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Recommendations for extraction of harvesting residues and ash recycling

SKOGSSTYRELSEN
SWEDISH FOREST AGENCY

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Preface to English Translation

Sweden has developed its technological use of forest biomass for energy over the last decades, and now almost 30 % of its total energy supply comes from bioenergy[A]. Sweden also has a long history of research on the effects of intensive biomass harvesting on forest nutrition, biodiversity and growth[B, C, D, E]. This knowledge was combined with operational experience[F] to produce the first guidelines for managing forest sites for intensive biomass removals in Sweden in 2001[G]. They were later translated into English[H]. Revised guidelines were published in 2008.

Nordic scientific findings, and guidelines and policies based on those findings, have long been of interest to other nations with similar temperate and boreal forests. This translation to English of the 2008 guidelines was made with the hopes that they would help other countries better understand the wider context of the bioenergy sector in Sweden, and be of use as other jurisdictions develop guidelines specific to their own circumstances. However, it should be underlined that the guidelines were developed for Sweden, with its present forestry practices and climatic and biogeochemical conditions.

The translation was facilitated with funding from the Canadian Forest Service and the International Model Forest Network on the initiative by Brian Titus who also made most of the technical corrections. Helpful comments were gathered from D.G. Maynard, J.R. Boyle, G. Egnell and B.A. Olsson. Efforts have been made to ensure technical accuracy in the translation, however, inevitably, some terms were difficult to find proper equivalents for, or were ambiguous already in Swedish as the knowledge area partly is relatively new. Hillevi Eriksson at the Swedish Forest Agency and Brian Titus are responsible for final corrections and choices of wording.

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[A] Swedish Bioenergy Association (SVEBIO). 2010. Bioenergy Explains Swedish Cuts in Emissions Despite High Economic Growth. Available at http://www.svebio.se/?p=726. Accessed on 15 Oct. 2010.

[B] Lundkvist H. 1988. Ecological effects of whole tree harvesting: some results from Swedish field experiments. In: Williams, T.M. and Greshum, C.A., editors. Predicting consequences of intensive harvesting on long-term productivity by site classification. IEA/BE Project A3, Report No. 6. Georgetown, SC, USA: Baruch Forest Science Institution of Clemson University. p. 131–40.

[C] Andersson, F. 1991. Effects of whole tree harvesting on long-term site productivity—some Swedish views. In: Mahendrappa, M.K., Simpson, C.M. and van Raalte, G.D., editors. Proceedings of the conference on the impacts of intensive harvesting, Fredericton, NB, 1991. p. 35–41.

[D] Lundkvist H. 1994. Whole tree harvesting: ecological consequences and compensatory measures examples from Sweden. In: Mahendrappa, M.K., Simpson, C.M. and Smith, C.T., editors. Proceedings of the IEA/BE workshop in Fredericton, New Brunswick, 1994. Can. For. Serv.—Maritimes Region Information Report M-X-191E, 1994. p. 1–7.

[E] Egnell G., Dahlberg A., Westling O., Bergh J. and Rytter L. 2006. Miljöeffekter av skogsbränsleuttag och askåterföring i Sverige. En syntes av Energimyndighetens forskningsprogram 1997 till 2004. Rapport 2006:44. Statens energimyndighet, Eskilstuna. [Environmental effects of forest biofuel extractions and wood ash recycling. A synthesis of the Swedish Energy Agency's research program 1997–2004. Swedish Energy Agency, ER2006:44. Summary in English. Document currently being translated by the Canadian Forest Service]

[F] Levin, R. and Eriksson, H. 2010. Good-practice guidelines for whole-tree harvesting in Sweden: Moving science into policy. For. Chron. 86:51-56.

[G] Skogsstyrelsen. 2001. Rekommendationer vid uttag av skogsbränsle och kompensationsgödsling. Meddelande 2:2001.

[H] Swedish National Board of Forestry. 2002. Recommendations for the extraction of forest fuel and compensation fertilizing. Meddelande 3:2002.

Preface

Forests can play an important role as a renewable resource in a society focused on recycling and having a low impact on the environment. Fuels from the Swedish forests are renewable, and have a minimal negative impact on the greenhouse effect in a tree generation time frame. They also reduce Sweden's dependency on imported energy.

The following recommendations specify how the Swedish Forest Agency believes extraction of harvesting residues (mainly branches and tree tops) and ash recycling should be done to avoid negative effects on biological diversity or on contents of nutrients, acids or harmful substances in the soil or runoff water.

Provided these recommendations are followed, the Swedish Forest Agency is in favour of the use of forest fuels.

These recommendations replace the directive Recommendations for the extraction of forest fuel and compensation fertilizing (Swedish Forest Agency Letter 2/2001).

Göran Enander
General Director

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1 Background

1.1 Purpose

Increased utilization of harvesting residues from forestry for energy production can replace fossil fuels and hence contribute to decreasing the negative impact humans have on the climate. It is then important that extraction does not affect the environment in other ways. Intensive extraction of biomass from the forest is estimated to often contribute to the acidification of soil and drainage water. Without countermeasures, the extraction of biofuels from the forest is judged unsuitable in parts of Sweden[1]. The Swedish Forest Agency recommends ash recycling as the proper countermeasure. The March 2008 government forest bill[2] states that ash recycling on forest sites should increase, and that extraction of branches and tree tops could increase at suitable locations. When harvesting residues are removed, so does also material that could act as substrate and breeding habitat for different organisms. Similar to other forestry interventions (i.e., operations, treatments and activities), wrongly conducted extraction of harvesting residues and ash recycling could damage natural and cultural environments.

Negative effects on the environment must therefore be counteracted or limited if extraction of harvesting residues is to be consistent with sustainable forestry. Thus, the purpose of these recommendations is to state under which circumstances extraction of harvesting residues and ash recycling can be done without reducing the possibilities to meet other environmental quality and production goals.

Ash can be used as a fertilizer to increase tree growth on peatlands or nitrogen-rich sites. In some cases, it may be advantageous to use a higher ash dosage than that used for compensation purposes. The current recommendations do not apply to the use of ash at such higher dosages.

