Towards biodiversity assessment for boreal forests in the Pechora River Basin (Russian Federation)

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Towards Biodiversity Assessment for Boreal Forests in the Pechora River Basin (Russian Federation)

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Abstract

A method for biodiversity assessment and natural resources management in the Pechora River Basin is developed, to evaluate the sustainability of land-use. Data were collected on the abiotic and the biotic system, and models are being developed on forest production, regeneration and changes in biodiversity. Species diversity differs per taxon, but also alpha and beta diversity differs, and management has large impact on the species diversity. We show that high species diversity is often associated with harvesting, due to invasion of plant and bird species in open vegetation. In other ecosystems we observe a high species diversity for disturbed areas (e.g. gardens, with ruderal species and neophytes), and low diversity for species-poor ecosystems such as peatlands or even some pristine forests.

Species diversity was found to be a poor approximation of biodiversity in the sense of ecosystem value, since different succession stages and disturbance regimes result sometimes in high species numbers, compared to undisturbed ecosystems. We propose therefore a different approach, based on a number of indicators at both landscape (ecosystem) and stand level. At landscape or ecosystem level we propose ecosystem rarity, landscape pattern, naturalness, and representativeness as indicators. At stand level we propose species diversity, species rarity and dead wood.

Introduction

The Pechora River Basin (Komi Republic and Nenets Autonomous District) is situated in the Russian Federation, just west of the Ural Mountains (Figure 1). The territory is larger than Germany and is covered with tundra in the north, and boreal forests (far northern, northern and middle taiga subzones) in the south. Parts of these forests have been harvested, but still

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Figure 1. Pechora River Basin, Russia.

large areas can be considered as pristine areas. Within this territory lies the Komi Virgin Forest Reserve, which was included in the UNESCO World's heritage sites in 1995 and forms with 3.28 million ha the largest protected taiga forest in the world (Anon. 1999; Anon. 2001).

The Pechora River is, with a length of 1809 km, one and half time as long and with a catchment basin of 288 000 km^2, twice as large as the river Rhine. The river itself is however almost in its natural state, with only one bridge crossing the river and no major river improvement works established (Van Eerden 2000). Only one railway line connects the northern industrial town of Vorkuta with the southern part of the Komi Republic, and the Russian hinterland, no roads are present in the north outside the few urban areas.

Forestry and mineral exploitation (oil, gas, minerals) are important economical activities in Komi. Several processing industries related to these are present in the region, in particular Neusiedler-Syktyvkar, one of the largest pulp and paper factory of Europe. Small scale farming activities, hunting, fishing and haymaking take place, concentrated around existing settlements and villages. Production is mainly for subsistence, since the infrastructure is very limited.

Over the past 80 years vast areas of mainly pristine forest have been harvested, with a steady increase from the forties onwards up to the 1980s of the past century, when 26 million m^3 were harvested annually (Figure 2). Low prices for timber have lead to a decrease in wood demand from this region, production being only some 5.5 million m^3 per annum at present (Kozubow and Taskaev 2000; Angelstam et al. 1995). However, with more strict conservation policies being implemented in Western Europe, it is to be expected that demand will increase, leading to more harvesting, and eventually also increased pressure on pristine forests or valuable secondary forests. In addition, the following problems are encountered in forestry:

- large scale clear-cuts in primary forest;
- unsatisfactory regeneration after clear-cut, leading to commercially uninteresting stands as secondary forests;
- loss of biodiversity;
- small share of commercial stems and large losses of commercial stems at harvest;
- limited rural development

