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Future directions for biodiversity conservation in managed forests: indicator species, impact studies and monitoring programs

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Abstract

The validity and use of the indicator species concept, the design of logging impact studies, the need for long-term monitoring programs and how they might be designed, and, trade-offs between conservation strategies and economic costs are topics critical to the future direction of biological conservation in managed forests. The indicator species concept can make an important contribution to biodiversity conservation because of the impossibility of monitoring all taxa in species-rich forest environments. However, the concept has yet to be rigourously tested by validating relationships between an indicator species and entities for which it is hypothesized to be indicative. There can be serious negative consequences if the indicator species concept is incorrectly applied or inappropriate species are selected as indicators. Long-term monitoring will be critical for assessing not only the validity of concepts like indicator species, but also for appraising other rarely tested approaches to conservation in managed forests such as: (1) stand level management strategies to create and maintain key structural and floristic attributes that form critical habitat components for wildlife (e.g. large living and dead trees), (2) landscape level strategies to ensure the maintenance of landscape heterogeneity and connectivity, such as the establishment of networks of riparian protection zones and wildlife corridors, and, (3) landscape and regional level management involving the identification of reserves. While the importance of monitoring is often discussed, more programs are needed to gather the data needed to inform the development of ecologically sustainable forest management practices. Treating forestry activities as an experiment and overlaying well-designed monitoring programs on such disturbance regimes is one useful way to accumulate key information on the effects of logging on biodiversity and how to mitigate such impacts. However, some major changes will be needed to instigate greater commitment to monitoring programs. These include: (1) identifying innovative ways to secure long-term funding that can be guaranteed beyond typical political and institutional timeframes, (2) education of funding bodies to ensure they recognise that useful results may take a prolonged period to obtain and that monitoring is not a second-rate science, (3) greater participation in the design and execution of monitoring programs by the scientific community, and, (4) stronger links among researchers and between researchers and managers to both improve the quality and validity of monitoring studies and to ensure that the results of such programs are incorporated into management practices. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Forests are species-rich ecosystems supporting a wide array of taxa from numerous groups ranging from birds (Gill, 1995) and canopy arthropods (Recher

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et al., 1996) to soil microbes (Torsvik et al., 1990). The long-term maintenance of such biological diversity represents a major management challenge in forests also designated for other uses like timber and pulpwood production (Franklin, 1993). This paper is based on the closing address delivered at a conference in Uppsala, Sweden in 1997 and it briefly addresses a number of key issues are briefly critical for informing the way forward for conserving biodiversity in managed forests. These issues include: (1) the validity and reliability of the indicator species concept and its potential value for forest conservation and management, (2) studies of the impacts of logging on biodiversity and possible problems associated with some investigations completed to date, and, (3) the key role of monitoring in achieving long-term ecological sustainability. The topics chosen are far from a comprehensive list. Nor are discussions of each topic extensive or thorough; rather, they are short and designed to promote further critical thought and debate about approaches to the conservation of biodiversity in production forests. Finally, many of the key points made are supported with case examples from studies of Australian fauna. However, it is likely that most of the major conclusions drawn in the paper will be relevant to plants and other organisms in forested regions elsewhere in the world.

2. Indicator species

The concept and use of indicators, particularly indicator species, has received increasing attention for application in ecologically sustainable forest management (e.g. Landres et al., 1988; Noss, 1990; McKenney et al., 1994). The concept is potentially important given the impossibility of managing the huge array of taxa that inhabit forest ecosystems (Margules and Lindenmayer, 1996). Consequently, numerous major international and national forest management organisations are developing criteria and indicators for sustainable forestry practices (Arborvitae, 1995). However, the potential widespread use of the indicator species approach as part of these criteria warrants careful scrutiny because major negative effects could arise if it is inappropriately applied.

The appropriate use of the indicator species concept requires explicit statements of what a given species is meant to indicate. For example, is a particular indicator species indicative of the presence of a large number of other taxa, or the abundance of certain rare organisms of management concern, or some key attribute of a stand or landscape (Lindenmayer and Cunningham, 1997)? This is especially important when designing studies to assess the robustness and reliability of a given species as an indicator of some other entity.