1.2 Some background documents

The *Environmental Code* and *Swedish Forestry Act* were used as important base documents when the Swedish Forest Agency developed recommendations for the extraction of harvesting residues and ash recycling (see Section 2.5). The recommendations are also based on research results that are summarized in environmental impact assessments on the extraction of harvesting residues, ash application and other nutrient compensation treatments[3], and lime treatment and revitalization[4]. In addition, the recommendations are based extensively on later research results (see Section 1.3) and experiences from ash recycling conducted in practice. To a varying degree several of the Swedish Environmental Quality Objectives have also contributed to the basis, such as *Reduced Climate Impact, Flourishing Lakes and Streams, Good-Quality Groundwater, Natural Acidification Only, Zero Eutrophication, Living Forests, A Rich Diversity of Plant and Animal Life, A Non-Toxic Environment, A Good Built-up Area Environment,* and *A Safe Radiation Environment.*

The regulations and general advice in Section 30 of the *Swedish Forestry Act* contain a

[1] European Environmental Agency. 2006. How much bioenergy can Europe produce without harming the environment? Report No 7/2006. EEA, Köpenhamn.
[2] Regeringen. 2008. En skogspolitik i takt med tiden. Regeringens proposition 2007/08:108.
[3] Egnell G., Nohrstedt H O., Weslien J., Westling O. och Örlander G. 1998. Miljökonsekvensbeskrivning (MKB) av skogsbränsleuttag, asktillförsel och övrig näringskompensation. Rapport 1998:1. Skogsstyrelsen, Jönköping.
[4] Johansson M.B., Nilsson T. och Olsson M. 1999. Miljökonsekvensbeskrivning av Skogsstyrelsens förslag till åtgärdsprogram för kalkning och vitalisering. Rapport 1999:1. Skogsstyrelsen, Jönköping.

clause that directly concerns the extraction of harvesting residues and compensatory treatments. Among other things, the regulations state that:

"Damage caused by forestry interventions must be avoided or limited on land and in water.

When clear-cutting forest, nutrient leakage to lakes and watercourses must be limited. Any forest fertilization, lime treatment of forest land, revitalization fertilization, or application of pesticides must be done in a manner that avoids or limits damage to the environment. When tree parts other than stemwood are extracted from the forest, measures shall, when necessary, be taken before, in conjunction with, or after the extraction to ensure that the long-term nutrient balance of the forest land is not damaged."

Among other things, the general advice states that:

"In coniferous forests, damage to the nutrient balance when extracting other tree parts than the stem can be limited if most conifer needles are left behind as evenly dispersed as possible in the felled area. Such damage can also be avoided or limited by application of mineral nutrients (for example, ash). Without addition of mineral nutrients, extraction should not take place more than once during a stand's rotation period. Furthermore, extraction on heavily acidified land should not be conducted unless mineral nutrients are applied. On nitrogen-rich land, extraction may include the conifer needles, provided application of mineral nutrients takes place. Without the application of mineral nutrients, extraction should not be done on peatland.

When using ash for revitalization fertilization and compensation fertilization, the amount, form, and composition of the ash, as well as the time of fertilization, should be chosen so as to limit nitrogen leaching and loss of added nutrients in order to avoid or limit damage to the environment. For example, the ash should be derived from biofuels and be stabilized and slow-dissolving. In addition, the total amount of harmful substances (such as heavy metals) introduced during a stand's rotation period should not exceed the total amount of such substances removed through biomass extraction.

At compensation fertilization, the total input during the stand's rotation period should not exceed 3 DM (dry matter) tonnes of ash per hectare."

The recommendations in this directive are in large an interpretation of the practical significance of the referenced regulations and general advice.

1.3 Impact of extraction of harvesting residues

1.3.1 Biological Diversity

A sufficient supply of dead wood is needed to maintain the biological diversity of wood-living species in the forest[5]. Access to large dead wood in different stages of decomposition is especially important. However, many insect species

are dependent on small wood[5]. In addition, the soil environment is affected when harvesting residues are extracted from the forest, which negatively affects some ground-living species[6, 7]. As a precautionary measure, it is therefore appropriate to leave some harvesting residues behind, regardless of the type of wood, in order to protect the biological diversity of the forest[8] (see recommendations in Section 2.1). Special care should be taken when extracting harvesting residues from deciduous forests. Aspen and high-value deciduous trees (see p. 7) are especially important for wood-living species, partly because many insects lay their eggs in residue piles of these tree species[9,10].

1.3.2 Acidification and nutrient depletion

When a tree grows, nutrients are absorbed from the soil through the roots. For the tree to maintain its ion balance, it emits an acid hydrogen ion for every positively charged nutrient and a basic hydroxide ion for every negatively charged substance it absorbs. The absorption of positively charged nutrients is normally greater than the absorption of negatively charged nutrients, which leads to slow acidification of the soil. In an untouched forest, net acidification is marginal because the nutrients are released again when the tree dies and decomposes. Moreover, in the decomposition process, about the same amount of acidifying hydrogen ions are consumed as the tree contributed during its lifespan. Hence, tree felling and extraction of biomass impacts the balance. The more biomass that is extracted from the forest, the higher the risk that weathering and deposition of nutrients will be insufficient to compensate for the loss of nutrients and alkalinity. Thus, the risk of acidification and nutrient depletion is greater when harvesting residues are extracted in addition to conventional stemwood extraction. Concentrations of nutrients are higher in tree branches and tops than in stems.

When the amount of harvesting residues extracted is large compared to the site's ability to compensate for its loss, the soil surface is acidified first and the degree of base saturation and pH decreases. Field studies have shown that base saturation decreases by 10-20 %[11] and pH by 0-0.4 pH units[12]. The acidification then spreads downwards in the soil profile and causes acidification of drainage water. Nutrient mass balance budgets, where the inflow of nutrients (especially base cations and phosphorus) to the forest site through deposition and weathering is compared to the outflow through leaching and biomass extraction, show that compensation is often needed to avoid net losses of nutrients when harvesting residues are extracted from the forest[13].

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[5] Dahlberg A. och Stokland J.N. 2004. Vedlevande arters krav på substrat - sammanställning och analys av 3.600 arter. Rapport 2004:7. Skogsstyrelsen, Jönköping.
[6] Gunnarsson B. och Nittérus K. 2004. Uttag av grot på hyggen och biologisk mångfald hos några leddjursgrupper. Rapport TB-04/1 3. Statens energimyndighet, Eskilstuna.
[7] Åström M. och Nilsson C. 2005. Effekter av grotuttag på växters mångfald. Rapport TB-05/10. Statens energimyndighet, Eskilstuna.
[8] Egnell m.fl. 1998. See Footnote 3.
[9] Jonsell M., Hansson J. and Wedmo L. 2005. Diversity of saproxylic beetles in harvesting residues—preference for tree species and dimensions. Rapport TB-05/14. Statens energimyndighet, Eskilstuna.
[10] Egnell G., Bergh J., Dahlberg A., Rytter L. och Westling O. 2006. Miljöeffekter av skogsbränsleuttag och askåterföring i Sverige – En syntes av Energimyndighetens forskningsprogram 1997 till 2004. Rapport 2006:44. Statens energimyndighet, Eskilstuna.
[11] Olsson B.A., Bengtsson J. and Lundkvist H. 1996. Effects of different forest harvest intensities on the pools of exchangable cations in coniferous forest soils. Forest Ecology and Management 84: 135–147.
[12] Egnell m.fl. 1998. See Footnote 3.
[13] Akselsson C. 2005. Regional nutrient budgets in forest soils in a policy perspective. Doctoral thesis. Department of Chemical Engineering, Lund University, Lund.
[14] Akselsson C. 2005 (see 13).

Compensation is especially important when harvesting residues are extracted from spruce stands[13].

If there is no compensation for the extraction of base substances, the extraction of harvesting residues may increase the soil acidity, which in turn may have a negative impact on the quality of drainage water. Even small changes in pH may have a significant negative impact on biological diversity in watercourses. The availability of phosphorus affects the nitrogen fixation ability of forest sites and may be important for counteracting nitrogen leaching during periods of good nitrogen availability.

