Framework for and review of biodiversity indicators for forest management in the context of product life cycle assessment

Final report

21st February 2008

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1. Introduction

This study has been commissioned by AB TetraPak, Global Environment.

The objective of the study is to review existing proposals for biodiversity indicators for forest management, placing the indicators within a common framework.

2. Framework for comparing and aligning indicators

A conceptual framework provides an organising structure for the indicators that ensure indicator comparability, facilitate identification of indicators and areas where indicators are missing, and may be useful for communicating indicators.

Several frameworks for logical organisation of indicators can be found. One of the most popular and widely accepted is the DPSIR (Driving force – Pressure – State – Impact – Response) framework developed by the European Environment Agency (1999) based on earlier proposals stemming back to Rapport & Friend (1979). Organising indicators according to the DPSIR framework allows a more meaningful comparison of the indicators, since only indicators at the same logical level are compared. It is also possible to focus on the causal relationships between the indicators at different logical levels: Driving forces cause Pressures that cause Impacts, which can be interpreted as changes in States. Responses are then aimed at reaching more desirable outcomes by modifying Driving forces, Pressures, States or Impact mechanisms. Another concept that can be used to structure indicators is the impact pathway: Pressure – Midpoint impacts – Endpoint impacts, developed in the context of Life Cycle Impact Assessment (Jolliet et al. 2004). This concept focuses more on the causal links between indicators.

Combining the DPSIR and the impact pathway concepts implies a division if the "I" of DPSIR into two: Midpoint impacts and Endpoint impacts, thus resulting in the following DPSMER framework, which we will apply to structure the indicator review in this study:

- Driving forces: The human activities and developments that are the ultimate causes of pressures and changes in pressures – and thereby in impacts. Fundamental developments may be changes in population parameters, consumption levels and patterns, or in technologies. Specific human activities may be e.g. forestry or pulp production in its different forms.
- Pressures: The interaction or exchanges between the human activities and the environment, i.e. emissions to, harvests from, and physical alterations to habitats.
- State: The composition, structure and function of the environment. State indicators may both reflect the resulting environment under a given level of pressure, and be used as reference or background scenarios when studying a specific change in pressure.
- Midpoint impacts: Impacts are changes in the state of the environment resulting from specific pressures. It may be difficult to distinguish State and Impact indicators, because

any change in state may be interpreted as an impact. However, in the meaning of the DPSIR framework, impacts are only state changes of environmental concern, i.e. that contribute to changes (either damages or beneficial changes) in safeguard subjects that have direct instrumental or intrinsic value to humans. Indicators of such damage are called "endpoint indicators" or "damage indicators", while midpoint indicators denote changes at earlier points on the impact pathway. Thus, midpoint indicators can be on issues such as fragmentation, which may not be seen as valuable in itself, while the resulting loss of biodiversity would be an endpoint impact.

- Endpoint impacts: Changes in safeguard subjects that have direct instrumental or intrinsic value to humans. For biodiversity impacts, an endpoint indicator should express the change in biodiversity as such, e.g. changes in species numbers and distribution, possibly for selected species only, or with differentiated weights to different species.
- Responses: Policy actions modifying Driving forces, Pressures, States or Impact mechanisms to reduce impacts and reach a more desirable state. Being human activities, responses are a specific kind of Driving forces, distinguished only by their specific focus on modifying undesired impacts of other Driving forces. Examples of Response indicators are "Protected area" and "Demand for products from known licensed sources".

3. Indicator sets reviewed

Official biodiversity indicator sets all refer back to the UN Convention on biological diversity. At the international level, indicator sets have been developed by UNEP for the Global Biodiversity Assessments. Indicator sets for forest biodiversity have been developed by several inter-regional, regional or national organisations, such as:

- The International Tropical Timber Organization, ITTO, which is an intergovernmental organization promoting the conservation and sustainable management, use, and trade of tropical forest resources. Its 59 members represent about 80% of the world's tropical forests and 90% of the global tropical timber trade. The most recent revision of the indicator set is ITTO (2005).
- The African Timber Organization, a regional intergovernmental organisation with 14 member countries. A regional specific indicator set was developed in ITTO (2003).
- Ministerial Conferences on the Protection of Forests in Europe, MCPFE, a high-level intergovernmental process covering 46 countries and the European Union. The most recent set of improved indicators is MCPFE (2002). National or regional implementation of these indicators will often involve additional indicator development, as e.g. Stokland et al. (2003) for the Nordic countries. This is also included under the UNECE Convention on Long-range Transboundary Air Pollution, which has been broadened by the Forest Focus Regulation (EC N° 2152/2003) to include ICP Forests (the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests). A field manual is available (Expert Panel on Ground Vegetation Assessment 2002, Working Group on Forest Biodiversity 2007) with some national variations <www.icp-forests.org/EPbiodiv.htm>; see also the survey of academic research below. Pan-

European work to co-ordinate the National Forest Inventories takes place under the auspices of COST action E43 <www.metla.fi/eu/cost/e43/>.

- Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests, also known as the Montreal Process, an inter-regional process covering 12 countries (Argentina, Australia, Canada, Chile, China, Japan, South Korea, Mexico, New Zealand, the Russian Federation, USA, Uruguay) having agreed by the Santiago Declaration to implement a common set of 67 indicators (The Montreal Process 1999). The 12 countries cover 90% of the world's temperate and boreal forests. Several of the Montreal countries have further developed their own indicator sets, notably Australia (Bureau of Rural Sciences 2003) expanding to 74 indicators developed during regional consultations with forest management, conservation agencies and other stakeholders; Canada (Canadian Council of Forest Ministers 2003) reducing to 46 indicators by focusing on indicators that are "most relevant to Canadians' values, are most often measurable with available data, and are understandable to policy makers, forest managers and an informed public". In the USA, the 2003 survey (USDA 2004) used and commented on the Montreal indicators, while individual states have developed their own indicator sets, e.g. the 19 indicators of the Oregon Department of Forestry (2007).
- The Tarapoto process of the Amazon Cooperation Treaty (Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela) resulting in 70 indicators (Tarapoto process 2001).
- Four regional processes (Lepaterique, Near East, Dry Zone Asia, Dry Zone Africa), facilitated by FAO and only reported through Castañeda et al. (2001).

In total, around 150 countries are participating in these processes. Coordination between some of these indicator development processes has taken place through a conference (FAO 2003), an expert consultation (FAO/ITTO 2004), and a workshop (ITTO 2006), and by the facilitating and coordinating efforts of FAO (Castañeda et al. 2001), not least in the area of terminology (see http://www.fao.org/forestry/site/cpf-definitions/en/), and the adoption of the indicator approach to the FAO Forest Resources Assessment 2005 (FAO 2005).

Some of these indicator sets have a wider scope than just biodiversity. For example, the Montreal criteria include besides maintenance of biodiversity, also maintenance of the productive capacity of forest ecosystems, forest ecosystem health and vitality, soil and water resources, forest contribution to global carbon cycles, socio-economic benefits to meet the needs of societies, as well as the legal, institutional and economic framework for sustainable forest management. Out of 67 Montreal indicators, only 9 are placed under the heading of "Maintenance of biodiversity", but most of the indicators are nevertheless also relevant in the context of biodiversity protection.

Sustainable forestry certification systems use indicators as part of their labelling criteria.
The Forest Stewardship Council (FSC) is an International accreditation NGO that develops principles and criteria for forest management. Through a network of currently 45 national initiatives, FSC accredits 28 national or sub-national standards and 18 certification bodies that certify forest management of 90 million hectares in more than 70 countries and several thousand forest products that carries the FSC trademark. Each national or sub-national standard has its own

indicator list referring to the 10 FSC principles. Principle 6 is on environmental impact. Although the 28 national or sub-national standards are publicly available according to FSC policies, they are not easy to find. We have used the access via <http://www.gtz.de/en/themen/laendliche-entwicklung/5426.htm>.

The Programme for the Endorsement of Forest Certification (PEFC) is an International accreditation NGO for forest management, relying mainly on the MCPFE, ATO, ITTO processes and similar official indicator sets. PEFC accredits 25 national standards, each with its own indicator list. These are publicly available via <http://www.pefc.org/internet/html/members_schemes/4_1120_59.htm>.

Principle 9 of the FSC requires High Conservation Value (HCV) forests to be managed in ways that ensure that their high conservation values are maintained or enhanced. The HCV concept has gained a wider application than within the FSC accreditation scheme, and is especially promoted by the WWF in cooperation with the World Bank (WWF/World Bank 2006), IKEA and TetraPak. The HCV concept operates with 6 types of HCV, of which the first three are relevant from a biodiversity perspective:

- HCV1. Forest areas containing globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia).
- HCV2. Forest areas containing globally, regionally or nationally significant large landscape level forests, contained within, or containing the management unit, where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance.
- HCV3. Forest areas that are in or contain rare, threatened or endangered ecosystems.