2.1. Testing the indicator species concept

The notion that a given taxon is an indicator species for some other biological entity must be regarded as a hypothesis until it has been rigourously assessed. Such tests must involve establishing both the statistical relationships and the causal and functional linkages between an indicator and the entities for which it is considered to be indicative. This procedure helps identify both the conditions where an indicator does and does not work, and the types and numbers of ecosystem attributes that need to be created and/or conserved. Establishing these types of relationships will not be a trivial task, but failing to test them may cause severe problems. For example, in Australia, the freshwater mollusc, *Velesunio ambiguus* Phillipi was considered to be an indicator species for the presence of heavy metals in the Murray River (Walker, 1981). Subsequent work revealed that the species accumulated heavy metals at a level disproportionate to that characteristic of the surrounding aquatic environment (Millington and Walker, 1983; Maher and Norris, 1990). Hence, careful studies demonstrated from a statistical, casual and functional perspective that *V.ambiguus* had limited potential as a indicator for other key ecosystem properties (Burgman and Lindenmayer, 1998). Failure to rigourously appraise and then subsequently reject *V.ambiguus* as an indicator species could have had serious negative consequences for the management of Australia's largest freshwater river system.

Similar types of studies should accompany the recommendation of the adoption of any taxon as an indicator species in forest ecosystems. Indeed, this must become a major new area of research given the present emphasis on the use of indicator species for sustainable forest management (Arborvitae, 1995). Other related types of concepts like umbrella and keystone species should be examined in a similar way and also become focal topics for future research. Some of these types of studies have already commenced but many more are needed. Notably, such efforts will contribute valuable new information about forest ecosystems even if the particular species targeted for study does not prove to be a reliable indicator of other taxa.

2.2. Potential limitations of the indicator species concept

Part of testing the indicator species concept might involve examining patterns of co-occurrence between an indicator species and the assemblage of taxa for which it is hypothesized to be indicative (e.g. Lindenmayer and Cunningham, 1997). However, it is unlikely that there will be complete overlap in the broad distributions of both an indicator species and the full suite of taxa for which it is considered to be indicative. Thus, it is important to develop an understanding of both: (1) the location of those places where an indicator species will be operative and those where it will not, and, (2) the spatial and temporal scales for which the indicator species will be suitable if there are marked differences in the mobility of taxa in such assemblages (like plants and flying insects or birds). For example, problems may arise at spatial and temporal scales where phenomena like the dynamics of metapopulations (*sensu* Hanski, 1991) of indicator species are important. Metapopulation theory suggests that localised extinctions result in suitable habitat patches remaining temporarily unoccupied (van Dorp and Opdam, 1987; Hanski, 1994) although such areas will be important for the long-term persistence of an indicator species. When the indicator species is absent from particular patches, populations of associated taxa may nevertheless survive in these same patches. These and other factors might make the interpretation of conditions where there is a lack of species co-occurrence difficult and/or weaken linkages between an indicator species and associated taxa. For example, in circumstances where there is rapid and extensive species turnover (e.g. Margules et al., 1994), the selection of an indicator species would be virtually impossible.

Different species in an assemblage thought to be associated with an indicator species may respond differently to disturbance, even when they are closely related or appear to be functionally similar. For example, of five sympatric, closely-related and morphologically similar species of rainforest birds studied by Thiollay (1992), one declined markedly, another substantially increased, and three were moderately influenced by the same type of human perturbation (selective logging). Thus, an understanding of the response of any single species would not have provided a reliable prediction of the response of all the others, despite the group comprising just a few apparently very similar species. Equivalent results have been recorded from studies of a range of groups including arboreal marsupials (Lindenmayer and Cunningham, 1997) and carabid beetles (Davies, 1993; Niemela et al., 1993; Margules et al., 1995). Indeed, from an evolutionary perspective, it should be expected that functionally similar or closely related taxa will have developed strategies that allow them to co-exist. Therefore, different responses to processes like human disturbance also should be expected.

3. Impact studies

Franklin (1993) and Franklin et al. (1996) have outlined the array of important reasons for managing off-reserve forests (i.e. the 'matrix') for the conservation of biodiversity. Identification of those key attributes of stands and landscapes that need to be retained as part of off-reserve management can, in part, be determined from studies of the impacts of logging, both on stand structure and on forest biota associated with such structural elements (e.g. Lindenmayer, 1994). However, a number of factors can complicate studies of harvesting impacts and they need to be considered as part of such investigations. Some of these are outlined briefly below.

