Environmental Quality Criteria for Forest Landscapes

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Preface

The following assessment criteria are intended to facilitate the interpretation of chemical and biological data on forests and forest land.

Contents

Summary

The forest landscape with its flora and fauna is affected primarily by forestry, but also by atmospheric deposition of pollutants.

Forestry changes the species composition and age structure of forests, usually in ways that lead to reductions in biological diversity. The potential for species diversity in a forest landscape depends to a large extent on the proportion of broad-leaved trees, standing or fallen dead trees, large old trees, and stands of intact old-growth forest. Several of the assessment criteria presented here relate to the extent of such elements in the forest landscape. With few exceptions, they are all less widespread today than in the past.

Among the most serious effects that pollution can have on the land and water of the forest landscape are heightened levels of heavy metals, and leaching of nitrogen from nitrogen-saturated soils to nearby bodies of water. These effects are also dealt with by the assessment criteria.

Old-growth Forest

Forest that is older than 130–150 years may be regarded as old growth, the proportion of which in the forest landscape is essential to the survival of many species.
Background

Many species of the forest landscape are associated with old-growth forest that has not been significantly affected by modern forestry. The life cycles of many species are so long that they do not have time to reproduce if the forest does not become old enough. Some species may also have special habitat requirements, such as the presence of deadwood or moist air, which can only be met by old-growth forest.

The total area of old-growth forest has declined dramatically in Sweden during the 20th century, and the stands that do remain have become increasingly isolated from each other. It is primarily species with limited migration potential that are threatened when old-growth forest is fragmented in this way.

For the purposes of this discussion, old-growth forest is defined as any forest that is over 150 years old in northern Sweden (regions 1–3), or over 130 years old in southern Sweden (regions 4–5). This refers to the average age of a stand, which may also include a few much older trees that rise above the dominant canopy, and/or younger trees growing beneath the main canopy.

In northern Sweden, especially in forest tracts bordering the mountains in the west, there are many areas containing over ten percent old-growth forest. But in southern Sweden, less than two percent may now be regarded as old-growth.

Assessment of current conditions – old-growth forest

Class	**Proportion of old-growth forest**	**Percentage of total area**	**Description**
1	Large	50-100	Contiguous biotope with little fragmentation.
2	Fairly large	30-50	Partially disconnected biotope with minor fragmentation.
3	Fairly small	10-30	Disconnected biotope; many species dependent on large intact stands of old-growth forest cannot survive.
4	Small	5-10	Very disconnected biotope; long-term threat to species with limited migration potential.
5	Very small	0-5	So little of biotope remaining that survival is uncertain for essentially all species dependent on old-growth forest.

The proportion of old-growth forest in the forest landscape is here used as a general index of living conditions for species dependent on such a habitat. A proportion of fifty percent is roughly the dividing line between contiguous biotopes and those that are starting to become fragmented. The minimum requirement for several bird and mammal species is 10–30 percent old-growth forest.

Reference value

Due to fires and other natural disturbances, the proportion of old-growth forest is limited even in forest landscapes that have not been subjected to the effects of human activity. The proportion of old-growth stands may vary considerably between different types of forest.

In boreal forests (regions 2–4), however, a proportion of twenty percent can be used as an approximate reference value for old-growth forest, i.e. as an estimate of conditions in a pristine environment. There is no suitable basis for a corresponding reference value for the broad-leaved forests that grow further south.

Class	Extent of deviation	Percentage of total area
1	None or insignificant	> 16
2	Slight	8-16
3	Significant	4-8
4	Large	2-4
5	Very large	0-2

This classification indicates the extent to which the old-growth proportion of forest in regions 2–4 differs from the estimated reference value.

Broad-leaved Forest

Stands with over fifty percent broad-leaved species can be regarded as broad-leaved forest. Their proportion of a forest landscape's total area is decisive for the survival of many species.

