Soil protection is better than damage detection

- but both will be necessary in modern forestry

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Talk contents

(a) Soil protection

1. Context for soil protection
2. Instruments for soil protection
3. Methods of soil protection
4. Conclusions

(b) Soil monitoring

5. Soil condition monitoring systems
6. Soil condition monitoring methodologies
7. Practical considerations
8. Conclusions and recommendations


Soil
Degradation
Risks
in Planted
Forests
2015
EUSKO JAURLARITZA
GOBIERNO VASCO

Soil damage risk

Some examples

Soil functions

Soils deliver ecosystem services that enable life on Earth

2015 International Year of Soils

fao.org/soils-2015

Food and Agriculture Organization of the United Nations

with the support of

Schweizerische Eidgenossenschaft
Confédération suisse
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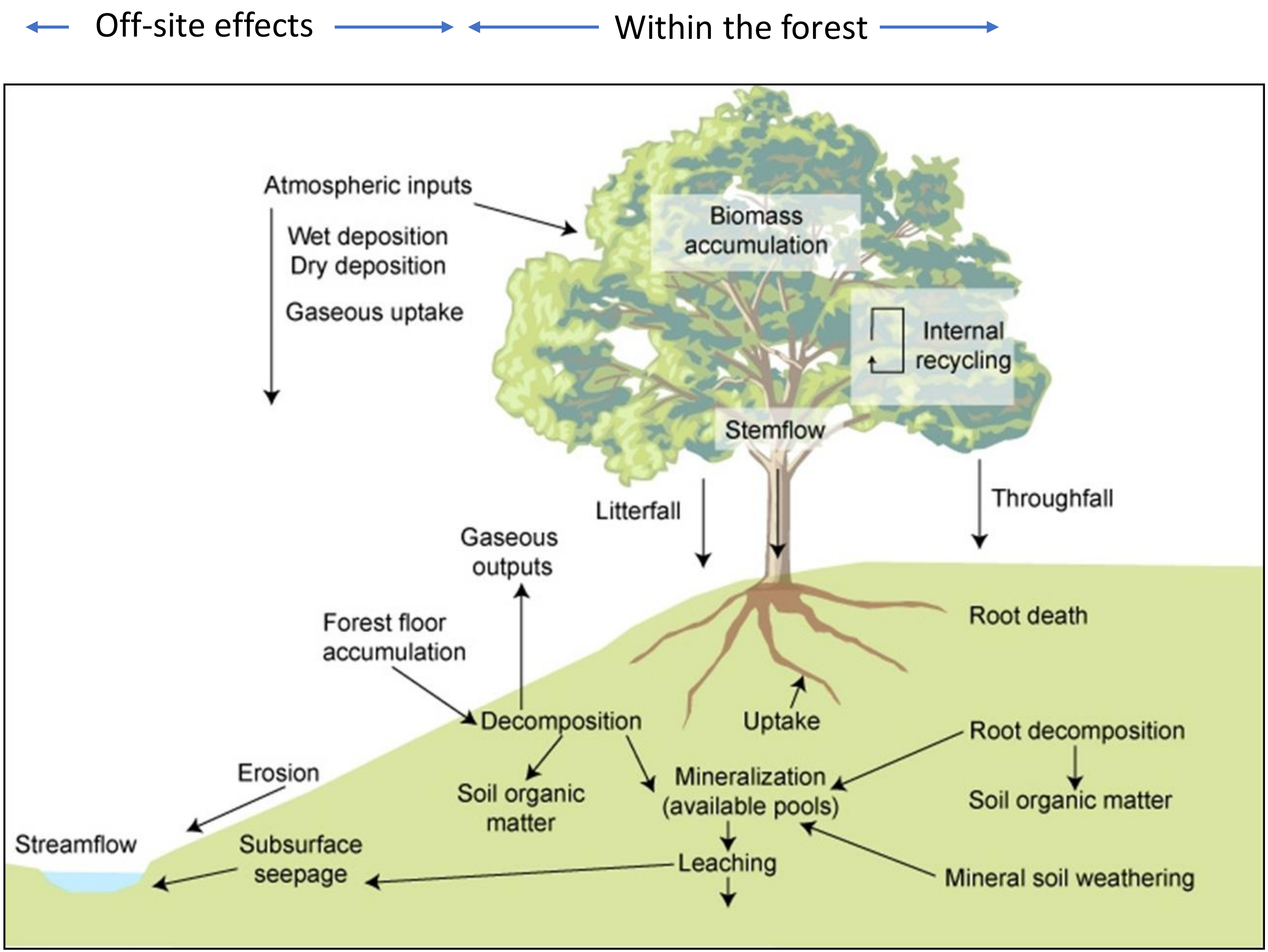
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
Federal Office for Agriculture FOAG


Off-site effects
Within the forest
Atmospheric inputs
Wet deposition
Dry deposition
Gaseous uptake
Biomass accumulation
Internal recycling
Stemflow
Litterfall
Throughfall
Gaseous outputs
Forest floor accumulation
Root death
Decomposition
Uptake
Root decomposition
Erosion
Soil organic matter
Mineralization (available pools)
Soil organic matter
Streamflow
Subsurface seepage
Leaching
Mineral soil weathering