3.1. Narrowly focussed studies on logged vs. unlogged forests

Studies that have a narrow focus on only the simple contrasts between logged and unlogged forests can produce either misleading results or outcomes of limited value for enhanced forest management. Many logged forests contain structural components remaining from the previous uncut stand. For example, some areas of recently harvested forest in south-eastern Australia support large diameter living and dead trees that were left uncut at the time the stand was logged. Hence, these trees have their origins with earlier stands and not the present one. These trees may enable some species dependent on large trees to survive in a younger logged forest (e.g. Lindenmayer et al., 1991a; Kavanagh and Turner, 1994). The persistence of these groups of animals in harvested forests has led some authors to conclude that there are only very limited effects of logging on wildlife (e.g. Florence, 1989). However, in these cases, the response of some species was more of a reflection of forest structure than simply whether the stand had been logged or not. For example, studies in the Central Highlands of Victoria identified strong relationships between the availability of large trees with hollows and the abundance of a range of cavity-dependent species of arboreal marsupials (Lindenmayer et al., 1991a, 1994). Statistical models from these studies did not contain a variable for harvesting history per se as the parameter describing the availability of large trees with hollows provided a better fit to field data. However, other studies in these forests showed highly significant differences between the abundance of trees with hollows in logged and unlogged areas (Lindenmayer et al., 1991b). Sites with a limited number of large trees support few, if any, arboreal marsupials and these areas are typically those that have been intensively logged (Lindenmayer et al., 1991a). Moreover, successive harvesting events were predicted to result in the further depletion in the availability of important residual legacies that derived from the original unlogged stand (Lindenmayer et al., 1991b). Thus, there may be cumulative long-term effects of logging and the response of species after the first cut may be different from that following successive ones.

In summary, simple comparisons of logged and unlogged areas in the forests of south-eastern Australia would not have revealed the underlying factors governing patterns of the abundance of arboreal marsupials. Nor would they have revealed either: (1) potential problems associated with cumulative long-term impacts of timber harvesting on stand structure, or, (2) the types of structures that should be the target of management to facilitate the persistence and re-invasion of cutover areas by wildlife. Given this, impact studies may be particularly insightful and robust if they are underpinned by an understanding of, or produce new information on, the relationships between stand attributes and the distribution and abundance of target taxa. These relationships could then be coupled with studies of the changes in such stand characteristics resulting from forest cutting and help inform contrasts between logged and unlogged stands with respect to the prevalence of both structural attributes and the associated flora and fauna.

3.2. Statistical power and cumulative effects

Studies of logging effects are often relatively short term and/or focussed on few sites. As a result they may lack sufficient statistical power to detect impacts that may be taking place. Thus, results showing an absence of impacts may simply be a reflection of the lack of ability to detect such effects, rather than a true absence of impacts. This has been a major criticism of several studies of harvesting impacts in parts of south-eastern Australia (Gruen et al., 1989). Power analyses prior to the instigation of field studies can be useful to calculate the intensity of sampling required to be confident that effects can be detected if they are taking place (Burgman and Lindenmayer, 1998).

Additive or synergistic impacts that lead to cumulative effects (*sensu* McComb et al., 1991; Forman, 1996) of timber harvesting on forest biota may be difficult identify even with well-designed, powerful studies. For example, long-term changes in stand architecture that result from the loss and depletion of those structural legacies derived from original uncut stands (see above) may remain undetected within the time-frames typically employed in impact studies. However, the ability to detect responses to disturbance may vary depending on the assemblages targeted for study. For example, some short-lived taxa (e.g. univoltine insects) may show a rapid response to disturbance (Niemela et al., 1993).

Cumulative effects at a landscape scale may also be extremely difficult to detect. For example, species that persist in forest landscapes during a given harvesting rotation may disappear during a subsequent one if key refugia are destroyed and sources of colonists to re-invade logged and regenerated areas are eliminated (Crome, 1985). Indeed, these types of impacts may be very difficult to predict and hard to identify with traditional forms of landscape analysis and metapopulation models.

Cumulative effects could be particularly important in locations that have experienced only a relatively short history of human perturbation such as western North America and Australia. These types of potential responses mean that we need to be wary of over-confidence in our ability to ensure the conservation of some taxa in the long term (Niemela et al., 1993). Thus, the present existence of a species may not be a good indicator of its future persistence (Lindenmayer, 1995). Indeed, extinctions may occur a prolonged period after disturbance has occurred (even if such perturbations are halted), leading to what Tilman et al. (1994) termed an 'extinction debt.'