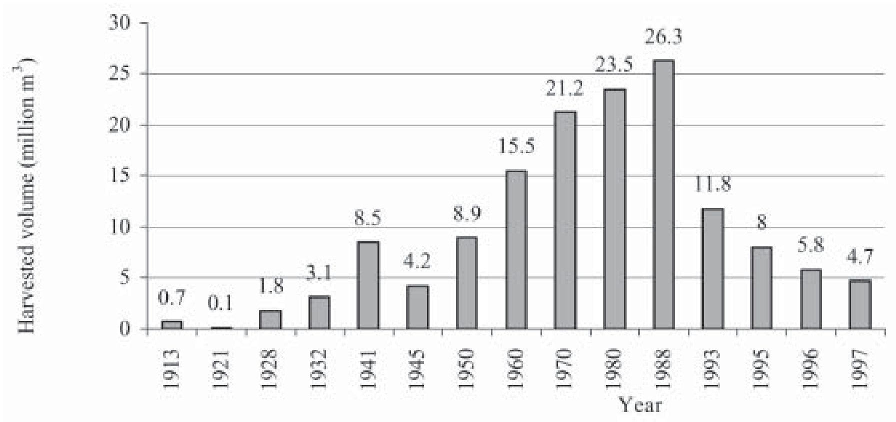

Figure 2. Harvested timber volume in the Komi Republic (Kozubow and Taskaev 2000).

A method for biodiversity assessment and natural resources management in the Pechora River Basin is necessary if a sustainable land-use is to be accomplished. Such a method is at present being developed in the framework of the PRISM project. The PRISM (Pechora River Integrated System Management) project focuses on sustainable management of natural resources. The results of the project should give indications for more sustainable forestry management in Russia, but also help in understanding natural processes in forests in Western Europe.

A first step is to collect and compile spatial data on the abiotic (soils, hydrology) and the biotic systems (flora, fauna). This information should be stored in a digitized form and be made available to planners and decision-makers. Second, models are required to develop and evaluate different development scenarios. Important input data for such models are forest structure, forestry production and biodiversity. Models currently developed in the PRISM project are the Pechora Basin Hydrological Model, the ForGra forestry model (Jorritsma et al. 1999) and a biodiversity model. Based on these models the evaluation of different strategies for forest management is possible as well as predictions on forest production, regeneration and changes in biodiversity.

This paper presents criteria and indicators and proposes a biodiversity model for boreal forest.

What is biodiversity?

The definition on biodiversity is central in any assessment method. A common indicator is the species number per area; often the number of vascular plant species. However, it is well known (e.g. Newton and Kapos 2002) that species number only is not a good indicator, since relatively high values are encountered in disturbed situations, and relatively low species numbers are found in pristine ecosystems.

'Biodiversity' is a contraction of biological diversity. Diversity is a concept which refers to the range of variation or differences among some set of entities; biological diversity thus refers to variety within the living world. It has become a widespread practice to define biodiversity in terms of genes, species and ecosystems, corresponding to the three fundamental and hierarchically related levels of biological organization (WCMC 1992; http://ceres.ca.gov/biodiv/Biodiversity/biodiv_def2.html).

Box 1. Principles for choosing indicators (CBD 1999, 2003).

On individual indicators:

Policy relevant and meaningful
Indicators should send a clear message and provide information at a level appropriate for policy and management decision making by assessing changes in the status of biodiversity (or pressures, responses, use or capacity), related to baselines and agreed policy targets if possible.

Biodiversity relevant
Indicators should address key properties of biodiversity or related issues as state, pressures, responses, use or capacity.

Scientifically sound
Indicators must be based on clearly defined, verifiable and scientifically acceptable data, which are collected using standard methods with known accuracy and precision, or based on traditional knowledge that has been validated in an appropriate way.

Broad acceptance
The power of an indicator depends on its broad acceptance. Involvement of the policy makers, and major stakeholders and experts in the development of an indicator is crucial.

Affordable monitoring
Indicators should be measurable in an accurate and affordable way and part of a sustainable monitoring system, using determinable baselines and targets for the assessment of improvements and declines.

Affordable modelling
Information on cause-effect relationships should be achievable and quantifiable, in order to link pressures, state and response indicators. These relation models enable scenario analyses and are the basis of the ecosystem approach.