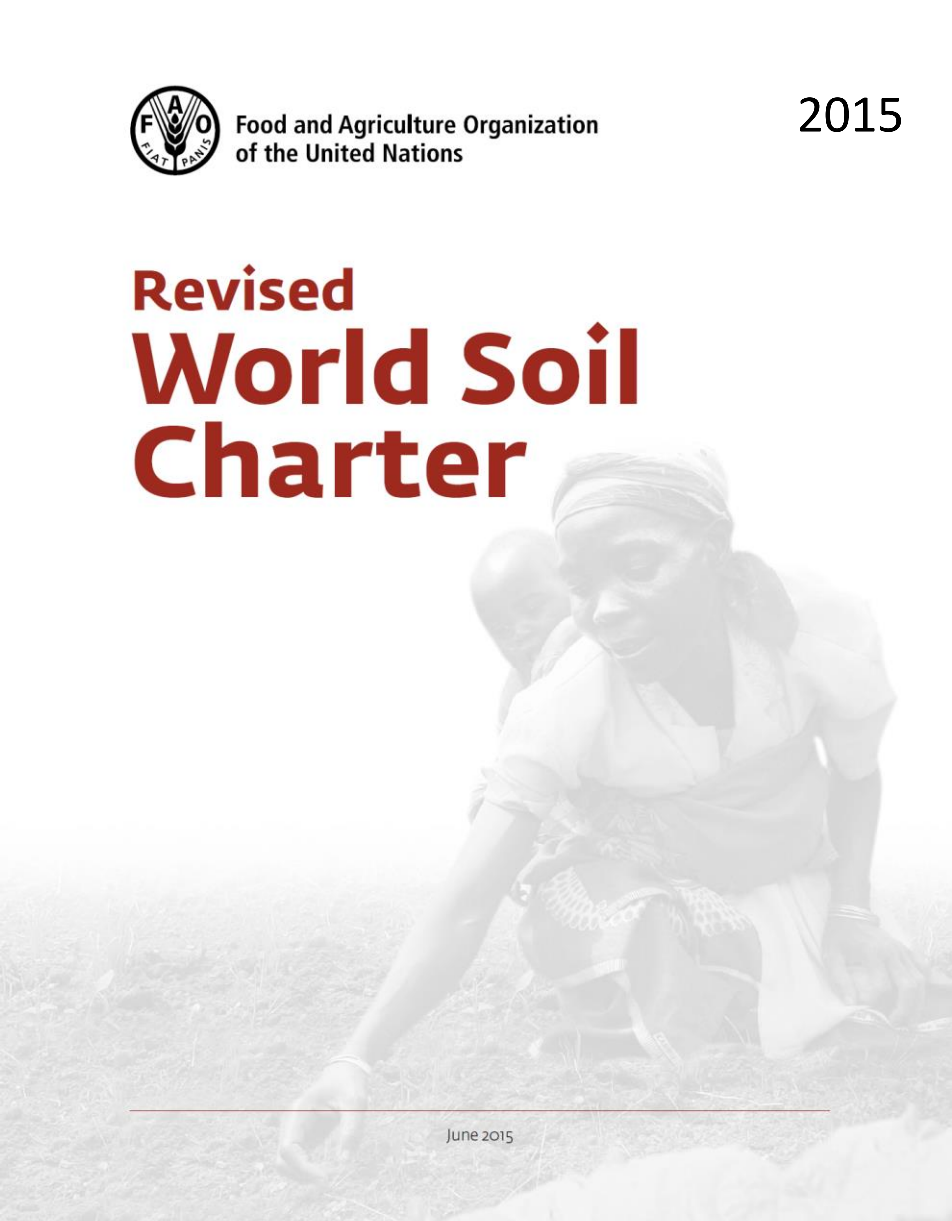
2015
International
Year of Soils

Mandates for forest soil protection

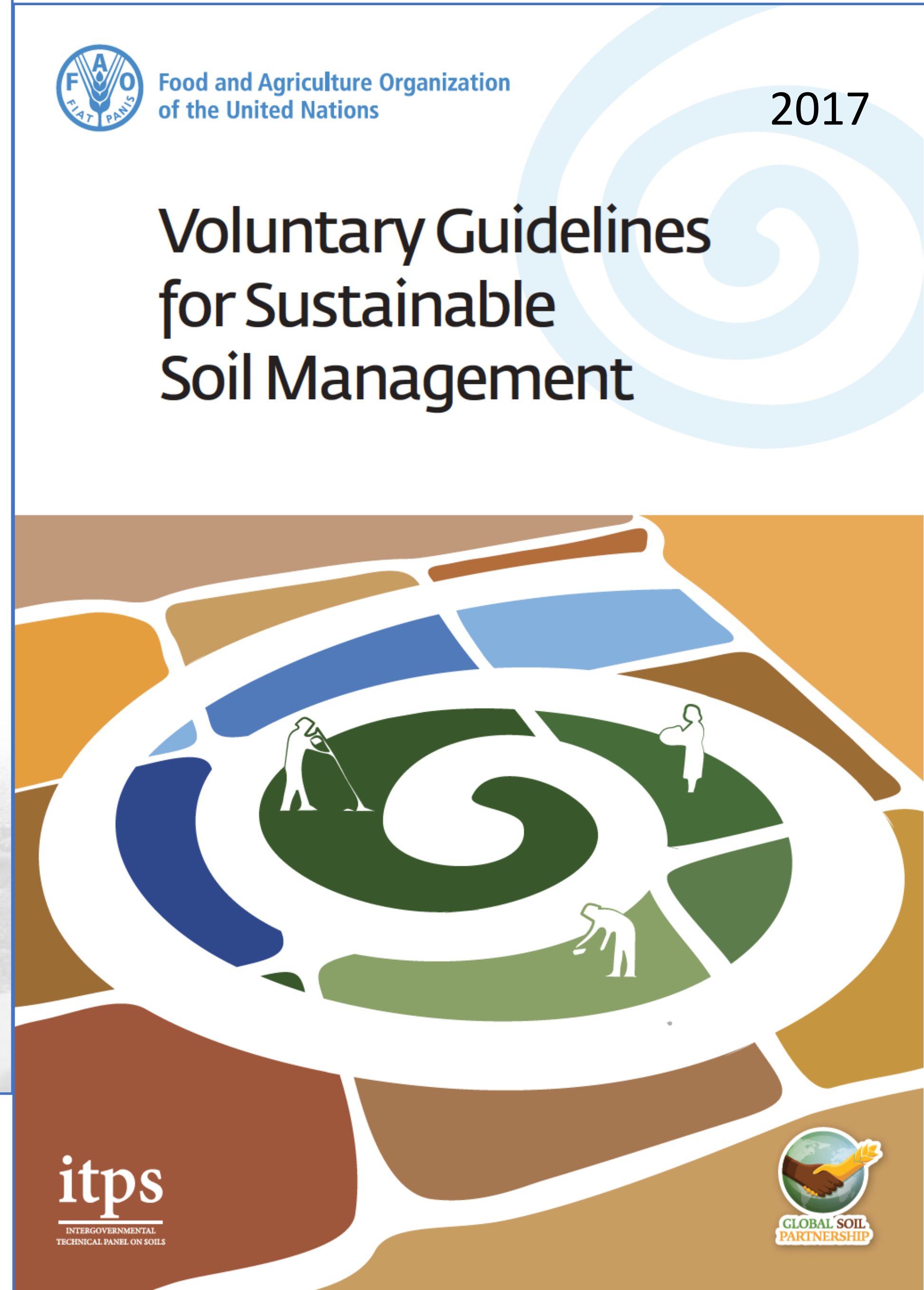
Some examples

- European Soil Charter (1972)
- World Soil Charter (1981, 2015)
- Forest Europe, formerly the Ministerial Conference on the Protection of Forests in Europe (MCPFE) (from 1994) – 'Sustainable Forestry'
- EU Environmental Impact Assessment (EIA) Regulations (EC Directive 85/337/EEC)
- EU Water Framework Directive (2000)
- EC Thematic Strategy for Soil Protection (2006)
- National interpretations of 'Sustainable Forestry''
- Forest Certification Schemes, e.g. FSC

2015


Food and Agriculture Organization
of the United Nations
Revised
World Soil
Charter
June 2015

2017


Food and Agriculture Organization
of the United Nations
Voluntary Guidelines
for Sustainable
Soil Management
itps
INTERGOVERNMENTAL
TECHNICAL PANEL ON SOILS
GLOBAL SOIL
PARTNERSHIP

Government instruments for soil protection

I. **Promote sustainable soil management** that is relevant to the range of soils present.

II. **Create socio-economic and institutional conditions favourable to sustainable soil management** by removal of obstacles associated with land tenure, the rights of users, access to financial services and educational programmes.

III. Participate in the development of multi-level, interdisciplinary **educational and capacity-building initiatives** that promote the adoption of sustainable soil management.

IV. **Support research programmes** that will provide sound scientific backing for development and implementation of sustainable soil management relevant to end-users.

V. Incorporate the principles and practices of sustainable soil management into **policy guidance and legislation** at all levels of government, ideally leading to the development of a national soil policy.

(From Revised World Soil Charter)

Government instruments for soil protection

VI. Explicitly consider the role of soil management practices in **planning for adaptation** to and mitigation of climate change and maintaining biodiversity.

VII. **Establish and implement regulations** to limit the accumulation of contaminants beyond established levels to safeguard human health.

VIII. **Develop and maintain a national soil information system** and contribute to the development of a global soil information system.

IX. **Develop a national institutional framework for monitoring** implementation of sustainable soil management and overall state of soil resources.

