Biodiversity Indicators for Sustainable Forestry: Simplifying Complexity

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ABSTRACT

Maintaining biodiversity is a primary goal of sustainable forestry. However, maintaining "life in all its forms" can be daunting to forest managers. "Biodiversity," as commonly defined, is simply too complex to measure or monitor. The only practical solution is to use indicators. In theory, good indicators are simple to measure and correlate with many other elements of biodiversity so *they* do not also have to be measured. All sustainable forestry programs use indicators; however, there is much confusion and frustration among forest managers and stakeholders about their usefulness. The primary limitation to selecting effective indicators has to do with process, not science. Here, we propose a framework for selecting biodiversity indictors that will better inform decisionmakers and stakeholders.

Keywords: biodiversity, indicators, sustainable forestry

All major sustainable forestry efforts explicitly state that conserving biodiversity is a fundamental goal (e.g., Sustainable Forestry Initiative [SFI; SFI 2004], Forest Stewardship Council [FSC; FSC US Standards Committee 2001], and Montreal Process [Montreal Process 1995]). However, the biodiversity element of sustainable forestry has been especially challenging to forestland owners, states, countries, and many other policy-making bodies. The challenge can seem overwhelming because biodiversity typically is defined as *life in all its forms, from the level of the gene, to species, to whole ecosystems, including all the processes that maintain these various levels* (Hunter 1996, 19). Although this definition is widely recognized by ecologists, it is of almost no practical value to managers. In most forests there are thousands of plant and animal species and countless possible species interactions. How is a forest manager supposed to maintain "life in all its forms?"

The only practical approach to assess biodiversity is to use indicators—a relatively few elements of the forest system (e.g., species, processes, and habitats) that correlate with as many other *unmeasured* elements of the system as possible. Despite the inherent appeal, practical necessity, and a prolific scientific community on the subject (e.g., Noss [1999] and Lindenmeyer et al. [2000]), the usefulness of indicators in sustainable forestry remains constrained by confusion and misunderstanding (Failing and Gregory 2003, Whitman and Hagan 2003). This confusion often has resulted in the selection and application of indicators that are not instructive for assessing biodiversity in sustainable forestry (Guynn et al. 2004), or it is not known *why* they are instructive. The following are some key reasons indicators have not been effective:

1. Different decisionmakers make decisions at different spatial and temporal scales. An indicator that might be appropriate at a large spatial scale (e.g., for a state or federal agency) *may or may not* be appropriate at the forest management unit level or the small woodlot level.
2. Different decisionmakers work in different biological, cultural, and socioeconomic settings. Indicators that work for one forest type and social situation may not be appropriate for another.
3. Often, an indicator is selected without considering what biodiversity values it is intended to indicate. For this reason, practitioners sometimes do not know *why* they are measuring some indicators.
4. Benchmarks or target levels are almost always lacking for indicators; therefore, once an indicator is measured, often, it is not clear what action needs to be taken, or if *any* action is needed.
5. Inherent conflicts often exist among indicators. Positive change in one indicator (wood production) can result in a negative change in another indicator (e.g., amount of late-successional forest). There can even be negative relationships between two biodiversity indicators (e.g., amount of early successional habitat versus amount of late-successional habitat).
6. Finally, indicators that landowners and managers select may be ineffective because the selection of indicators was not a socially inclusive, transparent process; therefore, efforts to achieve sustainable forestry are met with skepticism and suspicion by stakeholders. One reason sustainable forestry has emerged formally in recent years is to provide assurance to for-

Table 1. Some examples of biodiversity components encountered in indicator selection workshops throughout the US. There is no single "correct" set of components. Each group must decide for themselves how they wish to partition biodiversity into components that are meaningful.

Biodiversity component	Definition
Forest structure	The structural attributes of a forest (such as tree size, snags, fallen logs) that are important to many species.
Late-successional habitat	Forest ecosystem elements characteristic of forest older than typical rotation length.
Presettlement condition	Ecosystem conditions as they occurred before settlement by Europeans.
Early-successional habitat	Forest ecosystem elements characteristic of forest usually younger than 10 to 15 years old.
Range of natural variation	Ecosystem elements occur at levels with the range of natural variation, which is usually identified based on data from the presettlement period or old growth forests.
Aquatic & riparian habitat	Ecosystem elements related to wetlands and water bodies (streams, rivers, ponds, and lakes) including water quality, aquatic species and habitat, flood control, riparian species and habitats, and hydrology.
Game species	Vertebrate species (including fish) hunted for consumptive or recreational purposes.
Other harvestable species	Other nontimber species harvested for foods (nuts, fruits, fungi, etc.), medicinal purposes, fiber, decorative materials (moss, boughs, etc.), and flavoring.
Nongame species	Vertebrate species not hunted for consumptive or recreational purposes (e.g., watchable wildlife).
Species richness	The variety of native species occurring in a specific region.
Habitat diversity	The variety of natural habitats occurring in a specific region.
Ecosystem function	The productivity, soil characteristics, biogeochemical cycle, hydrologic cycle, and other processes associated with ecosystems.
Carbon cycle	Ecosystem elements related to carbon cycles and carbon sequestration.
Rare species and rare habitats	Rare species and rare habitats including rare species and habitats protected by law, and imperiled species and habitats.
Pest species	Species greatly detrimental to ecosystems (exotic and invasive species and species unusually abundant).
Landscape elements	Ecosystem elements occurring at large scales or strongly sensitive to ecosystems elements that occur at large scales (e.g., area-sensitive species).

est stakeholders that their values—social, economic, or environmental—are being maintained.