The remaining three types are HCV4. Forest areas that provide basic services of nature in critical situations (e.g. watershed protection, erosion control). HCV5. Forest areas fundamental to meeting basic needs of local communities (e.g. subsistence, health). HCV6. Forest areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities).

The HCV concept is also beginning to be used beyond the forest sector, for example by the Argentine Wildlife Foundation for identifying grassland areas with HCV and by the Roundtable on Sustainable Palm Oil (RSPO) and the Basel Criteria for Responsible Soy Production (ProForest 2005) requiring that new plantations avoid HCV areas. The HCV Network has published a toolkit (Jennings et al. 2003), which encourages National Interpretations (<www.hcvnetwork.org/resources/national-hcv-interpretations>), which is currently available for 11 countries (Bolivia, Bulgaria, Canada, Ecuador, Ghana, Indonesia, Papua New Guinea, Poland, Romania, Russia, Viet Nam).

The Global Forest Watch initiative <www.globalforestwatch.org> of the NGO World Resources Institute (WRI) performs regional forest assessments mainly by combining different GIS-based data sources. The applied indicators vary between assessments, which makes it difficult to compare across assessments.

Academic research in indicator development has taken place in several different contexts, mainly:

- The Center for International Forestry Research (CIFOR) proposed a preliminary list of indicators, together with a practical framework for applying biodiversity criteria and indicators in field situations (Stork et al. 1997), see also <www.cifor.cgiar.org/acm/methods/candi.html>.
- Research related to WWF activities include the often cited review of Noss (1999) and the work of Dudley et al. (summarised in Dudley et al. 2006).
- In the context of their "State of the Nation's Ecosystems" project, the H. John Heinz III Center for Science, Economics, and the Environment <www.heinzctr.org/ecosystems/ index.shtml> uses 6 forestry-specific indicators as well as core indicators applicable across ecosystems. The Center works to develop a core indicator for "Biological Community Condition" based on the relationship between observed and expected species numbers.
- The National Commission on Science for Sustainable Forestry in the USA has an extensive research programme for indicator development, including a web-based decision support tool for indicator selection (Whitman & Hagan 2003) based on a review of over 2000 biodiversity indicators from primary scientific literature, a direct mail survey of 605 scientists, sustainable forestry certification programs, and other national, state, or regional programs, classified into 137 groups of related indicators, and organised against 45 variables of which 4 are DPSIR categories and 36 are evaluation criteria, mainly related to practicability and applicability for decision-making.
- The EU has financed a number of research projects, starting with BEAR (Indictors for monitoring and evaluation of forest biodiversity in Europe) published in Larsson (2001), Bioassess <http://www.nbu.ac.uk/bioassess/Methods_Results.htm>, and most recent the ForestBiota (publications at www.forestbiota.org), BioSoil (Working Group on Forest Biodiversity 2007) and EFORWOOD projects (Raulund-Rasmussen et al. 2006).
- With a broader focus than forestry, some indicators have developed from considerations of establishing measures for biodiversity offsets (ten Kate et al. 2004). The most applied of these are the 10 indicators for measuring Habitat Hectares (Victorian Government Department of Sustainability and Environment 2004), which provides a summary score of "vegetation quality" relative to a natural benchmark, i.e. similar to the Natural Capital Index of UNEP/OECD (ten Brink 2000).
- In the field of life cycle assessment (LCA), biodiversity indicators have distinguished three aspects: area, duration and quality. Duration refers both to human activities and the relaxation period after these activities. To measure ecosystem quality it has been suggested to combine a relative measure of current biodiversity (expressed as species richness or proxy indicators) with inherent ecosystem scarcity and ecosystem vulnerability (Weidema & Lindeijer 2001, Michelsen 2008). In practical applications for life cycle assessment, the measure of relative current biodiversity has been very simplistic, using only one default value for all types of forestry, assuming managed forest to imply reductions in biodiversity of around 10% (Goedkoop & Spriensma 2001) compared to natural, undisturbed forests.

