over time is likely to be cost-effective, because only a subsample need be measured to produce measures of change within acceptable confidence limits.

10. Recommendations

- A consortium approach is recommended as the only viable means by which an unbiased spatially extensive national coverage of indigenous forests can be realised. Such a consortium would feature the Department of Conservation, and would also include agencies with reporting requirements under domestic legislation and international agreements (i.e. at least MfE, Ministry of Agriculture and Forestry, and territorial local authorities).
- The Department needs to reach a consensus, internally and with other key agencies (as above) on key parameters to be estimated from indigenous forests, and on how many plots would be required. A recent draft discussion paper (Allen 1999) forms a basis for this discussion. Only after broad agreement has been reached on parameters to be measured could an appropriate sampling intensity be determined.
- In the interim the Department should support, at a strategic level, key local plot networks that would also contribute to a national monitoring strategy. We list some key local plot networks that should be maintained to allow finer-scale resolution of national trends, and to capitalise on the historical data (up to 40 years) that will enable predictions to be made. Plots should be established to fill key geographic deficiencies in the existing plot network. This should receive attention and support from Conservancy and Head Office levels. Areas of very poor coverage for local plot networks include Northland forests, and those of inland Taranaki and north Westland.
- The Department can encourage, through its own funding, and through leverage in the Public Good Science Fund, the development and maintenance of some key areas with histories of multi-disciplinary research as sites to be maintained for long-term ecological research. Such areas can yield finer-scale, mechanistic explanations for phenomena detected at national and local scales. The Department should assess those areas with outstanding histories of vegetation measurement as areas to consider supporting as sites for long-term ecological research, alongside areas that also have outstanding histories of information about fauna and other aspects of flora.

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Appendix 1

LIST OF ACRONYMS

BRIM	Biosphere Reserve Integrated Monitoring programme
CBD	Convention on Biological Diversity
CIFOR	Centre for International Forestry Research (Bogor, Indonesia)
COP	Conference of Parties (to the Convention on Biological Diversity)
CSD	Commission on Sustainable Development
CTE	Committee on Trade and Environment
DOC	Department of Conservation
ESSA	Statistical Analysis Service
FAO	Food and Agriculture Organisation (United Nations)
FCCC	Framework Convention on Climate Change
FHM	Forest Health Monitoring (USA)
FIA	Forest Inventory and Analysis (USA)
FOR	Forest Resources Division (FAO)
GEP	Group on Environmental Performance (OECD)
GPS	Global Positioning System
IFF	Intergovernmental Forum on Forests (CSD)
IGBP	International Geosphere - Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
IPF	Intergovernmental Panel on Forests (CSD)
ITFF	Inter-agency Task Force on Forests
ITTO	International Tropical Timber Organisation
LCDB	Land Cover Data Base (of New Zealand)
LTER	Long-term Ecological Research (USA)
LUCC	Land Use and Land Cover Change
MAB	Man and The Biosphere (UNESCO programme)
MfE	Ministry for the Environment
NGO	Non-Governmental Organisation
NVS	National Vegetation Survey
OECD	Organisation for Economic Cooperation and Development
PSR	'Pressure-State-Response' model
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice (to the Convention on Biological Diversity)
SI	Smithsonian Institute (USA)
TBF	Temperate and Boreal Forests Assessment
TROPIS	Tree Growth and Permanent Plot Information System
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USDA-FS	United States Department of Agriculture - Forest Service
VCM	Vegetation Cover Map (of New Zealand)
WTO	World Trade Organisation

