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Action plan to counteract soil acidification and to promote sustainable use of forestland

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Preface

For more than 10 years the Board of Forestry has conducted experiments into measures to control soil acidification of forestland, and herewith present the third proposal on a programme of corrective measures. Few questions in forestry have been debated so intensely during the 20th century. Numerous scientists as well as private persons interested in the forest or the environment, etc. have been involved and many persons have expressed comments on the Board of Forestry's proposals of corrective measures. In preparing the new action plan we have attempted to evaluate and balance the arguments heard in the debate. Our ambition has been to examine the problems with soil acidification and imbalance of nutrients in a holistic perspective where consideration is paid to the environmental and production goals of forest policy as well as to other social and environmental goals of relevance in this context.

Important knowledge has been obtained during the years that the experimental work has been in progress. In order to collect knowledge of relevance to the design of the action plan, nine supporting reports were prepared before the plan was compiled. The authors of these reports are thanked for their contributions, which were of great value to the Board of Forestry.

We also wish to thank the Board of Forestry's reference group for liming and vitalisation, and all those responding to our proposal when sent out to almost 90 different locations for comments. We received numerous responses and several of the comments have been incorporated in the final plan.

In comparison with earlier action plans proposed by the Board of Forestry, the present plan is smaller and focuses more distinctly on the quality of runoff water and on the question of nutrient imbalances in forestland.

If the action plan is introduced it will be of great importance for achieving the national goals on environmental quality, i.e. "Only natural acidification", "Living lakes and waterways" and "Living forests". Furthermore, the plan is also of importance for possibilities to make use of forest fuel in a sustainable manner. In this way, fossil fuel can be replaced and the plan will thus contribute to achieving the goal of "Limited climatic effects".

Jönköping, 20 August 2001-10-01

Göran Örlander	Hans Wickström
Head of Division	Project Leader

Summary

This report consists of the National Board of Forestry's proposals on a plan to counteract soil acidification and to promote sustainable use of forestland. In 1989 the government requested the National Board of Forestry to start experimental activities to find measures to counteract soil acidification. In 1997 the Board presented a proposal for liming and vitalisation of forestland. An Environmental Impact Assessment of the proposal was submitted in 1999, after which a revision of the plan was started. In order to obtain better basic knowledge of the situation, the Board of Forestry commissioned nine reports that dealt with different aspects of soil acidification and corrective measures. Major emphasis has also been placed on the national environmental quality goals and the national plan for liming of lakes and waterways.

The report is divided into three parts. The first part explains the Board of Forestry's proposals on measures to counteract soil acidification, and the second part, the description of the situation today, presents the conditions for the design of the plan such as political goals and guidelines that affect the plan and its design, the knowledge available today on soil acidification, its effects, possibilities for recovery, and possible measures that can be used. The third and final part contains brief summaries of the responses to the plan when circulated for comments.

The action plan allows a return of the buffering capacity of the most acidified forestland, mainly in southern and southwestern Sweden. The Board of Forestry proposes that the spreading of ashes and lime is done within drainage areas where the natural recovery is assessed to be slow and insufficient, and where the leaching of toxic aluminium from forestland is hazardous to the aquatic ecosystem. In the assessments made by the Board, between 200 000 and 350 000 hectares of forestland may require measures of this kind.

The Board of Forestry is of the opinion that a three-year phase of research and method development is both essential and sufficient for obtaining robust criteria for selection of suitable or unsuitable areas, and tools for planning and coordination, e.g., with liming of surface waters. Further, the Board proposes that research and method development into adaptation of silviculture in areas suffering from acidification are initiated and that recommendations are elaborated during this 3-year preparatory phase. The subsequent operative part of the countermeasures, when most of the practical spreading will occur is estimated to take about 10 years. The cost of the 3-year preparatory phase is estimated to be 90 million SEK, plus the cost of the operative phase, which is between 430 and 750 million SEK for the entire 10-year period. The Board of Forestry proposes that the state is responsible for these costs. The lakes and waterways liming programme costs about 210 million SEK annually and today is financed to about 93% by the state and otherwise mainly by individual municipalities.

The action plan also aims to improve the conditions for sustainable utilisation of forestland in connection with removal of forest biofuel. The National Board of Forestry is positive to the use of biofuel but considers that measures in the form of

follow-ups and extension should be introduced in order to speed up and stimulate the development with regard to nutrient compensation for biomass removal, including whole tree harvest. The cost of the actual nutrient compensation is expected, as formerly, to be dealt with by the actors on the market without financial assistance from the state. On the other hand, the National Board of Forestry proposes that the follow-up and extension inputs are started within the framework of the action plan and thereby obtain state financing.

The action plan contributes directly to fulfilment of the national environmental goals “Only natural acidification”, “Living lakes and waterways” and “Living forests”. The plan also contributes to strengthening the sustainability in forest biofuel production and thus, via replacement of fossil fuels by forest biofuel, to fulfilment of the environmental quality goal “Limited climatic effects”.

Background

In the early 1980s the Swedish Environmental Protection Agency started research and developmental work into liming of forestland in order to test different measures for counteracting the effects of acidification on forests, soil, and groundwater as well as on flora and fauna. In 1989 the Ministry of Environment and Energy, as it was called at that time, commissioned the National Board of Forestry to plan and develop, during a 3-year period, preparations for liming and vitalisation fertilisation inputs of forestland. The experimental period has subsequently been extended by one year at a time. Consequently, the Board of Forestry has been conducting experimental work into measures to counteract soil acidification for more than ten years.

In 1997 the National Board of Forestry presented a proposal on an action plan for liming and vitalisation fertilisation of forestland where fertilisation with 2 tonnes of lime and 2 tonnes of ashes would be introduced. An Environmental Impact Assessment (EIA) of the proposal was presented in 1999 and in the same year the government gave the Board of Forestry, the Environmental Protection Agency and the provincial administrations the task of describing how a liming and vitalisation fertilising plan for soil and water in southwestern Sweden should be designed. The commission was reported as part of the “National plan for liming of lakes and waterways, 2000-2009”.

During 2000 the National Board of Forestry started revision of the 1997 proposal on an action plan against a background of the EIA, comments on the EIA, the work with liming of surface waters, and the national environmental quality goals. In order to obtain a better base for decisions on the revision, the Board initiated a wide compilation of knowledge in this sector. About thirty researchers have been involved in this work and have produced nine reports dealing with different aspects of soil acidification and corrective measures (National Board of Forestry, Reports 2001/11a-i, 2001). During the work with the revisions, discussions have been held with the Board’s reference group for liming and vitalisation fertilising.

Summary

Acidification of forests in southwestern Sweden has been ongoing during recent decades and has resulted in decreasing pH and a reduced level of base cations. Water flowing out of forestland is frequently so acidic that it severely affects the biological diversity in the aquatic ecosystem. In many places in southwestern Sweden the acidification effect will probably remain for up to a century, even if the deposition of acidifying substances is radically reduced. The National Board of Forestry considers that corrective measures should be introduced in southwestern Sweden in order to speed up the recovery of soil in these places.

The Board regards the use of forest biofuel as positive. Harvesting of forest biofuel may, however, lead to the removal of nutrients from forestland in excess of what is sustainable in a long-term perspective. In the opinion of the Board of Forestry, return of ashes or other means of compensating the removal of nutrients should always be done in connection with removal of logging residues/slash[1], particularly in acidified areas. These activities are expected to be dealt with by the market's actors without financial assistance from the state. The development with return of ashes has not yet started in a satisfactory manner. The National Board of Forestry considers that measures such as follow-ups and extension inputs should be introduced in order to speed up and stimulate this process.

Table 1. Impact assessment. Parliament has stated that national environmental quality goals should be achieved within 20-25 years. The table below summarises the consequences for the water quality of forestland (more correctly: the quality of run-off water) and the nutrient balance if no measures are taken, compared with the situation if the Board of Forestry's proposal on an action plan is introduced.

	Quality of water in forestland in 20.25 years			Nutrient balance of forestland
No measures are taken	About 200 000-350 000 ha of forestland[2] in southwestern Sweden continues to supply acidified water to lakes and waterways. Surface water liming is still required in these areas		**No measures are taken**	Tens of thousands of hectares of forestland will suffer negative nutrient balances since nutrient compensation does not occur to a sufficient extent. About 40 000-50 000 ha/year[2] will require treatment. Today compensation is done on 2 000-4 000 ha/year.[3]
The action plan is introduced: - Supply of mineral nutrients - Silvicultural extension advice	Most of the forestland has started to recover. It is possible that there is no longer a need for surface water liming[4].		**The action plan is introduced:** - Follow-up - Extension	Most of the forestland will have long-term sustainable nutrient balances.

[1] Regulations and recommendations can be found in directives and general recommendations relating to the Silvicultural Law (SKSFS 1998:5) and in the Board of Forestry's Report 2/2001 "Recommendations for the extraction of forest fuel and compensation fertilising".

[2] Areas given are estimates. They will be given more precisely during the preparatory phase of the action plan. See footnote 17 on p.11 (referring to water quality) and note 19 on p.12 (referring to nutrient balance) for explanation of the estimates.

[3] Estimates within the framework of "Evaluation of forest policy, 2001. SUS 2001 (working material, National Board of Forestry)

[4] Some areas are severely acidified but which, for various reasons should be omitted from the action plan and in these areas the effects will remain.

The National Board of Forestry proposes that the action plan is initiated without delay. The proposal means a preparatory phase (called the P-phase) lasting 3 years followed by an action phase (called the A-phase) lasting about 10-years. When considering the comprehensive work that has been done so far, for example in the Board's experimental activities and other research programmes, the Board of Forestry estimates that a 3-year preparatory phase is both essential and sufficient to enable satisfactory evaluation of the questions that need to be analysed in greater detail. In addition, relatively comprehensive practical work will be done during the P-phase in order to develop tools for the practical accomplishment. Evaluation of the work will be done continuously during the P-phase and will result in a detailed plan for the A-phase at a "check-point" following the end of the P-phase, three years after the start of the plan. The evaluation and planning will be done in such a manner that a transfer to the A-phase will be possible without delay. The work will be led by a project group assisted by guiding and reference groups, that will also participate in the evaluation.

The Board of Forestry estimates that the cost of the 3-year P-phase will amount to more than 90 million SEK and that the subsequent A-phase will totally amount to between 430 and 750 million SEK during a 10-year period. Since the area requiring countermeasures is an estimation, the cost of the A-phase may need to be revised during the P-phase. The work required and the goals for the P- and the A-phases are presented in a work plan. The follow-up of effects is proposed to continue during the entire period during which the measures are expected to have effect, i.e., for several decades.

The National Board of Forestry proposes that the state finances 100% of the activity concerning the supply of nutrients within areas that are assessed to have a slow and insufficient recovery, as well as related research, method development, planning, follow-ups and information. Nutrient compensation in accordance with the Board's guidelines for removal of forest biofuel will continue to be financed by the actors on the market without financial support from the state. This applies also within areas with slow and insufficient recovery. On the other hand, follow-ups and extension are proposed to be financed by the state.

Liming of lakes and waterways costs about 210 million SEK per year and is financed today to about 93% by the state and otherwise by individual municipalities. The Environmental Protection Agency proposes that lakes and waterways of national interest should be financed to 100% by the state. The subsidy percentages are currently being revised. About half of the subsidy today is used on objects that receive full state contributions. These amount to about 15% of the total number of liming objects.