(From Revised World Soil Charter)

Soil protection – the **positive** role of forests

Forests can play a vital role in preventing soil erosion, protecting water supplies and maintaining other specific ecosystem functions. Measures are in place in some countries for either recognizing or safeguarding these specific functions. Such measures may include the restriction or enhancement of certain management practices and the zoning of forests. Forest designations are administrative in nature or the result of decisions made in the context of land-use and forest management planning.

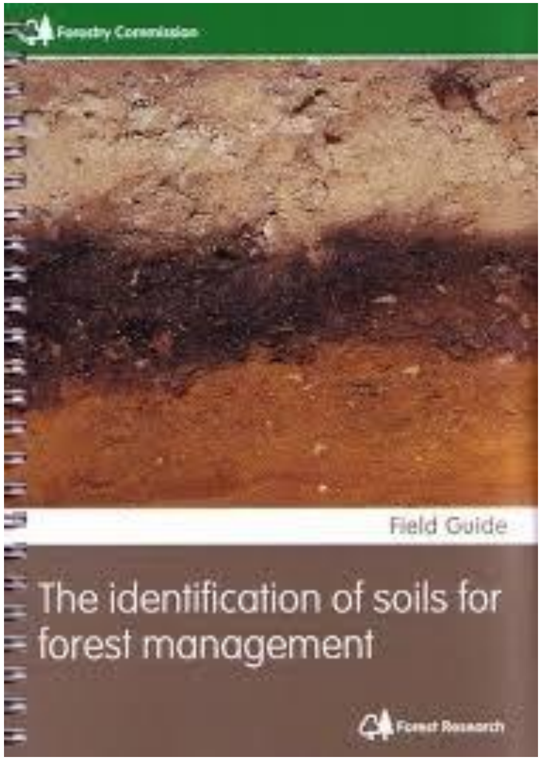
From: *State of Europe's Forests* (2015)

More than **110 million ha** of forests in Europe are designated for the protection of water, soil and ecosystems, as well as the protection of infrastructures, managed natural resources and other services

Most reporting countries identified **soil protection** as a **main policy objective**. About a third of the reporting countries identified **protection of water** as a priority

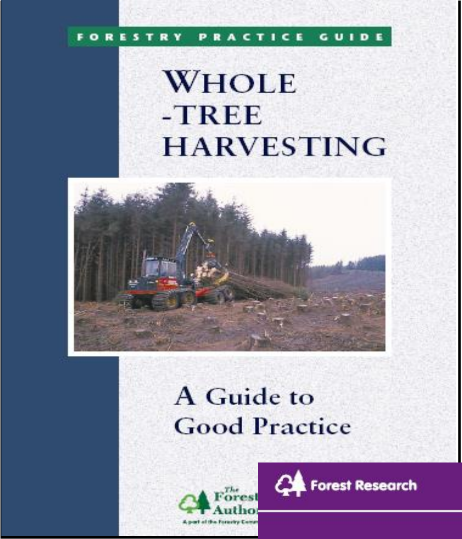
Target Government grants to, or away from, specific soil types