Appendix 2

CBD INDICATORS OF STATE, PRESSURE, AND USE

ELEMENT	FIRST TRACK INDICATOR	SECOND TRACK INDICATOR
STATE INDICATOR		
Extent of ecosystem	Self-regenerating and man-made area as percentage of total area.	Self-regenerating area per habitat type as percentage of 1993 and of postulated pre-industrial baseline. Remaining self-regenerating area by size-class category.
Quality of ecosystems: (1) threatened or extinct species and habitat types	Number of threatened and extinct species as a percentage of particular groups considered per country.	As first track, but extended data.
Quality of ecosystems: (2) Species abundance relative to postulated baseline	Distribution or abundance of a few selected species as percentage of postulated baseline per country.	Extended list of selected species which provide a more detailed and representative picture of the change in biodiversity per country.
Quality of ecosystems: (3) Ecosystem structure	Patches of natural vegetation in agricultural habitat (<100 ha). Structural analysis of forests: • The ratio of dead to living wood. • Areas of an ecosystem which is: (a) intact in its canopy cover; (b) intact in its understorey; (c) is Bio-reserve or primary forest; (d) sustainably managed forest; (e) secondary forest; (f) degraded forest; (g) tree plantations with or without endemics; (h) major habitat qualifying as wilderness. Identification of remaining flood-plain characteristics from satellite images to show distribution of natural river systems. The number of well-defined habitat types as an indicator of agricultural diversity related to the postulated baseline (traditional agricultural ecosystems). Vital reefs, mangrove and/or sea grass coverage in marine ecosystems.	
PRESSURE INDICATORS		
Habitat loss	Annual conversion of self-generating area by habitat type as percentage of remaining area. Annual land-use change from self-regenerating area into agriculture, permanent pasture, and built-up land. Share of riversheds dammed or channelised as percentage of the whole river. Percent of coastal zone with a population density exceeding 100 inhabitants/km^2. Percent of coastal zone within 30 km of a town or city >100 000 inhabitants.	A range of region-specific variables and decision rules.
Species introductions	Total number of non-indigenous species as a percentage of a particular group per country.	Relative abundance/biomass of non-indigenous species as a percentage of a particular group.
Climate change	Change in mean temp. per 50-km × 50-km grid cell averaged per country over 20-years.	Change in the maximum and minimum precipitation per 50-km × 50-km grid cell over 20 years.
Harvest	Total amount harvested per unit effort.	Total amount harvested relative to estimate of sustainable offtake levels. Average size per unit of offtake of a given species relative to a baseline. Amount of agricultural area lost in 10 years due to erosion as % of agricultural area brought into agriculture in this period.

ELEMENT	FIRST TRACK INDICATOR	SECOND TRACK INDICATOR
Pollution		Average exceedence of soil water and air standards (critical loads) of particular pollutants.
USE INDICATORS		
Ecosystem goods	Total amount harvested per species and grand total over time.	Percentage of wild species with known or potential medicinal uses.
Ecosystem services	Total and per km^2 carbon stored within forests per country referenced to baseline.	Percent of transboundary watershed area assessed as 'low risk of erosion'. People's perception of biodiversity compared with other political issues.

Appendix 3

CBD INDICATORS OF FOREST BIODIVERSITY

International

Forest Cover

Forest Condition

Protected Areas

Core Set

Area of natural forest

Area of natural forest as a proportional of total forest

Change in natural forest over 10 years

Forests protected areas by IUCN classes I–VI

Forest protected areas by ecoregion

Number of forest-dependent species

Proportion of forest-dependent species at risk

Areas of forest managed to prioritise biodiversity conservation

Air pollution levels exceeding forest critical loads

Existence of legislation to protect biodiversity

Existence of forest management code to protect biodiversity

Detailed National Information

Mapped details of forest types

Mapped details of old-growth/natural forests by types

Mapped details of forest protected areas

Mapped details of forest under special management regime

Percentage and extent in area of forest types relative to historical condition and to total forest cover

Percentage and extent in area of forest types by age class

Levels of fragmentation and connectiveness

Percentage of mixed stands

Area and representativeness of forest protected areas

Number of forest-dependent species, categorised as (a) indigenous (b) non-indigenous (c) endemic

Number of forest-dependent species, categorised as (a) threatened (b) endangered (c) rare (d) vulnerable

Population levels and changes over time of selected indicator species

Number of forest-dependent species, occupying a small proportion of their former range