There is an immense volume of recent literature on ecological indicators (e.g., National Research Council [2000]) and sustainable forestry indicators (e.g., Franc et al. [2001] and papers therein, and Raison et al. [2001] and papers therein; Wright [2002]). Unfortunately, many good ideas are still relatively unorganized and a coherent framework for selecting biodiversity indicators does not yet exist, perhaps because of the still-young age of sustainable forestry as a social concept. Many mistakes are made in the selection of indicators, sometimes to the point that the indicators are even counterproductive (Failing and Gregory 2003). Because there is no generalized or standardized process for selecting indicators, decision-makers often end up with a "wildly mixed bag" of indicators (Duinker 2001) and it is not clear to anyone what values are being tracked or what decisions might be made with the information.

What is sorely needed is a simple but structured framework for the selection of biodiversity indicators that results in sensible indicators for the situation/location they are intended. We reviewed the scientific and policy literature to try and develop such a framework for the National Commission on Science for Sustainable Forestry (NCSSF 2005). Through a literature review, mail surveys of scientists and policymakers about indicators throughout the United States, and a series of workshops on how to select indicators, we have developed some unifying principles that we think can help improve the use of indicators in sustainable forestry. Although we focus on biodiversity indicators, the same principles are relevant to the selection of indicators for any value (e.g., economic or social).

Finding the Handle on "Life in All Its Forms"

As mentioned, the textbook definition of biodiversity in not very useful to decision-makers, except perhaps that it conveys the enormity of the task before them. It can be overwhelming to try to select indicators for something so large and so abstract. Therefore, the first step in selecting useful indicators is to break biodiversity down into components that are less abstract and more understandable and more meaningful to forest stakeholders and managers. Then, indicators can be selected and linked with these more-specific, concrete parts of biodiversity. A list of major biodiversity components that we have encountered in indicator selection workshops around the United States is shown in Table 1.

We recommend breaking biodiversity into 5–15 components that capture the major biodiversity values of the relevant forest stakeholder community. There is no single, correct set of biodiversity components, and the components will vary depending on the particular forest system and associated stakeholder community.

If biodiversity is broken into too many components the task of indicator selection again becomes overwhelming. The purpose of breaking biodiversity down into components is to identify, define, and organize forest stakeholders' key biodiversity values. Stakeholders therefore must be engaged in the process of identifying biodiversity components. As pointed out previously (in key reason 6), breaking biodiversity into components can be contentious if some stakeholders feel that an important aspect of biodiversity is not represented in the resulting set. A well-facilitated, thoughtful social process for including or excluding (or consolidating) biodiversity components is critical.

Types of Indicators

Different types of indicators convey different kinds of information about sustainability. One of the first indicator frameworks to be widely adapted and used was the Pressure-State-Response system (Friend and Rapport 1979, Adriaanse 1993). This fundamental system has been modified in many ways, but all derivations retain the ability to partition the current condition of the system from pressures (stressors) that affect the system. The three types of indicators are defined as follows:

- **Condition** (or state) indicators describe the current status, or condition, of a

Table 2. Examples of condition, pressure, and policy response indicators for two biodiversity components. Terms in boldface will need to be precisely defined before the indicators can be useful.

	Indicator Type		
Component	Condition	Pressure	Policy response
Late-successional forest	(1) Percent of area in **late-successional condition**, by **forest type**.	(1) Percent of landscape with rotation length shorter than **time required to develop late-successional characteristics** (negative pressure).	(1) Written policy for conservation and management of **late-successional forest**.
	(2) **Large-tree** (> *X*' dbh) density in **designated late-successional forest stands**, by **forest type**. (3) Percent of area in **late-successional reserves**.	(2) Percent of acres managed for timber with **late-successional retention practices applied** (positive pressure).	(2) Tax break for timberland in a **late-successional management regime**.
Habitat diversity	(1) Number (or percent) of **naturally occurring habitat types** that exist in each watershed, county, township, management unit (or whatever spatial unit is appropriate).	(1) Percent of area converted **from forest cover** to other **nonforest land** uses (e.g. development, mining, grazing).	(1) Written policy to maintain all **naturally occurring habitat types** within each watershed, county, township, management unit (or whatever spatial unit is appropriate).
	(2) Number of acres in each **forest type** and **age class**, within the spatial unit of interest.	(2) Percent of landscape with rotation length shorter than **time required to develop late-successional characteristics** (see also under Late-successional forest). (3) Number of acres restored to **natural fire regime**.	(2) "Conservation Reserve Program" that provides incentives for landowners to restore natural **habitats**.

resource (or biodiversity component, using our language).