Measures required

Soil acidification has increased during recent decades, foremost in southwestern Sweden. Both pH and the amount of exchangeable base cations in the mineral soil have decreased. The content of inorganic aluminium in soil water and runoff water has increased. This has led to negative effects on the biological diversity in water. The reason for the soil acidification is foremost atmospheric depositions of sulphur but removal of biomass from the forests and modified land use have also been involved. As a result of comprehensive restrictions on emissions most of the forestland will probably recover. However, in some cases a long and incomplete recovery of acidified forestland will imply continued negative effects on biodiversity in water for a considerable period (up to about a century) on account of continued leaching of inorganic aluminium and hydrogen ions. The proposal of the Board of Forestry assumes that the “multi-effect, multi-pollutant” agreement will be ratified. *The Board of Forestry considers that it is important to treat areas of land with a slow and incomplete natural recovery, most of which are located in southwestern Sweden.*

Harvest and removal of biomass from the forest may, in some cases, lead to losses of minerals in excess of the total supply from weathering and deposition. This will probably lead to a reduction in the soil’s reserves of plant-available nutrients. In the long run this reduction of nutrients may lead to the biological system becoming affected, which directly or indirectly may result in negative effects on the biodiversity and on tree production and vigour. The Board of Forestry has issued regulations and recommendations designed to counteract this risk. The Board states, for example, that nutrient compensation with ashes should be done in connection with the removal of logging residues/slash, that this applies to all of Sweden, that it is particularly important in severely acidified areas, and that removal of needles from logging residues before they are taken from the forest may have a positive effect. However, this development has not yet been satisfactorily established. *The Board of Forestry considers that there should be equilibrium between additions and losses of minerals in forestland, and that measures in the form of follow-ups and extension should be taken for this to be achieved in a satisfactory manner.*

Changes to the terrestrial biodiversity that have occurred on account of acidification are probably small in comparison with the effects resulting from intensified forestry, modified land use and eutrophication. Also, it would appear that soil acidification has not decisively affected tree production capacity or vigour. As regards effects in the long run, the level of knowledge is poor. *The Board of Forestry considers that, in the short term, there is no immediate need for measures on account of acidification-related damage to terrestrial biodiversity, or in relation to tree production or vigour.*

Objectives

Main objectives

The nutrient and acid/base status of forestland shall allow preserved biodiversity in the forest and aquatic ecosystems of the forest landscape, together with sustainable timber production.

Sub-objectives

- Leaching of aluminium and hydrogen ions from forestland to surface water and groundwater must be reduced in the long-run to levels that do not lead to damage to the biological diversity in the aquatic ecosystem.
- In the long-term perspective there should be equilibrium between the total additions and the total losses of minerals in forestland.

Proposed measures

The most important measures in counteracting acidification problems are to limit the emissions of acidifying substances. Liming of lakes and waterways has been done since the early 1980s. However, these measures fall outside the framework of the Board of Forestry. In the present plan the discussion only concerns measures on forestland, i.e., supply of buffering substances and nutrients together with adaptation of silviculture. On the other hand, *it is important that all countermeasures are regarded from a holistic perspective* in order that there may be cooperation between the different inputs, a factor that is of particular importance as regards supply of buffering substances to soil and water. The measures proposed by the Board of Forestry are printed in *italics.* The various measures are described in greater detail in the working plan.

Measures within catchment areas with insufficient recovery

Supply of buffering substances and nutrients to forestland

The Board of Forestry assesses that measures on forest mineral soils should be introduced in areas that risk becoming acidified and which will not recover within 20-25 years. The measures should be treatment with buffering substances and nutrients (foremost ashes and lime) in order to speed up and strengthen the recovery. The Board of Forestry considers that, in general, these areas are located in southwestern Sweden where there is high sulphur deposition and forestland acidified through anthropogenic action. If the biomass removals are large within these areas the recovery will be hindered. The Board of Forestry considers that the planning of measures on mineral soils through supply of ashes or lime should be done per catchment area, where the runoff gives an integrated measure of the acidification situation in the catchment area in question. Inorganic aluminium and hydrogen ions in the runoff should be decisive goal parameters for measures introduced. The Board of Forestry proposes that, during the P-phase there is a development of models to be used in identifying catchment areas requiring measures on account of unsatisfactory recovery, and that criteria are developed for unacceptably high aluminium and hydrogen ion concentrations.

Coordination of measures for soil and water

Measures on mineral soils should be planned in accordance with the acidification situation in the surface water and with regard to the liming activities of surface water in order to supplement and increase its efficiency. Coordination enables a combination of long-term effects to be achieved where leaching of inorganic aluminium from mineral soils is reduced at the same time as water quality is retained in the short-term through treatment of surface water. Where possible, the countermeasures on mineral soils can be supplemented, for example, with liming of suitable riparian wetlands and moist sections close to streams. In this way the liming of surface waters can be terminated earlier. Measures on mineral soils also allow the recovery of smaller lakes and waterways as well as water that conventional surface water liming does not reach. Spreading of nutrients within identified catchment areas should also be done in cooperation with the actors involved in measures for compensating the nutrients removed in harvest of biomass. The new EU directives for water must also be considered. In order to achieve as good a grip of the acidification problem as possible, both as regards soil and water, there must be coordination of inputs between the authorities and actors involved, i.e., the National Board of Forestry, the Regional Forestry Boards, the Environmental Protection Agency, the municipalities and other relevant actors. *The Board of Forestry is of the opinion that one of these should have the main responsibility. The Board of Forestry considers that, during the P-phase, the forms for coordination and surface water liming should be developed, together with activities concerning compensation for loss of nutrients when biomass is removed.*

Choice of product and dose

When introducing countermeasures on mineral soils the nutrients provided should have an all-round composition and good liming effect. The main method consists of providing a mixture of ashes and lime (2+2 tonnes per hectare). Also other products with suitable nutrient compositions and quality may be of interest. Ashes to be used should foremost originate from combustion of forest biomass. The ashes should be processed to enable them to be slowly dissolved. Guidelines on the quality of ashes, e.g., with regard to maximum contents of heavy metals and stability of the ashes are found in the National Board of Forestry's Report 2/2001. Lime products to be used should foremost be carbonate limestone and/or dolomite limestone, and should have a particle size distribution that allows the dissolving process to proceed slowly.

The objective is that, within one or more decades, ashes and lime will lead to reduced leaching of aluminium to surface water and groundwater. The proposed method has yielded positive changes to the soil and soil water chemistry. Model calculations demonstrate that effects will be achieved in the run-off water after one or more decades. Today there are no experiments where developments have been followed sufficiently long to enable the desired long-term effects in run-off water to be confirmed. Despite this uncertainty, the Board of Forestry considers that the spreading of ashes and lime in the proposed doses implies a meaningful treatment with limited negative secondary effects. Higher doses and a more easily dissolved forms of ashes and lime would lead to faster effects but would imply a risk of negative effects on flora and fauna, and that nutrient leaching would increase.

There will not be a shortage of lime. Ashes from forest biomass that are suitable for spreading on forestland will, on the other hand, be available only in limited amounts. It will be important that suitable ashes are processed in the correct manner and made available. Access to such ashes will affect the extent of the areas that can be treated. *The Board of Forestry proposes that during the P-phase efforts are made to ensure that suitable ash products are developed, that the volume of suitable ashes available is established, that available alternatives to ashes are identified, together with the consequences that would arise following the use of them.*

Only lime products should be used on discharge areas or other wet areas needing treatment. Lime products used shall be applied in doses and have a grain size distribution that allows them to slowly dissolve. Thus, the risk for negative effects on flora and fauna is minimised. The Environmental Protection Agency is presently working on an environmental impact assessment of the effect of liming riparian wetlands. *The Board of Forestry proposes that, during the P-phase,* *criteria should be developed for identifying riparian wetlands that should remain untreated, and that criteria should be developed for suitable doses and suitable grain size distribution.*

Areas that should remain untreated

The National Board of Forestry assesses that the spreading of ashes or lime may give rise to negative effects on the terrestrial biodiversity, and that this risk should be considered when planning the measures intended. The risk of negative effects on flora and fauna is foremost dependent on the dose, rate of dissolving and grain size distribution of the product. The lower the dose and rate of dissolving, and the larger the particle size, the lower the risk that negative effects may occur. *The Board of Forestry proposes that criteria are developed during the P-phase to identify areas where spreading of ashes and lime with the proposed doses, rate of dissolving and particle size distribution should be avoided with regard to the terrestrial flora and fauna.*

The Board of Forestry considers that spreading of ashes or lime can lead to increased risk of nitrate leaching from soils with low CN-ratios (below about 25) and that this risk should be taken into consideration during the planning of countermeasures. In addition, the risk for nitrate leaching depends also on the product's dose and rate of dissolving. The lower the dose and rate of dissolving, the lower the risk that there will be nitrate leaching. *The Board of Forestry proposes that, during the P-phase, criteria are developed to identify soils where there is a high risk of nitrate leaching and where spreading of ashes and lime should therefore be avoided.*

The Board of Forestry considers that certain areas are naturally acid and that such areas should not be treated. *The Board of Forestry proposes that, during the P-phase, criteria are developed to identify soils where the acidity of the runoff water is foremost of natural origin and therefore should not be corrected.*

The Board of Forestry considers that solubility of certain metals (e.g., mercury, lead and copper) may increase somewhat in the soil surface after the spreading of ashes and lime, but that the effect is of short-term duration and that it does not markedly affect the concentrations of these metals in running water. However, knowledge is deficient. *The Board of Forestry proposes that, during the P-phase, measures are taken to improve the level of knowledge concerning mobility of metals (foremost mercury) in soil and water following the spreading of ashes or lime.*

Selection criteria

Summary of selection criteria for measures to be taken in catchment areas with insufficient recovery.

Recovery measures are needed within a certain catchment area[5]:

- If the concentration of inorganic aluminium and hydrogen ions in the runoff water is unacceptably high[6].

And

- If the natural recovery is assessed to be insufficient[7].
- A certain catchment area is omitted from recovery measures:
- If acidity in runoff water is of natural origin

Or

- If areas where ashes or lime should not be applied together amount to more than X%[8] of the areas within the catchment area. This includes:
  - *areas where spreading of ashes or lime may lead to considerable negative effects on the flora and fauna of the forest ecosystem[9]*
  - *areas with documented high nature values that may be damaged[10]*
  - *soil with high risk for nitrogen leaching[11]*
  - *soil where spreading of nutrients has a limited effect[12]*
  - *areas where technical, economic or social factors prevent spreading[13]*
  - *Clear-cuts[14,15] without covering field vegetation, inasmuch as, for example, a shelterwood has not been left in connection with final felling.*
  - *Forest[14,15] that is planned to be finally felled within the immediate future (within 5 years)*

The Board of Forestry estimates that the total area of forestland that can be considered for countermeasures in accordance with the above may amount to between 200 000 and 350 000 ha[16].

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5 *The Board of Forestry proposes that criteria are developed to enable assessment of suitable sizes of catchment area.*

6 *The Board of Forestry proposes that criteria for unacceptably high concentrations of inorganic aluminium and hydrogen ions are developed during the P-phase, in cooperation with the Environmental Protection Agency, and that development of analytical methods for aluminium takes place.*

7 The Board of Forestry considers that catchment areas that have an insufficient recovery will primarily be found in areas where deposition of sulphur has been high, where anthropogenic soil acidification has penetrated deep into the mineral soil, and where removals of forest biomass have been large. Such areas are found foremost in southwestern Sweden. *The Board of Forestry proposes that, during the P-phase, there are developments of model tools that can be used to identify such areas.*

8 *The Board of Forestry proposes that, during the P-phase, criteria are developed for estimations of the proportion of the catchment area that must be treated for the countermeasures to have the intended effect in the aquatic ecosystem.* This part can probably vary with regard to differences in soil and water factors between different catchment areas.

9 Criteria will be developed during the P-phase. This work is coordinated with, e.g., sub-objective 4 in the environmental quality objective “Living forests”, that deals with developing an action plan for threatened species.

10 Estimated in consultation with the authorities involved and other relevant actors.

11 *The Board of Forestry proposes that, during the P-phase, criteria are developed for identification of soils where there is a high risk for nitrogen leaching and where spreading of ashes and lime should be avoided.* This may concern, for example, soils with low CN ratio (below about 25).

12 *The Board of Forestry proposes that, during the P-phase, criteria are developed for identification of soils where spreading of nutrients and buffering substances has limited or no effect.* This may, for example, concern soils with moderate levels of acidity or a thick humus cover.

13 This may concern, for example, cultivated land, land where neither ground-based nor helicopter spreading is possible, or land where the landowner does not agree to spreading measures.

Nutrient compensation for biomass removal

If the long-term removal of nutrients from forestland is larger than the amount returned, the resulting changes in the soil chemical composition might, either directly or indirectly, have a negative effect on the forest's biological systems, including the soil's productive capacity. In removal of stemwood and with normal leaching the nutrient losses are generally compensated by weathering and atmospheric deposition. The larger the share of trees harvested, the greater the risk that there will be a negative balance. If both stemwood and logging residues (branches and crowns) are removed (whole tree utilisation) this will probably lead to a net loss of nutrients on many soils. In certain highly productive forests (particularly in southern Sweden) there is probably a net loss of base cations even when only stemwood is removed. The need for nutrient compensation may decrease or is no longer required if the harvest level is reduced.