Areas of forest cleared annually containing endemic species

Percentage of annual natural regeneration

Natural regeneration as a percentage of total regeneration

Percentage of stands managed for genetic resource conservation

Amount of *ex situ* genetic resource conservation

Proportion of trees suffering damage

Area of land set aside into special management regimes

Area of land independently certified as being managed sustainably

Human disturbance index

Main threats to forest biodiversity

Area of forest annually affected by major threats

Appendix 4

CHAPTER SUMMARIES TAKEN FROM AGENDA 21 OF THE UNCED

Chapters 2–8 Social and economic aspect of sustainable development	
8: Integrating environment and development in decision making	Integrating environment and development at the policy, planning and management levels Providing an effective legal and regulatory framework Making effective use of economic instruments and market and other incentives Establishing systems for environmental accounting
Chapters 9–22 Conservation and management of resources for development	
11: Combating deforestation	Sustaining the multiple roles & functions of all types of forests, forest land & woodlands Enhancing protection, sustainable management, & conservation of all forests, & the greening of degraded areas, through forest rehabilitation, afforestation, reforestation, and other rehabilitative means Promoting efficient utilisation & assessment to recover the full valuation of the goods & services provided by forests, forest lands and woodlands Establishing and/or strengthening capacities for the planning, assessment & systematic observation of forests and related programmes, projects and activities, including commercial trade and processes
14: Promoting sustainable agriculture and rural development	Ensuring people's participation Improving farm production and farming systems Land-resource planning information and education Land conservation and rehabilitation Water for sustainable food production and rural development Conservation and sustainable utilisation of plant genetic resources Conservation and sustainable utilisation of animal genetic resources Integrated pest management Sustainable plant nutrition Rural energy transition Evaluation of the effects of ozone depletion on plants and animals
15: Conservation on biological diversity	Conservation on biological diversity—Convention on Biological Diversity
17: Protection of the ocean, coastal areas, etc.	Integrated coastal zone management Marine environmental protection (including land- and sea-based sources of marine pollution) Addressing critical uncertainties for the management of marine environment and climate change
18: Protection of the quality and supply of freshwater resources	Integrated water resources development and management Water resources assessment Protection of water resources, water quality and aquatic ecosystems Impacts of climate change on water resources
Chapters 33–40 Implementation	
35: Science for sustainable development	Strengthening the scientific basis for sustainable management Enhancing scientific understanding Improving long-term scientific assessment Building up scientific capacity and capability.
40: Information of decision making	Bridging the data gap Improving information availability.

Appendix 5

CORE INDICATORS FOR AGENDA 21

CHAPTER	INDICATOR	
10: Land	Driving Force	Land use change
	State	Changes in land condition
	Response	Decentralised local-level natural resource management
11: Forestry	Driving Force	Wood harvesting intensity
	State	Forest area change
	Response Indicator	Managed forest area ratio
		Protected forest area as a percentage of total forest area
14: Agriculture	Driving Force	Use of agricultural pesticides
		Use of fertilisers Irrigation percent of arable land
		Energy use in agriculture
	State	Arable land per capita
		Area affected by salinisation and waterlogging
	Response	Agricultural education
15: Biological Diversity	Driving Force	
	State	Threatened species as a percent of total native species
	Response	Protected area as a percent of total area

Appendix 6

A SUMMARY OF THE FOREST PRINCIPLES

PRINCIPLE	DESCRIPTION
Preamble	Forests are integral to the full range of environmental and development issues The guiding objective is to contribute to the conservation, management, and sustainable development of all forests Recognition of the place of forest in ecology and role in providing resources to satisfy human needs which means that sound management and conservation is a concern of all Forests are essential for economic development and maintenance of all forms of life
1	States have a sovereign right to exploit their forests and a responsibility to ensure no environmental damage occurs to other states
2	States have the sovereign right to use their forests. Forests should be managed sustainably to meet needs of this and future generations Information on forests and forest ecosystems needs to be available to support decision-making There is a requirement for participation of other interested parties in the forest policy formulation process.
3	National polices should provide a framework for the increased effort in conservation and sustainable development
4	Recognised the role of forest in maintaining ecological processes and balance, through their role in protecting fragile ecosystems, watersheds and fresh water resources, biodiversity, genetic material and photosynthesis
5	Rights of indigenous people recognised
6	Role of forests in bio-energy recognised and met through sustainable forest management Sustainable forest management will benefit from the economic and non-economic values of forest goods and services and of environmental costs and benefits Role of planted forests should be promoted
7	International economic climate for sustainable forest management
8	Effort undertaken towards greening of the world