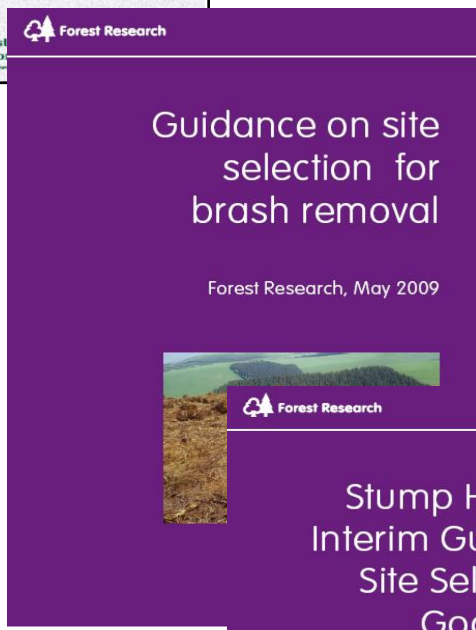
Educational / training materials

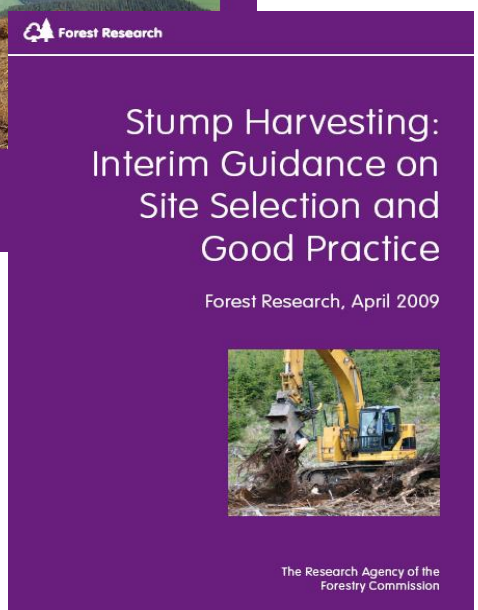


Educational / training materials

Training courses, webinars, videos, website resources, publications







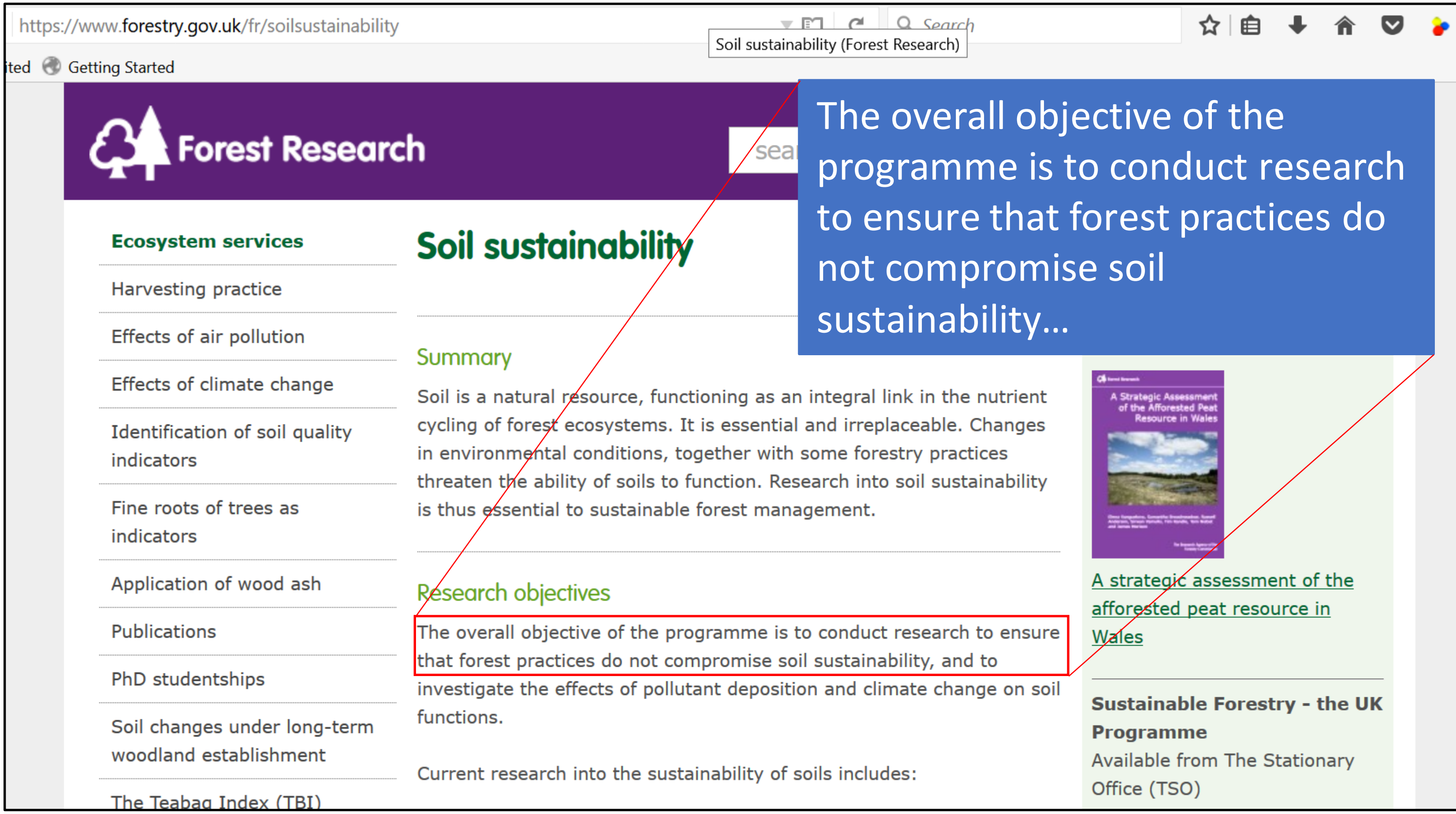
Best practice guidelines

Soil suitability

Soil group	Soil type	Ground damage	Soil carbon	Soil infertility	Soil acidification	*Combined Risk*
Brown earths	1, 1d, u	L	L	L	L	L
	1z	L	L	M	M	M
Podzols	3, 3m	L	L	H	H	H
	3p	M**	M	H	H	H
Ironpan soils	4, 4p	M**	M	M	M	M**
	4b	M	L	M	M	M
	4z, 4e	M	L	H	H	H
Calcareous soils	12b, t	L	L	L	L	L
	12a	L	L	H*	L	H*
Ground-water	5	M	L	L	L	M
	5p	M**	M	L	L	M**
Peaty gleys	6	M	M	M	M	M
	6z	M	M	H	H	H
	6p	H	M	M	M	H
Surface-water	7, 7b	M	L	L	M	M
	7z	M	L	M	M	M
Juncus bogs	8a, b,	H	H	L	L	H
Molinia bogs	9a, b	H	H	M	M	H
	9c, d, e	H	H	H	H	H
Unflushed	11a, b,	H	H	H	H	H
Rankers	13b, z	L	L	H	H	H
	13g	M	L	H	H	H
	13p	M	M	H	H	H
Skeletal soils	13s	L	L	H	H	H
Littoral soils	15s, d,	L	L	H	H	H
	15g, w	H	L	H	H	H

L: low risk; M: medium risk; H: high risk. *Only for conifer stands, otherwise low risk. **3p, 4p and 5p are high risk where the depth of the peaty surface layer is >25 cm.

Research programmes


https://www.forestry.gov.uk/fr/soilsustainability

Soil sustainability (Forest Research)

Getting Started

Forest Research

Ecosystem services

- Harvesting practice
- Effects of air pollution
- Effects of climate change
- Identification of soil quality indicators
- Fine roots of trees as indicators
- Application of wood ash
- Publications
- PhD studentships
- Soil changes under long-term woodland establishment
- The Teabag Index (TBI)

Soil sustainability

Summary

Soil is a natural resource, functioning as an integral link in the nutrient cycling of forest ecosystems. It is essential and irreplaceable. Changes in environmental conditions, together with some forestry practices threaten the ability of soils to function. Research into soil sustainability is thus essential to sustainable forest management.

Research objectives

The overall objective of the programme is to conduct research to ensure that forest practices do not compromise soil sustainability, and to investigate the effects of pollutant deposition and climate change on soil functions.

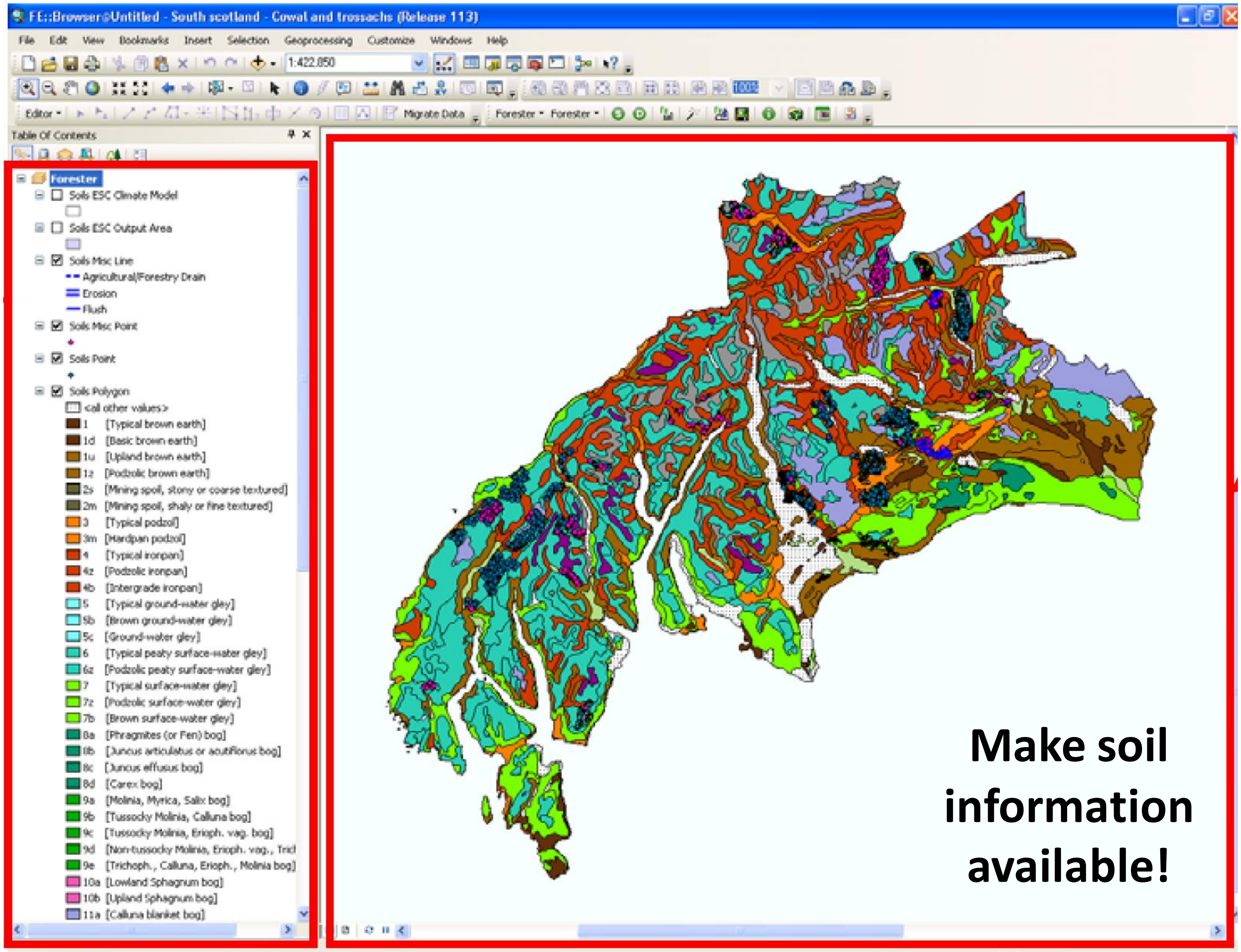
Current research into the sustainability of soils includes:

A strategic assessment of the afforested peat resource in Wales

Sustainable Forestry - the UK Programme
Available from The Stationary Office (TSO)

The overall objective of the programme is to conduct research to ensure that forest practices do not compromise soil sustainability…

You can’t protect what you don’t know!



