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Editorial

Understory and epiphytic vegetation as indicators of the ecological integrity of managed forests: a synthesis of the special issue

Understory and epiphytic plants have long been used in forestry as bioindicators for evaluating site quality (Cajander, 1926; Klinka et al., 1989) and in the environmental sciences for monitoring air, soil and water pollution (Gilbert, 1968; Skye, 1979; Kovalchuk et al., 1998). In the 1990s, interest by scientists and managers in the so-called ‘‘minor vegetation’’ grew exponentially as an outcome of a series of international initiatives, including the Helsinki Process (1990), the United Nations Convention on Biological Diversity (1992), the Montreal Protocol (1994) and the Santiago Declaration (1995), that set out formal requirements for developing comprehensive criteria and indicators to monitor the state of the world’s forests and the sustainability of forest management practices. In the intervening years, many advances have been made in scientific understanding of how biological indicators can be used at stand, landscape, regional and larger scales to monitor short and long-term environmental change and the impacts of forest management on biodiversity and ecosystem function.

The seven papers in this special feature are drawn from oral and poster presentations of an Organized Session at the 2005 joint meeting of the Ecological Society of America (ESA) and the International Association for Ecology (INTECOL) in Montréal, Québec. The session included presentations by plant ecologists from North America and Western Europe. Its purpose was to synthesize advances, discuss challenges and issues, and present ongoing research into the use of understory and epiphytic plants as indicators of the ecological condition of managed forests and for detecting and predicting environmental change in forests.

Ecological integrity has been defined in various ways, but in managed forests it is most often assessed by departure from the condition of an unmanaged forest exposed to a natural disturbance regime (Haeussler and Kneeshaw, 2003). This departure can be in productivity, successional pathway, species composition, biodiversity, environmental condition (e.g., microclimatic, edaphic) or ecosystem function (e.g., hydrology, nutrient cycling, carbon fixation). The use of vegetation indicators relies upon an understanding of the relationship between the response of individual species, functional groups, or whole plant communities and these metrics of ecological integrity. We also need effective monitoring programs and rigorous research approaches in order to tease out these relationships within the context of constantly changing forest ecosystems. We summarize here the contribution of this collection of papers towards meeting these needs and further identify the highest priorities for future research (see Table 1).

Understory and epiphytic vegetation are defined in this special feature to include the full variety of vascular and non-vascular plant life forms that grow below or on forest canopy trees, including tree regeneration, tall and low shrubs, lianas, herbs, ferns, and epiphytic, epixylic and terricolous mosses, liverworts and lichens. Their use as indicators generally falls into one of three approaches: (1) single species indicators, (2) plant functional groups or guilds, and (3) whole plant communities. We have organized the seven papers according to this scheme, beginning with a study of a single indicator species, followed by two research articles addressing the use of particular plant functional groups, then two articles taking a whole plant community approach, and ending with two review papers that address broader issues in the use of vegetation indicators.

The first research article, by Coxson and Stevenson (2007), illustrates well how focused research on the autecology of a single indicator plant species contributes to overall understanding of forest ecological function and to the development of more sustainable forest management practices. Transplants of *Lobaria pulmonaria*, an epiphytic macrolichen widely recognized as an indicator of healthy, humid, old growth forest conditions, were grown under varying light levels within rainforests of British Columbia, Canada to help to predict how variable retention logging could alter ecological conditions for endangered cyanolichens. Autecological knowledge of *Lobaria pulmonaria* has grown rapidly in recent years as a result of multiscale research in FennoScandia, central Europe, eastern and western North America. Coxson and Stevenson’s work highlights two important questions themes related to the use of indicator species. First, can a common, readily studied species such as *Lobaria pulmonaria* serve as a surrogate for rarer, poorly understood and difficult-to-study species occupying

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Table 1
Some advances and research needs in the use of vegetation indicators to monitor forest ecological integrity