3.3. Confounding between characteristics of logged and unlogged sites

The interpretation of logging impact studies needs to be guided by potential problems created by confounding between human disturbance regimes and the characteristics of locations where such perturbations typically do and do not occur. In many parts of the world, areas where logging has not taken place (and often used as uncut comparator sites in impact studies) will be those parts of the landscape not useful for production (like stands on steep terrain). However, inherent differences between the suitability of flat productive and steep unproductive areas for fauna may complicate the interpretation of impact studies. For example, field studies in south-eastern Australia show negative relationships between steep terrain and the presence and abundance of several species of arboreal marsupials (Lindenmayer et al., 1991a, 1998). Thus, conclusions about limited impacts of timber harvesting on organisms may not be valid if productive logged areas are compared with unlogged low productivity areas. In these cases, matching potentially important features of site quality in logged and unlogged areas (like slope and elevation) will be important. Uncut high productivity places may not exist in landscapes with a prolonged history of intensive human use such as many parts of Europe. These situations will require a very careful appraisal of field results. Well-designed experimental approaches such as BACI (before–after-control-impact) designs (Underwood, 1995) can help overcome some of these types of potential problems.

3.4. Validity of the response variable for study

The response variable for analysis in many studies of logging impacts has been the number of species. Unfortunately, the notion of species diversity has often been applied in the sense that 'more species are better' and maximum species-richness is the most important resource management goal (e.g. Attiwill, 1994). However, the scale at which the concept of maximum species diversity should be employed needs to be carefully considered (see Murphy, 1989; Gilmore, 1990). For example, in some forest environments, maximum species diversity may occur at a local scale following timber harvesting because of invasions by birds and other species more typically associated with open vegetation-types (e.g. Shields and Kavanagh, 1985; Niemela et al., 1993; Kaila et al., 1997). Although a higher number of species might occur under such a management regime, wildlife that depend on intact forest ecosystems may be eliminated from such modified ecosystems. Indeed, species-richness at a broader scale (e.g. across entire forest landscapes) may be reduced as taxa sensitive to logging operations are lost (Noss and Cooperrider, 1994).

Finally, the use of species diversity as a measure of impact may mask important changes among assemblages. For example, Bennett (1990) found no changes in the overall diversity of mammal taxa between an intact forest landscape in western Victoria (south-eastern Australia) and the same highly fragmented landscape following more than a century of intensive human disturbance. However, a suite of native mammals was lost and had been replaced by an array of exotic vertebrate pests (Bennett, 1990).

4. Monitoring

The importance of monitoring has been stressed by researchers and managers for years (e.g. Noss and Cooperrider, 1994) and several books have been published on the subject (e.g. Goldsmith, 1991). Despite this, few effective long-term forest-monitoring programs have been instigated. Yet, long-term monitoring will be pivotal to testing many concepts associated with attempts to conserve biodiversity in managed forests, ranging from the validity of the indicator species concept to the efficacy of logging mitigation strategies like retaining vegetation structure (Gibbons and Lindenmayer, 1996) and establishing wildlife corridors (Hobbs, 1992; Rosenberg et al., 1997).

Long-term financial, political, institutional, logistic and intellectual commitment will be integral to the success of monitoring programs. This will require the development of novel and innovative ways to design and support monitoring to ensure that such programs: (1) receive sufficient funding and support to make them effective and scientifically valid, (2) continue to be supported even though prolonged periods may elapse before useful results are generated, (3) can persist substantially longer than the short time frames which characterise political and institutional agendas, (4) are acknowledged as important by granting bodies and researchers and, as a result, attract sustained input from the scientific fraternity, and, (5) are characterised by extensive dialogue among scientists and between scientists and managers to facilitate the adoption of new findings into modified forest management regimes. In addition, a key aspect of well-designed monitoring programs will be to ensure that they are well focussed with a limited number of entities being studied. This is because statistically robust information for a few well-monitored taxa is a far better outcome than a wide array of species examined poorly.