4. Driving force indicators

Many human activities influence forest biodiversity indirectly through emissions of nutrients and toxic substances. These are not dealt with here. We focus on those human activities that are either forest management activities or may influence forest management through demand changes. Thus, driving force indicators for biodiversity of forest management may be either:

- indicators of specific types of forest management, forest use, or forestry technologies that are expected to have different biodiversity impacts, or
- indicators of the demand for forestry products, either the general demands for timber, pulpwood, firewood, secondary forest products (edible, decorative, medical, or fibre products), hunting or recreation, or the specific demands for such products from known licensed sources (to exclude illegally harvested products), from "sustainable forestry", or from plantations in areas of relatively low biodiversity value (WWF 2001, Patel-Weynand 2002, Sedjo & Botkin 1997). Such specific demands may also be seen as response indicators.

In the context of Life Cycle Assessment (LCA), these indicators are part of or derived from the reference flows.

Commercial forest management primarily aim at increasing the output of specific commercial species. This implies forest technologies that typically involve:

- Activities to reduce the occurrence of competing species,
- Activities to increase yields, including drainage, soil working, planting, stocking, fertilisation, thinning, pruning, and disease control,
- Selection and/or introduction of higher-yielding species or varieties,
- Harvesting of the commercial species earlier than their natural senescence, thus reducing the amount of old specimens and dead wood,
- Harvesting in plots, leading to even-aged stands,
- Incidental damage during maintenance or harvesting operations, including the building of roads and soil compaction from machinery.

Indicators of harvest intensity may be annual yield per area, and spatial distance and age-distribution of harvested specimens. These indicators may be used to quantify concepts such as "variable retention harvesting", which is based on varying the densities and spatial arrangements of different structural elements (live or dead trees) retained from the harvested stand.

Indicators of intensity of other forest management activities may be annual man-hours, machine-hours, use of fuels and other inputs, and/or economic costs per area.

Forest use, other than for physical outputs, i.e. recreational use, may also lead to damages to biodiversity, mainly due to noise, soil compression, roaming of pets, and accidental fires. Indicators of intensity of use may be annual number of visitors and duration of visits, specifying accompanying animals and use of vehicles (motorised or not).

In protected forests or forest nature reserves, forest management has the opposite role than in a commercial or recreational forest, namely to *protect* against damages from commercial and recreational uses. The demand for designating forest areas as protected or "High Conservation Value" forests can therefore be seen as a driving force indicator in itself, although it may more typically be defined as a response indicator; see Chapter 9.

In addition to the intensity of management and use, the extent of the impact of a specific driving force depends on the nature of the affected ecosystem. Driving force indicators must therefore include some information on this, such as:

- The current biodiversity value of the affected ecosystem (see under state indicators).
- The position of the affected species within the ecosystem (moderate harvesting of a dominating species within a high productivity ecosystem can be beneficial in liberating space and thereby creating conditions for larger variation in successional stages).
- The sensitivity of the affected ecosystem to disturbances, i.e. characteristics such as its natural productivity (in a low productivity ecosystem, disturbances can threaten the affected populations and any other populations that depend on them. The lower the natural productivity of the ecosystem, the more damaging a disturbance may be. Conversely, in a high productivity ecosystem, the protection of a dominating species against natural disturbances may reduce biodiversity, cf. the dynamic equilibrium model of Huston 1979).

The demand for forest products may be classified, e.g. according to the 5 categories of the Global Forest & Trade Network (GFTN) of WWF (White & Sarshar 2006):

- Known source
- Licensed source (legal source, including verified legal timber)
- Source in progress to credible certification
- Credibly certified source
- Recycled source

A Forest Products Tracking Database has been developed by GFTN to allow participant companies to standardise their data gathering, assessment and reporting, see also Miller et al. (2006). The WRI's Forest Transparency Initiative (Méthot et al. 2006) also contributes to this.

Since we expect a large variation in biodiversity impact within "credibly certified source", it would be beneficial if this source could be further specified, primarily distinguishing "plantation forest" and "biodiversity-managed forest" from "other certified source", and possibly further sub-dividing these management systems if it is possible to distinguish their intensity of management and the nature of the affected ecosystems or even to quantify the biodiversity impact.

It is particularly important to note that an unspecified change in demand for a forestry product may lead to changes in the amount of product supplied from unknown sources, so that an unspecified demand will have the average biodiversity effects associated with unknown sources. The assumption is here that the supply of products from unknown sources is unconstrained.