Background

The proportion of broad-leaved tree species is often much lower in forests that have been subjected to intensive forestry than in those left undisturbed. This applies especially to older stands. Logged areas and young forest may have a large proportion of broad-leaved species, but there is usually a lack of older trees. In addition to forestry, broad-leaved species have suffered from the grazing pressure of recent years' large populations of elk (moose) and roe deer. This development has had negative consequences for many species of birds, insects and plants which are dependent on broad-leaved trees.

Broad-leaved forest is here defined as any forest including a proportion of broad-leaved trees that exceeds fifty percent. Most forest of that description is located in the southernmost part of Sweden, which is included in the earth's temperate broad-leaved forest zone. But due to the widespread planting of spruce, such forest now comprises less than half of the total even in this part of Sweden. In the rest of Sweden, it often covers less than ten percent of the forest landscape.

Assessment of current conditions

Class	Proportion of broad-leaved forest	Percentage of total area	Description
1	Large	50-100	Largely contiguous biotope with little fragmentation.
2	Fairly large	30-50	Partly disconnected biotope which may be slightly fragmented.
3	Fairly small	10-30	Disconnected biotope; many species dependent on large intact stands of broad-leaved forest cannot survive.
4	Small	5-10	Very disconnected biotope; long-term threat to species with limited migration potential.
5	Very small	0-5	So little of biotope remaining that survival is uncertain for essentially all species dependent on broad-leaved forest.

The proportion of broad-leaved forest in the forest landscape is here used as a general index of living conditions for species that are dependent on such a habitat. For such species to survive, the distance between individual stands of broad-leaved trees must be kept to a minimum.

Due to a lack of data, it is not possible to determine reference values and deviations for broad-leaved forest.

Deadwood in Forest Landscapes

Standing and fallen dead trees, and other deadwood, have become scarcities in the modern forest landscape. This has created difficulties for a large number of species which are in various ways dependent on the availability of such wood. In the following discussion, fallen trees are used as the primary indicator of the deadwood supply.

Background

Deadwood in the form of standing or fallen tree trunks is a basic requirement for a number of very different species. For some organisms, deadwood is a source of food; for others, it provides shelter or sites on which to live and grow. Many wood-dependent species have special requirements relating to tree species, the stage of decay and trunk width.

One consequence of modern forestry is that not many trees live long enough to die of natural causes. The supply of deadwood is therefore much less than under pristine conditions, and many species associated with deadwood are currently rare or endangered.

By the mid-1980s, in Swedish forests subject to modern forestry, there was an average of 6.1 cubic metres of deadwood per hectare (2.471 acres). Of that amount, some three-fourths consisted of fallen tree trunks, and the remainder of standing trees or snags.

The proportion of deadwood decreases from north to south, from an average 15 cubic metres per hectare in the forests near the mountains, to less than four cubic metres in the forests of central and southern Sweden. (These figures refer to trunks more than ten centimetres in diameter.)

Assessment of current conditions

Class	**Quantity**	**Fallen trunks** (> 10 cm diam.) No./hectare	**Fallen trunks** (> 25 cm diam.) No./hectare	**Potential for biological diversity**
1	Large	> 150	> 15	Very high
2	Fairly large	75-150	8-15	High
3	Fairly small	30-75	4-8	Moderate
4	Small	15-30	2-4	Low
5	Very small	< 15	< 2	Very low

This classification is based on accumulated knowledge of how the number of fallen trunks affects the survival chances of wood-dependent species. Trees or sections of trunks that have decayed to such a degree that their original forms can no longer be distinguished, are not included.

Reference values

Forest type/region	% deadwood	Quantity	No. fallen trunks	
	Trunk diameter > 10 cm		Diam. > 10 cm	Diam. > 40 cm
Evergreen forest, regions 1-4	20% of total wood volume	30 m^3/ha	90/ha	
Broad-leaved forest, region 4				15/ha

The reference values are estimates – possibly underestimates – of the amount of deadwood in pristine forests.