Sensitive
Indicators should be sensitive to show trends and, where possible, permit distinction between human-induced and natural changes. Indicators should thus be able to detect changes in systems in time frames and on the scales that are relevant to the decisions, but also be robust so that measuring errors do not affect the interpretation. It is important to detect changes before it is too late to correct the problems being detected.

- Genetic diversity: the heritable variation within and between populations of organisms.
- Species diversity: the number of species in a site or habitat (is also called species richness)
- Ecosystem diversity: the diversity of ecosystems. Since there is no unique definition and classification of ecosystems at the global level, it is difficult to assess ecosystem diversity other than on a local or regional basis and then only largely in terms of vegetation.

Under the Convention on Biodiversity (CBD) countries are obliged to monitor biodiversity. Monitoring is important to detect ecosystem changes, or effects of e.g. specific restoration measures or air pollution.

The UNDP formulated a number of criteria, which should be met by the indicators (see Box 1, CBD 1999, 2003).

Indicators should be appropriate for use at a local scale level, but it should be possible to aggregate data to larger scale levels (FAO 2003). Also the CBD has emphasised the need to adopt the ecosystem approach in indicator development (Newton and Kapos 2002).

Table 1. Used indicators to determine conservation value of areas. Source: De Groot (1992), modified after Usher (1986) and Spellerberg (1992).

Criteria	Relative importance*	Ranking	Relative importance**	Ranking
Diversity (of species and/or habitat /only species)	12.2	1	18.1	1
Rarity (of species and/ or habitat)	11.3	2	9.2	4
Representativeness	10.2	3	2.5	11
Area size needs/minimum critical ecosystem size	9.9	4	1.3	13
Naturalness/heritage value	8.9	5	8.1	6
Scientific value	8.4	6	-	-
Ecological fragility/species vulnerability	8.3	7	2.5	11
Uniqueness/endemicity	8.0	8	-	-
Threat of human inference	8.0	9	11.2	3
Wildlife reservoir potential	7.4	10	-	-
Potential value	5.0	11	3.3	10
Management factors	4.8	12	0.7	15
Position in ecological geographical unit	4.7	13	4.0	8
Replaceability	3.8	14	13.1	2
Amenity value/aesthetic qualities	2.8	15	-	-
Record history	2.0	16	0.8	14
Education value	1.5	17	-	-
Availability	0.7	18	-	-
Special environmental conditions	-	-	0.7	15
Maturity	-	-	9.0	5
Completeness	-	-	4.5	7
Protection function for abiotic factors	-	-	0.7	15
Synecological importance	-	-	4.0	8

* The importance of values calculated are based on Margules and Usher (1986) using the Delphi-method
** Weighting in 20 analysed assessment methods for areas (biotopes), which were within impact regulation in Germany

Many aspects are in general considered important for biodiversity, or conservation value. Table 1 presents indicators generally used for biodiversity. Different combinations and weighting of criteria can be compounded to a ‘total value’ for conservation. The approach with different criteria and their associated weighting includes a large element of subjectivity, which might lead to widely differing evaluation results between different evaluators (Spellerberg 1992).

The PRISM biodiversity assessment method aims to describe and quantify impacts of certain scenarios. The indicators should be sensitive to impacts of forestry, changes in hydrology and land use, and pollution and fragmentation.

Method

The biodiversity assessment of our method is based on the number of species per ecosystem type, since this type of estimate is easily measurable and well understood (Noss 1997). Although it is difficult to cover all species, in particular in large areas such as the Pechora River Basin, using a relevé basis gives a reasonable approximation. The species-richness approach used here seems justified, considering the scale of the area, and the fact that a large number of relevés is available.

In 2002 and 2003 surveys were performed in the Pechora Basin, both in nearly pristine areas and areas where land use (mainly forestry, mining activities, fisheries, infrastructure) had a large impact on the ecosystem. A multidisciplinary expedition team collected data on different aspects of the ecosystem. Various abiotic parameters were described in a multi-disciplinary approach: soil type, hydrology, geomorphology, and humus profile. Also flora and fauna were surveyed: composition of lichens, mosses, vascular plants, mammals, birds, fishes, insects and herpetofauna. Plots of 400 m^2 were sampled in different land units, for abiotic conditions, flora and insect composition. Transects of several kilometers were sampled in different land units to define composition of birds and herpetofauna.