The Board of Forestry is positive to the use of forest biofuel provided that regulations and recommendations for its removal and for nutrient compensation[17] are followed. Fuel from Swedish forests is renewable, domestic and contributes minimally to the greenhouse effect and related effects on the climate. In directives and recommendations, the Board of Forestry writes that nutrient compensation should be done in connection with removal of logging residues. This applies to the entire country but is particularly important in heavily acidified areas, e.g., catchment areas with insufficient recovery. As in the former situation, the activities are expected to be the responsibility of market actors without financial support from the state. The Board also writes that needles should be removed from logging waste, and that this leads to a reduction in the removal of nutrients and that the need for compensation is thereby also reduced. *The National Board of Forestry proposes that, during the P-phase, a study is made of the consequences that different forms of needle removal from logging residues will have on the nutrient balance and leaching of mineral nutrients.*

If logging residues are removed from forestland that has a high nitrogen load (low CN ratio, below about 25) there will probably be a decreased risk of nitrate leaching through nitrogen being removed and as a result of easier establishment of clear-cut vegetation. *The National Board of Forestry proposes that, during the P-*

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[14] When planning measures, consideration must be taken to the need to return to these areas on later occasions.

[15] If ashes that do not cause any particular leaching during the clear-cut phase can be developed, then they can be spread in connection with final felling or on forestland where felling is being planned.

[16] These areas are estimated against a background of the selection criteria discussed above. Soils with pH in the C-horizon up about 2% of the Swedish forest area (in accordance with the site classification in the Board of Forestry's report 2001/11D.) Using this area as starting point, the following criteria have also been considered: C/N>25 (the area increases in size), S-deposition >8kg/ha (the area decreases). In addition, consideration shall be taken to the areas where spreading of ashes or lime should not be done. In summary, the need for corrective measures can be estimated to about 1-1.5% of the forested area (ca. 200 000-350 000 ha). *An accurate estimation of the area is proposed to be made during the P-phase.*

[17] Regulations and recommendations relating to the Silvicultural Law are published in Directives and General Recommendations (SKSFS 1998:5) and in National Board of Forestry Report 2/2001 "Recommendations relating to removal of forest biofuel and compensation fertilisation".

phase, study is made of the consequences of removal of logging residues for nitrate leaching in both short-term and long-term perspectives.

Despite the regulations and recommendations concerning removal of logging residues and nutrient compensation, these measures have not yet been introduced to a sufficient extent. There is a need for nutrient compensation on about 40 000-50 000 ha/year[18], of which about 10 000 hectares are within the area where nutrient compensation is particularly urgent. Altogether, compensation is done on only about 2 000-3 000 hectares per year[19]. Consequently, the Board of Forestry is of the opinion that measures should be taken to speed up this process. *The Board of Forestry proposes that, during the P-phase, there is development and initiation of a follow-up programme for removal of logging residues, needle removal and compensation fertilisation, and also that information and extension inputs are initiated.*

The Board of Forestry is of the opinion that the need for measures should be based on the losses of nutrients via the total removal of biomass, and not only on the losses in connection with removal of logging residues[20]. The Board of Forestry proposes that, during the P-phase, there is development of models and methods that will enable assessment of situations where also removal of stemwood requires nutrient compensation.

Cooperation should take place between activities concerning nutrient compensation for biomass removal and measures with catchment areas with insufficient recovery. This question is discussed under the headings “Coordination of soil and water measures” (p. 9) and “Planning” (p.14).

Adapted silviculture

Silviculture can affect the acid/base and nutrient status in the soil in several different ways, e.g., the size of biomass removal chosen, by leaving a shelterwood in connection with final felling, by choice of soil preparation method, by leaving border zones along waterways, etc. Certain measures affect the acidification situation in the soil surface whereas others may result in changes in deeper soil

[18] The Board of Forestry’s latest inventory suggests that the area in which logging residues are removed (in connection with final felling) is at least 40 000-50 000 hectares. Almost the same amount is removed in the provinces of Götaland and Svealand (about 20 000 ha in each) whereas the share of residue removals in Southern and Northern Norrland is on a level of one or a few thousand hectares. The Board of Forestry estimates that about 10 000 hectares of this are within the area where the measures are of particular importance (southwestern Sweden). The areas where removal of forest biomass is done in connection with cleaning and thinning are not included in these calculations.

[19] Estimation within the framework of “*Evaluation of forest policy 2001, SUS 2001”* (working material, National Board of Forestry).

[20] Harvest and removal of biomass from the forest can, in certain cases, lead to a situation where losses of minerals are in excess of the total supply through weathering and atmospheric deposition in situations of removal only of stemwood. This area is difficult to estimate because of varying results from model calculations. Criteria for identification of such soils will be elaborated during the P-phase. For the time being, the Board of Forestry assesses that the net loss of mineral nutrients in connection with stemwood removal is foremost to be found on the most fertile soils of Götaland and Svealand. Removal of logging residues probably takes place on most of these soils, and consequently they are probably included in the estimated area where removal of logging residues takes place (see note 18).

horizons and in the runoff water. Certain measures may give results quickly whereas others have a very long time perspective. Most of the measures influence forest production.

Choice of tree species

The choice of tree species is of great importance for the biological diversity in the entire landscape. Many species are specifically associated with deciduous trees and deciduous forests. The Board of Forestry works to increase the share of deciduous forests in accordance with current nature protection objectives. This is done through extension and supervision of legislation as expressed in the Silvicultural Law's paragraph on nature consideration, through habitat protection and nature protection agreements, and through inventories (e.g., the key habitat inventory).

An increased share of forests with abundant features of broad-leaf trees has been discussed as a measure to counteract soil acidification. Some broad-leaf trees have litter properties that result in the surface layers of forest soils being less acid. Forests with a large share of broad-leaf trees or pines have a lower loading of acidified atmospheric pollution because they capture dry deposition less effectively than spruce forests. It is possible that forests with large features of certain broad-leafs may imply a reduction of soil acidification in severely loaded areas, but there is no scientific evidence confirming that certain tree species result is a less acidic environment in deeper soil horizons or in ground-or surface water. Knowledge of the importance of a tree species for the acid/base status in deeper soil horizons and in runoff water is, however, deficient. The Board of Forestry is of the opinion that it is important that knowledge in the field is improved, which is essential if recommendations are to be issued. *The National Board of Forestry proposes that, during the P-phase, the level of knowledge is improved as regards the choice of tree species and its effect on the acid/base status in deeper soil horizons and in ground- and surface water.*

Volume production of coniferous trees is generally higher than that in broad-leaf trees, which means that there is a greater uptake of nutrients during the growing phase, a greater removal at harvest, and consequently a larger supply of hydrogen ions. Against this background, we can state that the acidification contribution is normally less from broad-leaf trees. At the same time, there is a lower production of timber.

Leaving a tree layer in connection with final felling

By leaving a tree layer (e.g., a shelterwood) in connection with final felling the risk of nitrate leaching and possibly also leaching of other nutrients, e.g., cadmium, can be counteracted. On soils with high nitrogen load (low CN ratio) there is a greater risk of nitrate leaching. On such soils it may thus be particularly positive to leave a tree layer. When using tree layers it is important, for example, to take note of the risk for windthrows and insect damage. *The National Board of Forestry proposes that, during the P-phase, the level of knowledge is improved with regard to possibilities to prevent nutrient leaching by leaving a tree layer, e.g., a shelterwood, in connection with final felling.*

Silviculture close to waterways

Nutrient leaching can be limited if border zones with trees and bushes are saved along the shores of lakes and waterways, and if machinery is used with great care (SVL §30). This is particularly important on soils that are severely nitrogen loaded (low CN ratio) and in severely acidified areas, particularly in catchment areas with insufficient recovery. Border zones along waterways also imply that the base cations of importance for the water can be taken up by the trees and therefore do not enter the water. Border zones have the result that deposition of leaves and needles, and shading, will increase, which is of great importance for biodiversity in the waterways. *The Board of Forestry proposes that, during the P-phase, knowledge of possibilities to prevent nutrient leaching by saving border zones along waterways is improved.*

Consequences for forest production

Adaptations of silviculture such as those discussed here, e.g., changing to another tree species, long shelterwood periods or application of regeneration methods where a tree layer is left after felling may involve major changes to the direction of production. *The Board of Forestry proposes that, during the P-phase, studies are made of the consequences that such silvicultural adaptation will have on forest production.*

Silviculture in areas suffering from acidification

During the P-phase, the level of knowledge will improve as regards adaptations of silviculture in order to counteract effects related to acidification. It is important that information and knowledge concerning such silvicultural adaptations is transmitted to the actors concerned and that the information at the same time includes the effects that adapted silviculture may have on timber production. *The Board of Forestry proposes that, during the P-phase, recommendations are developed for adaptation of silviculture in areas suffering from acidification, and that these coincide with the overall objective of preserved biological diversity and sustainable timber production.*

Planning

Planning of countermeasures against acidification should be done individually in each catchment area and coordination with spreading of lime on surface waters should be done where possible. In the National Liming Programme it is stated that if the government invests in both a surface water programme and a forest soils programme the planning of these programmes should ensure that the countermeasures are directed at the most severely acidified areas where there are also limed surface waters or difficultly limed waters such as, for example, small lakes or waterways where it is difficult to achieve the established surface water objectives. Coordination should also be done with the nutrient compensation for biomass removal that occurs within the area, and with other work directed at nature protection. All authorities involved (i.e., The National Board of Forestry, The Regional Forestry Boards, The Environmental Protection Agency, the Regional Administrations and Municipalities), together with other actors, must cooperate. *One* of the above-mentioned should have the main responsibility. Also other measures taken in the catchment area that may relevantly influence the acid/base status in the soil and water, or in other ways influence, or be influenced by, the measures should be regarded. EU's new framework directive for water must be observed. *The Board of Forestry proposes that, during the P-phase, activities within a catchment area to be considered should be identified, and that a strategy should be developed for cooperation and coordination in soil acidification measures, particularly with regard to liming of surface waters and nutrient compensation for removal of biomass.*

Legislation

The action plan may lead to changes in directives and general recommendations relating to the Silvicultural Law. Naturally, the action plan should be conducted in accordance with all other legislation. *The Board of Forestry proposes that, during the P-phase, there is a review of, and where necessary revision of, relevant parts of the Silvicultural Law's directives and recommendations. In addition, the Board of Forestry proposes that studies are made of the consequences of other legislation, e.g., the Environmental Code and EU's Water Directive, on the accomplishment of the action plan.*

Practical activities

Practical activities during the P-phase should be conducted within certain catchment areas in order to develop tools for the various parts of the action plan (e.g., selection criteria for catchment areas requiring treatment, selection criteria for omission of measures, coordination with liming of surface waters, cooperation with authorities, following-up of effects, information, etc.). An objective should also be to develop a state of preparedness for the increase of spreading areas that will occur when the A-phase is initiated.

The Board of Forestry is of the opinion that measures within catchment areas with insufficient recovery should be financed by the state in agreement with the financing of the surface water liming. Measures concerning nutrient compensation for removal of biomass (compensation fertilisation) are proposed to continue being dealt with by the actors on the market without financial support from the state. This will apply both within and outside catchment areas with insufficient recovery from acidification. *The Board of Forestry proposes that, during the P-phase, study should be made of how the conditions of the action plan will affect the distribution of ashes originating from forest biomass, and also develop tools for how a possible competition for ashes can be handled.*

Follow-up

Spreading of lime and ashes in the proposed doses and particle size distributions is expected to have effect in running waters within one or more decades. A follow-up of the effects should run for about 25 years. The follow-up should evaluate the effects on water and soil chemistry (including heavy metals), aquatic and terrestrial flora and fauna, forest production, and tree vigour. The follow-up of effects should also consider relevant goals of environmental quality, foremost "Only natural acidification", "Living lakes and waterways" and "Living forests". The follow-up shall also include the practical activities, e.g., spreading quality, mechanical damage to soil and trees, and the attitude of landowners. Reports will be published on the follow-up activities. *The Board of Forestry proposes that, during the P-phase, there is development of a programme for following-up the effects (with regard to national objectives relating to environmental quality) and* *practical following-up running during the period the measures have an effect, i.e., during several decades.*

Information

Many landowners within the areas to be treated will be affected (about 6 000-10 500 forest holdings[21] in southwestern Sweden). Initially, fellings needing nutrient compensation will be done on between 500 and 1000 holdings[22] annually. It is important that these groups are given detailed information and a good base for decision-making in order to be able to decide on measures to be taken on their own land. It is also important that actors involved as well as the general public are given satisfactory information. *The Board of Forestry proposes that, during the P-phase, an information input directed at landowners, other central actors and the general public is planned and initiated.*

Accomplishment

Accomplishment of the action plan involves a preparatory phase (P-phase) over three years followed by an action phase (A-phase) during about ten years. The P-phase involves studying and answering the remaining questions that have been identified. A relatively comprehensive practical programme of activities will also be conducted during the P-phase in order to develop tools for the practical accomplishment. Thereafter, the A-phase will be conducted, being the operative part of the programme. A detailed account of the P- and A-phases is presented in the working plan on pp.18-24.