As long as it is demanded that the forestry product is *not* from unknown sources, a change in demand will exclusively lead to changes in the amount of product supplied from the most competitive type of forestry, since this is the type of forestry that will change its area or volume output in response to changes in demand. In general, plantation forestry can be expected to be the most competitive type of forestry (except for unknown sources). Thus, an unspecified demand for forestry products, with the restriction that these should at least be from known sources, will have the average biodiversity effects associated with the marginal plantation forest. This implies that as long as products from unknown source are excluded, there is no immediate biodiversity effect of demanding products specifically from "plantation forest". However, there may be an important "signal effect" of such a demand, implying that such a demand could lead to political decisions that eventually may influence forest management to abandon other forestry types with higher biodiversity impact. Since this "signal effect" is difficult to quantify, it should only be used for sensitivity analysis.

For products from "recycled source", a particular situation exists, since the supply of recycled material is constrained by the amount of waste product available for collection. Thus, the consequences of using "recycled source" depend on the market situation. In general, as long as the price of recycled fibre is close to that of virgin fibre of the same technical quality, increased use of recycled source will simply lead to less recycled source being available for other users who do not place demands on their source, thus implying that these users would use more of the average unknown source. Thus, use of "recycled source" should be classified on par with "unknown source". If this in time leads to an outlet problem for recycled fibres, which would be indicated by a significantly lower price for recycled fibre than for virgin fibres of the same technical quality, the recycling can be stimulated by raising the classification of recycled source to be at par with the average of the remaining sources used in the same product. This raise in classification should be done with priority for use in product types that are not recycled into pulp after use, i.e. products such as tissue paper, since this would maximise the quality of the remaining paper available for recycling, thus increasing the efficiency of the recycling process.

Thus, to have a biodiversity effect different from that of "unknown sources" or "plantation forests", respectively, the change in demand must be for a specified and unconstrained source, or imply a specific change in forest management, forest use, or forestry technologies.

A specific indicator of changes in forest area may be required to account for situations where forests are established on land previously used for other purposes, or where harvesting (clear-cutting) leads to deforestation, i.e. where the forest is not re-established after the harvest. However, since forestry is typically the least competitive land use, such changes in land use are generally not related to forestry management decisions or to changes in demand for forest products, but rather to changes in land requirement of alternative land uses.

5. Pressure indicators

While driving force indicators focus on measuring the nature and extent of the activities of forest management and use, the corresponding pressure indicators focus on the physical inputs or outputs from these activities, i.e.:

- harvests from forest ecosystems,
- emissions to forest ecosystems, or
- physical alterations to forest ecosystems.

In forest ecology, all of these pressures are typically denominated as antropogenic *disturbances* of the current state of the forest.

For harvests, indicators related to the physical output (annual yield per area, and spatial distance and age-distribution of harvested specimens) were already suggested under driving force indicators, and no further pressure indicators seem necessary.

Emissions with a potential to influence biodiversity may be in the form of:

- Noise,
- Nutrients from fertilisation,
- Toxic substances, such as pesticides and oil spills,

Physical indicators for these emissions exist, but due to the cost of measurement, it is unlikely that they will play any significant role in practice. Rather, proxy indicators can be constructed from corresponding driving force indicators (fertiliser and pesticide use, introduction of foreign species) or a combination of driving force and state indicators (combining visitor statistics and data on core area to estimate noise pressure).

Introduction of invasive species is an issue of specific concern. Potentially invasive species may be introduced by accident, as a contamination in timber and other living or dead biomass imports, or introduced intentionally to enhance production of primary or secondary forest products, including new game species, or used to control pests. Separate risk indicators are necessary to reflect the volume of transport of forest products between ecoregions with similar habitat conditions and the management activities to reduce the risk (e.g. behavioural measures, visual inspection, fumigation).

Physical habitat alteration can take the form of:

- Barrier construction (roads, fences, dams). May be measured in length, but more relevant in terms of the area delimited by the barrier. For example, core forest area can be defined as that with a distance above 100 metres from edges, roads or other barriers.
- Draining. May be measured as area drained.
- Felling, weeding, thinning, pruning (without removal, as opposed to harvests). May be measured as volume, possibly in size classes.
- Antropogenic fires or fire prevention. May be measured as area affected.
- Stocking of game or domestic animals. May be measured as number of animals by type, or aggregated in terms of biomass.

- Roaming of pets. May be measured as number of animals by type.
- Planting. May be measured as number of plants by type, especially distinguishing native and introduced species and varieties, as these can be expected to have very different numbers of associated species (Southwood 1961).
- Soil compaction and soil working (tillage, ploughing, scarification, mechanical weeding). May be measured in terms of area affected.