- **Pressure** indicators represent the level of a pressure (positive or negative) that affects the condition of a resource (e.g., a force or action [usually human] that is causing the condition to degrade or to improve).
- **Policy response** indicators represent institutional plans or policies to maintain or improve the condition of a resource.

An example illustrates how the three types of indicators convey different information to a decisionmaker. Large-diameter snags are well known for their importance for biodiversity in many forest types. A *condition* indicator for large snags might be the density of large snags in the land unit of concern (e.g., ownership, county, state, or nation). This metric tells us about the status or condition of the resource at the present time and has units of measure (e.g., snags per hectare).

A *pressure* indicator provides insight into where the resource is headed in the future. A good pressure indicator might be harvest rotation length. If the present-day rotation length is too short to allow large-diameter snags to develop, then we can predict there will be fewer large-diameter snags in the future, *regardless* of the current density as indicated by the condition indicator. In this respect, condition indicators alone can be misleading—evidence of change in a condition indicator may come too late, whereas pressure indicators can provide early warning about a future change in a condition.

Finally, a *policy response* indicator might be the existence of a written management plan for snags. Condition and pressure indicators usually are expressed with units of measure (e.g., snags per acre, rotation length [years], or percent of stream miles restored). Often, policy response indicators have no units of measure (they are binary, e.g., "yes" or "no"). Some other examples of condition, pressure, and policy response indicators for two common biodiversity components are provided in Table 2.

It is easy to see why condition, pressure, and policy response indicators all would be useful in making management decisions; each type provides a different kind of information to the manager or decisionmaker that is not contained in the other two types. Interestingly, SFI (SFI 2004) and FSC (FSC US Standards Committee 2001) contain only policy response indicators; *there are no units of measure for current condition or pressure in any of the indicators in either system* (Table 3). The actual current condition of biodiversity (with units of measure) is not required to be reported as an indicator. Rather than reporting the amount of forest by forest type and age class (a condition indicator), landowners must show that they have a plan or policy for managing for forest types and age classes (a policy response indicator). Having a plan and measuring on-the-ground conditions are two very different things. By contrast, the Montreal Process biodiversity indicators (which emerged from the Santiago Declaration in Chile in 1995) are all condition indicators with units of measure; there are no policy response indicators (Table 3). The odd incongruity of these sets of prominent indicators helps fuel the confusion about indicators, how they are selected, and who they are supposed to inform.

Policy response indicators are important because they indicate an effort by forest managers to adjust their practices, through management plans and policies, to protect a particular value. Policy response indicators have accounted for huge changes in on-the-ground management for biodiversity in sustainable forestry. However, without condition indicators, and appropriate units of measure, it must be taken on faith that the policy responses are in fact protecting the biodiversity component of interest.

Ideally, each component of biodiversity would be supported by condition, pressure, and policy response indicators. A hierarchical framework that links the overarching concept of sustainable forestry, down through values, subvalues, and components, and, finally, indicators, helps to clarify what indicators are supposed to indicate and how they are supposed to support sustainable forestry (Figure 1).

Five Evaluation Criteria for Indicators

There are five characteristics to consider when evaluating candidate indicators for sustainable forestry:

Table 3. Biodiversity-related indicators from SFI, FSC, and the Montreal Process.