Advances	Example from this issue	Research needs
(1) Improved autecological knowledge of select indicator species to help predict response to forestry practices	*Lobaria pulmonaria*, Coxson and Stevenson (2007)	Trials in operational settings of varying climate and disturbance history to verify the response to treatments for indicator species of known autecological characteristics. Experiments and effectiveness monitoring to ensure that surrogates effectively conserve species at risk
(2) Use of reference areas and experimental controls to monitor background changes in indicator species abundance	Lianas, Allen et al. (2007)	Better integration of global, regional and local monitoring networks through data-sharing, linked geographic information systems, and cross-scale analysis
(3) Demonstrated links between forest ecosystem processes and understory plant response	Paludification and *Sphagnum* succession, Fenton and Bergeron (2007)	Determining whether short-term results reliably predict long-term processes
(4) Demonstration of vegetation response to silvicultural treatments by using operational-scale trials with fully replicated and randomized BACI designs	Vascular community response to variable retention harvesting in the EMEND project, Macdonald and Fenniak (2007)	Analysis of similarities and differences among bioindicator groups (birds, mammals, vascular plants, bryophytes, lichens, fungi, invertebrates). Design of comprehensive monitoring systems across a range of forest types and scales
(5) Identification of plant functional groups that respond consistently to gradients of forest disturbance severity	Summer-flowering hemicryptophytes vs. spring-flowering animal-dispersed geophytes, Gachet et al. (2007)	Developing and testing plant functional group classifications based on objectively defined life history criteria. Developing robust multi-metric indices of forest integrity
(6) Standardized frameworks and models for measuring and predicting plant response	Quantifying disturbance severity, Roberts (2004, 2007)	Meta-analyses of research studies. Predictive models of plant response
(7) Recognizing strengths and limitations of various plant groups for monitoring impacts of operational forestry practices	Bryophytes, Frego (2007)	Translating scientific knowledge into operational forest monitoring tools. Distinguishing between habitat and dispersal limitations to indicator plant abundance

similar ecological niches? Secondly, can results obtained in one forest region be applied to another region with different environmental conditions? In both cases, the answer appears to be ‘‘partly yes and partly no’’. Surrogacy and geographic transferability of results are cornerstones of a coarse-filter adaptive approach to sustaining biological diversity in managed forests. Improving knowledge about autecological properties of individual species and their ability to indicate changes in environmental conditions has contributed valuable tools for monitoring forest management. Yet the more our knowledge of individual species indicators grows, the more evident it becomes that each species and each geographic locale has unique characteristics. Thus, approaches will need to be tailored to local ecological conditions and local at-risk organisms.

In their study of liana abundance in protected floodplain forests of South Carolina, USA, Allen et al. (2007) show how plant indicators are used to monitor environmental change at an entirely different scale of investigation. While global declines in the abundance of amphibians have been widely publicized (Alford and Richards, 1999), it is less well known that lianas have increased in abundance in tropical forests around the world. Allen and his co-authors present new evidence that lianas may also be increasing in southern temperate forests. Both the liana and the amphibian examples illustrate the important role that bioindicators can play in alerting scientists and society to complex, poorly understood phenomena that likely result from the interplay of changes in climate, disturbance regimes and other habitat conditions. The study also highlights the important role that reference areas can play in monitoring background changes in forest condition that are not directly caused by forest management activities. Many contributors to the ESA/Intecol vegetation indicators session pointed out that constant turnover in understory plant species composition and abundance occurs even in undisturbed, apparently stable forests (see also Frego, 2007) and emphasized the importance of properly established controls or reference areas for monitoring change at all scales of forest management.

Fenton and Bergeron (2007) selected another a *priori* plant functional group, the *Sphagnum* peat mosses, as a bioindicator of changes in forest ecosystem function. Their study is an excellent demonstration of how shifts in understory vegetation composition can be used to monitor a change in the forest environment – in this case, forest paludification – that may be difficult to detect in its early stages through direct environmental measurement and could take much longer to be expressed through the composition and growth of canopy trees. Fenton and Bergeron use to full advantage the unique niche preferences of each *Sphagnum* species to interpret how alternative harvesting practices alter the forest environment and to make an early assessment of the success of the experimental silvicultural treatments in meeting the objective of accelerating development towards old forest characteristics.

Macdonald and Fenniak (2007), working at the EMEND (Ecosystem Management Emulating Natural Disturbance) site in northern Alberta, found that responses of the vascular understory plant community to canopy composition were similar to the findings of researchers who studied epigaeic (forest floor-dwelling) invertebrates at the same study sites (Work et al., 2004). One important benefit of the growing world-wide network of large integrated forestry experiments such as EMEND will be the ability to make cross-system and cross-disciplinary comparisons. To date, the first results for single biotic groups from these integrated experimental projects are just beginning to be published. Early comparisons indicate that some significant generalizations are common to all organismal groups. For example, most biotic groups contain r-selected early seral specialists, mid-seral generalists with mixed regeneration modes, and K-selected late seral specialists that respond in broadly similar ways to variable retention harvesting. On the other hand, non-trivial differences between biotic groups usually reflect differences in the spatial and temporal scales at which organisms of different sizes, dispersal abilities and longevity respond to their environment and the specific components of the forest that they utilize (Jonsson and Jonsell, 1999; Dangerfield et al., 2003). Changes in richness and composition of vascular plants that root in the forest floor, for example, are likely to be poorly correlated with the response behaviour of invertebrates that live in decaying logs. There should, however, be a much better correlation between beetles and old forest lichens that both colonize hollow trees (e.g., Nilsson et al., 1995). We anticipate that a great deal more integrative, cross-disciplinary analysis will take place over the next decade to help refine how plants can best be used (or not) as surrogates for other biotic groups.