Initially, a project group will be formed with the National Board of Forestry as principal. This group will conduct projects during the P-phase and ensure that this preparatory part of the programme is conducted in accordance with the goals established in the working plan. In addition, a steering group and a reference group will be formed. These groups will consist of representatives of national authorities, research, the forest- and energy industries, nature protection and other relevant actors. The steering group will assist in guiding the programme throughout the entire accomplishment, with stand-points and decisions of policy character, whereas the reference group will contribute with knowledge and advice during the same period.

Following the three years of the introductory P-phase a control station will be introduced into the programme where results are presented and a plan for the accomplishment of the A-phase will be submitted. Evaluation and interpretation of results will be done continuously during the P-phase to enable decisions concerning the design of the A-phase to be made at the control station. The project, steering and reference groups will hold parallel discussions concerning the design of the A-phase. A strategy for leadership of the programme during the

[21] The estimate is based on a required treatment of 200 000-350 000 hectares in southwestern Sweden and an average area of forestland per holding of 33 hectares.

[22] See footnotes 18 on p.12 and 20 on p. 13 for estimates of the requirement for nutrient compensation. These areas have then been related to the following average areas of forestland per holding for different parts of Sweden: Götaland, 41 ha; Svealand, 67 ha; Southern Norrland, 132 ha; and Northern Norrland, 172 ha.

A-phase will be developed during the P-phase and presented at the control station, together with a strategy for cooperation with other actors involved.

Follow-up of effects will be done throughout the entire period that effects are expected to occur, i.e., during several decades.

The Board of Forestry proposes that the state finances 100% of the activities concerning spreading of nutrients within areas assessed to have a slow and insufficient recovery, together with related research, method development, planning, follow-ups and information. Nutrient compensation done against a background of the guidelines drawn up by the Board of Forestry concerning removal of forest biomass for fuel is assumed to be financed also in the future by the actors on the market without financial support from the state. This applies also within areas with slow and insufficient recovery. On the other hand, it is proposed that the follow-ups and extension inputs are financed by the state.

A cost plan for the action plan is given below, followed by a working plan that describes in relatively great detail the different problems that have been identified and that are to be studied during the P-phase. The working plan gives a rather superficial description of results from the P-phase that are expected to emerge in the A-phase.

Cost plan

	Year	Spreading of ashes and lime in catchment areas with insufficient recovery (ha)	Cost of: **Research and method development.** *Administration:* The Swedish Forest Administration *Performed by:* Research departments and other actors. (million SEK)	Cost of: **planning, follow-up and information** *Administration:* The Swedish Forest Administration *Performed by:* The Swedish Forest Administration, research departments, and other actors. (million SEK)	Cost[23] of: **Spreading of ashes and lime** within catchment areas with insufficient recovery *Administration:* The Swedish Forest Administrati *Performed by:* Others (million SEK)
P-	1	3 000	10	4	7.5
	2	5 000	12	6	12.5
	3	7 000	15	8	17.5
	Σ	**15 000**	**37**	**18**	**37.5**
A-phase	The spreading activities continue in the operative Action phase		Research and method development concluded	*Administration during the A-phase:* The Swedish Forest Administration or another authority. *Performed by during the A-phase:* The Swedish Forest Administration, research departments and other actors.	*Administration during the A-phas* The Swedish Forest Administrati or another authority. *Performed by during the A-phas* Others
	4	10 000		6	20
	5	15 000		6	30
	6	20 000-40 000		6	40-80
	7	20 000-40 000		6	40-80
	8	20 000-40 000		6	40-80
	9	20 000-40 000		6	40-80
	10	20 000-40 000		6	40-80
	11	20 000-40 000		6	40-80
	12	20 000-40 000		6	40-80
	13	20 000-40 000		6	40-80
tot	**Σ**	**200 000-350 000**	**37**	**78**	**410-730**

[23] The cost of spreading ashes and lime is estimated to be 2 500 SEK per hectare during the P-phase and 2 000 SEK per hectare du on spreading costs that fall within the framework of the National Board of Forestry's research activities. The Board of Forestry esti least 20% can be achieved before the A-phase, which means a cost of 2 000 SEK per hectare. The figures include a combination of The Board of Forestry proposes that the state should be responsible for the entire cost. It should be noted that these costs do not co with removal of logging residues which, as earlier, is expected to be dealt with by the actors on the market without financial suppo ups and extension related to nutrient compensation are proposed to be financed by the state.

Working plan

Summary of working plan

Input	Sub-input
A. Spreading of nutrients	a. Practical spreading in catchment areas
B. Research and method development	a. Within which catchment areas are there needs for countermeasures? b. Which areas should be omitted from spreading inputs with ashes and lime? c. Products and doses d. Nutrient compensation for biomass removals e. Adapted silviculture (choice of tree species, leaving tree layer in connection with final felling, silviculture close to waterways, consequences for forest production, recommendations for silviculture)
C. Planning	a. Coordination and cooperation b. Legislation
D. Follow-up	a. Follow-up of effects b. Follow-up of implementation
E. Information	a. Landowners b. Other actors

Detailed working plan

		P-phase	
Input	**Sub-input**	**Work area**	**At end of P-p control static**
A. Spreading of nutrients	a. Practical spreading in catchment areas.	Practical activities are conducted within a number of catchment areas well distributed throughout southern Sweden. Tools are developed for accomplishment of all the different parts of the action plan (selection criteria, coordination with liming of surface waters and nutrient compensation, cooperation between authorities, follow-up of effects, information, etc.).	All projects – of how the ac been accomp practice, how inputs have b considered. Regional prep accomplishin phase.
B. Research and method development	a. Within which catchment areas is there a need for corrective measures ?	Develop criteria for assessment of unacceptably high concentrations of aluminium and hydrogen ions in runoff water. Develop analytical methods for aluminium. Develop tools to assess the suitability of the catchment's size. Develop tools to assess the suitability of the minimum proportion of a certain catchment area that should be treated in order to achieve a certain effect. Develop model tools capable of identifying the catchment areas in need of countermeasures.	Present criter aluminium an with a suitable method. Present a pla which catchm suitable for countermeasu

P-phase

describing

Input	Sub-input	Work area	At end of P-p control statio
B. Research and method development	b. Which areas should be withdrawn from the spreading of ashes and lime?	Develop criteria to enable identification of areas where spreading of ashes and lime should be avoided with regard to the terrestrial flora and fauna. Cooperation takes place with other activities, e.g., that concerning the elaboration of an action plan for threatened species (in accordance with the environmental quality goal “Living forests”). Develop criteria to enable identification of soils where the risk of nitrate leaching is high and where measures should be avoided. Map the availability of data concerning nature protection that may need to be considered in the action plan, in consultation with authorities concerned and other actors. Develop criteria to enable identification of discharge areas where spreading of lime should be avoided with regard to the terrestrial flora and fauna. Develop criteria to enable identification of soils where the acidity of runoff water is foremost of natural origin. Develop criteria for identification of soils where the spreading of nutrients has a restricted effect. Work to improve the state of knowledge with regard to the mobility of metals (foremost mercury) in soils and waters following addition of ashes or lime.	Present a ma selection of a should be with countermeasu

		P-phase	
Input	**Sub-input**	**Work area**	**At end of P-p control statio**
B. Research and method development	c. Products and doses	Work for development of suitable ash products. Find out the availability of suitable ashes. Identify available alternatives to ashes and the consequences (economic, ecological, practical) of using them. Develop criteria for suitable doses and suitable grain size distribution of lime for spreading on discharge areas (an EIA has been initiated by the National Environmental Protection Agency).	Presentation o that will becor for use in the programme a to which they available. Presentation o for suitable tre discharge.
B. Research and method development	d. Nutrient compensation for biomass removal	Develop and initiate a follow-up programme for removal of logging residues, removal of needles and compensation fertilisation. Develop model tools and methods of assessing cases where removal of forest biomass leads to a need for nutrient compensation. Investigate the consequences of removal of logging residues for leaching of nitrate within areas with nitrogen loading. Investigate the consequences of removal of needles in logging residues for the nutrient balance and nitrate leaching.	Present a follo extension pro removal of for and compens fertilisation. Revision, if re general advic recommendat

		P-phase	
Input	**Sub-input**	**Work area**	**At end of P-p control statio**
B. Research and method development	e. Adapted silviculture • Selection of tree species • Tree layer left in connection with final felling • Silviculture close to waterways • Consequences for forest production • Recommend-ations for silviculture	Work to improve the level of knowledge concerning the effect of choice of tree species on the acid/base status in deeper soil horizons and in groundwater and surface water. Work to improve the level of knowledge as regards possibilities to prevent nutrient leaching by leaving a tree layer (e.g., a shelterwood) in connection with final felling. Work to improve the level of knowledge with regard to possibilities to prevent nutrient leaching by saving border zones along waterways. Investigate the consequences of silvicultural adaptation on forest production. Develop recommendations for adaptation of silviculture in areas suffering from acidification with regard to environmental and production goals.	Presentation o improved leve knowledge wi adapted silvic Presentation o recommendat adaptation of areas sufferin acidification.
C. Planning	a. Coordination and cooperation	Develop tools for how the system with selection criteria for soils that should be treated or not treated should function, and to design an approach enabling certain areas to be given priority. Map which activities within a catchment area should be considered when planning measures. Develop a strategy for cooperation and coordination with the liming of surface waters. Develop a strategy for cooperation and coordination with nutrient compensation for removal of biomass. Identify which authority or actor should have main responsibility for acidification countermeasures within a catchment area. Examine how the conditions of the action plan affect the flow of ashes, and identify how a possible competition for ashes can be handled.	Presentation o selection of ar Give an overa which areas s treated, the ar concerned, ar plan for accor Presentation o on coordinatio of surface wat Presentation o on coordinatio nutrient comp biomass remo Presentation o coordination w catchment are

		P-phase	
Input	**Sub-input**	**Work area**	**At end of P-p control static**
	b. Legislation	Review suitable parts of the directives, general advice and recommendations in the Silvicultural Law. Examine the consequences of other legislation, e.g., the Environmental Code, for the action plan. Examine how the EU's water directive affects the action plan.	Revision, if re directives, ger and recomme Revision, if re action plan wi the Environm other legislatio EU's water di incorporated i action plan.
D. Follow-up	a. Follow-up of effects	Develop a follow-up programme for effects on soil and water chemistry (including heavy metals), aquatic and terrestrial flora and fauna, forest production and tree vigour. Consider the follow-up of the national environmental quality goals in relevant parts.	Presentation c programme to effects that is the follow-up c environmenta goals.
	b. Practical follow-up	Develop a follow-up programme for the practical accomplishment, such as spreading quality, mechanical damage to ground and trees, and land-owner attitudes.	Presentation c programme fo practical mea
E. Information	a. Land-owners	Plan and initiate an information strategy directed at land-owners possibly affected by the action plan.	Presentation c information st
	b. Other actors	Plan and initiate an information strategy directed at authorities, branch actors, researchers and the general public.	Presentation c information st

Description of the situation today

This chapter gives a brief description of the political goals relating to the soil acidification problem, the reasons and effects of soil acidification, and possible countermeasures and their effects. The summary of the present state of knowledge is based on current research and on experience obtained from the National Board of Forestry's own experimental activities.