Indicator	Indicator type
SUSTAINABLE FORESTRY INITIATIVE (SFI 2005–2009)	
Program to promote the conservation of native biological diversity, including species, wildlife habitats, and ecological or natural community types, at stand and landscape levels.	Policy response
Program to protect threatened and endangered species.	Policy response
Plans to locate and protect known sites associated with viable occurrences of critically imperiled and imperiled species and communities. Plans for protection may be developed independently or collaboratively and may include Program Participant management, cooperation with other stakeholders, or use of easements, conservation land sales, exchanges, or other conservation strategies.	Policy response
Development and implementation of criteria, as guided by regionally appropriate science, for retention of stand-level wildlife habitat elements (e.g., snags, mast trees, down woody debris, den trees, nest trees).	Policy response
Assessment, conducted individually or collaboratively, of forest cover types and habitats at the individual ownership level and, where credible data are available, across the landscape, and incorporation of findings into planning and management activities, where practical and when consistent with management objectives. Natural fire where appropriate.	Policy response*
Support of and participation in plans or programs for the conservation of old-growth forests in the region of ownership.	Policy response
Participation in programs and demonstration of activities as appropriate to limit the introduction, impact, and spread of invasive exotic plants and animals that directly threaten or are likely to threaten native plant and animal communities.	Policy response
Program to incorporate the role of prescribed or natural fire where appropriate.	Policy response
Collection of information on critically imperiled and imperiled species and communities and other biodiversity-related data through forest inventory processes, mapping, or participation in external programs, such as NatureServe, state or provincial heritage programs, or other credible systems. Such participation may include providing nonproprietary scientific information, time, and assistance by staff, or in-kind or direct financial support.	Policy response
A methodology to incorporate research results and field applications of biodiversity and ecosystem research into forest management decisions.	Policy response
FOREST STEWARDSHIP COUNCIL (FSC)	
Indicator	Indicator type
Ecological functions and values shall be maintained intact, enhanced, or restored, including: a) forest regeneration and succession, b) genetic, species, and ecosystem diversity, c) natural cycles that affect the productivity of the forest ecosystem.	Policy response*
Management actions lead to a distribution of age classes, appropriate to the size of ownership, forest condition, management objectives, and local ecosystems.	Policy response*
Forest owners or managers maintain or restore a portion of the forest to the range and distribution of forest structures (including size and condition of trees) and species composition consistent with naturally occurring stand development patterns for the region.	Policy response*
Natural diversity is maintained and/or restored at the landscape level.	Policy response*
A diversity of habitats for native species is protected, maintained, and/or enhanced.	Policy response*
Unless exceptional circumstances can be documented, known areas of intact old-growth forests are designated as representative sample areas.	Policy response*
MONTREAL PROCESS	
Indicator	Indicator type
Extent of area by forest type relative to total forest area.	Condition
Extent of area by forest type and by age class or successional stage.	Condition
Extent of area by forest type in protected area categories as defined by IUCN or other classification systems.	Condition
Extent of areas by forest type in protected areas defined by age class or successional stage.	Condition
Fragmentation of forest types.	Condition
The number of forest-dependent species.	Condition
The status (threatened, rare, vulnerable, endangered, or extinct) of forest-dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment.	Condition
Number of forest-dependent species that occupy a small portion of their former range.	Condition
Population levels of representative species from diverse habitats monitored across their range.	Condition

* Because these indicators are not actual measurements of the resource, they are listed as policy response indicators. "Condition" and "Pressure" indicators could easily be generated for each of these policy response indicators.

1. **Scientific merit.** Good indicators will have strong scientific merit, i.e., there has been a well-established scientific relationship between the indicator and the biodiversity component of interest. One of the most commonly used indicators is the extent of area by forest type and by age class or successional stage (a Montreal Process condition indicator). It is well established in thousands of scientific articles that different species depend on different forest types and age classes. Therefore, this indicator has high scientific merit. However, science still can not inform us very well about *how much* of each forest type and age class is needed to successfully maintain biodiversity in any geographic unit. The same is true of standing and fallen deadwood; we know many species cannot survive without deadwood (i.e., strong science), but for most forest types we have a poor understanding of *how much* deadwood is needed to support this array of deadwood-dependent species (i.e., inadequate science).

It is important to distinguish between the scientific merit of an indicator versus the scientific merit of establishing a target level for an indicator. For the latter, scientific merit typically is still very weak. Setting targets (or goals) for indicators is more of a social question, i.e., "how

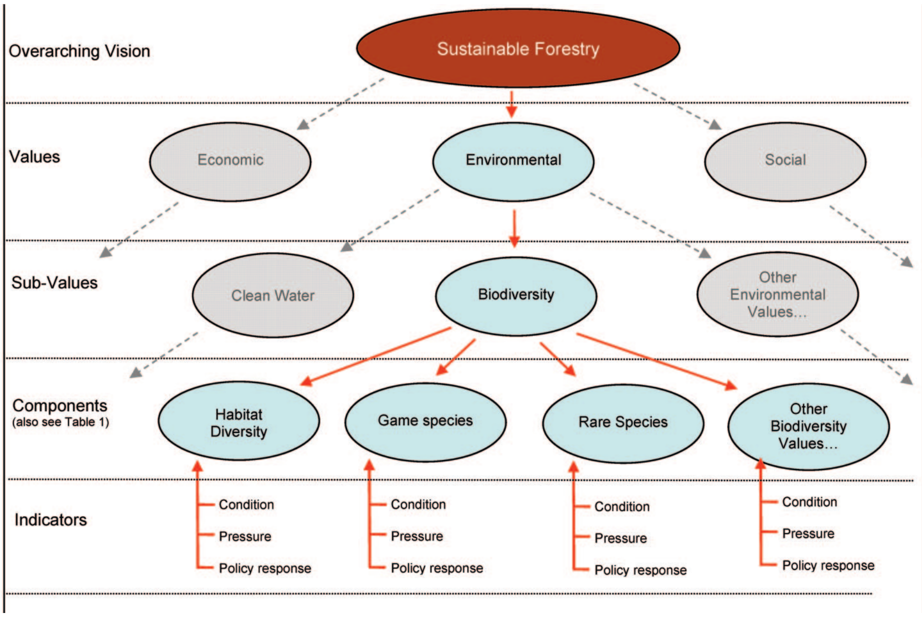

Figure 1. Hierarchical schematic of how indicators support sustainable forestry. The biodiversity branch of the hierarchy is highlighted for the purposes of this article. Indicators can be most effective when they provide information about clearly defined components that more precisely describe stakeholder interests and/or concerns (i.e., what they seek to sustain); "biodiversity" (at the subvalue level) is too broad (and too abstract) to identify useful indicators.