Appendix 7

INDICATORS FOR THE MONTREAL PROCESS, ARRANGED BY CRITERIA

Criterion 1: **Conservation of biological diversity (includes the elements of the diversity of ecosystems, the diversity between species, and genetic diversity in species).**

Ecosystem diversity
Extent of area by forest type relative to total forest area;
Extent of area by forest type and by age class or successional stage;
Extent of area by forest type in protected area categories as defined by IUCN or other classification systems;
Extent of areas by forest type in protected areas defined by age class or successional stage;
Fragmentation of forest types;
Species diversity
The number of forest-dependent species;
The status (rare, threatened, endangered, or extinct) of forest-dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment;
Genetic diversity
Number of forest-dependent species that occupy a small portion of their former range
Population levels of representative species from diverse habitats monitored across their range.

Criterion 2: **Maintenance of productive capacity of forest ecosystem**

Area of forest land and net area of forest land available for timber production;
Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production;
The area and growing stock of plantations of native and exotic species;
Annual removal of wood products compared to the volume determined to be sustainable;
Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game), compared to the level determined to be sustainable.

Criterion 3: **Maintenance of forest ecosystem health and vitality**

Area and percent of forest affected by processes or agents beyond the range of historical variation, e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinisation, and domestic animals;
Area and percent of forest land subjected to levels of specific air pollutants (e.g. sulphates, nitrate, ozone) or ultraviolet B that may cause negative impacts on the forest ecosystem;
Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersion, pollination) and/or ecological continuity (monitoring of functionally important species such as nematodes, arboreal epiphytes, beetles, fungi, wasps, etc.).

Criterion 4: Conservation and maintenance of soil and water resources

Area and percent of forest land with significant soil erosion;

Area and percent of forest land managed primarily for protective functions. e.g. watersheds, flood protection, avalanche protection, riparian zones;

Percent of stream kilometres in forested catchments in which stream flow and timing has significantly deviated from the historical range of variation;

Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties;

Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities;

Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variance of biological diversity from the historical range of variability;

Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variation from the historical range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change;

Area and percent of forest land experiencing an accumulation of persistent toxic substances.

Criterion 5: Maintenance of forest contribution to global carbon cycles

Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages;

Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon (standing biomass, coarse woody debris, peat and soil carbon);

Contribution of forest products to the global carbon budget.

Criterion 6: Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies

Production and consumption

Value and volume of wood and wood products production, including value added through downstream processing;

Value and quantities of production of non-wood forest products;

Supply and consumption of wood and wood products, including consumption per capita;

Value of wood and non-wood products production as percentage of GDP;

Degree of recycling of forest products;

Supply and consumption/use of non-wood products;

Recreation and tourism

Area and percent of forest land managed for general recreation and tourism, in relation to the total area of forest land;

Number and type of facilities available for general recreation and tourism, in relation to population and forest area;

Number of visitor days attributed to recreation and tourism, in relation to population and forest area;

Investment in the forest sector

Value of investment, including investment in forest growing, forest health and management, planted forests, wood processing, recreation and tourism;

Level of expenditure on research and development, and education;

Extension and use of new and improved technology;

Rates of return on investment;

Cultural, social and spiritual needs and values

Area and percent of forest land managed in relation to the total area of forest land to protect the range of cultural, social and spiritual needs and values;

Non-consumptive-use forest values;

Employment and community needs

Direct and indirect employment in the forest sector and the forest sector employment as a proportion of total employment;

Average wage rates and injury rates in major employment categories within the forest sector.

Viability and adaptability to changing economic conditions, of forest-dependent communities, including indigenous communities;

Area and percent of forest land used for subsistence purposes.