Political goals and guidelines

The political goals with bearing on the soil acidification problem and the design of countermeasures mainly concern forest policy and the goals of the national environmental quality programme. Other overall social goals that are relevant in this context will also be considered, such as climate, energy and nature protection policies, together with current EU legislation, e.g., EU's water directive.

Forest policy is characterised by two goals of equal importance: an environmental goal and a production goal. These are summarised in §1 of the Silvicultural Law:

"The forest is a national asset that shall be managed in such a manner that it gives good sustainable yields, at the same time as biological diversity is maintained."

This means, for example, that the natural productive capacity of forestland shall be preserved. The directives that foremost affect the design of an action plan to counteract acidification are found in §30 of the Silvicultural Law where, for example, the following is stated:

"Damage to soil and water resulting from silvicultural measures shall be avoided or limited, e.g., in liming of forestland and vitality fertilisation. When felling, nutrient leaching to lakes and waterways shall be limited. When forest fertilisation, liming of forestland and vitalisation fertilising is done, it shall be done in such a manner that damage to the environment is avoided or limited. When parts of trees in addition to the stemwood are removed from the forest, it shall be done in such a manner that damage does not occur to the long-term nutrient balance of the forestland."

In addition to directives and relevant general recommendations, the Board of Forestry has also formulated "Recommendations for removal of forest biomass and compensation fertilisation." (National Board of Forestry, Report 2-2001). The Swedish Environmental Protection Agency is also preparing new general recommendations for liming of lakes and waterways.

The Swedish *Riksdagen* approved the national environmental quality goals in 1999. Here it is stated that the goals shall be achieved within 20-25 years. Several of the 15 environmental quality goals have links with the effects of soil acidification and to possible countermeasures (for example, "Only natural acidification", "Living forests", "Living lakes and waterways", "Restricted climatic effects", Groundwater of good quality", "No excess fertilisation". "Thriving wetlands" and "Good urban environment"). In April 2001 the government submitted a proposal on Swedish environmental goals – subgoals and strategies for countermeasures (Bill 2000/01:130). The text in the Bill with relevance to acidification of forestland is given below:

- Unnatural[24] acidification of soil shall be counteracted so that the natural productive capacity of the soil, objects of archaeological interest, and the biological diversity are preserved ("Only natural acidification").

- The contribution of land use to the acidification of soils and waters should be counteracted by forestry being adapted to the sensitivity of the forest site to acidification ("Only natural acidification").

- The natural productive capacity of the forest shall be preserved ("Living forests").

- Lakes and waterways shall have a good surface water status with regard to species composition and chemical and physical conditions in accordance with EU's framework directive on water (2000/60/EC). ("Living lakes and waterways"). This means that legislation relating to future treatment of water must be reviewed and that cooperation must take place among those living and working within one and the same catchment area.

- Biological diversity shall be recreated and preserved in lakes and waterways ("Living lakes and waterways").

- The quality of the leaching groundwater shall be such that it contributes to a good living environment for plants and animals in lakes and waterways ("Groundwater of good quality").

As a means of achieving the political goals relating to climate and energy, the Swedish *Riksdagen* in 1997 approved a new energy policy where a shift was made from fossil to renewable energy production. The increased use of forest biomass has an important role to fill in this realignment.

Causes and effects of soil acidification

Soil acidification has increased during recent decades, foremost in southwestern Sweden. Site class mapping from 1983-87 and 1993-96 shows that pH has decreased in Swedish forestland. The level of exchangeable base cations in mineral soil has decreased. The concentration of inorganic aluminium in soil and runoff water has increased.

What is soil acidification?

Weathering means that soil material in the soil is dissolved or converted whereby hydrogen ions are consumed and base cations (Ca, Mg, K, Na) are released and supplied to the exchangeable pool in the soil or are leached out. With time, if the soil is supplied with a larger number of hydrogen ions than the weathering can consume, the exchangeable base cations will be replaced by hydrogen ions on the surfaces of the soil particles. In this way, the leaching of base cations increases whereas the pH in the soil decreases. This is called buffering of base cations. When the availability of base cations decreases further down in the soil profile a continued excess of hydrogen ions will, in due course, lead to increases in the

[24] The Board of Forestry is of the opinion that the terms "unnatural" and "natural" acidification are unsuitable choices since the growth and harvest of biomass cannot self-evidently be included in their definitions. Growth of biomass is a soil acidifying biological process. All land use leading to removal of biomass (e.g., agriculture and forestry) leads to increased acidification pressure as a result of the soil losing buffering elements in this manner. The relevant factor for preservation of the soil's acid/base and nutrient status is whether the acidifying processes can be compensated through weathering, deposition of buffering substances, return of ashes, liming or other supply of buffering substances.

concentrations of inorganic aluminium (Al^{3+}) in soil water and to leaching into lakes and waterways. Inorganic aluminium has a toxic effect on many animals and plants, particularly in the aquatic ecosystem.

Thus, in accordance with this definition, soil acidification is the pH reduction that depends on consumption of substances that neutralise acidity in the soil. In a system where the supply of hydrogen ions per unit of time is limited, it may be neutralised by natural processes, foremost through weathering and deposition of base cations. The weathering rate varies strongly between different sites on account of different geology, climate, hydrology, vegetation, etc.

What causes soil acidification?

Acidification of forestland is caused by several factors, the most important being atmospheric deposition of sulphur- and nitrogen compounds, growth and harvesting of biomass, and changes in land use, e.g., increased afforestation.

Emissions of sulphur dioxide, which is converted into sulphuric acid in the atmosphere, increased in northern Europe during the late 19th century and culminated during the 1970s. Today, the atmospheric deposition of sulphuric acid has fallen to the same level as in the 1950s, which implies a reduction of more than 50%. Sulphuric acid is a strong acid, which means that it divides itself entirely into sulphate ions and hydrogen ions when it enters the soil.

Emissions of nitrogen oxides increased later than the sulphur emissions and started to decrease during more recent years. Nitrogen oxides are converted into nitric acid in the atmosphere. This is another strong acid, which separates completely into hydrogen ions and nitrate ions in the soil. The atmospheric deposition of nitric acid contributes to the soil acidification in situations where the nitrate ion is not taken up but is leached from the forest soil. Nitrate leaching from growing forest is still unusual but has been measured in the highly nitrogen-loaded areas along the west coast of Sweden. However, only part of the deposited nitrogen is taken up by the trees, a lot is absorbed by soil organisms and, in due course, will become stored in humus. Nitrate leaching during the clear-cutting stage has probably increased during recent decades in areas where deposition is high. This means that even if the immediate acidification effect is small, the atmospheric nitrogen deposition builds up a potential for future acidification. Emissions of ammonia from livestock farming result in atmospheric deposition of ammonium ions and hydroxide ions that, in a corresponding manner, are neutralised when taken up by plants.

Growth of biomass is a process that normally leads to a net addition of hydrogen ions to the soil. In plants there is a balance between positively and negatively charged ions (cations and anions, respectively). This balance is maintained by the plants, through their roots, releasing ions in the same amount and with the same charge as those that are taken up. Because the plants take up nutrients in the form of cations (e.g., Mg^{2+}, K^{+}), a corresponding amount of hydrogen ions is released. When the plants take up nutrients in the form of anions (e.g., SO_4^{2-}, NO_3^{-}, basic anions are released. Because the plants generally take up more cations than anions there will be a net addition of hydrogen ions to the soil. The more nitrogen that is taken up in nitrate form, the less will be the addition of hydrogen ions to the soil. The greater the amount of nitrogen taken up in the form of nitrate, the less will thus be the addition of hydrogen ions from plants. When the plants die and decay, the surplus of basic elements that has been bound in the plants will be released. If the biomass is harvested there will be, on the other hand, a permanent removal of buffering substances from the forest soil.

During the decomposition of litter, organic acids are formed as interim stages that, due to their large volumes, largely govern the pH levels in the soil. Litter from certain tree species results in lower pH in the soil surface (e.g., spruce) than others (e.g., birch) These acids are probably largely utilised during later stages of decomposition. However, there is a certain movement downwards which affects the pedogenesis in the upper layers of mineral soils. The question of whether a tree species can influence soil acidification at greater depths is still under discussion. Results from the Forest Site Mapping Programme suggest that the humus layer in southern Sweden is becoming thicker, which is probably largely a result of changes in land use (reforestation, no planned or natural forest fires, etc.) and atmospheric nitrogen deposition. When the humus layer gets thicker, then the amount of organic acids in the soil should also increase.

The atmospheric deposition of sulphuric acid is the foremost cause of soil acidification in the areas of southwestern Sweden that have suffered most. In places where the deposition is large, sulphuric acid is responsible for the main supply of acid to the soil. In places where the deposition is lower the supply from harvested biomass may be of relatively greater importance. However, high growth rate and harvest of forest biomass alone do not appear to have achieved any particular acidification in deeper layers of mineral soils. Sites with high acidity in deeper soil layers are very rare in places where the deposition is and has been moderate. It is difficult to quantify the effect of the different factors. For example, analyses from the Site Mapping Programme indicate that the acidification effect of the growth rate in southwestern Sweden contributed one-tenth of the pH-reduction noted between 1983-87 and 1993-96, whereas model calculations suggest that the growth and harvest of biomass might have been of the same magnitude as the supply from the atmosphere.

Effects in water

Within large areas the lakes and waterways have been strongly acidified because they have received acid rain, and runoff water with high concentrations of hydrogen ions and inorganic aluminium from surrounding land. This has led to comprehensive damage to the biological diversity in aquatic ecosystems, with extermination of foremost fish, but also other plant and animal species. Acidic deposition has in fact decreased since the 1970s but continued consumption of buffering capacity in mineral soils on increasingly larger forestland areas gives the forest the largest contribution to acidification of lakes and waterways. In this way the depletion of biodiversity in water continues because of the leaching of inorganic aluminium from heavily acidified soils. Acidic runoff water, however, is not necessarily acidified but may be naturally acidic, e.g., on account of high concentrations of organic acids. In areas close to the coast, the episodic deposition of sea salt may also have an acidifying effect on lakes and waterways.

In some places in southern and southwestern Sweden the groundwater has such low pH values that excessive cadmium and aluminium concentrations may cause health problems also among humans. This applies foremost to groundwater close to the surface in areas with thin soil cover and high deposition of acidifying substances.

Effects on terrestrial biological diversity

The flora and fauna of forestland has gone through comprehensive changes during the 20th century. There are numerous reasons for this. Changed land use, for example, afforestation and the termination of traditional grazing rights, together with modified silvicultural methods are important factors. In addition, increased grazing pressure from game and increased nitrogen deposition, mainly in southwestern Sweden, has also been of importance. The effects of soil acidification appear to be less than the above even though negative effects have been demonstrated on vascular plants, soil fungi, epiphytic lichens and shell-bearing??? organisms (several rare and red-listed species) and earthworms. In a long-term perspective, continued decreases in the soil's reserves of mineral nutrients may have a negative effect on the forest's biological system. The state of knowledge, however, is deficient as regards long-term effects.

Effects on tree production and vitality

Most evidence suggests that soil acidification has not yet resulted in any particular deterioration in the productive capacity of trees or their vigour. The National Forest Survey reports that the mean growth increment of the forest has increased during recent decades. There are probably several reasons for this. An increased timber reserve and a more intensive silviculture are important factors, together with the effects of more intensive land use and accumulation of organic matter. In addition, there is the fertilising effect of increased atmospheric nitrogen deposition. At present it is not possible to identify any particular relationships between soil acidification and nutrient deficiency in the trees or increased crown thinning. However, it is difficult to estimate the effect of soil acidification over a perspective of several decades. In the long-term, continued reductions in the soil's reserves of mineral nutrients, directly or indirectly, may have a negative effect on the productive capacity or vitality of forestland.

Natural recovery of soils and waters

The natural recovery of acidified forest soils and its development in time is dependent on several factors, e.g., the degree of anthropogenic acidification effect, the chemical, biological and physical properties of the soil, together with former and present land use. Model calculations from acidified areas indicate that a recovery may require up to 100 years, and that stabilisation on some soils will occur at a level where the soil is still characterised as acidified, which means that even in the future these forest areas will supply the water ecosystem with high concentrations of inorganic aluminium. Nonetheless, as a result of restrictions on emissions, indications of a recovery have been noted and many soils will recover. Among other signs, for example, increased pH and ANC (acid neutralising capacity) have been registered in waterways in southwestern Sweden. Prolonged and incomplete recovery processes will foremost be found in soils in southwestern Sweden that have low capacity for neutralising supplied hydrogen ions through weathering and where sulphur deposition is still relatively high. The recovery process will be hindered if large removals of biomass are made.