The increased removal of nutrients when harvesting residues are extracted may also cause reduced forest growth, most probably because the supply of nitrogen is reduced [15, 16]. When extraction occurs in conjunction with regeneration felling, growth reduction is generally offset because extraction of harvesting residues facilitates soil scarification, and the length of the fallow period before planting can sometimes be reduced[17]. However, in some parts of Sweden, the extraction of harvesting residues results in more nitrogen being removed than what is added through deposition and nitrogen fixation[18]. In these cases, it may be necessary to compensate also with nitrogen at some point during the next rotation, to avoid nitrogen depletion at the site which could have a negative impact on tree growth and ultimately on flora and fauna.

Recycling of ash, which contains all macronutrients except nitrogen, has been proven to have an impact on tree growth when the ash is spread in growing forests[19, 20, 21].On more fertile sites, the ash may increase growth[22, 23]; on less fertile soils, both increasing and decreasing growth trends have been reported[24, 25]. A possible explanation for increased growth is that the ash increases nitrogen mineralization in the soil. Other possible explanations are that in nitrogen-rich soils, phosphorus or some other substance from the ash limits productivity and therefore causes growth increase, or mitigation of soil acidity by the ash has a positive impact on phosphorus availability in the soil. In nitrogen-poor soils, the ash can favour bacteria and cause them to bind the nitrogen in a way that temporarily reduces its availability for the trees. However, a low nitrogen dosage is enough to compensate for any reductions in growth that may occur in these situations[26]. In addition, in areas with low soil nitrogen content, it is possible to disperse the ash on recently felled areas, which should cause any growth reduction to be negligible.

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[15] Egnell G. and Valinger E. 2003. Survival, growth, and growth allocation of planted Scots pine trees after different levels of biomass removal in clear-felling. Forest Ecology and Management 177: s65. * *correct this*.
[16] Egnell G. and Leijon B. 1999. Survival and growth of planted seedlings of *Pinus sylvestris* and *Picea abies* after different levels of biomass removal in clear-felling. Scandinavian Journal of Forest Research 14: 303–311.
[17] Egnell m.fl. 2006. See Footnote 10.
[18] Zetterberg T., Hellsten S., Belyazid S., Karlsson P.E. och Akselsson C. 2006. Regionala förutsättningar och miljörisker till följd av skogsmarksgödsling vid olika scenarier för skogsskötsel och kvävedeposition. Rapport B 1691. IVL Svenska Miljöinstitutet, Göteborg.
[19] Jacobson S. 2003. Addition of stabilized wood ashes to Swedish coniferous stands on mineral soils—Effects on stem growth and needle nutrient concentrations. Silva Fennica 37: 437–450.
[20] Saarsalmi A., Mälkönen E. and Kukkola M. 2004. Effect of wood ash fertilization on soil chemical properties and stand nutrient status and growth of some coniferous stands in Finland. Scandinavian Journal of Forest Research 19: 217–233.
[21] Thelin G. 2006. Askåterföring till gran- och bokbestånd - effekter på näring, tillväxt, kvävedynamik och kolbalans. Rapport 965. Värmeforsk, Stockholm.
[22] Jacobson. 2003. See Footnote 19. [23] Thelin 2006 See Footnote 21. [24] Jacobson 2003 See Footnote 19.
[25] Saarsalmi et al. 2004. See Footnote 20.
[26] Jacobson S., Kukkola M., Mälkönen E. and Tveite B. 2000. Forest Ecology and Management 129:41–51.

If removal of soil nutrients exceeds input over a long period, the availability of nutrients could be reduced. Over time, this may impact the production capacity of the site. It is possible that trees can compensate for a lower supply of nutrients by increasing nutrient absorption through mychorrhizae.[27, 28] However, since field studies have shown that the extraction of harvesting residues causes acidification (cf. above), this process does not sufficiently counteract the acidification of soil and water. Furthermore, the soil's capacity to support forest-living organisms other than trees may decrease. Having a sustainable budget for the nutrients that trees and other plants need can be a long-term insurance for future nutrient supply. In many older soils on more southern latitudes, lack of phosphorus is the primary growth limiting factor. Since global phosphorus deposits are limited, phosphorus fertilizers are likely to become more expensive over time.

The Swedish Forest Agency assesses that extraction of harvesting residues representing more than half a ton of ash per hectare (ha) per rotation period risks causing acidification and nutrient depletion that is too severe to be defined as sustainable use of forest sites; therefore, extraction needs to be compensated (see recommendations in Section 2.2). Compensation may take place before as well as after residue extraction. The application of ash is cheaper when several adjacent sites are treated at the same time, but such rational application may delay the compensation. However, the Swedish Forest Agency conclude that there should normally be a rough balance between extraction of harvesting residues and ash recycling in a medium-sized felling area (300–2000 ha) over a 20-year period to prevent deterioration of water quality in affected forest streams. Forest owners with medium to large holdings may also want to consider such a balance for their own property.

1.4 History

Regulations concerning extraction of harvesting residues have been in place since 1985, when the Swedish Forest Agency first issued general advice on limiting the extraction of tree parts other than stemwood. In 1998, a provision on the reporting of extraction of harvesting residues was added, as well as an amendment which, among other things, specified that damage to soil and water from extraction of tree parts should be avoided or limited. The Swedish Forest Agency's recommendations were developed on the basis of these and other documents. In 2001, amendments were added to cover ash dosage and quality requirements, and quality control of ash products used as compensation for the removal of nutrients. Since 2001, additional knowledge has emerged; therefore, the Swedish Forest Agency found it appropriate to update the recommendations. One major update concern the testing of minimum hardening of ash. Also some of the recommended minimum nutrient and maximum heavy metal concentrations of the ash have also been revised based on increased knowledge about the contents of tree parts. Various results from the Swedish Energy Agency's research program have also affected the new recommendations.[29]

[27] Rosling A. och Finley R. 2004. Mykorrhizasvampar kan vittra mineraljord. Fakta Skog nr 15. SLU, Uppsala.
[28] Smith S. and Read D. 1997. Mycorrhizal Symbiosis. Academic Press.
[29] Egnel, etc. 2006. See footnote 10.

1.5 Definitions

Ash: In this directive, ash refers mainly to ash from biofuels. Recycling ash from biofuels is considered to be positive from an element recycling perspective. The Swedish Forest Agency's recommendations are aiming at that ash recycling should only return the amount of heavy metals that was present in the grown-up trees and that would have ended up in the soil had the trees remained in the forest. Ash from other fuels may also be used provided the ash quality is high—i.e., it meets the quality requirements set out in the current recommendations, and does not contain harmful substances which are not present in pure biomass ashes.

Ash recycling: Since the Swedish Forest Agency states that mainly ash should be used to compensate for extraction of base cations, the term "ash recycling" is generally used in this directive. However, other alkaline products that contain nutrients may also be used. Ash and mineral products may also be combined.