Mammals were classified according to their size. Elk, brown bear and wolf were considered large mammals, red fox, stoat, red squirrel and arctic hare medium sized, and muskrat and water vole were considered small mammals.

In key sites seven ecological transects were laid out, their length varying up 2 up to 5 km from the river through the floodplain into the upland territory. Transects were selected on the basis of satellite images. At the selected sites in different land units along the transects, detailed information was collected on plant communities and diversity of vascular plant species at plots of 400 m^2 (in total 275 releves).

The structure of vegetation communities was described according to the different layers identified – tree stand, shrub and tree undergrowth, grass, dwarf-shrub and moss cover. In forest communities a number of parameters were described – composition of stand, crown density, height, trunk diameter, age, regeneration. The species composition and abundance of vascular plants, lichens and bryophytes were noted.

In the same locations also data on soil type, mosses, lichens and soil invertebrate diversity was collected. Lichen (3000 samples) were taken from different types of substratum – the bark of trees and shrubs, stumps, fallen trees, dead trees, soil, stones, treated timber. Mosses (500 samples) were taken mainly from the soil and dead wood. Insects were collected using generally accepted quantitative and qualitative methods of recording: excavation and manual sorting of soil samples with a volume of 0.0625 m^2, catching by Berber's soil traps and window traps, and about 3000 entomological soil-litter samples were collected. Species composition of lichens, mosses and invertebrates were stated more precisely after determination of samples in the laboratory.

In all studied areas direct observation of mammals, their tracks and droppings were recorded to obtain an impression on mammal species composition and distribution in different habitats. Mammal presence were studied along transects by foot, by car and by boat. For investigation of bird species composition so-called "territory mapping method" was used in accordance with generally accepted methods in zoogeographical research. Also here the survey routes were done on foot, by car and by boat. During surveys singing male, spotted birds (mainly territory holders) and families were counted.

Results

The α-diversity for vascular plants (i.e. the total number of species within a local habitat) was highest in the land units related to the fluvial area, i.e. meadows, willow stands and to some extent birch forests (Figure 3).

The highest macro-lichen diversity was found in the forests with and accumulated total of 123 species and 93 species in spruce forests. In willow stands 74 species were recorded, in swamps 50 species, and only 27 species on meadows.

Although not tested statistically, there seemed to be a tendency for higher vascular plant species number per relevé in undisturbed forests relative to forests affected by forestry (Table

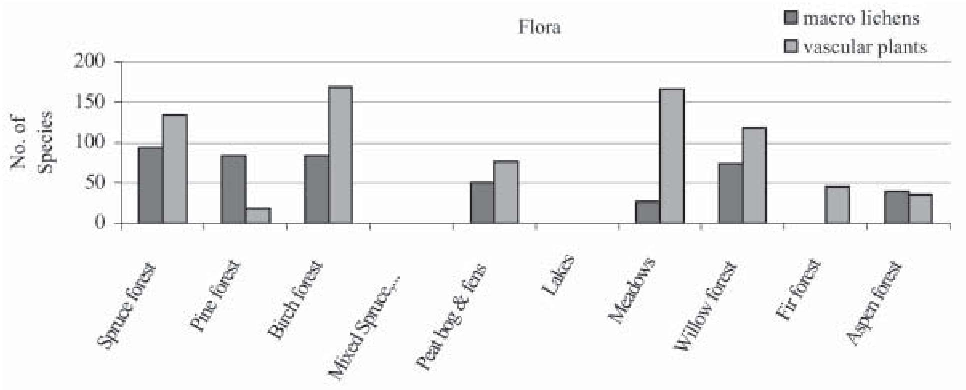

Figure 3. Number of vascular plant species and macro-lichens (total number, accumulated) as observed in 2002 fieldwork (Leummens et al. 2002).