much do we want?" A more sophisticated approach to setting targets would be an assessment of risk (Margolis 1996); e.g., "if we set a target of 'X' (and met it), we would face a probability (risk) 'Y' of still losing the value." This more sophisticated risk-evaluation approach would lead to a much more powerful use of indictors. However, the level of scientific understanding needed to evaluate risk in this manner for biodiversity components usually is unavailable and costly to acquire.

2. **Ecological breadth.** An indicator has good *ecological breadth* when it correlates with many other biodiversity components that are not being measured. Indicators that have strong ecological breadth help reduce the overall number of indicators that are needed to inform decisionmaking about biodiversity. For example, the indicator "area and extent of forest by forest type and age class or successional stage" can provide useful information on nearly all components listed in Table 1, although by itself it is unlikely to adequately satisfy all stakeholder biodiversity interests. Another indicator with high ecological breadth is the density of large living trees ("large" defined by the forest type and informed by science in a region). Large living trees are good indicators of mature forest epiphytes (mosses and lichens), nesting habitat for raptors, and future large-diameter standing snag and fallen log density—aspects of biodiversity that generally are important to forest stakeholders. Once a list of biodiversity components has been established, the set of indicators that best represents the full suite of components of interest to stakeholders can be determined.
3. **Practicality.** Practicality refers to the ease and cost of measurement. An indicator is practical if it is not expensive to measure, does not require special skills to measure (e.g., a plant taxonomist or bryologist), does not require complicated analysis, or if it is already being measured and summarized within an existing data-collection system. Practicality usually trumps all other evaluation criteria because available funds for monitoring are limited. For example, if the cost of the indicator is too high, a high level of scientific merit is irrelevant.
4. **Utility.** Utility refers to the ability of the forest manager or policymaker to make a decision with the indicator. If the indicator measurement does not provide any guidance to the manager as it increases or decreases, then the indicator has low utility (e.g., the indicator cannot be used to make a decision). To have utility there must be some sense of what is a good level or a bad level for an indicator. Indicators have the most utility when target levels or goals have been set for a biodiversity component. If goals have been set, the indicator has high utility because it informs the forest decisionmakers whether the system is above or below the target or goal, and action can then be taken if warranted. Often, goals are not set in sustainable forestry because goal setting is so contentious among stakeholders and because science generally performs poorly for helping answer the question "how much is enough," especially when "enough for what and whom and where" has not been addressed.
5. **Relevance.** Relevance refers to how well an indicator represents the biodiversity values of forest stakeholders. The purpose of indicators is to inform forest stakeholders about whether forest sustainability is being achieved. Therefore, indicators must be linked to stakeholders' values. The best way to ensure high relevance is to involve key stakeholder representatives in the indicator selection process, preferably with leadership responsibilities.

Indicators rarely are evaluated for these criteria. Practicality is usually addressed by default; only indicators that can be afforded are selected. By parsing the various important qualities of indicators this way, however, participants better understand the tradeoffs of using different indicators. Even when cost is the number one constraint, this evaluation system can help select those with the best scientific merit, or those single indicators that cover the most biodiversity components, or the smallest set of indicators that most efficiently covers the desired suite of components. Indicator evaluation also provides transparency—stakeholders can better understand why certain indicators were selected and why others were not.

Integrating the Concepts

The foregoing concepts help organize the multidimensionality of sustainability indicators in a conceptual framework that is understandable and tractable to decisionmakers/managers and stakeholders. The challenge is to integrate these concepts into a structured, logical, transparent process for selecting indicators. Based on indicator se-

Box 1. A generalized stepwise process for selecting biodiversity indicators for sustainable forestry. These steps should be completed in a timely manner (e.g., 6 to 12 months) so as to avoid "stakeholder fatigue," whereby key stakeholders begin to drop out of the selection process due to lack of perceived progress.

Step 1. **Break biodiversity down into components (see Table 1 for examples) that are meaningful to forest stakeholders so that indicators can be selected to track those components.**

Recommended procedure: Engage a diverse group of stakeholders that is willing to commit to a 6–12 month process of indicator selection involving one or several meetings. Have the group review, edit, and amend the list of components provided in Table 1 (or start from scratch). Keep the number of components as low as possible to avoid producing long lists of indicators. Consolidate similar components into 1 component. Define each component so that it is clear what the biodiversity value is (and is not). Have the group rank each component for importance (e.g., low, medium, high). Select the top-scoring 5–15 components for indicator selection, and move to Step 2.