Base cations: The positively charged metal ions in the soil are called base cations. These are potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and sodium (Na^+). All base cations, except sodium, are nutrients. The soil also contains positively charged acid ions, such as hydrogen ions (H^+) and aluminum (which can occur in various forms).

Degree of base saturation: This refers to the base cation proportion of cations attached to negatively charged exchange complexes in the soil.

Liming effect: Nutrient absorption by trees leads to enrichment of acidic ions (H^+) in the soil and enrichment of basic nutrients in the tree. After combustion, bases are recovered in the ash as anions and hence returned to the soil if the ash is returned to the forest. The liming effect of the ash can be expressed as the equivalent of the base cations it contains.

Harvesting residues: In this letter, harvesting residues refers to branches and tree tops.

2 Recommendations

2.1 Preserve biological diversity

The Swedish Forest Agency holds the view that:

When extracting harvesting residues, it is important that trees, shrubs, and dead wood that have been spared because of natural and cultural environmental considerations are left behind unharmed.

Forests with a high natural value, as key biotopes and certain wetland forests, should be excluded from extraction of harvesting residues in case those values thereby could be damaged.

Extraction of harvesting residues should include only tree species that common in the landscape.

At least one fifth of the harvesting residues should be left in the clearcut area, preferably in locations exposed to the sun. It is particularly important to leave tops, coarse branches and dead wood from deciduous trees, as well as tops of pines.

Extraction of harvesting residues and ash recycling should be avoided in sensitive biotopes and during periods when animal life could be harmed.

Extraction of harvesting residues is a more intensive use of forests and forest sites compared to traditional harvesting. In consideration of the natural and cultural environment, it is therefore especially important not to damage trees and shrubs, standing as well as fallen, that have been left behind from previous forestry operations. This is especially important when extracting harvesting residues from grazing land, forest edges facing cropland or meadows, burnt forests, and deciduous borders along lakes and watercourses. Protective zones with trees and shrubs, where no regular extraction of harvesting residues should occur, should be left as boundaries around low-productive land (e.g. mires, bare rock), open agricultural land, lakes, and watercourses. Also, harvesting residues should not be stored within protective zones adjacent to lakes and watercourses.

Harvesting residues should not be extracted from forests that have a high natural value—for example, key biotopes—if that value could be harmed. Wetlands usually have a high natural value. Since the soil's load-bearing capacity in wetlands is often poor, driving equipment across a site when extracting harvesting residues can easily cause damage because there is less harvesting residue to protect the ground than when only stemwood is extracted. For the same reason, extraction of harvesting residues from waterlogged sites with a low load-bearing capacity generally should be avoided (see Section 2.4).

When extracting harvesting residues from mixed forests, uniform extraction of deciduous trees should be avoided. It is especially important to protect areas with a high proportion of aspen, goat willow, alder, and 'high-value deciduous trees' (= oak, beech, elm, ash, mapletree, lime, cherry, hornbeam). Regulations on respecting the interests of nature conservation and the cultural environment (Section 30, *Swedish Forestry Act*) also apply to the extraction of harvesting residues.

To protect biological diversity and the organisms that live on dead wood, 20 % of the harvesting residues should be left behind. Coarse dead wood (with a diameter greater than 10 cm) is especially important for the flora and fauna, so it should be left behind when extracting harvesting residues. Wood from pine and deciduous trees, especially coarse wood from high-value deciduous species, is the most important for maintaining biological diversity. However, the risk of possible insect infestation should also be considered (see Section 2.4).

The time of year when harvesting residues are extracted is important for biodiversity. Extraction of harvesting residues should be avoided during periods when animal life may be harmed. For example, during the summer, some rare insects use wood from high-value deciduous trees as breeding habitat. Therefore, wood from such trees should be extracted as soon as possible after felling or not later than 15 April if felling occurs between 1 September and 15 April. If this is not possible, the uppermost layer of the residue piles should be lifted off and left behind.

Ash recycling should not be done within areas that support sensitive flora— for example, key biotopes—if its dispersal could have a negative impact on the flora. In other areas, ash recycling should be timed so as to minimize the risk of disturbances to endangered species.

Several studies have shown that Sphagnum (peat moss) is especially sensitive to ash that has not been sufficiently vitrified. Areas with sphagnum should not be treated in such a way that the vitality of the moss is significantly impaired. If the ash used is close to the allowed lower limit of hardening, the dosage can be lowered somewhat when treating areas that contain sphagnum[30]. Only well-hardened ash should be used when ash is recycled on drained forest sites.

The extraction of harvesting residues is probably positive for reindeer husbandry since the residues may impede the growth of ground lichen. However, extraction of harvesting residues on snow-covered ground in areas with hanging lichen should be avoided until the next snow-free period. Extraction of harvesting residues should not be done in the most valuable forest areas with hanging lichen. Stricter regulations apply to caesium content when recycling ash in reindeer pastureland (see Section 2.3.3). If new information indicates that ash recycling may have a negative impact on reindeer pasture, this should be taken into account in areas that support reindeer husbandry.

[30] See Appendix 1 for information about hardening testing.

2.2 Avoid acidification and nutrient depletion of forest land

The Swedish Forest Agency holds the view that:

Ash recycling should be done on sites where extensive amounts of harvesting residues are extracted at some point during the rotation period. The purpose is primarily to counteract acidification caused by the extraction of biomass. The treatment may take place before, in conjunction with, or after extraction.

Extraction of harvesting residues should be compensated with ash if:
- the total extraction of tree parts other than the stem over the rotation represents more than half a tonne of ash per hectare, and
- most of the conifer needles are not left fairly evenly dispersed[31].

Exceptions can be made if the extraction takes place within a watershed area where extraction of harvesting residues is likely to exceed half a tonne of ash in only a small part of the area.

However, ash should always be recycled when harvesting residues are extracted at regeneration felling, even if the extraction represents less than half a tonne of ash per hectare and the conifer needles have been left well dispersed, if:
- the soil is severely acidified, *or*
- the forest grows on peatland.

In nitrogen-rich areas, it is preferred that conifer needles be removed from the site, provided that the ash is recycled. In areas with low levels of nitrogen deposition and high levels of biomass extraction, compensation may need to include both ash and nitrogen.

A balanced budget for alkaline substances and nutrients increases the possibility of preserving the quality of drainage water and maintaining the supply of accessible nutrients in the soil. Therefore, the Swedish Forest Agency judges that substantial extraction of harvesting residues should be compensated by ash recycling. Compensation may be done *before, in conjunction with* or *after* extraction of harvesting residues. The ash could be dispersed in thinned stands if extraction of harvesting residues is likely to occur, with time, in conjunction with clear-felling.

The Swedish Forest Agency finds that extraction of harvesting residues representing more than half a tonne (dry matter) of pure, non-hardened ash per hectare per rotation period normally causes too much acidification and nutrient depletion to be defined as sustainable land use. Hence, in areas dominated by spruce, the ash should be recycled if the extraction of wood is 200 m^3 per hectare or more and the residual extraction is close to maximum, i.e., 80 % (see Table 1).