Make soil information available!

Supporting a national forest soil spatial database

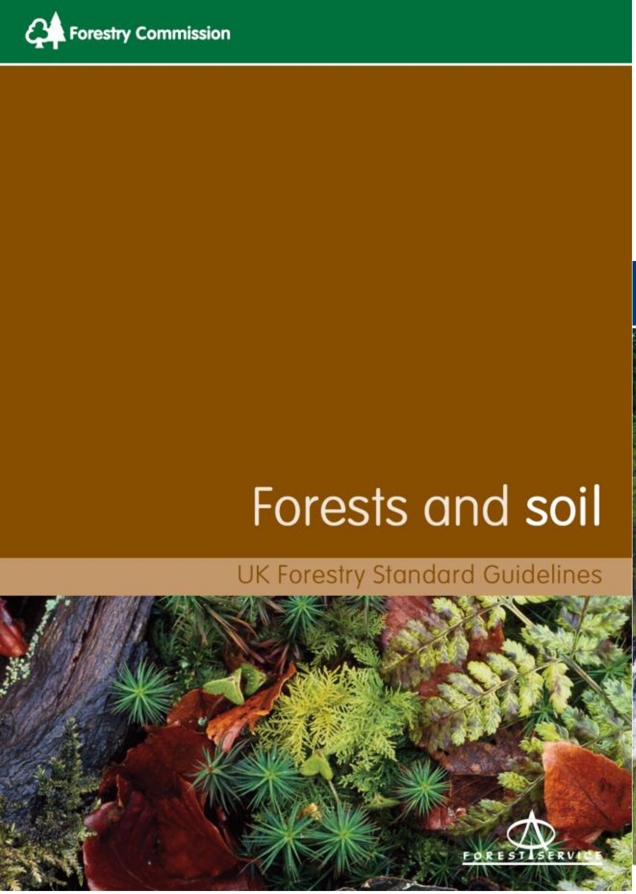
Forestry Commission User Guide

Forester GIS Soils Module

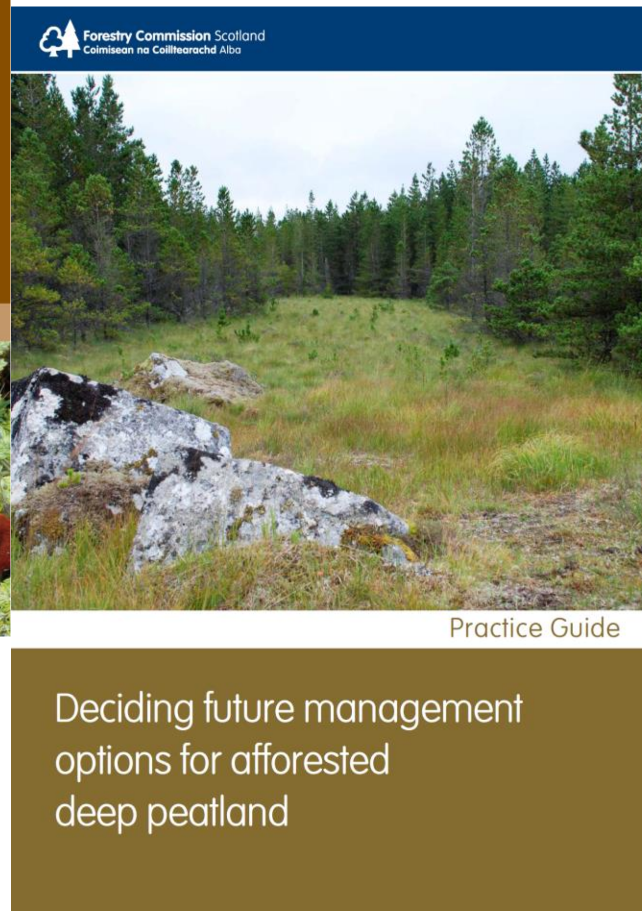
Technical User Guidance Browse only

Contents

Ensuring soil is accounted for in policy and practice



'High-level' policy



Practice guidance

Technical information


Forestry Commission

Research Note

Environmental effects of stump and root harvesting

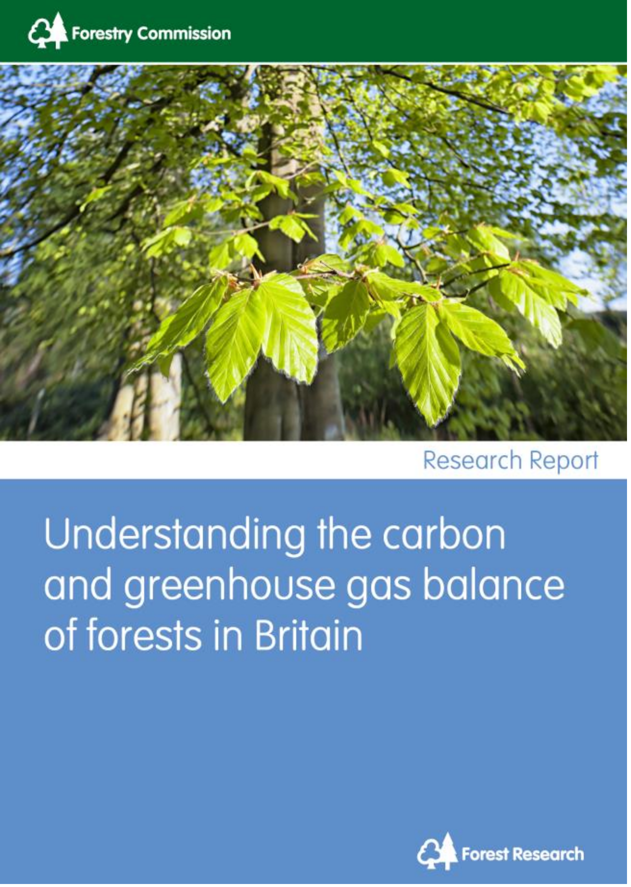
Andy Moffat, Tom Nisbet and Bruce Nicoll September 2011

The removal of tree stumps and coarse roots from felling sites as a source of woody biomass for bioenergy generation is well established in parts of Europe, and interest has been expressed in replicating this practice in some regions of the UK. Overseas research shows that stump harvesting can pose a risk to sustainable forest management, unless care is taken in site selection and operational practice. Poor practice can lead to detrimental effects on soil structure, increasing the risk of soil erosion, and depletes soil nutrient and carbon capital. Stump and root harvesting can also have impacts on woodland biodiversity, archaeological heritage and tree health. This Research Note offers a synthesis of available evidence on the effects of stump harvesting, drawn from largely overseas sources but critically considered for their applicability to British conditions. The overall environmental effects of stump harvesting on forest sites in the UK, and the relative magnitude of these effects compared with conventional restock site preparation, are under ongoing investigation. The results will be used to develop more definitive guidance. Preliminary guidance published by Forest Research sets out how the risks of potential damaging effects can be minimised, notably by careful assessment of site suitability and location of activities on low risk sites. It is recommended that this is used to guide the planning and location of stump and root harvesting operations in Britain.