Cautions: Identification of biodiversity components strikes at the heart of sustainability. Components that do not emerge from this step may not be captured by indicators, and therefore may not be sustained. Component selection, in essence, identifies what values are to be sustained. It can be a contentious process and expert facilitation is usually needed.

Step 2. **For each biodiversity component, identify Condition, Pressure, and Policy Response Indicators.**

Recommended procedure: Break into small groups of 6–12 people. Each group should be assigned 1 or more components (depending on the number of participants) from Step 1. Each group should identify candidate Condition, Pressure, and Policy Response indicators.

Cautions: This step can lead to long lists of indicators, often more than can be measured. Step 3 below will help to winnow the candidate indicators to a smaller set. Make sure scientists, managers, and stakeholders are in each breakout group.

Step 3. **Evaluate each proposed indicator for scientific merit, ecological breadth, utility, practicality, and relevance to stakeholder values.**

Recommended procedure: Using volunteers from the full group of participants, create a Science Workgroup (of scientists or technical experts) and a Manager Workgroup (of forest managers/decision makers). The Science group should rate each candidate indicator for scientific merit and ecological breadth. The Manager group should rate each indicator for practicality and utility. Ratings of each indicator, including a brief justification should be presented to the full group of participants. Finally, stakeholders should rate each indicator for how well it reflects their values. This step provides a transparent evaluation of the strengths and weaknesses of each candidate indicator. A system for rating indicators is provided in Hagan and Whitman (2003).

Cautions: This step is best accomplished with workgroups that have the time and skill to adequately evaluate the indicators. Some stakeholders should be involved in the workgroup meeting(s) to ensure transparency.

Step 4. **Select the highest ranking indicators for implementation.**

Recommended procedure: Sum the evaluation scores for scientific merit, ecological breadth, practicality, and utility for each indicator from Step 3. Compare the summed score with the stakeholders' score for the indicator. Indicators that score poorly for stakeholders should be eliminated if group discussion does not lead to modification of stakeholder assessment. Select top-scoring indicators for implementation.

Cautions: Resources for monitoring are always limited. Thus, practicality will likely be a dominant factor in the selection of the final set of indicators; select those indicators that are practical, but also strong for all other characteristics.

lection workshops we have led, effective use of indicators is much more constrained by the lack of a structured, transparent selection process than by a lack of science or availability (Whitman and Hagan 2003).

We have developed and implemented an indicator selection process (Box 1) that incorporates these concepts. Other indicator selection processes have been developed and also should be considered (e.g., Meadows [1998], Hart [1999], and Wright [2002]). The strengths of our process are its (1) stakeholder inclusion, (2) transparency of process, (3) logical stepwise sequence, and (4) relative simplicity. Selected indicators clearly are linked to stakeholder values and evaluated so that the best indicators can be selected and used. The structure of our process helps participants to focus on each sequential step and to avoid time-consuming digressions on subjects that might be perfectly appropriate at another point in the selection process (Schmoldt and Peterson 2000).

Important Consideration for Selecting and Using Indicators

We have encountered several principles or "lessons learned" from our experience leading different groups in indicator selection; these appear to be universally important, regardless of the process used to select indicators for forest sustainability.

1. Establish an indicator decisionmaking framework before selecting indicators.

Romm (1993) describes sustainable forestry as an ongoing "regime of actions" rather than an endpoint or specific condition to achieve. The reason we need indicators is to inform forest managers, forest decisionmakers, and forest stakeholders as to whether or not particular forest values are being sustained so that appropriate actions can be taken if needed. Therefore, a decisionmaking framework needs to be in place so that indicator results can be put to the use they are intended. A decisionmaking framework should address the following: What resources are available to measure the indicators and to process the information? Who is responsible for measuring the indicators? How often will the information be reported and to whom? How will decisions be made to respond to what the indicators indicate? Who will be included in making those decisions? What actions might be put into play if indicators suggest a problem? How will stakeholders participate in an ongoing discussion and evaluation of results? It can be counterproductive to try to select indicators if these questions have not been answered. Selection of indicators in the absence of a framework to do something with the results can lead to frustration among stakeholders because they can not see how the indicators will be used in forest decisionmaking to protect their values.

2. Stakeholder representatives, forest managers/decisionmakers, and scientists have discrete roles in the indicator selection process. Stakeholders play the important role of identifying the forest values that they seek to sustain; scientists (or technical specialists) identify candidate indicators that best track the values identified by stakeholders; and forest managers/decisionmakers are primarily responsible for ensuring that the indicators will be practical (i.e., affordable) to implement and useful in decisionmaking. Partitioning roles this way helps to ensure clarity about who the indicators are for (stakeholders) and helps to avoid confusing the *values* of managers and scientists with their technical *knowledge*. We suggest that scientists or managers who wish to participate as stakeholders in indicator selection (which is perfectly legitimate), should forgo their role as technical advisors. Ultimately, the responsible decisionmaking body (whether public or private) must decide which indicators will be put into practice, be prepared to justify why certain indicators will not be used (e.g., prohibitively expensive), and be responsible for winning or losing social legitimacy.