If harvesting residues are extracted only during pre-commercial thinning or thinning, the extraction often represents less than 0.5 DM tonne of fresh ash per hectare.

[31] With today's harvesting techniques in Sweden, extraction of harvesting residues is rarely combined with leaving the conifer needles well dispersed.

Most often, extraction of harvesting residues in conjunction with regeneration felling of pine stands can be done without the need for compensation (see Table 1). The threshold limit for stands containing pine and/or a lower percentile extraction of existing harvesting residues can be estimated using Table 1.

Table 1. Estimated production of pure, non-hardened[32] ash (DM tonnes of ash per hectare) from combusted harvest residues from sites with different levels of wood extraction, and with either 40 % or 80 % of total harvesting residue removal (i.e., total amount of branches and tree tops).[33] Estimates for mixed stands can be calculated by adding the wood extraction of pine and spruce.

	Residual extraction (%)	Wood extraction (forest cubic metre/hectare)							
		50	100	150	200	250	300	350	400
Pine	40	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2
	80	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4
Spruce	40	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5
	80	0.1	0.3	0.4	0.5	0.7	0.8	0.9	1.0

On sites with an especially high weathering rate (base-rich sites), extraction can exceed the equivalent of 0.5 DM tonnes of ash per hectare without causing substantial acidification. Nevertheless, there may be reason to recycle the ash to ensure a sustainable phosphorus balance is maintained on base-rich sites.

If residue extraction is large enough to have an acidifying effect is possible only in a small part of a drainage area (during one century), it will not significantly reduce the quality of runoff water. Therefore, extraction may take place without ash recycling in drainage areas (300–500 ha) where less than 10 % of the total area could at some point generate extraction of harvesting residues that correspond to more than 0.5 DM tonnes of ash per hectare, provided there is no extraction from severely acidified sites or peatland.

Leaving most conifer needles well dispersed on clearcut objects significantly limits the extraction of nutrients because the needles are rich in nutrients.

In the most southern and south-western parts of Sweden, a significant part of the growth-accessible base cation supply has been lost through leaching due to several centuries of high acid deposition. To avoid exacerbating the situation, ash recycling should be done if the harvesting residues are extracted during regeneration felling, even if the conifer needles are left well dispersed or the extraction corresponds to less than 0.5 DM tonne of ash per hectare per rotation period.[34]

In forest ecosystems on peatlands, the supply of certain nutrients, especially phosphorus and potassium, is often limited. On such sites, much of the nutrients are bound in the trees. Therefore, it is particularly important that ash is recycled when harvesting residues are extracted from peat-lands at regeneration felling, even if the conifer needles are left behind. Ash may also be added to peatlands to compensate for stemwood extraction.

[32] When ash is hardened, the weight increases by several tenfold percentage points, mainly because oxides are converted to carbonates, using CO_2 from the air. In addition, the pure ash is often blended with tenfold percentage points of non-combusted material or sand from fluid beds in the pan.

[33] The calculations are based on a pine and spruce density of 0.4 DM tonnes per cubic metre of wood, a dry weight of residues (including conifer needles) of 41% of the weight of the stem with bark for spruce and 22% for pine, and an ash content in the residues of 2% for spruce and 1.5% for pine.

[34] These recommendations apply to forest sites in Skåne, Blekinge, Kronoberg, Halland, Jönköping and Västra Götaland counties.

Extraction of harvesting residues entails significant removal of nitrogen. On forest sites with high nitrogen content[35], extraction of harvesting residues may counteract nitrification and nitrogen leaching by reducing the risk of a "compost effect" under the piles of harvesting residue and by reducing the amount of nitrogen in the system. Ground vegetation can also re-establish faster and absorb released nutrients, thereby further reducing nitrification. Lower nitrification prevents the addition of acid to the soil.

In regions with low nitrogen deposition, extraction of harvesting residues may cause nitrogen loss to exceed input over the rotation, which in the long term may result in reduced tree growth or a negative impact on flora and fauna. Extraction of harvesting residues in these areas should be compensated for with both ash and nitrogen. Nitrogen supplementation may also counteract the temporary growth reduction reported after ash recycling on sites with low site productivity. Guidelines regarding nitrogen supplementation are provided in the Swedish Forest Agency's general advice, SKSFS 2007:3.

[35] Forest sites with high nitrogen content refers primarily to coastal locations in south-western Sweden. In other areas of Götaland and parts of Svealand provinces, where nitrogen deposition is high, extraction of harvesting residues that include conifer needles may also be positive from the standpoint of alleviating high nitrogen inputs.

2.3 Use ash correctly

The Swedish Forest Agency holds the view that:

The ash product should be sufficiently hardened and slow dissolving to prevent damage to sensitive species.

When harvesting residues have been extracted at regeneration felling, it can be generalized that a dose of 2 DM tonnes of ash per hectare is appropriate as compensation dose if the site index low (<G23), and 3 DM tonnes of ash per hectare is appropriate if the site index is medium and higher.

To avoid undesirable effects, at most 3 DM tonnes of ash per hectare should be recycled per 10-year period and 6 DM tonnes of ash per hectare per rotation.

When recycling ash, total addition of heavy metals and other harmful substances over a rotation should not be greater than what is removed through biomass extraction. For guidelines on content of nutrients and heavy metals, see Table 2.

When recycling ash, nitrogen leaching and loss of introduced nutrients should be prevented.

A 25-metre ash-free zone should be left around sensitive areas.

2.3.1 Hardening of ash

Ash applied in the forest should be treated so that direct damage to soil and vegetation, and mechanical damage to trees is avoided. Ash should be applied evenly and in a manner that allows for slow dissolution. Ash may be hardened (made less soluble) through water infusion combined with mechanical processing to an appropriate particle size and hardness (for example, granulation or pelletizing). It may also be hardened after water infusion through self-hardening, if necessary with subsequent breakdown and/or sifting (so-called "crushed ash"). The objective is for the ash product to dissolve over a 5- to 25-year period in the field. The initial dissolution rate should be sufficiently slow so as to avoid causing undesirable effects after application. Poorly hardened ash may damage flora and fauna and increase the risk of nutrient leaching from the ash.

To ensure that the ash solubility requirements are met, the Swedish Forest Agency developed a method of testing if an ash product is sufficiently hardened. The method, described in Appendix 1, tests whether a sufficiently even application of ash in a forest stand causes damage to different species of peat moss (*Sphagnum* spp.), which are the most sensitive of common mosses in Sweden. Ash that is insufficiently hardened should be applied to forest sites only if it can be demonstrated that it will not chemically ‘burn’ peat moss.

There is less risk of leaf damage if the ash consists of large granules. This is because the greater distance between particles makes leaf damage more dispersed, and the ash granules fall more easily to the ground under the leaves. The degree of hardening does not have to be tested of ash products for which at least 95 % of the weight consist of particles with a diameter of at least 4 mm.

2.3.2 Dosage

Ash should be recycled to compensate for the loss of alkalinity and the total removal of base cations due to the extraction of harvesting residues during the rotation period. Compensation for estimated removals of individual nutrients may lead to unacceptably high ash dosages in terms of available ash supply and potential environmental impact.