All of the measures must be relative to total area and indicating duration or temporal spacing between disturbances, e.g. as annual averages per hectare.

As for driving force indicators, pressure indicators must also include some information on the nature of the affected ecosystem, i.e.:

- The current biodiversity value of the affected ecosystem (see under state indicators).
- The position of the affected species within the ecosystem.
- The sensitivity of the affected ecosystem to disturbances, i.e. characteristics such as its natural productivity.

In line with the early understanding of the Pressure-Response framework (Rapport & Friend 1979), some interpretations of the DPSIR concept still denote some indicators, such as forest fires and animal browsing, as "natural disturbance … that cause environmental change" (Stokland et al. 2003 page 19 and 99). However, the intention behind the modern DPSIR framework is to study the antropogenic impacts on the environment, where the variation in natural processes is seen as a background variation in the State indicators rather than as Pressures. While it may indeed be possible to make an indicator framework for natural processes of biodiversity change (e.g. succession or evolution), this is not the intention of the DPSIR framework. In fact, most forest fires are antropogenic and animal browsing is also to a large extent influenced by human activities, such as stocking of game. It is therefore reasonable to include these indicators as indicators of antropogenic pressure. The sum of antropogenic and natural forest fires may be seen as a State indicator, alongside any other indicators that reflect the – sometimes rapidly changing – state of the environment.

In the context of LCA, pressure indicators are named "inventory results", since they indicate the pressures that result from the human activities that are "inventoried" to be part of the analysed product system.

6. State indicators

State indicators for forest biodiversity report on:

- Forest biodiversity itself, i.e. the variability of ecosystems, species and genes.
- Non-biodiversity aspects of forest ecosystems that may influence forest biodiversity, such as the structural and functional aspects of the forest ecosystems.
- Non-biodiversity aspects of forest ecosystems that may influence how much a specific pressure will impact on forest biodiversity. Example: Natural productivity.

Whitman & Hagan (2003) note that published research in the U.S.A on state indicators "has focused mostly on composition indicators, secondarily on structural indicators, and very little on function indicators." At the overall level, compositional variety is most often measured as species richness. Because of the large effort required to make complete species richness assessments, much effort has been focused on the usefulness of selecting indicator species with specific characteristics, such as flagship, focal, keystone or umbrella species[1]. The Bioassess project <www.nbu.ac.uk/ bioassess/Methods_Results.htm> found that birds, butterflies, lichens, and plants significantly predicted the species richness of each other, although lichens were a poorer predictor of the richness of other groups of species than birds, butterflies and plants. Macrofauna were found to be the most promising of the soil (or soil-surface) dwelling organisms as an indicator of the richness of other taxa. However, the usefulness of indicator species have been questioned, partly because the geographical range of single indicator species is limited, partly because the state of an entire forest ecosystem simply cannot be adequately represented even by several indicator species together. Species richness or abundance indicators are therefore seen as more relevant for validation of the relevance of other more easily measurable parameters, such as exotic species ratio, stand age distribution, deadwood amount, core forest area, and connectivity.

Already in relation to driving force and pressure indicators, we noted that the nature of the affected ecosystem is key information. First of all, this identifies the type and area of the ecosystem, its inherent scarcity (e.g. measured as its global potential area relative to the ecosystem type with the largest potential area) and its sensitivity to disturbances (e.g. measured by its natural productivity and how much of the original ecosystem area is left unmanaged).

Closely related to sensitivity is the issue of habitat fragmentation, which has two aspects:

- Habitat size: Fragmented forests provide less habitat area for species that require large habitat areas for survival. A good measure of continuous habitat area is "core forest area", typically defined as area further than 100 metres from nearest edge, road or other barrier. To distinguish from paths, roads are constructed. The Bioassess project (see above) found that total core area correlated with the richness of lichens, butterflies and ground beetles.
- Isolation: Fragmented forests provide fewer options for migration. Populations in small, isolated habitats are more at risk for extinction and loss of genetic diversity. Thus, the

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[1] Flagship species are charismatic species that can stimulate public support for conservation, focal species are vulnerable species that can represent a larger set of vulnerable species, keystone species are species that many other species depend on for their existences, and umbrella species are species whose habitats support many other species.

connectivity of the landscape, the existence of adequate corridors for migration, is important for biodiversity. Many metrics have been proposed to quantify landscape pattern and structure (see www.umass.edu/landeco/research/fragstats/fragstats.html). It appears that area-informed isolation measures, such as the amount of available habitat within a given radius around a patch, are generally more reliable than distance-based metrics (Bender et al 2003, Tischendorf et al. 2003).