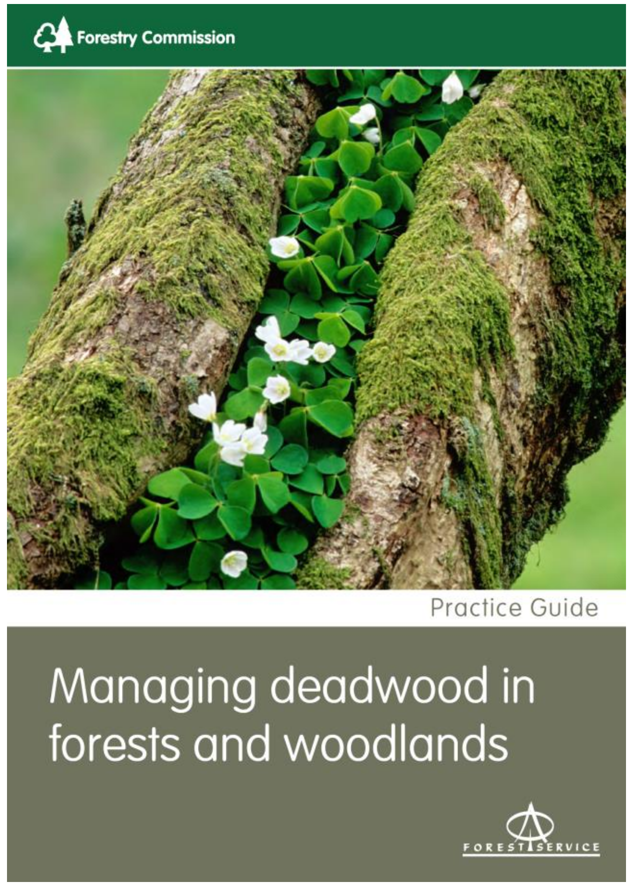
FCRN009 1 Forest Research

Always write as simply as possible – don't make soils mysterious or difficult to understand

Links to other forestry policy areas
(which might be regarded as more important!)



Climate change



Biodiversity

Soil protection as part of forest planning

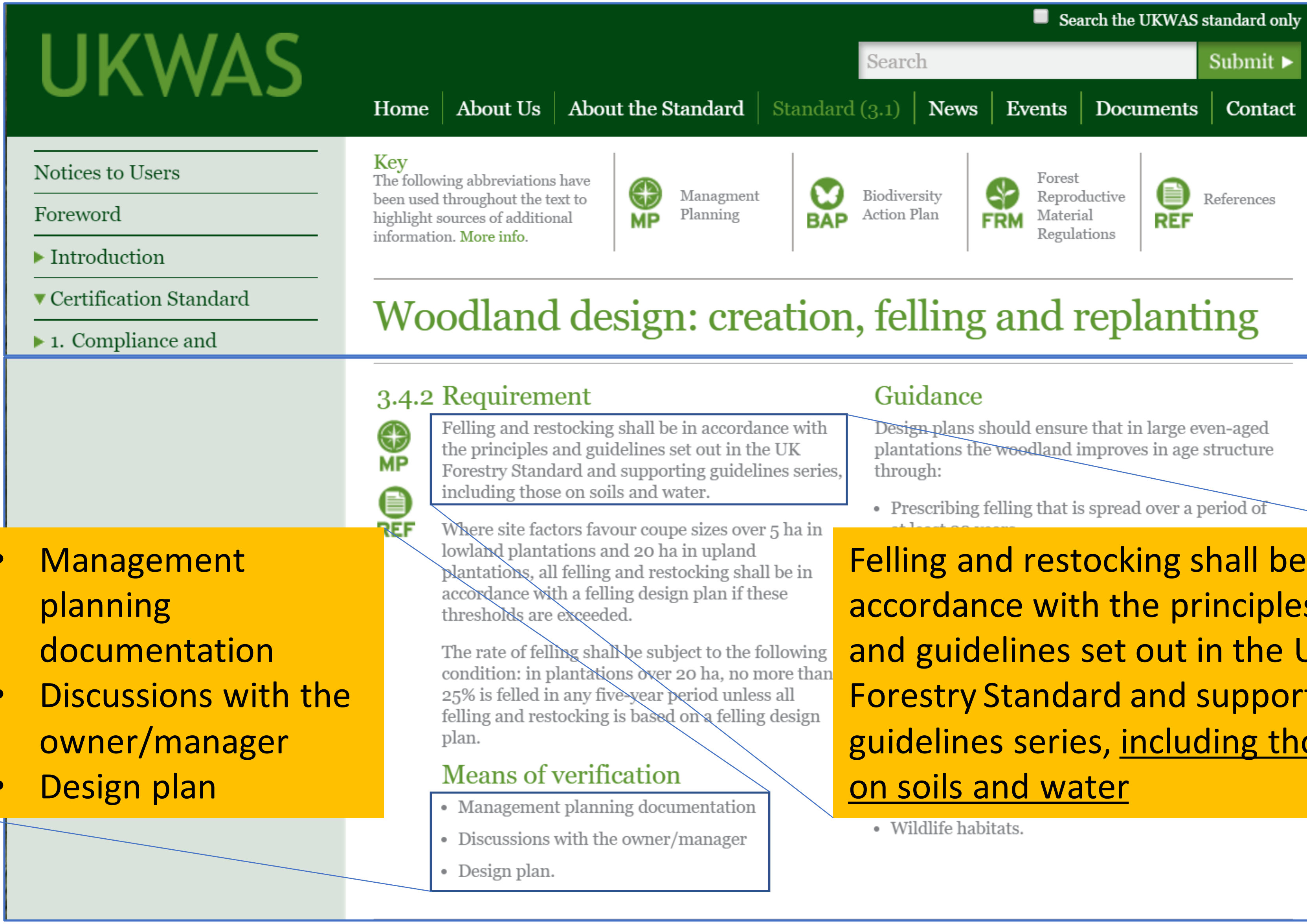
Forest management plans	Forest management plans allow the manager to demonstrate that all aspects of Sustainable Forest Management have been considered. They provide the basis for monitoring and assessment.
Operational plans	Operational plans help to ensure safe and efficient working practices on a site and the protection of the forest environment.
Contingency plans	Contingency plans set out what happens in the event of accidents, unexpected or unplanned events so that damage to the forest environment can be minimised.