The risk of negative environmental effects increases with ash dosage. However, the negative environmental effects are expected to be very limited with dosages of up to 3 DM tonnes of sufficiently hardened ash per hectare[36]. No more than 3 DM tonnes per hectare should be recycled per 10-year period. During the total rotation period, no more than 6 DM tonnes per hectare should be added. This amount will compensate for total biomass extraction also on highly productive spruce sites, without causing significant negative effects. If the demand for biofuel increases, harvest systems that entail greater extraction and/or extraction of tree stumps in conjunction with felling may become more common, and hence require compensation that exceeds 6 DM tonnes of ash. However, in most cases, an infusion of 3 DM tonnes per hectare should be enough to compensate for the extraction and then ash recycling should be limited to 3 DM tonnes also during the rotation period.

The ash dosage required to compensate for the extraction of harvesting residues does not normally have to be calculated exactly. The Swedish Forest Agency estimates that 2 DM tonnes of hardened ash per hectare are sufficient compensation for a site index below G23 (less than average), while 3 DM tonnes per hectare are sufficient if the site index is higher. These dosages entail some over-compensation for extraction of harvesting residues at regeneration felling; hence, they also compensate for potential extraction in conjunction with precommercial thinning and thinning. The need for compensation can also be more precisely calculated based on the equivalent amount of liming effect extracted at the various harvesting occasions. The Forestry Research Institute of Sweden has developed a program in which the compensation requirement is based on liming effect of some investigated examples of hardened ashes[37]. Normally compensation should be done primarily for the extraction of harvesting residues, but it can also be done for part or all of the stemwood extraction. This may be justified on peatlands or within acidified areas in southern Sweden.

For the ash to have the desired effect on peat-land, it should have a high phosphorus and potassium content. On peatland, the compensation requirement should be calculated based on the removal of phosphorus and potassium[38]. As on other sites, ash application on peatland should not exceed 3 DM tonnes of ash per hectare per 10-year period or 6 DM tonnes per rotation period.

[36] The dosages refer to actual hardened ash, cf. Footnote 31.
[37] The calculation program is called “Snurran 1.0” and may be downloaded from the Forestry Research Institute of Sweden homepage: www.skogforsk.se.
[38] May be calculated using “Snurran 1.0”, available from the Forestry Research Institute of Sweden.

2.3.3 Ash quality

For ash to have the desired effect, it should contain sufficient amounts of desirable nutrients. The Swedish Forest Agency has specified the minimum levels that should be met (Table 2). If these levels are not met, consideration should be given to adding these nutrients to the ash product. If the ash product is diluted with more non-combusted material or dust, sand, gravel,[39] or bonding agents than the usual 20–30 % (which has been taken into account in the above estimation of suitable ash dosages and in the Forestry Research Institute of Sweden's calculation program), the nutrient level of the ash will be correspondingly diluted. The dosage may then be increased accordingly, and both nutrient and heavy metal levels should then be calculated per unit weight of pure ash.

Table 2. Recommended minimum and maximum levels of elements in ash products intended for application on forest sites. These recommendations are for dry matter levels in ash products applied in the forest—i.e., after potential infusion of fertilizer nutrients or bonding agents. The specified guidelines do not apply to residual products other than ash.

Element	Recommended levels	
	Minimum	Maximum
Macronutrients (g/kg DM)		
Calcium	125	
Magnesium	15	
Potassium	30	
Phosphorus	7	
Trace elements (mg/kg DM)		
Boron		800
Copper		400
Zinc	500	7,000
Arsenic		30
Lead		300
Cadmium		30
Chromium		100
Mercury		3
Nickel		70
Vanadium		70

Heavy metals can interrupt biological processes in the soil and affect the quality of surface water and groundwater. Therefore, the ash's heavy metal content must not exceed the total that can be removed through biomass extraction over one rotation. Since the amount of heavy metals recycled on forest sites through the ash is comparable to the amount that would have been released through decomposition of the harvesting residues, the risk of negative effects is deemed to be low. However, available data on measured levels of heavy metals in different tree parts show that concentrations vary between individual trees and areas in Sweden.

[39] In analysis protocols, the content of non-combusted organic matter is usually stated. The approximate content of dust, sand, and gravel is reflected in the levels of Si (SiO_2) and Al (Al_2O_3).

While guideline values for maximum and minimum levels of elements in recycled ash

(Table 2) have been based mainly on demonstrated levels in tree components, threshold values for certain elements (e.g. Cr) have been reduced on the basis of available data on contents in investigated biofuels ashes. Thus, in the coming well-combusted ash from pure biofuels, without admixture of dense bed material or bonding agents, may show higher contents of these elements that exceed the specified maximum level. Normally, all elements should meet the guideline values, but some variation is acceptable if it can be proven that the ash originates from pure biofuels and is not contaminated by harmful elements. Even if the high levels are natural - for example, they result from bedrock that is rich in arsenic - restrictions may apply as to where the ash can be dispersed.

In its *Code of Statues*, the Swedish Radiation Safety Authority has issued regulations and general advice on the handling of ash contaminated with caesium-137 (^{137}Cs) (SSI FS 2005:1)[40]. It sets the threshold level of ^{137}Cs in ash for application on forest sites at 10 kBq/kg DM. Areas where wood fuel ash levels may exceed the threshold value are shown (Figure 1). If ash from the combustion of harvesting residues from these areas is to be applied on forest sites, its ^{137}Cs content should always be tested. Recycling of ash with ^{137}Cs levels above 0.5 kBq/kg DM is not allowed on reindeer pasture land with lichen. An area is defined as a "lichen area" if lichen covers more than 25 % of the existing soil surface or the area is continuously used as reindeer pasture.

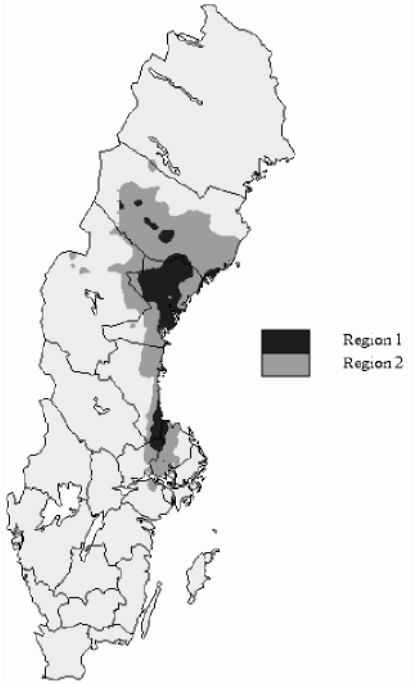

Figure 1. Areas where wood fuel ash may have ^{137}Cs (caesium-137) levels over 10 kBq/kg (Note: Gäddede and the Västerbotten mountains are not included in the database). Region 1: Levels of ^{137}Cs in the total ash from combustion of harvesting residues and sawmill residuals (bark, chips, etc) may exceed 10 kBq/kg. Region 2: Level of ^{137}Cs in fly ash from wood fuels may in some circumstances (fine granular ash fraction, type of warming pan, burn conditions, etc.) exceed 10 kBq/kg.