Deviations from reference values

Class	Extent of deviation	Deviation ratio (measured value/reference value)
1	None or insignificant	> 0.8
2	Slight	0.4-0.8
3	Significant	0.2-0.4
4	Large	0.1-0.2
5	Very large	0-0.1

Deviations from reference values indicate the extent to which the existing supply of deadwood differs from that under pristine conditions.

Large and Hollow Trees in Forest Landscapes

Species diversity in forest landscapes is dependent on the availability of very large trees and hollow trees (due to interior rot). Such trees are much less prevalent now than during the 1800s. The following reference values and classification of deviations are based on the number of large and hollow trees per hectare.

Background

Large old trees are of great importance to insects that live under bark or in wood, for a number of bird species that nest in tree-holes, and as growing sites for wood lichens. Exceptionally old and large broad-leaved trees often rot slowly from within. They are frequently hollow, with wood mould on the interior surfaces. Such hollow trees usually provide habitat to a very rich insect fauna.

Most of Sweden's large trees are located in the southern part of the country, where there is a higher rate of growth than in the north and a good supply of oaks and other broad-leaved species that can develop very large diameters. In the country as a whole, however, the supply of large trees has declined sharply since the 19th century, due largely to the expansion of modern forestry.

Today, the average number of trees with diameters greater than 40 cm is fourteen per hectare in Sweden's temperate zone (the southern region of broad-leaved forest). In the boreal zone of northern Sweden, there is hardly more than one such tree per hectare.

At present, there are no reliable data on which to base quantitative assessments of how the number of large and hollow trees affects the biological diversity of forest landscapes.

Reference values

Forest type/region	**Number of trees per hectare**			
	Diameter > 30 cm	Diameter > 40 cm	Diameter > 70 cm	Hollow tree
Evergreen, regions 2-4	40	8		
Broad-leaved, region 4		80	15	
Broad-leaved, regions 4-5				10

Reference values are estimates of the number of large and hollow trees in pristine forests. In southern Sweden, however, it is difficult to estimate the natural frequency of large trees. There, broad-leaved woods have often been part of the open agricultural landscape, which long benefited the growth of large broad-leaved trees.

Deviations from reference values

Class	Extent of deviation	Deviation ratio (measured value/reference value)
1	None or insignificant	> 0.8
2	Slight	0.4-0.8
3	Significant	0.2-0.4
4	Large	0.1-0.2
5	Very large	0-0.1

Deviations from reference values indicate the extent to which the existing number of large and hollow trees differs from their number under natural conditions. Since the reference values are broad generalisations for sizeable geographical areas that include many different types of forest, this classification must be applied with discretion. Where forestry is being conducted, consideration must be given to the current stage of production.

Acidification of Forest Land

Acidification of soils is often followed by several chemical changes, including increased levels of aluminium, and lower levels of calcium, magnesium and similar substances. Those levels are used here to supplement pH values in measuring soil acidity.

Background

During the 1900s, forest land has become distinctly more acidic throughout much of the country. In many parts of southern and western Sweden, the pH level of soils has declined by 0.3–1.0. Deposition of sulphur and other acidifying airborne pollutants is the main cause of that development, but intensive forestry can also contribute to soil acidification.

Acidification leads to lower levels of base cations (calcium, magnesium, sodium and potassium), and to increases in levels of aluminium in soluble forms. High levels of aluminium are harmful to many soil-dwelling organisms.

In general, plants and soil-dwelling animals are adapted to a specific level of acidity, which means that acidification may lead to the disappearance of some species. These may be replaced by other species, but the general tendency is for species diversity to decline with rising acidity.

There has been a significant decrease in acid precipitation during recent years, but it still exceeds the soils' capacity to neutralise it in large parts of southern and central Sweden. If acid precipitation does not continue to decrease, the acidification of soils in those regions will continue.