Some of the most conspicuous aspects of forest management, that also have a major impact on biodiversity, are the introduction of exotic species or varieties and the harvesting and removing trees at a young age. Therefore, some of the most relevant (and fortunately also easily measurable) state indicators are:

- The tree species mix, and the exotic species ratio. This ratio may also be relevant for game or other introduced species.
- Standing tree volume, and stand age distribution, especially as it reveals the extent of old trees. Schowalter (1995) found that arthropod diversity was 5 to 6 times greater in old growth stands. Arthropods commonly account for 70-90% of all species present (Schowalter 2000) with the diversity being greater in old growth stands compared to young plantations.
- The amount of deadwood. This can be calculated as the difference between the annual production and the annual harvest, but in order to determine the size structure of the deadwood, visual inspection is necessary. Especially standing deadwood, large logs and snags are important for a large number of species.

Other generally relevant structural state indicators are:

- Area of protected forest. A landscape level assessment is important to ensure landscape heterogeneity, providing a mosaic of different management regimes and protection levels.
- Stand structural complexity, measured by continuity of tree cover, number of canopy layers.
- Wetland protection: Forest wetlands are scarce and provide livelihood for many species. Aquatic ecosystem integrity may be measured by area of wetland and canopy cover of riparian zones.

Generally, the closer to the natural disturbance regime, the larger is the probability for high biodiversity. This is the background for indicators that seek to summarise biodiversity in a single concept of naturalness or authenticity.

7. Midpoint impact indicators

Impact indicators for forest biodiversity report changes in state indicators, when these changes can be derived from specific pressures or from changes in other impact indicators. Midpoint indicators report on changes in *non-biodiversity* state indicators, i.e. changes at any point on the impact pathway *before* the endpoint (the point where the ultimate damages or beneficial changes to biodiversity is measured).

Following the same order as in the previous Chapter on State indicators, the following midpoint indicators are found to be of particular importance:

- Fragmentation: Fragmentation is not only caused by reduced forest area, but also by clear-cuttings and construction of roads and other barriers within the forest area. Fragmentation will be reflected in reduction of core forest area and increase in isolation indicators.
- Changes in the exotic species ratio. Increased impact will be reflected in an increase in this ratio.
- Changes in stand age-distribution: Increased impact will be reflected in a reduction both in average age and in age classes above the average, and an increase in age classes below the average.
- Changes in amount of deadwood: Increased impact will be reflected in less deadwood, a reduction in the proportion of standing deadwood, and a lower size distribution of the remaining deadwood. Raulund-Rasmussen et al. (2006) suggest that the focus should be on hard and thick (>10 cm diameter) deadwood, since changes in its value can be detected over relatively short periods.
- Changes in stand structural complexity: Increased impact will be reflected in reduced continuity of tree cover and canopy layers, i.e. both horizontal and vertical complexity.
- Changes in wetland regime: Increased impact will be reflected in reduced wetland area and reduced canopy cover of riparian zones.

Invasive species were not mentioned explicitly under state indicators, since state indicators would not capture the concern that once released, the damage is difficult to control. Rather, pressure indicators that reflect the risk of introduction need to be combined directly with impact indicators that reflect the potential geographical spread and extent of competition of the potential invasion. Such indicators forecasting impact potentials can be based on evidence from historical introductions.

Further, the following indicators may be of interest in some situations, although generally of relatively limited importance:

- Changes in nutrient status: Increased impact will be reflected in increased level of the limiting nutrient (typically nitrogen in temperate forests and phosphorous in tropical forests).
- Changes in fire regime relative to the natural situation.
- Change in area affected by soil working and soil compaction.

As for the previous indicator groups, also midpoint indicators need to carry additional information on the nature of the affected ecosystem (see under State indicators).

8. Endpoint impact indicators

Endpoint impact indicators for forest biodiversity report on changes in forest biodiversity, i.e. the variability of ecosystems, species and genes, when these changes can be derived from specific pressures or from changes in other impact indicators.

Some examples of endpoint indicators are:
- Change in species numbers and distribution (possibly for selected species only, or with differentiated weights to different species), typically measured in terms of species richness.
- Change in status of red-list species.
- Percentage of red-list and/or extinct species.
- Endemic species with reduced habitat area.
- Change in species numbers and distribution of indicator species, e.g. those most sensitive to disturbances.