[40] Statens strålskyddsinstitut. 2005. Kommentarer och vägledning till föreskrifter och allmänna råd om hantering av aska som är kontaminerad med cesium-137. SSI Rapport 2005:07. Statens strålskyddsinstitut, Stockholm.

Polycyclic aromatic hydrocarbons (PAHs) may develop during combustion, and could therefore occur in ash. PAH levels in ash applied on forest sites should not be so high as to endanger the environment. The threshold level is unknown; therefore, emerging knowledge about this subject should be taken in to consideration.

Table 2 guideline values concern *total* levels of macronutrients and trace substances. Total levels should be determined by an accredited laboratory. Total levels include both easily soluble and poorly soluble fractions; therefore, analytical results may overestimate, for example, the value of the ash product as a source of phosphorus in the short term if it contains a lot of sinter material. Likewise, the total analysis of heavy metals does not reflect their availability.

2.3.4 Application

Ash sometimes has to be stored pending application. Ash is classified as waste and is subject to existing laws regarding transportation and storage of waste (see Section 2.5). Interim storage of ash and finished ash products should be done in a manner that minimizes leaching (potassium is the most likely nutrient to leach). The storage site should be dry and located on relatively high ground. Permanent interim sites should have a hard surface as well as access to water and a scale.

The ash should be applied in a way that does not damage sites and vegetation (see Section 2.4). Moreover, there should be a strive for even dispersal (<25 % of the treated area should receive more than a double dose). As with nitrogen fertilization, there should be no ash added in, or adjacent to, sensitive areas (Table 3).

Table 3. Areas where ash recycling should be avoided.

	Ash-free zone (min width in metres)
Lakes and watercourses	25
Wetlands with high or very high natural and cultural values (corr. to class 1 and 2 in the wetland/wet forest inventory)	25
Formally protected land	25
Key biotopes	25
Gardens	25
Land and roads owned by other landowners	10

Ash recycling aims to improve chemical quality of runoff water. Still, it may cause damage if it ends up directly in the water. Primarily this could be caused by its high salt content. And, in addition to base cations, ash contains substances that may be harmful to water organisms if deposited at a high dosage directly into the aquatic environment. Moreover, areas along the stream usually have high biodiversity values, and therefore an ash-free zone should be left around all lakes and along permanent (i.e., perennial) watercourses.

An ash-free zone also should be left along wetlands with a high natural value, key biotopes, and building sites. An ash-free zone should be established adjacent to formally protected land (i.e., areas protected by the regulations in Chapter 7 of the *Environmental Code* and/or nature conservation agreements) if the ash could have a negative impact on the values being protected.

Ash-free zones should be left around land and roads owned by others. However, if

these areas have no special natural value, a zone width of 10 metres is sufficient.

Ash recycling may be done at freshly clearcut areas if there is enough field vegetation to absorb nutrients and prevent leaching *or* if the ash is sufficiently hardened (see Appendix 1, Table 4) and slow-dissolving so that leaching from the clearcut area will be negligible.

Ash recycling on nitrogen-rich sites should be done in a manner that does not increase nitrogen leaching. Up until now, no studies have shown that ash recycling cause increased nitrogen leakage in practice. However, any emerging knowledge on this subject should be taken into account. In view of the precautionary principle in the *Environmental Code*, Chapter 2 (§3), it may be appropriate in some cases to avoid application of ash during the felling stage on nitrogen-rich sites if, for example, the sites is adjacent to a watercourse.

2.4 Limit physical damage on sites and trees, and prevent insect damage

The Swedish Forest Agency holds the view that:

The technology, method, and time of extraction of harvesting residues and ash recycling should be chosen so that driving equipment does not cause transfer of sediments and organic material to watercourses or damage to cultural and ancient remains, and so that mechanical damage to trees is limited.

Measures should be taken to prevent insect damage.

When extraction is prepared, less of the residues are often used as protection against deep track formation at moist soils. Moreover, extraction of harvesting residues and ash recycling entails increased transportation in the forest. This increases the risk of driving damage to soils, growing trees, and both downed and standing trees that are left behind out of consideration for natural values. When extraction is well planned during felling, there is a better chance that the harvesting residue will not have to be used to protect the soil on extraction trails. Soil damage can impact biological diversity in watercourses and damage cultural or ancient remains. Special care should be taken when driving on sites with poor load-bearing capacity. This can include avoiding driving during periods when the ground is waterlogged, or using bridges and soil protection measures. Driving damage must not occur in areas with ancient remains. Permanent ancient remains and the area around them are protected by the *Heritage Conservation Act*. Other ancient remains should be respected in accordance with Section 30 of the *Swedish Forestry Act*. In forests located near urban areas with significant human presence, harvesting residues could preferably be extracted.

Application of hard ash products to soils in forest stands may cause abrasion damage to trees that are closest to the road or trail on which spreading equipment drives, especially in young spruce stands and during periods when the sap is rising. The ash product used and the application technique should be designed to avoid such damage.

The provisions of Section 29 of the *Swedish Forestry Act* concerning measures to prevent insect damage also apply when large dimension fresh wood is classified as energy wood and is left in the forest to dry. However, biological diversity should also be taken into account (see Section 2.1).

2.5 Documentation, regulations, and contacts with local authorities

The Swedish Forest Agency holds the view that:

Extraction of harvesting residues and ash recycling should be documented.

Many years may pass between extraction of harvesting residues and ash recycling; interventions (i.e., operations, treatments) therefore should be documented. Appropriately, documentation is appropriately made in a Forestry Management Plan or equivalent. It should include information about the extracted tree species, time of extraction, whether conifer needles were extracted or left behind and evenly dispersed, and any ash recycling that was done (time, dosage, and chemical composition of the ash). The areas in which ash was dispersed should also be reported to the Swedish Forest Agency, which intends to use its GIS system to record information about these areas.

2.5.1 Swedish Forestry Act

Extraction of harvesting residues and ash recycling is regulated according to Section 30 (nature considerations) and Section 14 (notification of extraction of forest fuel) of the *Swedish Forestry Act*. Section 29 (forest protection) contains regulations on storage of forest biomass. Section 20 (reindeer husbandry) contains regulations on consultation with affected Sámi settlements about felling and subsequent forest conservation measures.

The landowner is responsible for ensuring that the long-term soil nutrient balance is not adversely affected when tree parts other than stemwood are extracted. The landowner is also responsible for ensuring that extraction of harvesting residues and ash recycling is conducted in a manner that avoids or limits damage to the environment.

2.5.2 Environmental Code

Chapter 2 of the *Environmental Code* (1998:808) contains general rules regarding any intervention that may impact the environment or human health.