Forest harvesting is not going to cease while monitoring studies are being developed and their results assessed. Given this, one way to implement monitoring programs in managed forests would be to overlay carefully designed monitoring 'experiments' on existing human disturbance regimes (see Walters and Holling, 1990). Thus, forest harvesting would be treated as a quasi-experiment (*sensu* Dunning et al., 1995) in which data would be gathered on the response of biota to logging effects and the efficacy of strategies for impact mitigation tested. For example, the value of retained vegetation in the landscape matrix (like large living or 'green' trees) for biodiversity conservation would become a hypothesis tested by subsequent monitoring. Such an approach has been suggested as part of the studies to determine the number, type and spacing of trees with hollows that need to be retained for the conservation of cavity-dependent fauna in Australian managed forests (Gibbons and Lindenmayer, 1996). Murphy and Noon (1992) further outline approaches to the integration of hypothesis development and testing, the examination of ecological principles and field-based disturbance studies.

Integrated disturbance-monitoring experiments would be underpinned by several principles (after Margules and Lindenmayer, 1996):

1. The way the forest is logged should be varied to provide a range of stand or landscape conditions to monitor the response of target taxa. This is because the application of the same prescription for timber harvesting provides only limited information on the response of forest biota to disturbance and impact mitigation strategies. Therefore, a proportion of sites might be clearfelled, some subjected to shelterwood harvesting, and others to the retention of vegetation in a clump. In addition, novel types of silviculture might be required to produce the types of stand conditions and structural components needed to conserve some elements of biodiversity (Lindenmayer and Franklin, 1997). Varying the cutting regimes has other potential benefits including: (a) reducing the risk of homogenising landscape patterns, and (b) creating the types of stand conditions that future managers might identify as optimal; an important consideration as strategies presently thought to be best will undoubtedly change in the future given new information on forest ecosystems.
2. Reserves and/or areas of unlogged forest will be critical as pseudo 'controls' (*sensu* BACI experiments – see Underwood, 1995) or reference areas (Margules, 1992) in which human disturbance does not take place. Care will need to be taken to ensure matching of environmental conditions (like climate and terrain) that may influence species distributions between treated and untreated sites (see above). These reference areas would then be compared with sites subject to different harvesting regimes.
3. Information must be carefully documented on the way each site was logged, what structures were retained (e.g. the number and position of retained trees) and the location of matched reference areas. This is because monitoring must be long-term to be effective and those responsible for instigating a

program are unlikely to be involved 10–50 years later. Moreover, data on the history of a site may well explain future patterns of species occurrence like those taxa dependent on structures that take a prolonged period to develop (e.g. old trees or highly decayed logs).

4. There must be close links among scientists as well as between scientists and forest managers. This is critical to highlight the range of the types of stand conditions that need (and are feasible) to be created by logging, the number of replicates of each 'treatment,' and where sites will be located. Strong links between scientists and forest managers are critical for other reasons. For example, they will facilitate the adoption of results from field studies into forestry practices thereby closing the feedback and implementation loop in a truly adaptive management (*sensu* Holling, 1978; Walters and Holling, 1990) approach to forestry. Such linkages could be facilitated by the development of specific sections within forest management agencies to facilitate the transfer and adoption of new research findings and technologies. The Canadian Forest Service has such a facility and it could be a useful model for other organisations.

Monitoring-by-experiment studies will take time to generate results that are meaningful for applied forest management. However, considerable useful information could be gleaned relatively quickly from retrospective studies designed using some of the criteria listed above and which aim to examine sites logged in the past. The value of such retrospective studies is dependent on the availability of good data on the history of past disturbance in managed stands. In these cases, sites cut with new types of silvicultural practices may need to be added to monitoring experiments to expand the range of conditions being tested.

5. Types of future research

Enhanced conservation of biodiversity in production forests will be underpinned by new knowledge to guide better informed decision making. Such information must come from different types of investigations ranging to true field experiments to observational studies and simulation modelling.

Designed field experiments are rare in forest research (although see Lovejoy et al., 1986; Margules, 1992; Schmiegelow and Hannon, 1993) and some have examined the effects of different timber harvesting regimes like the Demonstration of Ecosystem Management Options (DEMO) in the Pacific Northwest of the US, the Silvicultural Systems Project (SSP) in southern Australia (Squire et al., 1987) and the Montane Alternative Silvicultural Systems (MASS) experiment on Vancouver Island in Canada (Phillips, 1996). Clearly, more are urgently needed. However, while field experiments can provide valuable information they also may have a number of limitations. Two of these include:

1. They are expensive and may need to run for prolonged periods; typically longer than political, institutional and funding cycles. This makes them vulnerable to budget cuts and termination prior to the production of key results.
2. Experiments often require many potential sources of influence to be controlled, thus limiting the number of treatment effects being tested. As a result, the findings from some experiments (e.g. Tilman et al., 1994) may have limited generality for extrapolation to other systems or problems on larger scales (see McCarthy et al., 1997).