Effects of deposition of atmospheric nitrogen

Today the leaching of nitrogen even from the most nitrogen-loaded forests is still limited (as long as the forest remains intact). Only on small areas with growing forest is there nitrogen leaching to any considerable extent. Nitrogen leaching from stocked forestland in southwestern Sweden is, on average, around 3 kg/ha and year in comparison with an atmospheric deposition of 1-20 kg/ha. There is, thus, an accumulation of nitrogen in most of the southwest Swedish forestlands. This applies (in southern Sweden) also if we include the nitrogen loss implied by removal of biomass. However, in the felling phase the leaching is much larger than in closed forest, around 10-20 kg/ha and year. The extent to which trees are left, and how rapidly the ground vegetation can be re-established is of great importance for the level of nitrogen leaching after final felling. Continued high nitrogen load may also lead to larger forested areas starting to leach nitrogen. Studies indicate that the risk for nitrification (and thus nitrate leaching and acidification) is higher when the soil contains a lot of nitrogen in relation to carbon (low C/N ratio). As a comparison, it may be said that the average leaching of nitrogen from agricultural land is around 19 kg/ha and year in southwestern Sweden. However, because the share of the forested area is generally large, the forest may be responsible for a considerable supply of nitrogen to the aquatic ecosystem.

Measures to control the effects of acidification

Against a background of the causes and effects of the acidification of forestland, it is possible to distinguish four separate categories of countermeasures whereby the effects of acidification can be counteracted:

- Restrictions on emissions
- Liming of lakes and waterways
- Supply of nutrients to forestland
- Adapted silviculture

Soil and water acidification are intimately linked to each other and consequently it is important that there is coordination between countermeasures introduced on land and on water (see further below).

Restrictions on emissions

Limiting emissions is the most important measure to work with in order to counteract the acidification problem. Major international efforts have been made to reduce emissions of acidifying substances into the atmosphere. International negotiations (Europe and North America) are being conducted within the framework of the CLRTAP Convention on pollution. The first agreement was concluded in 1985 and the most recent in Göteborg in 1999. The latter is a "multi-effect, multi-pollutant convention that establishes emission levels for sulphur dioxide, nitrogen oxides, ammonia and volatile organic substances. This agreement means that sulphur deposition will be reduced further in Sweden (63% between 1990 and 2010) and that the atmospheric deposition of nitrogen oxides and ammonia will decrease by 43 and 17%, respectively, during the same period. If the agreement can be fulfilled the atmospheric deposition of sulphur will be 3-4 kg/ha and year in parts of southern Sweden with the highest loads, and about 2-3 kg nitrate nitrogen in corresponding parts of the country. On account of a tree's ability to capture dry deposition, the atmospheric deposition will be slightly higher in forestland and somewhat lower on open fields. Tree species and age distribution also influence the deposition pattern on stand level.

Liming of lakes and waterways

Acidification has led to markedly negative effects in the aquatic ecosystem, for example, elimination of fish and other species of animals. Consequently, an operative liming programme was started in 1982 in lakes and waterways. The state has invested about two billion SEK in the Swedish liming programme. More than 40% of the lakes that were estimated to be acidified have been treated and about 10% of the acidified waterways. The liming is done mainly by applications to lakes and wetlands or by liming by means of a dosing applicator. The effect is rapidly seen but has a limited duration, which means that the treatments must be repeated until emission-restricting measures have been introduced and a recovery has occurred. The current strategy for liming of surface waters has the result that many acidified lakes and waterways cannot be treated on account of technical or economic reasons. Treatments far up in the catchment area have not always been possible. This has the result that the acidic runoff with high concentrations of inorganic aluminium causes problems in waterways further downstream, even if they are limed. When wetlands are limed it is often done with repeated applications using large doses of lime (more than 10 tonnes per hectare), which have massive effects on the natural flora. The liming of lakes and waterways costs about 210 million SEK per year and is presently financed to about 93% by the state, the remainder being provided mainly by individual municipalities. The Environmental Protection Agency require that liming of lakes and waterways of particular national interest shall be financed to 100% by the state. The system of state subsidies for liming is presently being reviewed. Almost half of the funding is today used on treatment of sites receiving the full state subsidy. They represent about 15% of the total number of sites requiring liming.

In 1998 the government gave the Environmental Protection Agency and the Provincial Administrations the task of elaborating a national plan for the liming activities in lakes and waterways over the next 10-year period. In a supplementary directive, they were required to also work together with the National Board of Forestry in describing how a liming and vitalising programme for soils and waters in southwestern Sweden could be designed, and how it could be financed. The results have been published in the National Plan for Liming of Lakes and Waterways, 2000-2009[25]. The Plan emphasises that if the government invests in both a surface water and a forestland programme the planning of these programmes should be coordinated in such a manner that the measures taken are directed at the most acidified areas where there are also limed surface waters or difficultly-limed waters such as small lakes and waterways, or where it is difficult to achieve the established goals with regard to surface water quality.

Supply of buffering substances and nutrients to forestland

The acid/base and nutrient status of forestland can be changed if ashes, lime or other all-round nutrients are supplied. In this way, the negative effects of anthropogenic acidification can be counteracted. The effects that may occur on the soil chemistry, soil processes and organisms following spreading of lime, ashes or other nutrients depend mainly on the type of substance, the size of the dose, and the particle size distribution of the substance used. Additionally, soil properties will also affect the results obtained.

Ashes, lime and all-round nutrients

Spreading of ashes will increase the soil's content of base cations at the same time as the soil's acid-buffering capacity will be improved. Wood ashes have an all-round content of nutrients that additionally have a good liming effect and are therefore a suitable vitalisation material. There are also compound mineral fertilisers that can be obtained with a desired composition. The variation between different ashes is great with regard, for example to undesirable substances and hardening properties. Examples of the highest permitted concentrations of heavy metals, and what the ashes should consist of, together with the doses recommended to minimise the risk of negative spreading effects, are given in the Board of Forestry's Report 2/2001 (Recommendations on removal of forest biomass and compensation fertilisation). Ashes, for example, should be stabilised (i.e., granulates, pellets or self-

[25] A report on the benefits of coordination between the treatment measures on soils and waters was prepared as a subordinate document to the National Plan (Board of Forestry, Report 1/2000, "Coordinated measures against acidification of soils and waters").

hardened/disintegrated) and slowly dissolvable. A guideline is that the ashes should be dissolved over a period of 5-25 years in the field.

Liming materials can be applied with the intention of increasing the acid-buffering capacity of the forest soils. These materials consist of a single substance, give good liming effect and generally have a very low content of undesirable elements such as heavy metals. The liming materials generally used on forestland are limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Certain bi-products of, e.g., the paper, pulp, iron and steel industries, may also have a suitable nutrient composition.

The particle size distribution and the dose of the ashes and liming material will have a considerable influence on the effects. High proportions of fine grains and a high dose will give a higher pH increase in the soil and thus a more noticeable effect on the acid/base status. At the same time there will be an increased risk of nitrification (increased risk of nitrogen leaching) and for direct damage to flora and fauna. By adapting the proportion of fine grains and the dose, the liming material can be made to dissolve more slowly and gradually, thereby minimising the risk of nitrification and damage to flora and fauna at the same time as the soil chemistry is influenced in a positive direction.

Effects on soil acidity

The type of material used, the size of the dose and the material’s particle size distribution influences the effects of additions of lime or ashes on the soil acidity. Spreading of lime or ashes will rapidly increase the pH-value between 0 and 3 pH units in the uppermost soil layer depending on the material and the dose used. The increase in pH with depth in the soil profile is slower (1-2 cm/year) and a period of at least 10 years is needed before any effect is seen in mineral soil or in the soil water, regardless of the dose. Doses in amounts less than 2 tonnes per hectare give hardly any effects either in the humus layer or in soil- and groundwater. Doses of 3-5 tonnes/ha give an increased pH in the humus layer for a few years and may give a sufficient soil chemical and water chemical effect after some decades. The positive effects may last for up to 50 years. Generally, the higher the dose, the higher the pH increase and durability. When doses of lime are between 5 and 12 tonnes/ha the increase of pH in the uppermost soil layer may remain during an entire tree generation. Normal and high doses give contents of exchangeable base cations that are markedly increased in the humus layer 60-70 years after treatment. Spreading of lime and ashes may give an increase in the flow of base cations from the soil at the same time as the outflow of acid aluminium and hydrogen ions decreases. This effect increases with increased dose and increased content of fine grains. Experiments suggest that soil water contents of calcium may be increased at the same time as the concentrations of inorganic aluminium may be reduced for a period of up to 50 years after treatment, and that doses of 3-5 tonnes/ha are sufficient to achieve this effect. These results show relatively good agreement with model calculations.

Effects on soil nitrogen dynamics

Addition of a pH-increasing material such as lime or ashes generally leads to increased nitrification in soils with low CN ratios (C/N lower than 25), which may result in increased nitrate concentrations in the soil water. This, in turn, leads to an increased risk of nitrate leaching. The nitrification-enhancing effect will probably be less if a slowly dissolving material is used, giving a moderate increase in pH during the initial phase of the dissolving process. However, in a growing stand, the ability of the trees to take up nitrate is generally very good. Studies of limed catchment areas in southern Sweden have generally not shown any increased nitrate concentrations in runoff water. The largest risk of nitrate leaching occurs in the felling phase when mineralisation often increases. At this time the regrowth and dispersal of clear-cut vegetation and remaining parts of the tree layer after the final felling are very important for uptake of the released nitrogen.

It has not been possible to demonstrate any clear differences between runoff water from productive forest areas with a normal proportion of clear-cuts and non-productive forest areas as regards leaching of nitrogen. It remains uncertain how continued high nitrogen loading will affect the future nitrogen leaching from forestland. Removal of forest biomass may have a positive preventative effect because it leads to a certain reduction of the nitrogen load and therefore reduced risk of nitrogen leaching in the future.

Effects of solubility of heavy metals and radioactive substances

The spreading of lime or ashes increases the pH in the surface layer of the soil. This may affect the solubility of heavy metals and radioactive substances and thereby also their availability as well as the risk of leaching. Heavy metals occurring as cations (e.g., cadmium, cobalt, nickel and zinc) normally have reduced solubility at higher pH-levels and thus become bound harder to the soil following addition of lime or ashes. Because certain cations (e.g., copper, mercury and lead) form complexes with organic material their solubility increases and therefore also their mobility in situations of increased pH. Increased leaching of metals would lead to negative effects on flora and fauna. In many lakes, for example, the mercury concentration is so high that fish are recommended as unfit for human consumption. Also anions (e.g., selenium and molybdenum) get increased solubility at increased pH. However, no marked increases of heavy metals have been found in organisms, soil water or runoff water following liming or spreading of ashes with the proposed doses. Nonetheless, there are gaps in our knowledge with regard to the effects of spreading ashes and lime. It is probable that the effects on the solubility of heavy metals will be less if a slowly soluble material is used that does not increase the pH to any great extent during initial phases.

Caesium-137 has been accumulated in the humus layer following the Chernobyl accident but relatively little has penetrated down into the mineral soil. An increase in pH, for example through spreading of lime or ashes, would probably lead to the mineralisation of caesium. Studies have indicated that if potassium is added (e.g., via ashes) the uptake of caesium-137 in vegetation may possibly decrease. However, the level of knowledge is still deficient. In their “Policy for biofuel” (Dnr. 822/504/99), The National Radiation Institute (SSI) list the highest permissible concentrations of caesium in ashes for spreading on forestland (5 kBq/kg ashes).