2). For example, the average number of vascular plants, mosses and trees for relevees classified as birch and aspen forest is 48 in an undisturbed situation (n=9). Birch is mainly found as climax vegetation along streams and rivers or as pioneer vegetation after clearcut or other disturbance. In pioneer vegetations species diversity decreases to respectively 32 (n=8), 33 (n=2) and 28 (n=7). After disturbance or human impacts, e.g. floodplain meadows, farming or horticulture, the biodiversity increases, i.e. the absolute number and diversity of species might be larger (Table 2).

Two amphibian and one reptile species were observed in the study area: Common frog (*Rana temporaria*), Moorfrog (*Rana arvalis*), and Common lizard (*Lacerta vivipara*). Most observations were done on amphibians in the River valley, in particular in meadows and riverine grasslands (Figure 4).

The highest bird species diversity was observed in mixed forests, which were formed by spruce and birch (42 species) followed by spruce forest and floodplains (which includes a variety of riverine habitats such as sandbanks, gravel banks, channels and floodplains). In general, conifer forests seemed to have the highest diversity (Figure 5).

The largest number of mammals was observed in the pine forest (7 species, equally distributed over different groups), although differences were limited. The upland forests had in general higher species diversity than e.g. peat bogs, willow forest (along the river) and floodplains (Figure 6)

Discussion

Species diversity approach

Species diversity as a biodiversity indicator is usually applied in the sense that high species diversity is regarded as better and maximum species-richness is the most important management goal (Attiwell 1994, in Lindenmayer 1999). However, in our study we observed that high species richness for some species groups is associated with harvesting activities due to invasion of plant and bird species in open vegetation, also observed by e.g. Wohlgemuth et al. (2002). In other ecosystems we found high ‘biodiversity values’ for disturbed areas (e.g.

Table 2. Species diversity per relevé, (Van der Sluis in Leummens et al 2002b) ; n=148. - = no observations, n.a. = not applicable.

		Average # of vascular plant species			
		clearcut	selective cutting	otherwise disturbed	not disturbed
Upland Territory	Spruce forest	13.0	9.0	41.0	20.8
	Pine forest	10.0	-	10.0	-
	Birch & Aspen forest	19.0	13.0	16.6	34.4
	Mixed forest	-	-	9.0	20.1
	Sphagnum bog	n.a.	n.a.	17.0	9.8
	Fen	n.a.	n.a.	10.0	n.a.
River Valley	Meadow	n.a.	n.a.	36.4	n.a.
	Sandbank	n.a.	n.a.	n.a.	39.0
	Willow stand	n.a.	n.a.	n.a.	30.0

		Average # plants, trees, mosses			
		clearcut	selective cutting	otherwise disturbed	not disturbed
Upland Territory	Spruce forest	16.0	18.4	59.0	23.9
	Pine forest	24.0	-	18.5	-
	Birch & Aspen forest	32.3	33.0	28.1	48.2
	Mixed forest	-	-	23.0	36.4
	Sphagnum bog	n.a.	n.a.	31.0	20.0
	Fen	n.a.	n.a.	n.a.	16.5
River Valley	Meadow	n.a.	n.a.	41.8	n.a.
	Sandbank	n.a.	n.a.	n.a.	40.5
	Willow stand	n.a.	n.a.	n.a.	35.4