Already under State indicators, it was mentioned that direct measurements of biodiversity in the form of species richness assessments are of limited relevance because of the cost of measurement and the limited representativity of specific measurements. For the same reasons, the species richness or abundance indicators mentioned above are of little relevance as endpoint indicators, although important for designing and validating more simple and broadly applicable indicators.

Another approach is to estimate the relative endpoint impact via the midpoint indicators. Examples of this approach are:
- The Natural Capital Index of UNEP/OECD, which aggregates different pressure indicators or indicator species abundance data relative to their estimated pre-industrial baseline (ten Brink 2000).
- The Habitat Hectares (Victorian Government Department of Sustainability and Environment 2004), which provides a summary score of "vegetation quality" based on 10 indicators with different weights, summing to 100 (large trees 10, tree canopy cover 5, understorey 25, lack of weeds 15, recruitment 10, organic litter 5, logs 5, patch size 10, neighbourhood 10, distance to core area 5). Each indicator is measured relative to a pre-1750 benchmark for the ecological vegetation type.
- The "potentially-disappeared-fraction-of-species square-meter years" (Goedkoop & Spriensma 2001) or "biodiversity-adjusted hectare-years" (Weidema 2007) used in life cycle assessment.

Common for these approaches is that they seek to measure the current state relative to a natural reference situation, or the impact in terms of change in distance to such a natural reference situation. The correct choice of reference situation is discussed extensively in Weidema & Lindeijer (2001), concluding that the correct choice of reference situation for an impact indicator is the current natural relaxation potential, i.e. the steady state that an ecosystem would be able to reach if left unmanaged for long enough (typically 500 years).

An important difference between the above-mentioned approaches is their choice of weighting for inherent quality of the ecosystem. In the Natural Capital Index, all baseline/benchmark hectares are of equal importance, while the LCA approach of Weidema & Lindeijer (2001) weight the ecosystem hectares according to baseline species richness, inherent ecosystem scarcity and ecosystem vulnerability. However, it turned out that in practice the impact assessment is dominated by the occupied area of ecosystem, and only to a lesser extent influenced by the specific qualities of the ecosystems occupied. this can also be seen from the data at the biome level in Weidema & Lindeijer (2001), where the resulting quality of different biomes was not very different, since most ecosystems used by humans are not at the same time species poor, scarce and vulnerable. If this analysis was revisited with more recent data now available at the level of ecoregions, this may give a different result.

For the endpoint indicators to be meaningful in a DPSIR framework, it is essential that a link can be made between impacts at midpoint level and impacts on the endpoint indicator, i.e. that it is possible within the same ecosystem type to distinguish the relative level of endpoint impact:

- in core forest area versus non-core areas,
- at different levels of isolation indicators,
- resulting from different levels of the exotic species ratio,
- depending on the stand age-distribution,
- depending on the amount of deadwood,
- in areas with reduced continuity of tree cover and canopy layers,
- in drained wetlands,
- in riparian zones with reduced canopy cover,
- of changes in nutrient status or fire regime,
- of soil working and soil compaction.

Even rough indications of the relative endpoint impact will allow a first assessment. Combined with adequate uncertainty ranges, this can be used to guide further data collection and indicator development if needed.

9. Response indicators

To reduce biodiversity impacts of forestry, policy responses can be aimed at modifying:

- The driving forces, by reducing demand for forestry products, especially those which are related to high specific impacts on forest biodiversity, or by stimulating specific types of forest management, forest use, or forestry technologies with reduced biodiversity impacts.
- Pressures, by regulating the harvest and management intensity and forest fires, and by stimulating reductions in specific emissions and physical habitat alterations with high biodiversity impacts.

- The state of forest ecosystems, by stimulating aspects that favour a high level of biodiversity or by reducing their vulnerability to pressures.
- Impact mechanisms, by introducing measures that counteract or reduce the efficiency of important impact mechanisms.

Being human activities, responses are a specific kind of driving forces, distinguished only by their specific focus on modifying undesired impacts of other driving forces.

Thus, the specific demands for products from known licensed sources (to exclude illegally harvested products), from "sustainable forestry", or from plantations in areas of relatively low biodiversity value may be seen as response indicators.

Likewise, demands for specific forest management regimes are possible response indicators, e.g. "Protected area", "Area under sustainable management" or demands relating more specifically to decrease the level of one or more of the previously described indicators.

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