Soils in forest management planning

Stage	Objective
Scoping	Development of management objectives
	Analysis of interests or 'stakeholder analysis'
Survey	Collection of information
Analysis	Assessment of survey information
Synthesis	Development of a design concept
	Development of a draft management plan
	Finalisation of the plan and submission for approval
Implementation	Development and implementation of work programmes
Monitoring	Evaluation of progress
Review	Periodic updates of the forest management plan

- Distribution of soil types (e.g. from soil map)
- Identification of soil 'limiting factors'; risk analysis (e.g. erosion, compaction, infertility)
- Implications for species choice, site preparation, silvicultural systems; mitigating measures
- Identification of necessary soil treatment(s) – if any (e.g. fertilisers, herbicides)
- Need for *soil* monitoring? Choice of methodology

Forest Certification



- Management planning documentation
- Discussions with the owner/manager
- Design plan

Felling and restocking shall be in accordance with the principles and guidelines set out in the UK Forestry Standard and supporting guidelines series, <u>including those on soils and water</u>

UK Forests and Soil Guidelines

Factor	Importance for soil
Acidification	Acid deposition and other acidifying inputs can adversely affect soil biodiversity, soil fertility, tree growth and water quality.
Contamination	Contamination can prevent tree growth, reduce soil biodiversity and affect water quality and fisheries.
Compaction	Compaction reduces the permeability of soil and can inhibit tree growth, increase erosion and reduce soil biodiversity.
Disturbance	Disturbance affects soil characteristics and can result in erosion and leaching together with the oxidation of organic matter, which leads to carbon loss.
Erosion	Erosion reduces the soil resource, and can irreversibly damage soil productivity and result in the loss of carbon. It can affect water quality and damage aquatic habitats.
Fertility	Fertility has a major influence on the productivity of forest ecosystems and the composition of the vegetation and soil organisms.
Organic matter	Organic matter has a large influence on the physical, chemical and biological properties of the soil, as well as forming a major carbon store.

Also: soil sealing, soil loss through landslides, soil salinization and loss of soil biodiversity
Note: factors often act together

Sustainable forest management

THE right tree FOR THE right place

'**Place**' <u>includes</u> understanding of soil : plant relations throughout the forest rotation(s).

This implies knowledge of soil type and its behavioural characteristics

Soil (and water) contamination

Pesticide application

- Minimise the use of pesticides and fertilisers in accordance with Forest Service guidance
- Avoid the contamination of forest soils and have <u>contingency plans</u> in place to deal with accidental spillage and pollution

Minimise pesticide use

Table 1.2 Hazard from Fomes root and butt rot determined by climate and soil.

Fomes hazard	Climate type			
	Cool, wet	Cool, moist	Warm, moist	Warm, dry
High	Nil	Nil	Brown earth, Podzol	Brown earth, Podzol, Ironpan, Surface water gley, Ground water gley
Medium	Nil	Brown earth, Podzol, Surface water gley	Ironpan, Ground water gley, Surface water gley	Peaty gley (shallow)
Low	Brown earth, Podzol, Ironpan, Ground water gley, Surface water gley, Peat (>15 cm depth)	Ironpan, Ground water gley, Peaty gley, Peat (>15 cm depth)	Peaty gley, Peat (>15 cm depth)	Peat (>15 cm depth), Peaty gley

From ‘Reducing pesticide use in forestry’ (2004)

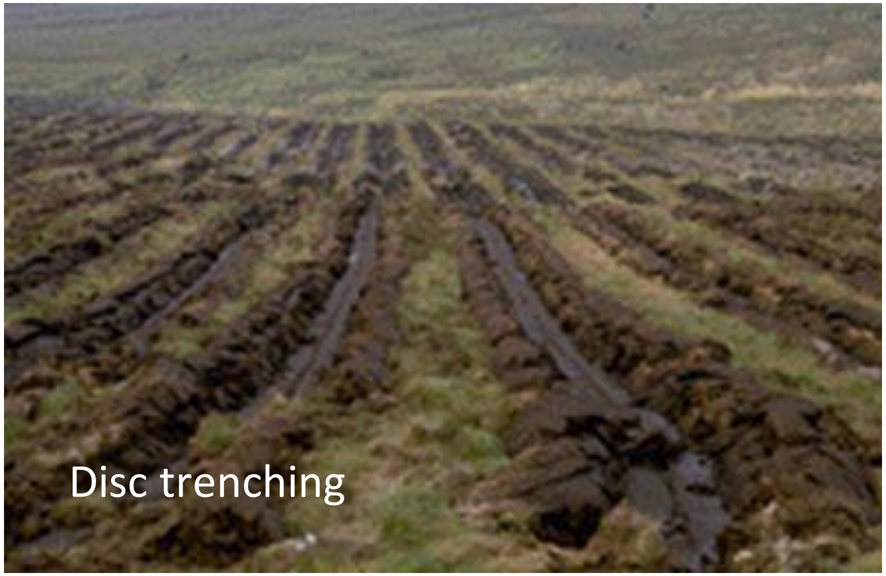
Compaction

- Minimise compaction, rutting and erosion by selecting the most appropriate working method for soil and site conditions; monitor operations and modify, postpone or stop procedures if degradation starts to occur – BE FLEXIBLE!
- Use the ‘brash mat’ system wherever there is sufficient material – amend site layout depending on harvesting and extraction equipment;
- Maintain adequate brash mats throughout extraction operations; import material on site if necessary;
- Consider the weather and aim to carry out risky operations during dry periods; plan ahead for changes in the weather that could affect site conditions;
- Where compaction has occurred, apply remedial treatment, but minimise the soil disturbance involved.

Soil disturbance - cultivation of heavy soils

- Minimise the soil disturbance necessary to secure management objectives, particularly on organic soils
- Consider the potential impacts of soil disturbance when planning operations involving cultivation, harvesting, drainage and road construction

Cultivation of heavy soils



Cultivation of light soils →

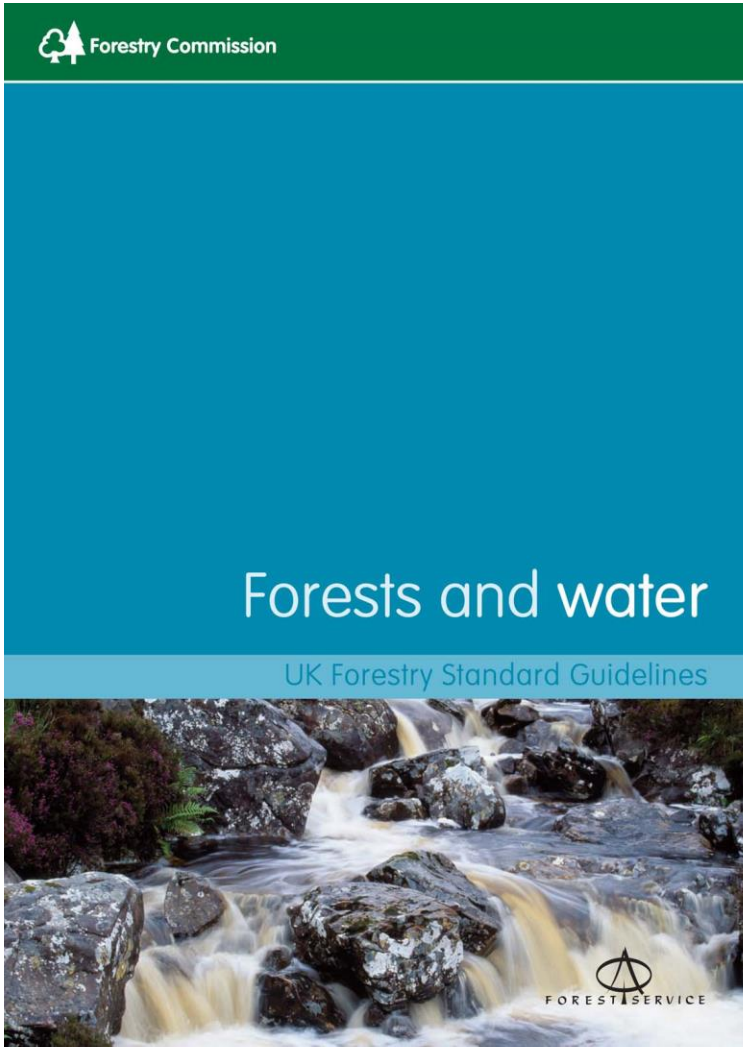
- Avoid ploughing as much as possible
- Minimise exposure of bare soil