Assessment of current conditions

Class	Acidity	pH_{H2O}	Effective base saturation (%)	Soluble aluminium (mmol/kg dry substance)
1-2	Low	> 5.5	> 50	< 3
3	Moderate	4.4 - 5.5	10 - 50	3 - 10
4	High	4.0 - 4.4	6 - 10	10 - 12
5	Very high	< 4.0	< 6	> 12

This classification is based on three different levels of soil acidity: pH value, base saturation, and aluminium level. The pH value is the primary basis of the classification. The soil is assigned the acidity classification indicated by its pH value, if at least one of the other two measures falls into the same class or if one is over and the other is under. If both of the other measures fall into a higher or lower class than the pH value, the latter is adjusted one step up or down, accordingly.

The classification applies to soil samples taken from the top five centimetres of the enrichment zone (B horizon) on well-drained (not too wet) land with half-mature or mature forest. On logged areas and in reproduction and young forests, the soil's pH value is usually 0.2–1.0 higher.

The pH value is measured in water solution. The effective base saturation is defined as the proportion of base cations as a percentage of the total amount of base cations and aluminium (Al3+). Base cations are extracted in 1 M ammonium acetate at pH 7.00. Aluminium is extracted in 1 M potassium chloride.

Together with data on the current level of sulphur precipitation, the acidity classification can provide some indication of the risk that soil acidification will continue. This indicates, in turn, the long-term risk of damage to living organisms from acidification of soils and adjoining bodies of water (see table below).

Long-term risk of damage from soil acidification

Acidity class	**Sulphur deposition from human activities**		
	Low (< 2.5 kg/ha/yr)	Moderate (2.5-12 kg/ha/yr) Risk of damage	High (> 12 kg/ha/yr)
1-2	Low	Low	Moderate
3-4	Low	Moderate	High
5	Moderate	High	High

If possible, the soil's sensitivity to acidification should also be considered in this evaluation of risks. For example, the risk of acid-related damage is low in areas with lime-rich soil, even with heavy deposition of sulphur.

Heavy Metals in Forest Soils

In the raw humus layer of forest soils, concentrations of metals such as cadmium, copper, mercury, lead and zinc are clearly elevated in much of the country. In areas near local sources of pollution, the increase is very great, with significant biological consequences as a result.

Background

Sharp rises in levels of heavy metals in forest soils occur in areas with extensive mining and metal industries. Less dramatic but more widespread increases, caused by long-distance transport of metals through the atmosphere, have occurred throughout Sweden – especially in the south, but even in the north.

Many heavy metals – copper, mercury and lead, in particular – are readily taken up by organic material in the surface layer of the soil, where they can reach such high concentrations as to be harmful to micro-organisms and small animals in the soil.

Other metals, including cadmium and zinc, are much more soluble and can therefore be transported through the soil more readily. Their mobility increases further if the soil becomes more acid. That is why zinc levels in soil surface layers are now lower than normal in southwest Sweden.

Assessment of current conditions

Class	Level	Cd	Cu	Hg	Pb	Zn
		μg/g dry substance				
1	Low	< 1	< 15	< 0.2	< 25	< 300
3	Moderately high	1-10	15-500	0.2-2	25-1000	300-500
5	Very high	> 10	> 500	> 2	> 1000	> 500

This classification applies to levels measured in the surface layer of podzol soils. The boundary between classes 1 and 3 has been set at the level of the incipient risk of measurable biological effects from the various metals. The levels of class 5 lead to significant and well-documented biological effects. Such levels normally occur only in areas affected by a local source of pollution.

Reference values

The reference values are estimates of metal concentrations in soils during the pre-industrial era.