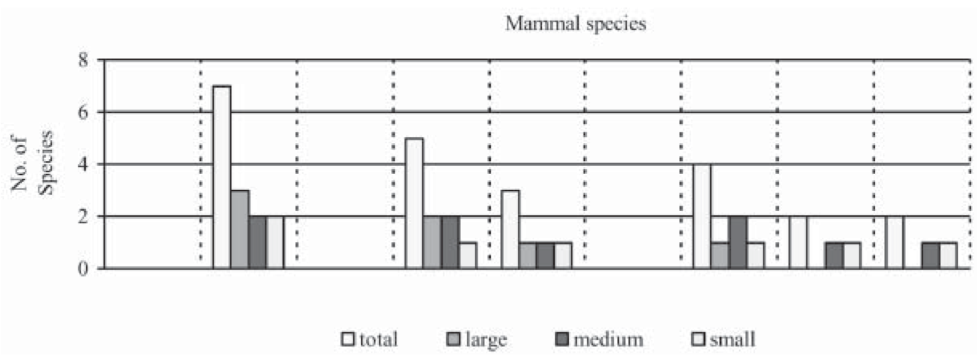

Figure 4. Number of mammals (grouped according to size) as observed in 2002 fieldwork (Leummens et al. 2002).

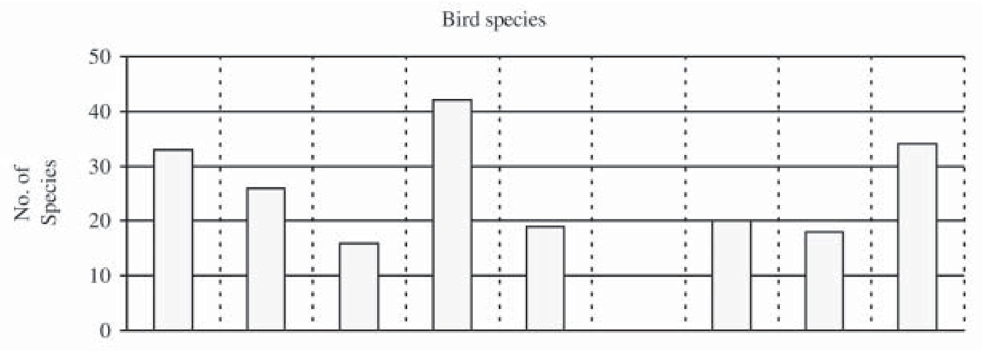

Figure 5. Bird species as observed in 2002 fieldwork (Leummens et al. 2002).

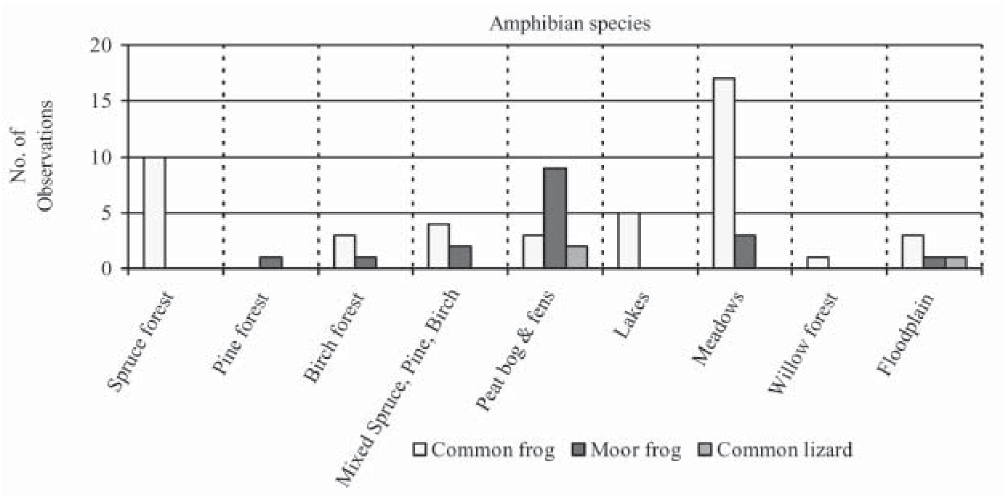

Figure 6. Observations herpetofauna, as observed in 2002 fieldwork (Leummens et al. 2002).

gardens, with ruderal species and neophytes), and low biodiversity for species-poor ecosystems such as peatlands or even some pristine forests. Species that depend on intact forest ecosystems may well disappear in such a dynamic situation, and in particular rare species might be absent despite the high species diversity (Lindenmayer 1999, Wohlgemuth et al. 2002). Species richness assessed at a scale exceeding local stand level might be reduced in these situations. It also shows that species richness is very much dependent on scale and time. Species diversity is therefore a poor approximation of biodiversity.