Criterion 7: Legal, institutional and economic framework for forest conservation and sustainable management

Extent to which the **legal framework** (laws, regulations, guidelines) supports the conservation and sustainable management of forests, including the extent to which it:

- Clarifies property rights, provides for appropriate land tenure arrangements, recognises customary and traditional rights of indigenous people, and provides means of resolving property disputes by due process
- Provides for periodic forest-related planning, assessment, and policy review that recognise the range of forest values, including co-ordination with relevant sectors
- Provides opportunities for public participation in public policy and decision making related to forests and public access to information
- Encourages best-practice codes for forest management
- Provides for the management of forests to conserve special environmental, cultural, social and/or scientific values

Extent to which the **institutional framework** supports the conservation and sustainable management of forests, including the capacity to:

- Provide for public involvement activities and public education, awareness and extension programmes, and make available forest related information
- Undertake and implement periodic forest-related planning, assessment, and policy review including cross-sectoral planning and co-ordination
- Develop and maintain human resource skills across relevant disciplines
- Develop and maintain efficient physical infrastructure to facilitate the supply of forest products and services and support forest management
- Enforce laws, regulations and guidelines

Extent to which the **economic framework** (economic policies and measures) supports the conservation and sustainable management of forests through:

- Investment and taxation policies and a regulatory environment which recognise the long-term nature of investments and permit the flow of capital in and out of the forest sector in response to market signals, non-market economic valuations, and public policy decisions in order to meet long-term demands for forest products and services
- Non-discriminatory trade policies for forest products

Capacity to **measure and monitor** changes in the conservation and sustainable management of forests, including:

- Availability and extent of up-to-date data, statistics and other information important to measuring or describing indicators associated with criteria 1–7
- Scope, frequency and statistical reliability of forest inventories, assessments, monitoring and other relevant information

Compatibility with **other countries in measuring**, monitoring and reporting on indicators.

Capacity to conduct and apply **research and development** aimed at improving forest management and delivery of forest goods and services, including:

- Sevelopment of scientific understanding of forest ecosystem characteristics and functions
- Development of methodologies to measure and integrate environmental and social costs and benefits into markets and public policies, and to reflect forest related resource depletion or replenishment in national accounting systems
- New technologies and the capacity to assess the socio-economic consequences associated with the introduction of new technologies
- Enhancement of ability to predict impacts of human intervention on forests
- Ability to predict impacts on forests of possible climate change.

Appendix 8

INDICATORS REQUIRED BY THE FRA2000

Core indicators

Area of forest
Areas of other wooded land
Area of forest by naturalness
Area of forest plantations by categories of species
Forest areas converted to other uses
Total forest biomass above ground
Total carbon stock in forests
Total volume of growing stock
Changes over time of total volume of growing stock
Changes over time of total forest biomass
Changes over time of total carbon stock
Area of forest and other wooded land available for wood production
Area of forest by ownership
Area of forest in protected areas
Area of forest and other woodland burned annually
Biomass of forest types (broadleaf and coniferous)
Quantity and/or total value of harvested non-wood goods and services

Indicators for which assessment should be 'attempted' or partially made

Fragmentation of forests
Area of forest and other wooded lands managed primarily for soil protection
Change in defoliation over past 5 years (if not FRA 2000, then later)
Area of forest and other wooded lands managed primarily for tourism and amenity
Area of forest and other wooded lands managed primarily for water protection
Maintenance of cultural, social and spiritual values

Appendix 9

LAND USE AND FOREST CHANGES THAT REQUIRE REPORTING UNDER THE IPCC

Changes in forest and other woody biomass stocks	Emissions and removals of CO_2 from decreases or increases in biomass stocks due to forest management, logging, fuelwood collection, etc. The category is either a net source if biomass harvest/ destruction exceeds regrowth in the inventory year, or a net sink if regrowth exceeds harvest/ destruction.
Forest and grassland conversion	This category includes conversion of existing forests and natural grasslands to other land uses. Emissions of CO_2 CH_4, CO, N_2O, NO_x and NMVOCs from the burning and decay of biomass.
Abandonment of managed lands	Removal of CO_2 from the abandonment of formerly managed lands (e.g. croplands and pastures). This category includes conversion of managed to abandoned lands. The type of biomass that regrows on the abandoned land determines the categories below.
CO_2 emissions and removals from soil	Emissions and removals of CO_2 in soil associated with land-use change and management. Includes CO_2 emissions from liming of agricultural soil.
Other	Emissions and removals (sources and sinks) of CO_2 from land use or land-use change activities which can not be included under the categories provided above. Emissions of NMVOCs from the living trees in managed forests and N_2O or CH_4 emissions/removals from the soil of managed forests are reported here. Managed forests include all trees planted or managed by man for profit, pleasure, wind or water-erosion protection, etc.