Metal	Reference value (µg/g dry substance)
Cadmium	0.2
Copper	6
Mercury	0.07
Lead	8
Zinc	60

Deviations from reference values

Class	Extent of deviation	Cd	Cu	Hg	Pb	Zn
		µg/g dry substance				
1	Insignificant	< 0.2	< 6	< 0.07	< 8	< 60
2	Slight	0.2-0.8	6-24	0.07-0.14	8-32	60-120
3	Significant	0.8-2	24-60	0.14-0.35	32-80	120-300
4	Large	2-4	60-120	0.35-0.70	80-160	300-600
5	Very large	> 4	> 120	> 0.70	> 160	> 600

Deviations from reference values indicate the extent to which measured levels of metals differs from the levels of pre-industrial times. The boundary between classes 1 and 2 constitutes the reference value for the metal in question. In much of the country, current levels fall into class 2 or class 3, as a result of large-scale distribution of metals through the atmosphere. Class 5 includes only the very highest levels that have been measured in Sweden during recent years; these occur only in areas exposed to heavy pollution from a local source.

Leaching of Nitrogen from Forest Land

The easiest way to evaluate the risk of nitrogen leaching from forest land to groundwater, lakes and watercourses is by reference to the amount of nitrogen deposited via precipitation. Such an evaluation can be enhanced with the use of data on the nitrogen content of evergreen needles or of the water contained in soils above the water table.

Background

Nitrogen is an essential plant nutrient. Additions of nitrogen to forests can lead to more rapid growth, but also to soil acidification and changes to the species composition of forest ecosystems.

Normally, vegetation takes up the greater part of the nitrogen that reaches forest land via the atmosphere. Over time, however, large additions of nitrogen via precipitation or fertilisation can lead to increases in the leaching of nitrogen from the land to adjoining lakes, watercourses and seas. This, in turn, implies an increased risk of eutrophication (sometimes called “over-fertilisation”).

The risk of increased nitrogen leaching is greatest in southwest Sweden, where deposition is the greatest. But leaching in this region varies widely from place to place. It can be less than one kilogram per hectare (2.471 acres) annually, but in other locations it may equal the amount added via the atmosphere every year, i.e. over ten kilograms per hectare.

Assessment of nitrogen leaching

An initial rough estimate of the risk of nitrogen leaching can be based on the extent of nitrogen precipitation, a term which in this context refers to the amount of nitrogen in nitrates and ammonium collected from the precipitation that penetrates the canopy of an evergreen forest.

Basic evaluation of risks

Class	Nitrogen precipitation (kg/ha/yr)	Risk of nitrogen leaching	Estimated nitrogen leaching (kg/ha/yr)
1	< 10	Very little	< 1
3	10-25	Significant	> 1
5	> 25	Very great	> 10

Risks that fall into class 3 can be further evaluated, and eventually revised, with the guidance of the following classifications, which are presented in order of increasing reliability.

Supplementary risk evaluation – nitrogen content of evergreen needles

Class	Needles' nitrogen content (mg/g dry substance)	Risk of nitrogen leaching
2	< 13	Slight
3	13-15	Increased
4	> 15	Substantial

If other nutrients are lacking – especially phosphorus, potassium and magnesium – the risk of nitrogen leaching can be significant even if the nitrogen content of the needles is less than 13 mg per gram. If there is reason to suspect deficiencies of such other nutrients, the risk should instead be evaluated on the basis of the needles' content of the amino acid, arginine. However, the class limits in the table below cannot be applied to peaty soils.

Supplementary risk evaluation – arginine content of evergreen needles

Class	Needles' arginine content (µmol/g dry substance)	Risk of nitrogen leaching
1	< 5	Very little
4	5-10	Great
5	> 10	Very great

The nitrogen level of soil water provides the best information as to whether or not all available nitrogen is taken up by vegetation. In this context, level refers to the total amount of nitrogen contained in nitrates and ammonium. The soil water's nitrogen content provides an approximate measure of the extent of nitrogen leaching.

Estimated nitrogen leaching

Class	Nitrogen level in soil water (mg/l)	Nitrogen leaching (kg/ha/yr)
1	< 0.1	< 0.3
2	0.1-0.5	0.3-1
3	0.5-1	1-3
4	1-2	3-6
5	> 2	> 6