Effects on terrestrial biodiversity

The possibility to counteract the effects of soil acidification on terrestrial biodiversity through liming or vitalising appear to be limited, at least in the short-term perspective. However, there are several examples where markedly positive effects have been obtained, an example being increases in the numbers of earthworms and molluscs (some of which are red-listed and rare). The increase in pH given by liming and vitalising may lead to an increase in nitrification (see above, *Effects on soil nitrogen dynamics*). In this way the eutrophication effect is increased in the soil horizons close to the surface, which is often more negative for the terrestrial biodiversity than the effects of acidification. This relative difference will probably be strengthened within the foreseeable future because the deposition of atmospheric nitrogen decreases at a slower rate than that of sulphur. The effect of liming or vitalising on vascular plants is often minor whereas negative effects on mosses and fungi are of greater importance (numerous rare and red-listed species), particularly in the most nutrient-rich and the most nutrient-poor soils. Even forests with long continuity have numerous pH-sensitive species. The risk of negative effects of these types of countermeasures is largely negated if moderate doses are used and if the material spread has a slow rate of coming into solution. Most of the risks mentioned with regard to supply of pH-increasing materials are often of a short-term nature. In a longer perspective, the spreading of lime or ashes may provide protection for acidification-sensitive species. However, here there is a lack of knowledge.

Effects on aquatic biodiversity

The acidification situation in lakes and waterways depends strongly on the acidification status of the surrounding land. The most decisive negative factor for biodiversity in water is increased levels of inorganic aluminium. Lime or ashes spread on forestland can, in the long-term, increase the base saturation and pH of mineral soils, which reduces the leaching of inorganic aluminium to the aquatic ecosystem.

The rate of soil recovery and the effects on the runoff water depend on the degree of acidity, the hydrology, the soil properties and the dose of the lime or ashes. Higher doses and faster dissolving give faster effects on the water chemistry and thereby on the aquatic biodiversity. However, in this situation there is a risk that there are larger negative effects on the terrestrial biodiversity and an increased risk that nitrate leaching will occur. Lower doses and slower dissolving reduce the negative effects considerably but at the same time they mean a longer time interval before there are improvements in the status of the water chemistry. With both higher and lower doses it takes a long time, more than 10 years, to influence the mineral soil horizon in the soil, as well as soil water, in a positive direction. Studies have shown that doses of 3-5 tonnes may give sufficient soil- and water chemical effects with a duration of up to 50 years.

Effects on forest production

As regards the effects of ashes and lime on forest production the results appear to depend mainly on the availability of nitrogen in the soil. Spreading of pH-increasing materials tends to increase the availability of nitrogen in fertile sites, which may result in growth increasing somewhat. In low-productive sites, on the other hand, there appears to be a risk that growth is reduced because of reduced accessibility of the trees to nitrogen. It mainly appears that spreading of other nutrients than nitrogen generally does not have any particular effect on forest production.

Coordinated measures with surface liming

By treating acidified forestland the problem with acidic runoff water can be treated at source. In this way, it is possible for the surface water to recover and the process to be speeded up and, in the long-term, for the treatment to be reduced and finally concluded. Additionally, treatment of forest soil may be regarded as an instrument enabling small acidified waters to be treated that are out of reach of conventional liming of surface waters.

In coordinated measures the treatment of recharge areas is combined with liming methods with rapid effects on surface waters, for example treatment of discharge areas. Coordinated measures that utilise both recharge areas and small discharge areas can reduce both the need for high doses (more than 10 tonnes per hectare) and the area of large wetlands that are limed to improve the surface water. Measures taken on forested mineral soils can also be combined with other methods of liming surface waters (lake liming and liming with an applicator), but the cost efficiency is not as good as that obtained with coordination of treatments in discharge areas as it is impossible to coordinate the spreading and the liming material (different materials and doses). At present, the effects of liming in discharge areas, the suitable doses and materials, and the durability of the effects, remain to be fully understood. They are discussed briefly in a document included in the National Liming Plan, “Coordinated measures to counteract acidification of soils and waters” (National Board of Forestry, Report 1-2000). This document assesses the benefit, the risk of bi-effects, and gaps in knowledge in connection with the application of coordinated measures. The National Environmental Protection Agency is presently preparing an environmental impact assessment of the treatment of discharge areas.

Adapted forestry

Silviculture may influence the acid/base and nutrient status of the soil in several ways, mainly through choice of size of biomass removal, choice of tree species, choice of soil preparation method and through leaving a tree layer in connection with final felling (e.g., a shelterwood).

Biomass removal

Growth of biomass leads to an increase of hydrogen ions because the plant takes up more nutrients in the form of cations than of anions, and when the cations are taken up they are exchanged for hydrogen ions. Harvesting means that buffering substances (organic bases) and base cations are removed from the forest soil. Whether or not removal leads to soil acidification will depend on the total balance between harvest removal and leaching on one hand, and supply through weathering, deposition, inflowing groundwater, return of ashes, liming, etc., on the other. If the removal of nutrients in the long-term is larger than the supply then it is probable that this will have a negative effect on the forest ecosystem and on the soil’s productive ability.

In situations of normal removal of stemwood and normal leaching, the nutrient losses are generally compensated through weathering and deposition, but in some highly productive forests (particularly in southern Sweden) a net loss of base cations is expected also when harvesting only stemwood. The larger the proportion of trees harvested, the larger the risk of obtaining a deficiency in the balance. If both stemwood and logging residues (branches and tops) are removed (i.e., whole-tree utilisation) this will often lead to a net loss of important nutrients. This can be counteracted if needles are removed from the logging residues before they are removed from the forest. The National Board of Forestry states in directives and general recommendations relating to the Silvicultural Law (SKSFS 1998:5) that compensation fertilisation (preferably with ashes) should be done in connection with removal of logging residues in severely acidified areas in southern Sweden. On soils with high nitrogen loading (low C/N ratio), removal of logging residues will probably mean that the risk of nitrate leaching, and consequently also leaching of base cations, will decrease.

Return of ashes, liming or other means of supplying nutrients are ways of avoiding net losses of nutrients. An alternative to such compensation for nutrient losses is to adapt the yield level, i.e., to reduce the amount removed by reducing the harvest levels.

Selection of tree species

Up to the late 19th century large parts of what is forest today in southern Sweden were used as an agricultural resource, with not only valuable hardwoods but also other deciduous trees such as fruit and berries. Changes in land use, intensified silviculture and heavy grazing by game during the 20th century have had great impact on the development of deciduous forests and deciduous trees. A richer biodiversity is associated to deciduous trees and a greater variation in tree species composition. Therefore it is important for nature protection that the share of deciduous forests increases, particularly older deciduous forests and valuable hardwoods. According to the environmental quality goal "Living forests" the share of land regenerated with deciduous forests should increase and the share of older deciduous forests should increase by 10%. The National Board of Forestry is working for an increased share of deciduous forests through extension and legislation (§30, nature consideration), through habitat protection and nature protection agreements, and through inventories (e.g., of key habitats)

The litter from certain deciduous trees (e.g., birch, alder, ash and elm) gives a higher pH during decomposition and a larger level of exchangeable base cations. Further, the size of the acidifying deposition in a forest is influenced by the distribution of trees because the dry deposition is caught with varying efficiency. Spruce forest, for example, captures gases and particles more efficiently than pine and deciduous forests of the same age. This means that forest with a large share of pines and deciduous trees has a lower loading of acidifying atmospheric pollutants. The volume production of conifers is normally higher than in deciduous trees, which means a greater uptake of nutrients during the growing period and a greater removal at harvest, and thus a larger supply of hydrogen ions to the soil.

A large admixture of birch results in the pH and base saturation being generally higher in the uppermost layer of the soil in comparison with the situation in pure stands of pine. There are no studies, however, that can confirm whether or not certain tree species would implicate a less acidic environment in deeper soil horizons or in surface- or groundwater. Knowledge of the importance of tree species for the acid/base status in deeper soil horizons and in runoff water is still deficient.

Leaving a tree layer at final felling

By using a shelterwood or other form of regeneration method where a tree layer is left after felling, the risk of nitrate leaching and possibly also leaching of other nutrients, such as potassium, can be reduced. A shelterwood means that a number of fully-grown trees (at least one hundred per hectare) are left at the final felling. After felling there is an increase in, for example, decomposition and thus access to leachable nitrogen. On soils that are severely nitrogen-loaded (low CN ratio) there is a greater risk of nitrate leaching. In such places it may be particularly positive to use shelterwoods or to leave a tree layer after final felling. On many soils, particularly with regard to spruce, there is, however, a risk of windfalls if use is made of shelterwoods.

Border zones

Nutrient leaching can be reduced if border zones consisting of trees and bushes are left along lakes and waterways, and if machinery is used with great care (SVL §30). This is particularly important on soils that are heavily nitrogen-loaded (low C/N ratio) and in highly acidified areas, especially in runoff areas with insufficient recovery. Border zones along waterways allow the trees to take up base cations that otherwise would enter the water, thereby withholding them from the water. Border zones result in an increase in litterfall (leaves and needles), as well as increased shading, something that is of great importance for biodiversity in waterways.

Soil tillage

Soil tillage results in parts of the field layer being removed, which decreases its possibility to take up available nitrogen. Tillage also affects the turnover of organic material and both these reasons cause the nitrogen leaching to increase slightly in the prepared areas. The difference in leaching between a clear-cut and a shelterwood is, however, larger than that between soil that has been tilled or not tilled.

Clear-cut burning

The burning of clear-cuts increases the pH of the soil and its buffering capacity in the short-term, which in turn leads to an increased pH in the aquatic ecosystem. However, at the same time the leaching of nitrogen and base cations increases and because no others are supplied this results in a net loss of base cations from the soil. Consequently, the burning of clear-cuts is not a suitable measure to control soil acidification. There are, however, other reasons within nature protection to increase clear-cut burning.

The Board of Forestry's experiments

The Board of Forestry has conducted experiments with liming since 1989. The experiments are being conducted at the request of the government and the Board has received a grant of 10 million SEK annually. After an initial 3-year period of financing the grant has been reviewed an annual basis since 1992, which has led to difficulty in the long-term planning. The main objective of the activities has been to collect knowledge and practical experience for design of an ecologically correct and economically adapted action plan without any particularly negative bi-effects. During the experiments the work has been directed at developing suitable products, identifying the need for measures, the selection of areas in which measure should be introduced, spreading techniques, documentation of the spreading and the follow-up of effects. The experimental work has also dealt with organisation, planning and economy. About 50 000 ha of acidified forestland in southwestern Sweden have been treated with ashes and/or lime during the experimental period. The experimental activities have generated knowledge that now makes up an important part of the background data used in the present proposals on an action plan.

Following-up effects

The liming and vitalisation programme in forestry has included a comprehensive follow-up of effects. In 1990/91 a total of 16 runoff areas were limed in southern Sweden and during 1996 an additional six experimental areas were treated with lime and wood ashes. Several plot trials were established in the early 1990s where the effects of different doses and types of lime and ashes, as well as times of treatment, were studied. Experiments with liming on clear-cuts and other environments where there are particularly large risks that nitrogen may leach out have been conducted. Two experiments with coordinated liming on recharge areas and in discharge areas were started in 1998. Special follow-ups have been made of the large-scale experimental activities, e.g., acute vegetation effects, where divergences were noted in connection with the treatments. The follow-up programme is mainly directed at effects on trees, soil and water, where liming and vitalisation fertilisation is done in accordance with the approach recommended by the Board of Forestry. The studies cover long-and short-term aspects on:

- Effects on pH together with concentrations, amount and leaching of base cations from forestland.
- Occurrence of aluminium in soil and water.

- Leaching of nitrogen and other nutrients from soil to water.
- Importance of present and former deposition, soil type, the stand's tree species and fertility, for treatment effects.
- Short and long-term effects of combined treatments of recharge areas with measures in discharge areas.
- Effects on tree vitality and soil vegetation in the form of fungi, vascular plants, mosses and lichens.
- Effects on bottom fauna and epiphytic algae in streams surrounded by limed or vitality fertilised recharged areas.

Within the framework of the follow-ups that were started in connection with liming of the selected catchment areas, studies have been made during the last 10 years of the short-term effects of the treatments. During year 2000 the follow-up programme started to study the long-term effects and benefits, which are the goals of the soil treatments. These effects are studied through a combination of model calculations and measurements in new and old trials. The treated catchment areas that were established in the early 1990s are now being studied more intensively. In addition to the follow-up of effects, the Board of Forestry's experimental activity, together with the energy sector, has taken the initiative to develop methods of characterising the properties of wood ashes for spreading on forestland.