Thus, other types of studies must make an important contribution to informing ecologically sustainable forest management. For example, Dunning et al. (1995) highlighted the value of 'quasi experiments' in which a rigourous experimental design is employed to take advantage of existing landscape characteristics. This approach has recently been applied in studies of spatial context effects on vertebrates in forest landscapes in south-eastern Australia (Lindenmayer et al., 1998). Haila (1988) described the value of 'analytical descriptions' in which ecological phenomena are systematically described and related to key underpinning ecological theory and assumptions. Other types of research techniques will also be important including observational and retrospective studies (e.g. Recher et al., 1987) as well as modelling (e.g. Lamberson et al., 1994). Modelling will have greatest use if it is underpinned by sound ecological data (Burgman et al., 1993), otherwise outcomes of limited generic value and management applicability may be generated (e.g. Tilman et al., 1994; see critique by McCarthy et al., 1997).

In summary, it is intuitively obvious that there are strengths and limitations of the various scientific approaches needed to generate the sorts of information required to guide ecologically sustainable management of forest ecosystems. All approaches have something to contribute; the key is to identify the method or combination of methods likely to give the best outcomes for a particular problem.

6. Tensions between economics and conservation

Managing production forests so that they have greater value for biodiversity has associated costs. Restoring the structural and floristic complexity of managed forests could require more complicated pre-logging survey and planning: factors that can add to the costs of production in the short-term, although long-term losses of forest productivity through the failure to maintain key ecosystem processes may have significant long-term economic costs (Pimental et al., 1992). For example, results from the MASS project in western Canada found that the costs of patch and shelterwood logging were 10–38% more expensive than traditional clearfelling methods (Phillips, 1996). Moreover, strategies such as the retention of clumps of living trees may retard rates of regrowth on cutover sites (Incoll, 1979) and, in turn, reduce yields of timber and pulpwood.

Silvicultural practices that are more sensitive to the needs of nature conservation will require a change in the general philosophy associated with cutting regimes from simply growing and cutting crops of trees to the creation and perpetuation of key components of stand structure and plant species composition (e.g. large, old hollow-bearing trees and intact thickets of understorey vegetation) (Lindenmayer and Franklin, 1997). Thus, there will be trade offs between the costs of production and the benefits for biodiversity conservation; tensions that may warrant exploration using integrated economic and ecological modelling tools (e.g. Hyde, 1989; McKenney and Lindenmayer, 1994). Indeed, there may be some instances where the best outcome for conservation may be intensive plantation forestry in a given area in return for enhanced stand retention strategies in another. However, areas targeted for intensive 'cropping' of trees would need to be selected very carefully to ensure that future options for conservation management were not foreclosed and/or key components of biodiversity lost. This is further complicated by findings in some forest-types that those flat, high productivity areas potentially best-suited for intensive plantation management are also important for biodiversity conservation (e.g. Braithwaite, 1984). Finally, the long-term productivity of forests may be dependent on the maintenance of some key components of biodiversity such as taxa involved in nutrient cycling or pollination. Thus, highly intensive forestry in a given area may jeopardise long-term sustained productivity.

7. Conclusions

The increasing world population will place increasing demands on forest resources. This, coupled with new information highlighting the diversity of forest ecosystems, means that the achievement of long-term ecological sustainability will be a complex and difficult task. Despite this, ecologically sustainable forest management must be underpinned by good science and it must operate using sound scientific principles (Murphy and Noon, 1992). Thus, hypotheses and concepts like indicator species must be rigourously tested using experiments and other forms of study including long-term monitoring programs. The results of these investigations must then be communicated to, and adopted by, forest managers, an exchange that can only occur if close linkages are established between research and management. This may require changes in the philosophies and approaches typically embraced by managers and forest researchers. However, such changes should not be perceived as a threat by both groups, but rather as a necessary challenge that will be an inherent part of conserving biological diversity in managed forests.

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