Finally, species diversity may mask important changes in community assemblages.

But biodiversity is not just the sum of species numbers for all taxa, we also find differences between species groups: the important habitats for lichens might differ totally from the areas with high species diversity for birds or mammals. This was also observed in other research (e.g. Jonsson and Jonsell 1999).

For vascular plants and amphibians we find a high species diversity in meadows, whereas these are rather poor for mammals and birds (Figures 3–6). So here we also see that species diversity as such is no good indicator in a diverse forest landscape with natural forest stands.

Another approach would be to use special indexes to describe species diversity. The simplest index is Simpson's diversity index, which considers both abundance (biomass), and species richness. Also Shannon-Weaver's diversity index is widely used (Huston 1994). This index uses both abundance and number of species present. Higher values are obtained in communities with many species, evenly distributed. Both methods have the disadvantage that they are more difficult to interpret. Besides, very specific and valuable aspects of biodiversity would still be lacking in this approach.

An alternative approach for biodiversity assessment

Since species diversity does not reflect very well biodiversity, it is considered important to use a wider definition of ecosystem biodiversity. To improve our assessment we have selected other indicators to be included in the biodiversity model. There is much overlap between different indicators. In addition, indicators are operational at different levels, e.g. at stand level or landscape level (Table 1).

For the PRISM project the following selection of the most relevant indicators is proposed for 'biological diversity':

- At landscape/ecosystem level
  - ecosystem rarity (e.g. number of rare or endemic species)
  - landscape pattern (minimum critical ecosystem size)
  - naturalness
  - representativeness
- At stand level, or local level
  - species diversity
  - species rarity (e.g. number of Red List, rare, protected or endemic species)
  - dead wood

Indicators at landscape level

Ecosystem rarity

Rarity or uniqueness of an ecosystem or species is an important component for biodiversity. Ecosystem uniqueness can be assessed by the mean of the endemism of various taxonomic groups. Another measure is the share of an ecosystem type in the total surface area.

Only one endemic (plant) species occurs in the area, this is therefore not of much use. There are rare ecotopes present like Mountain tundra on the Ural mountains, or specific abies forest types, which would be valued higher due to a small share in the study area.

Landscape Pattern (area size; minimum critical ecosystem size)

Each natural community or ecosystem requires a minimum amount of space, to maintain its diversity and to function properly. The size of an area therefore is of critical importance for its functioning as protected area (McArthur & Wilson 1967). Reserves that are too small can never support the full range of species that might be considered as part of the ecosystem. Besides, if the area is limited or if the carrying capacity is low, populations are too small to be sustainable (Groot Bruinderink et al. 2003).

Studies in Sweden and Finland show that species diversity might increase with the age of the forest. However, in some cases where forest fragments were less than 20 ha in size it was argued that the absence of these species might be due to fragmentation, since in similar areas in more intact landscapes specific indicator species like tree-toed woodpecker (*Picoides tridactylus*) or grey-headed woodpeckers (*Picus canus*) are present (Uliczka & Angelstam 2000).

Most common indicator for fragmentation or landscape pattern are landscape matrices, or indices, e.g. calculated by Fragstats (McGarigal & Marks 1995). However, these indices are of no value, as long as there is no proper relationship with specific species and species requirements.

Important indicator for large-scaled, intact forest ecosystems in Pechora (and therefore for the scale of the landscape) may be the Brown bear or Elk (*Alces alces*), or characteristic birds species such as Capercaillie (*Tetrao urogallus*), tree-toed woodpecker or White-tailed Eagle (*Haliaeetus albicilla*)

Naturalness

Naturalness of a site can be narrowly linked to species diversity. In general species numbers tend to increase after disturbance of virgin ecosystems, due to a different light regime and an increase in available (disturbed) habitat. We might see therefore e.g. an increase in vascular plant species, bird, insect and invertebrate species. On the other hand, some species groups clearly show a preference for undisturbed situations, in particular dead wood fauna, cryptogamic species and large mammals (Wohlgemuth et al. 2002).