Results from the follow-up of effects are presented in reports published by IVL (The Environmental Research Institute). So far, four reports have been published, dealing with the short-term effects of the liming of forestland on surface waters, soil chemistry, soil water, biological effects on the bottom fauna, epiphytic algae, tree vitality, as well as effects on soil water chemistry, nutrient content of needles, and tree growth at different doses and different kinds of lime. In addition, the conditions for coordinated liming and vitalisation of recharge areas and discharge areas are reported[26]. Results from investigations in previous liming experiments (20-90 years) have been reported as part of the compilation of knowledge on liming of forestland.

Results from the follow-ups

The objective of the treatments is to achieve a slow and long-term effect. At present, the follow-up of effects can provide answers only to the short-term effects of the treatments because the oldest experiments are from 1990. The experiments show that lime penetrates down through the soil horizon at different rates in different soils and areas. In general, there was a reduction in the concentration of exchangeable hydrogen and aluminium ions and an increase in the degree of base saturation in the humus layer and in the upper layers of the mineral soil. Similarly, there were increases in the contents of base cations in the soil water and a tendency for reduced concentrations of aluminium and hydrogen ions. Concentrations of base cations also increased in the runoff water. In most of the trials, acidity expressed as hydrogen ions and soluble aluminium compounds was also strongly reduced. Within the experiments, the liming has had only minor effect on nitrogen leaching or forms of occurrence. This also applied after liming of clear-cuts and catchment areas with high levels of atmospheric nitrogen deposition.

[26] A report on the benefit of coordination between measures on soil and in water was prepared as a basic document for the Nation Plan (Board of Forestry, Report 1/2000, "Coordinated measures to control acidification of soils and waters").

Studies of the bottom fauna have not yet revealed any effect of the liming if forestland. As regards epiphytic algae in streams, there was a tendency for increased species richness and a smaller share of acidity-indicating species following liming. It was not possible to demonstrate any negative effects of the treatments. Studies of nutrient concentrations in needles reveal that the trees have reacted rapidly to the treatments through increased calcium concentrations. Similarly, treatments with ashes give not only an increase in calcium but also in, for example, magnesium and potassium concentrations. However, it order achieve greater reliability in assessing the effects of treatments on tree vitality, it is necessary to have longer time series than those presently existing.

Experiments with different types and doses of lime illustrate that both factors influence the effects in soils and waters, particularly with regard to limestone. The effects of different doses of dolomite were not as clear. The treatments with wood ashes also gave dose-dependent effects on some elements in soil and water, particularly calcium. Neither liming, treatment with ashes or combinations of ashes and lime gave any significant short-term effects on tree growth.

Studies made in old liming experiments showed that areas limed with relatively moderate doses about 25-90 years ago have considerably higher degrees of base saturation in comparison with untreated areas. The increase in degree of base saturation down to greater depths in the soil also results in the soil water having higher pH-values and lower concentrations of inorganic aluminium. The effect was particularly large on areas in southern Sweden where soils had become acidified during the 1990s.

Model calculations of the recovery of forestland from acidification in southern Sweden have indicated that the massive reduction in atmospheric deposition that is expected to occur up to year 2010 will result in a reduced level of acidity in the soil. However, in many places the recovery will be incomplete on account of massively acidified soils and calculations suggest that there is a risk that the recovery will stop at a level that is still acidified. Preliminary calculations of the effect of different doses of lime on severely acidified forestland indicate that the treatment can improve the recovery considerably but will need several decades to do so because of the time required for the lime to penetrate down into the soil profile.

Av Skogsstyrelsen publicerade Rapporter:

1985	Utvärdering av ÖSI-effekter mm
1985:1	Samordnad publicering vid skogsstyrelsen
1985:2	Beskärning i tallfröplantager
1986:1	Bilvägslagrat virke 1984
1987:1	Skogs- och naturvårdsservice inom skogsvårdsorganisationen
1988:1	Mallar för ståndortsbonitering; Lathund för 18 län i södra Sverige
1988:2	Grusanalys i fält
1988:3	Björken i blickpunkten
1989:1	Dokumentation – Storkonferensen 1989
1989:2	Bok, ek och ask inom svenskt skogsbruk och skogsindustri
1990:1	Teknik vid skogsmarkskalkning
1991:1	Tätortsnära skogsbruk
1991:2	ÖSI; utvärdering av effekter mm
1991:3	Utboträffar; utvärdering
1991:4	Skogsskador i Sverige 1990
1991:5	Contortarapporten
1991:6	Participantion in design of a system to assess Environmental Consideration in forestry a Case study of the greenery project
1992:1	Allmän Skogs- och Miljöinventering, ÖSI och NISP
1992:2	Skogsskador i Sverige 1991
1992:3	Aktiva Natur- och Kulturvårdande åtgärder i skogsbruket
1992:4	Utvärdering av studiekampanjen Rikare Skog
1993:1	Skoglig geologi
1993:2	Organisationens Dolda Resurs
1993:3	Skogsskador i Sverige 1992
1993:4	Av böcker om skog får man aldrig nog, eller?
1993:5	Nyckelbiotoper i skogarna vid våra sydligaste fjäll
1993:6	Skogsmarkskalkning – *Resultat från en fyraårig försöksperiod samt förslag till åtgärdsprogram*
1993:7	Betespräglad äldre bondeskog – *från naturvårdssynpunkt*
1993:8	Seminarier om Naturhänsyn i gallring i januari 1993
1993:9	Förbättrad sysselsättningsstatistik i skogsbruket – *arbetsgruppens slutrapport*
1994:1	EG/EU och EES-avtalet ur skoglig synvinkel
1994:2	Hur upplever "grönt utbildade kvinnor" sin arbetssituation inom skogsvårdsorganisationen?
1994:3	Renewable Forests - Myth or Reality?
1994:4	Bjursåsprojektet - *underlag för landskapsekologisk planering i samband med skogsinventering*
1994:5	Historiska kartor - *underlag för natur- och kulturmiljövård i skogen*
1994:6	Skogsskador i Sverige 1993
1994:7	Skogsskador i Sverige – *nuläge och förslag till åtgärder*
1994:8	Häckfågelinventering i en åkerholme åren 1989-1993
1995:1	Planering av skogsbrukets hänsyn till vatten i ett avrinningsområde i Gävleborg
1995:2	SUMPSKOG – ekologi och skötsel
1995:3	Skogsbruk vid vatten
1995:4	Skogsskador i Sverige 1994
1995:5	Långsam alkalinisering av skogsmark
1995:6	Vad kan vi lära av KMV-kampanjen?
1995:7	GROT-uttaget. Pilotundersökning angående uttaget av trädrester på skogsmark
1995:8	The Capercaillie and Forestry. Reports No. 1-2 from the Swedish Field Study 1982-1988
1996:1	Women in Forestry – What is their situation?
1996:2	Skogens kvinnor – Hur är läget?
1996:3	Landmollusker i jämtländska nyckelbiotoper
1996:4	Förslag till metod för bestämning av prestationstal m.m. vid självverksamhet i småskaligt skogsbruk.
1996:5	Skogsvårdsorganisationens framtidsscenarier
1997:1	Sjövatten som indikator på markförsurning
1997:2	Naturvårdsutbildning (20 poäng) Hur gick det?
1997:3	IR-95 – Flygbildsbaserad inventering av skogsskador i sydvästra Sverige 1995
1997:4	Den skogliga genbanken (Del 1 och Del 2)
1997:5	Miljeu96 Rådgivning. Rapport från utvärdering av miljeurådgivningen
1997:6	Effekter av skogsbränsleuttag och askåterföring – *en litteraturstudie*
1997:7	Målgruppsanalys
1997:8	Effekter av tungmetallnedfall på skogslevande landsnäckor *(with English Summary: The impact on forest land snails by atmospheric deposition of heavy metals)*
1997:9	GIS–metodik för kartläggning av markförsurning – *En pilotstudie i Jönköpings län*

1998:1 Miljökonsekvensbeskrivning (MKB) av skogsbränsleuttag, asktillförsel och övrig näringskompensation
1998:2 Studier över skogsbruksåtgärdernas inverkan på snäckfaunans diversitet *(with English summary: Studies on the impact by forestry on the mollusc fauna in commercially uses forests in Central Sweden*
1998:3 Dalaskog - Pilotprojekt i landskapsanalys
1998:4 Användning av satellitdata – *hitta avverkad skog och uppskatta lövröjningsbehov*
1998:5 Baskatjoner och aciditet i svensk skogsmark - tillstånd och förändringar
1998:6 Övervakning av biologisk mångfald i det brukade skogslandskapet. *With a summary in English: Monitoring of biodiversity in managed forests.*
1998:7 Marksvampar i kalkbarrskogar och skogsbeten i Gotländska nyckelbiotoper
1998:8 Omgivande skog och skogsbrukets betydelse för fiskfaunan i små skogsbäckar
1999:1 Miljökonsekvensbeskrivning av Skogsstyrelsens förslag till åtgärdsprogram för kalkning och vitalisering
1999:2 Internationella konventioner och andra instrument som behandlar internationella skogsfrågor
1999:3 Målklassificering i "Gröna skogsbruksplaner" - betydelsen för produktion och ekonomi
1999:4 Scenarier och Analyser i SKA 99 - Förutsättningar
2000:1 Samordnade åtgärder mot försurning av mark och vatten - Underlagsdokument till Nationell plan för kalkning av sjöar och vattendrag
2000:2 Skogliga Konsekvens-Analyser 1999 - Skogens möjligheter på 2000-talet
2000:3 Ministerkonferens om skydd av Europas skogar - Resolutioner och deklarationer
2000:4 Skogsbruket i den lokala ekonomin
2000:5 Aska från biobränsle
2000:6 Skogsskadeinventering av bok och ek i Sydsverige 1999
2001:1 Landmolluskfaunans ekologi i sump- och myrskogar i mellersta Norrland, med jämförelser beträffande förhållandena i södra Sverige
2001:2 Arealförluster från skogliga avrinningsområden i Västra Götaland
2001:3 The proposals for action submitted by the Intergovernmental Panel on Forests (IPF) and the Intergovernmental Forum on Forests (IFF) - in the Swedish context
2001:4 Resultat från Skogsstyrelsens ekenkät 2000
2001:5 Effekter av kalkning i utströmningsområden *med kalkkross 0 - 3 mm*
2001:6 Biobränslen i Söderhamn
2001:7 Entreprenörer i skogsbruket 1993-1998
2001:8A Skogspolitisk historia
2001:8B Skogspolitiken idag - en beskrivning av den politik och övriga faktorer som påverkar skogen och skogsbruket
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2001:8E Fornlämningar och kulturmiljöer i skogsmark
2001:8F Ännu ej klar
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2001:8H De skogliga aktörerna och skogspolitiken
2001:8I Skogsbilvägar
2001:8J Skogen sociala värden
2001:8K Arbetsmarknadspolitiska åtgärder i skogen
2001:8L Skogsvårdsorganisationens uppdragsverksamhet
2001:8M Skogsbruk och rennäring
2001:8N Ännu ej klar
2001:8O Skador på skog
2001:9 Projekterfarenheter av landskapsanalys i lokal samverkan – (LIFE 96 ENV S 367) Uthålligt skogsbruk byggt på landskapsanalys i lokal samverkan
2001:10 Blir ingen rapport
2001:11A Strategier för åtgärder mot markförsurning
2001:11B Markförsurningsprocesser
2001:11C Effekter på biologisk mångfald av markförsurning och motåtgärder
2001:11D Urvalskriterier för bedömning av markförsurning
2001:11E Effekter på kvävedynamiken av markförsurning och motåtgärder
2001:11F Effekter på skogsproduktion av markförsurning och motåtgärder
2001:11G Effekter på tungmetallers och cesiums rörlighet av markförsurning och motåtgärder
2001:11H Ännu ej klar
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2001:12 Forest Condition of Beech and Oek in southern Sweden 1999
2002:1 Ekskador i Europa
2002:2 Gröna Huset, slutrapport
2002:3 Ännu ej klar
2002:4 Landskapsekologisk planering i Söderhamns kommun
2002:5 Miljöriktig vedeldning - Ett informationsprojekt i Söderhamn

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1985:2	Eldning med helved och flis i privatskogsbruket/virkesbalanser 1985
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1989:2	Gallringsundersökningen 1987
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2001:6	Utvärdering av samråden 1998 Skogsbruk - rennäring
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2002:4	Action plan to counteract soil acidification and to promote sustainable use of forestland

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