   Many indicator selection efforts fail to incorporate all three groups into their indicator selection process. Any indicator selection effort that attempts to circumvent the natural social discourse that can be expected among stakeholders will likely fail. Usually, it is the stakeholder group that is inadequately integrated into the process—a fatal mistake for winning social legitimacy. Often, a technical team is given responsibility for leading and selecting indicators, which then are presented to stakeholders after the fact—another fatal mistake (Pidot 2003).
3. Establish a diverse stakeholder/manager/scientist leadership team to guide the selection and use of indicators. Sustainability is pursued on behalf of forest stakeholders. Thus, stakeholders should participate in and share responsibility for the selection and use of indicators. Stakeholder involvement helps to ensure that indicators are relevant to their values, that a decisionmaking framework (see the foregoing principle 1) will be established to use the indicators, and that stakeholders will be informed by the indicators. "Ownership" of the indicators by stakeholders is one key to success.
4. Social capital is important for selecting and using indicators. "Social capital" refers to the institutions, relationships, knowledge, and values that govern interactions among people so they can achieve a goal (e.g., sustainability) (Lesser 2000). Indicators should reflect the values that people want to sustain. Therefore, indicator selection can be a contentious endeavor, especially because it is always the case that only a finite number of indicators can be measured. Values that are *not* measured with indicators therefore run a higher risk of unknowingly declining. The participants in indicator selection must be able to work productively together, even though values will differ. Working together to identify effective indicators requires a level of trust and respect that often takes time to develop. Social capacity refers to the degree to which participants can work together to pursue sustainability (Meadows 1998). Investment in building social capacity may be a necessary precursor to indicator selection or, if carefully organized and facilitated, indicator selection can be an effective vehicle for building social capacity.
5. Establish goals for each biodiversity component. The only way to know if management/policy action is required for a biodiversity component is to have set a goal for the component. If no goals are specified, there is little decisionmakers can do with the indicator results. This is a common cause of frustration with indicators—no one knows how to respond to the indicators. The next logical question is "then why are we measuring indicators?" If goals are set, then it can be straightforward to determine whether any action is needed and what action might be needed. It is not necessary to set numerical targets for indicators, although such targets do provide precise decisionmaking information. An example of a nonnumerical goal is "to maintain representation of all natural forest types and age classes in every county (or management unit or district). This is a qualitative goal, but it still is instructive for decisionmaking—if a forest type or age class is not present in a county or is rapidly disappearing, then the forest decisionmaker can initiate actions to maintain or achieve the specified goal.

   There is one situation for which setting a goal may not be wise, at least at the outset of indicator selection and use. When it is widely agreed that a particular biodiversity component is critically important, but stakeholder interests vary too much to set an agreed-on goal, it makes sense to measure the indicator anyway. Even in the absence of a goal it still can be extremely important to inform forest stakeholders of trends in a value they feel strongly about. Later, with better science and through a social process, a goal might be set for this highly relevant indicator.
6. Be clear about the spatial scale at which the indicators are to be applied. Indicators usually are selected for particular spatial scales (e.g., a watershed; a community, state, or national forest; or private industrial forest). In situations in which there are other jurisdictions nested within the target spatial scale (such as private forestland nested within a state scale), it can be unclear how the indicators might impact decisionmakers at the

smaller scale. Landowners nested within a proposed indicator spatial scale are naturally going to be concerned about the implications of the indicators to *their* decisionmaking rights. This issue also can be addressed by establishing a decisionmaking framework at the outset (see the foregoing principle 1).

7. Be aware of other indicator efforts at smaller or larger spatial scales. Indicators often are used simultaneously at a larger and/or smaller spatial scale by other jurisdictional entities: national forests might use indicators at the local landunit scale, as may large private forestland owners or larger conservation land owners. A state agency might use indicators at the state scale, while national-scale indicators are used for the United States as a whole. Statistical power for detecting trends is greatly enhanced by sample size; so, coordinating indicators among scales can yield insights that would not otherwise be possible. However, stakeholders within each scale legitimately have their own interests and values to track with indicators, and not all indicators will be relevant at all spatial scales or even similar scales between two different landowner types (e.g., national forest versus private commercial forest).