In contrast to the papers that precede them, Macdonald and Fenniak (2007) and Gachet et al. (2007) studied the entire vascular plant community and identified post hoc indicator species and groups that were most sensitive to particular stand conditions and treatments. Macdonald and Fenniak also used whole-community metrics such as alpha and beta diversity indices to contrast forest environments before and after the imposition of a range of forest harvesting treatments. Accumulating research evidence indicates that alpha diversity of vascular plants, despite being a popular and intuitive measure for assessing forest integrity in silvicultural experiments, is rather insensitive to the severity of forest disturbance as measured along the three axes proposed by Roberts (2004, 2007). Macdonald and Fenniak's research, like that of others, suggests that alpha diversity of vascular plant species should be used less often, and then only in combination with other metrics such as the relative abundance of particular plant functional groups and changes in beta diversity. Epiphytic lichens and liverworts, because they depend on live and dead tree substrates and are highly sensitive to microclimatic conditions, more consistently show a loss of alpha diversity in response to forest harvesting (e.g., Lesica et al., 1991; Ódor and Standovár, 2001; Fenton et al., 2003).

For vascular plants, multi-metric indices of forest integrity adapted from those employed in aquatic and wetland ecosystems (Karr, 1981; Mack, 2004) deserve further attention. This approach makes use of a complete gradient from severely degraded to pristine forest conditions and integrates metrics from a variety of plant functional groups that respond consistently across the gradient. Most forestry studies, particularly the silvicultural systems experiments described above, do not include such a broad gradient of disturbance severity (see Fig. 2 in Roberts, 2007). The study by Gachet et al. (2007), of vascular plant communty composition in plantation forests of north-western Quebec is an exception in including a gradient of forest disturbance ranging from agricultural fields, to afforested agricultural fields, reforested cutblocks and uncut mature forest. The study finds relatively minor differences between reforested cutblocks and mature forest, but substantial divergence in composition by plant functional groups between sites with and without an agricultural history. Their results illustrate how plant communities can potentially serve as long-term indicators of past disturbance history—even after the environmental conditions that induced the change may no longer be evident.

Roberts' (2007) overview paper provides a modelling framework for measuring herbaceous plant response to natural and anthropogenic disturbances. In doing so, he supplies a partial solution to the question of how to generalize plant responses across studies conducted in different geographic areas with varying treatment conditions. As illustrated by at least three of the papers in this issue (Fenton and Bergeron, 2007; Macdonald and Fenniak, 2007; Gachet et al., 2007), silvicultural treatment are typically ranked across a gradient of disturbance severity. Roberts' analytical framework sets the stage for a meta-analysis of understory plant response by providing a standardized approach to measuring disturbance severity. It can also potentially be used for ranking plant species and functional groups according to a ''disturbance sensitivity index'' (c.f. Fleishman et al., 2000, for butterflies). Along with improving predictability, such standardization is an important step in translating the results of scientific studies into operational monitoring tools for forest management.

The link between academic research and operational monitoring is also explored in Frego's (2007) review paper on the use of bryophytes as indicators of forest ecological integrity. Frego differentiates between the study of understory and epiphytic plants as objects of scientific interest in their own right (because they are important to forest function, or because they have intrinsic value) versus their use as field-based indicators to guide operational forest management. She concludes that although bryophytes are highly sensitive to forest practices, they are mostly unsuited for use as operational indicators because of the need for skilled taxonomists and the lack of fundamental ecological knowledge. Yet, fundamental and applied research on understory and epiphytic plants need not be carried out independently of one another as each can inform and improve the other. We conclude that plant ecologists will make a larger contribution to sustainable forest management and will benefit from greater appreciation of the value of their work by engaging with forestry practitioners during the planning stages of their research and by explicitly considering how the work can be adapted to meet operational monitoring needs.

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