The naturalness of an area depends on the degree of human presence, either in terms of physical, chemical or biological disturbance (De Groot 1992). The degree of naturalness defines the intensity of human interventions. In the Ministerial Conference on the Protection of Forests in Europe (www.mcpfe.org) naturalness has been described in three classes:

- undisturbed by man
- semi natural
- plantations

In the Pechora Basin the former two classes are prevalent. Undisturbed forests were classified in a number of international projects, but most of the forests have been cut during the past century. Plantations are rare, due to the extensive forests still presents and the relatively high costs for planting trees.

Representativeness

Representativeness does refer to the fact that a reserve should contain biota which represent the range of variation found within some land class or region (Usher 1986). The concept might have been introduced under the Man and Biosphere program, where the aim of the biosphere reserves was to represent the range of global biotic provinces.

The Yugid Va is a MAB reserve which contains forest and mountain biota, as well as undisturbed peatlands and tundra. However, for the Pechora Delta more specific biota might be selected still as specific representative area.

Indicators at stand level or local level

- Species diversity as discussed before under methods.
- Species rarity. The number of rare or endemic species is a measure of rarity. Measures of presence of rare species are the Red lists species, species that are under threat, at various levels.

Endemism might be a specific form of rarity, for species restricted to particular areas with a prescribed extent. Endemics, as mentioned, are few, but in the study area red list species occur: at least 24 plant species, 29 birds, 1 reptile and 6 mammals.

Rarity can also be based on range-size as well as density (http://www.nhm.ac.uk/ science/ projects/worldmap/ index.html).

Dead wood

In many assessments and evaluations dead wood is seen as an important indicator for biodiversity. Many species are dependent on dead wood, and its presence means therefore additional diversity in the ecosystem. Dead wood might also indicate more extensive management practices or no management at all, with associated higher biodiversity. There are many different approaches in assessment of dead wood (see e.g. Ståhl & Lämås 1996).

In the Pechora Basin dead wood is present, and very obvious, because transformation and decaying processes are very slow, due to climatic conditions. That may result in burned trees of 70 years old that are still standing, and sometimes up to 10 fallen trees per sampled area.

Biodiversity algorithm

The indicators listed above can be combined and integrated in one measure of biodiversity. Based on the available field data we can define for every relevé or sampled area and for every taxon an integrated measure for biodiversity. We propose the following algorithm for the Biodiversity Value (B_{tax}) for each taxon:

$$B_{tax} = \frac{DI + R + N + MA + Re + DW}{6}$$

in which:
DI = species diversity (e.g. α-diversity or Shannon’s diversity index)
R = rarity (number of Red-List species, protected species, endemism)
N = naturalness (i.e. rate of disturbance)
MA = meeting requirements for Minimum Area size (fauna)
Re = Representativeness
DW = Dead wood

The B_{tax} can be compiled for different ecosystems on the basis of values for all relevees. For all the taxa we can then come to an assessment of biodiversity for different ecosystems, which can be scaled, e.g. from 1 to10, to make them comparable.

An integrated measure for different taxa can also be compiled to define hotspots for biodiversity within the Pechora River Basin.

Conclusions

Species diversity is a poor approximation of biodiversity in the sense of ecosystem value. In particular comparing situations of climax vegetation with disturbed situations, the high species number in the latter would indicate higher biodiversity, which is not realistic. More appropriate indicators of biodiversity should then be selected to come to a sustainability-related assessment of biodiversity. In this paper we propose a number of indicators that are considered important in the framework of the PRISM project, these indicators are based on other studies and biodiversity assessments.

The indicators described here are relevant for Pechora, however, it should be tested still with data for the entire region.

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