Conclusions

The primary challenge to selecting effective biodiversity indicators and putting them to use is procedural, not technical or scientific. Science plays a major supporting role, but the best science in the world will not be able to provide legitimacy to sustainable forestry. Social legitimacy will be won or lost by the inclusion or exclusion of forest stakeholders. Therefore, an open, transparent, logical, stepwise approach is needed to select indicators that provide stakeholders with confidence that their values are being maintained. We have provided some guidelines in this article that will help select indicators that better inform stakeholders, forest managers, and policymakers, and thus help build social legitimacy of sustainable forestry.

Literature Cited

ADRIAANSE, A. 1993. *Environmental policy performance indicators.* Ministry of Housing, Physical Planning and the Environment, The Hague, The Netherlands. 175 p.

DUINKER, P.N. 2001. Criteria and indicators of sustainable forest management in Canada: Progress and problems in integrating science and politics at the local level. P. 7–27 in *Criteria and indicators for sustainable forest management at the forest management unit level*, Franc, A., O. Laroussinie, and T. Karjalainen (eds.). European Forest Institute Proceedings No. 38, Saarijarvi, Finland.

FAILING, L., AND R. GREGORY. 2003. Ten common mistakes in designing biodiversity indicators for forest policy. *J. Environ. Manage*. 68: 121–132.

FOREST STEWARDSHIP COUNCIL (FSC) US STANDARDS COMMITTEE. 2001. *National indicators for forest stewardship.* FSC US Standards Committee, Atlanta, GA. 42 p.

FRANC, A., O. LAROUSSINIE, AND T. KARJALAINEN. (EDS.). 2001. *Criteria and indicators for sustainable forest management at the forest management unit level.* European Forest Institute Proceedings No. 38, Saarijarvi, Finland. 277 p.

FRIEND, A., AND D. RAPPORT. 1979. *Towards a comprehensive framework for environmental statistics: A stress-response approach.* Statistics Canada, Ottawa, Canada. 90 p.

GUYNN, D.C., S.T. GUYNN, P.A. LAYTON, AND T.B WIGLEY. 2004. Biodiversity metrics in sustainable forestry certification programs. *J. For*. 102:46–52.

HART, M. 1999. *Guide to sustainable community indicators*, 2nd Ed. Sustainability Measures, North Andover, MA. 86 p.

HUNTER, M. 1996. *Fundamentals of conservation biology*. Blackwell Science, Inc., Cambridge, MA. 482 p.

LESSER, E.L. 2000. *Knowledge and social capital. Foundations and applications.* Butterworth Heinemann, Boston, MA. 304 p.

LINDENMAYER, D.B., C.R. MARGULES, AND D.B. BOTKIN. 2000. Indicators of biodiversity for ecologically sustainable forest management. *Conserv. Biol.* 14:941–950.

MARGOLIS, H. 1996. *Dealing with risk: Why the public and the experts disagree on environmental issues.* University of Chicago Press, Chicago, IL. 238 p.

MEADOWS, D. 1998. *Indicators and information systems for sustainable development.* The Sustainability Institute, Hartland, VT. 95 p.

MONTREAL PROCESS. 1995. *The Santiago Agreement: Criteria and indicators for the conservation and sustainable management of temperate and boreal forests.* Santiago, Chile. Available online at www.mpci.org; last accessed Feb. 3, 2006.

NATIONAL RESEARCH COUNCIL. 2000. *Ecological indicators for the nation.* National Academy Press, Washington, DC. 180 p.

NOSS, RF. 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators. *For. Ecol. Manage.* 115:135–146.

PIDOT, L. 2003. *Tapping the indicators knowledge-base: "Lessons Learned" by developers of environmental indicators.* Maine State Planning Office and the Gulf Summit Steering Committee. Augusta, ME. 28 p.

RAISON, R.J., A.G. BROWN, AND D.W. FLINN. (EDS.). 2001. *Criteria and indicators for sustainable forest management.* International Union of Forestry Research Organizations Research Series 7, Vienna, Austria. 462 p.

ROMM, J. 1993. Sustainable forestry, an adaptive social process. P. 280–293 in *Defining sustainable forestry*, Aplet, G., N. Johnson, J. Olson, and V.A. Sample (eds.). Island Press, Washington, DC.

SCHMOLDT, D.L., AND D.L. PETERSON. 2000. Analytical group decision making in natural resources: Methodology and application. *For. Sci.* 46:62–75.

SUSTAINABLE FORESTRY INITIATIVE (SFI). 2004. *Sustainable Forestry Initiative: 2005–2009 standard.* Sustainable Forestry Initiative, Sustainable Forestry Board, and the American Forest & Paper Association, Washington, DC. 26 p.

WHITMAN, A.A., AND J.M. HAGAN. 2003. *Final report to the national commission on science for sustainable forestry: Biodiversity indicators for sustainable forestry.* National Center for Science and the Environment, Washington, DC. 48 p.

WRIGHT, P.A. 2002. *Monitoring for forest management unit scale sustainability: The Local Unit Criteria and Indicators (LUCID) test.* USDA For. Serv. Inventory and Monitoring Institute Rep. 4. 286 p.

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