Chapter 12 (6) of the *Environmental Code* states that activities and interventions that may significantly change the natural environment must be reported for consultation. The party registering the extraction of harvesting residues under Section 14 of the *Swedish Forestry Act* is also considered to have registered for consultation under Chapter 12 (6) of the *Environmental Code*. The Swedish Forest Agency believes that incorrect ash recycling or the use of inappropriate ash may have major effects on the natural environment; therefore, ash recycling should be reported to the Agency. Reporting is required at least 6 weeks before the intervention. The Swedish Forest Agency is the supervisory authority responsible for ensuring that forestry interventions are done in accordance with the regulations set forth for Natura 2000 areas in Chapter 7 (28) of the *Environmental Code*. Supervision applies to interventions both within and outside of Natura 2000 areas. The Agency will assess, on a case-by-case basis, whether an intervention such as ash recycling is permissible. If the Agency determines that ash recycling may have a serious impact on the environment, the party will be notified accordingly and informed that permission for the intervention must be sought from the County Administrative Board.

If ash recycling could contaminate sites, aquatic areas, or groundwater, it also falls under the regulations for environmentally hazardous activity in Chapter 9 of the *Environmental Code* and its consequential legislation, which means that the municipality has the right to be notified. In cases where ash recycling could present such a risk, the Swedish Forest Agency will consult the municipality.

Since ash is classified as waste, the regulations on waste in Chapter 15 of the *Environmental Code* and its consequential legislation may also apply to ash recycling activities. This relates mainly to the treatment, transportation, and storage of ash, which means that, in certain cases, such interventions must be registered with the municipality, or permission must be sought from the County Administrative Board.

2.5.3 Heritage Conservation Act

Ancient remains are protected under the *Heritage Conservation Act* (1988:950). The Act prohibits unauthorized moving, removal, excavation, and covering of permanent ancient remains, as well as construction, planting, or other actions that may change or damage them. The area surrounding ancient remains, known as an ancient heritage site, are also protected according to Chapter 2 (2) of the Act. If a forestry intervention is intended in a forest stand with known ancient remains, the County Administrative Board must be consulted pursuant to Chapter 2 (10). If ash recycling has been registered with the Swedish Forest Agency, the Agency will initiate contact with the County Administrative Board, as required.

2.5.4 Other legislation

In Statute SSI FS 2005:1, the Swedish Radiation Safety Authority (SSI) provides regulations and general advice on the handling of ash contaminated with ^{137}Cs, and on ash intended for dispersal on forest sites.

Appendix 1

1. Sampling

Testing should be done on the finished ash product, but could also be done on incoming ash before processing. The collection of samples for hardening and quality analysis is critical since the ash can vary with both sampling time and within a larger volume of ash.

Sampling should be done in accordance with the guidelines in Nordtest Metod NT ENVIR 004 for sampling of solid waste and particulate material, or SS 197113 for biofuels and peat. Generally, sampling for analysis is required for lots of 250–500 tonnes of ash or finished ash product, or at least once per combustion season. At larger incineration plants and facilities that use clean biofuels, sampling may be done less often than at facilities that use more varied fuels and functions. It is important that the protocol of analysis represents the ash actually dispersed in the forest.

For optimal representation of the finished product, sampling should be done by taking at least 15 subsamples of 1 litre each. The subsamples should then be carefully blended into a single bulked sample. The total number and size of subsamples depends on the homogeneity of the ash. More subsamples will be required if the ash is substantially non-homogeneous. Subsamples should be taken from conveyor belts or falling flows. When obtained from a pile, the subsamples must be taken from different parts of the pile and at different depths.

Reference samples of every bulked sample from the finished product should be saved with its analytical values for at least 3 years. Note that hardening during the storage period may decrease the reactivity of the reference samples.

2. Control of minimum hardening of spreadable ash

Use a standard method to obtain ash samples. Withdraw a representative sample of ash that weighs at least 500 g. Sift the sample using a 4-mm sieve, and select a sample of sifted particles for further analysis.

Determination of dry content, Swedish standard SS 028113. Measure about 50 g of ash, place it in a beaker, and let it dry in a drying oven at 105ºC to constant weight (about 24 hours). Preferably, use at least five replicates. After drying, the samples should be weighed immediately or left to cool in desiccators before being weighed. Calculate the mean dry content.

Calibrate electrodes according to the manufacturer's instructions.

Weigh out about 25 g of ash in a 250-mL glass Erlenmeyer flask. Preferably, use at least three sample replicates.

Based on the dry ash content, calculate the amount of water needed to make a dilution of one part dry ash to five parts water. Measure and add distilled water. Seal the Erlenmeyer flask with a bung.

Set the solution to stir (e.g., using a magnetic stirrer) and leave it for an hour. The stirring is sufficient if it produces about a 5-mm deep hole in the middle of the Erlenmeyer flask and leaves no ash sediment on the bottom.

Filter the mixture using Munktell 3 filter paper. **Measure the electrical conductivity** (according to Swedish standard SS-EN 27888) in the clear solution.

Table 4. Recommended maximum electric conductivity (EC) levels [mS/m] in recyclable ash after measurement in accordance with the above method (DM = dry matter, ha = hectare).

Dose (ton DM/ha)	Threshold value for EC
Clearcut area[41]	2400
2–3	2800
1–2	3200
< 1	3600

Ash products with at least 95% of the ash (by weight) consisting of granules with a diameter of 4 mm or greater can be dispersed regardless of electrical conductivity. If at least half of the ash (by weight) contains granules greater than 4 mm in diameter then the threshold electrical conductivity value for the next lower dose may be used. For example, the 3200 mS/m threshold value may be used for dispersal of 2–3 DM tonnes of ash with 60% of granules larger than 4 mm in diameter.

[41] Lacking vegetation on most of the area.

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1988:1 Mallar för ståndortsbonitering; Lathund för 18 län i södra Sverige
1988:2 Grusanalys i fält
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
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1992:1 Allmän Skogs- och Miljöinventering, ÖSI och NISP
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1997:3 IR-95 – Flygbildsbaserad inventering av skogsskador i sydvästra Sverige 1995
1997:5 Miljeu96 Rådgivning. Rapport från utvärdering av miljeurådgivningen
1997:6 Effekter av skogsbränsleuttag och askåterföring – *en litteraturstudie*
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1997:8 Effekter av tungmetallnedfall på skogslevande landsnäckor *(with English Summary: The impact on forest land snails by atmosphericdeposition of heavy metals)*
1997:9 GIS–metodik för kartläggning av markförsurning – *En pilotstudie i Jönköpings län*
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The forest plays an important role in the Swedish energy supply. While most energy from the forest comes from stemwood, the contribution from extraction of branches and tree tops for energy purposes has increased.

In this publication, the Swedish Forest Agency gives its view on how extraction of harvesting residues and related ash recycling should be done to conform with today's forest policy objectives with respect to environmental status, sustainable productivity, and maintenance of biological diversity.

Increased removal of nutrients must be combined with compensation for alkalinity and nutrients that are not naturally replenished. Ash recycling is an important action that is now being carried out on an operational scale. According to the forestry sector objectives adopted 2003, the area that receives ash should be approximately equal in size to the area from which harvesting residues are extracted.