Skidding – avoid on soft soils

Forwarder extraction and use of traction and flotation aids (chains and tracks)

Harvesting: the brash mat system

Cable-crane extraction – for steep slopes and sensitive soils



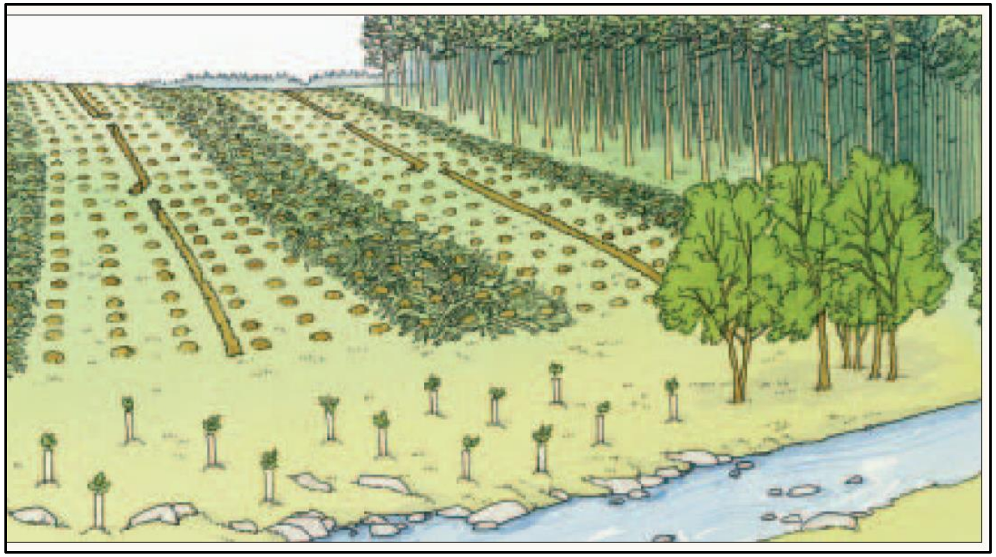
Soil erosion

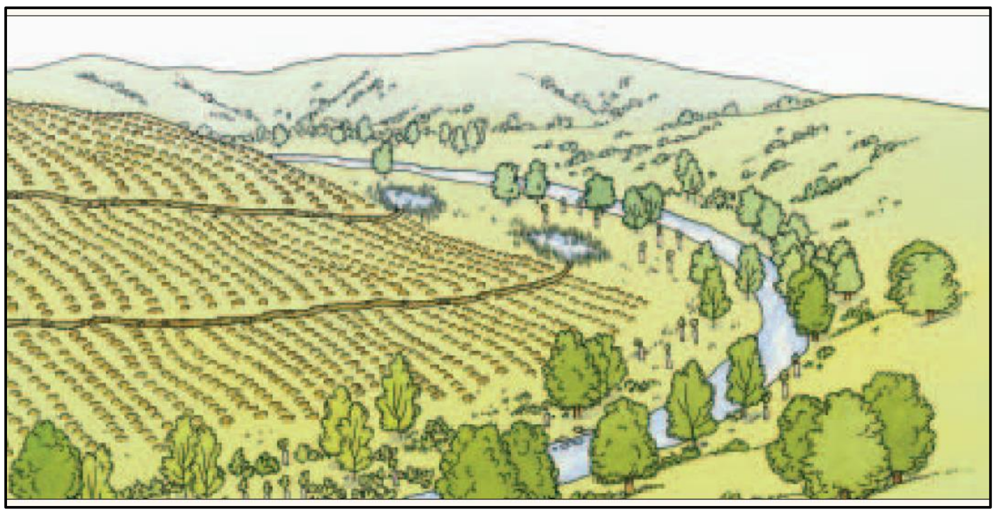
- Soil erosion can be caused by wind or water, but (in the UK) it is <u>water</u> that is the dominant force.
- Protection of the soil from erosion should be tackled primarily by good planning of water management, taking special account of extreme events such as storms
- Modelling can be useful
- Civil engineering expertise will be needed

Drainage / water management

- Collecting (cross) drains should be installed at a spacing that will control run-off in cultivation channels, including mole channels, e.g. at 40–70 m on slopes less than about 5% (3°).
- Cut-off drains should be provided so that cultivation channels do not carry water from large areas lying above the site.
- Align drains up-valley to maintain an even gradient throughout their length. Drain gradients should not exceed 3.5% (2°) and should be less on easily erodible soils.
- Discharge from a drain should, as far as possible, be on flat ground so that the water can fan out rather than be allowed to emerge in a concentrated flow.
- Never end drains in natural channels, ephemeral streams or old ditches running directly into a watercourse.

Soil erosion

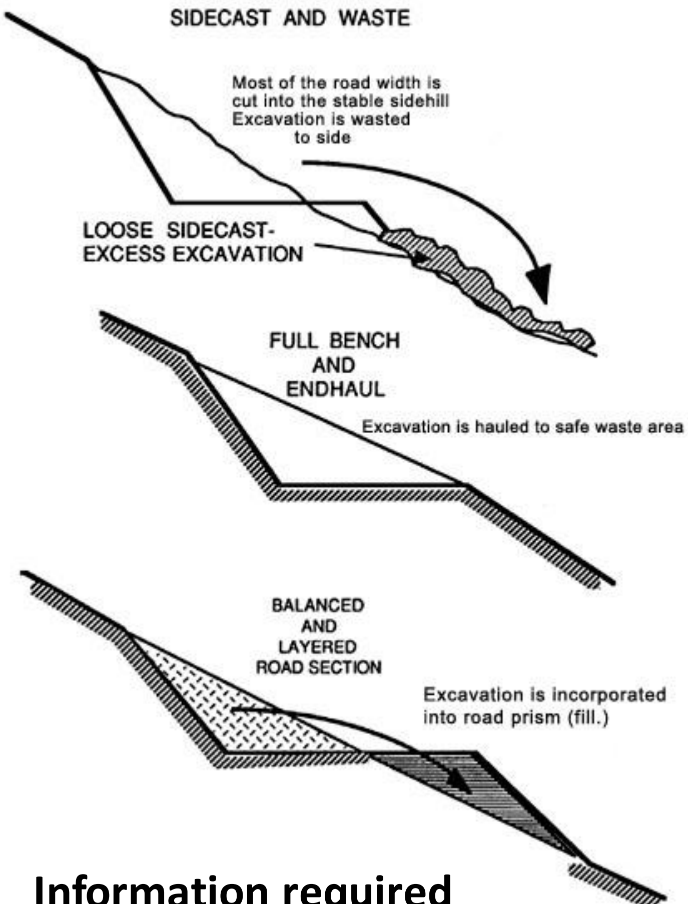




Plantation and drainage planning are essential for preventing soil erosion. <u>Don't forget extreme events and climate change</u>!

- Address the risks of soil erosion as part of the forest and operational planning processes
- On steep slopes where there is a risk of slope failure or serious erosion, consider alternatives to clearfelling
- Consider planting woodland to <u>protect</u> erosion-prone soils and intercept sediment-laden run-off

Forest road planning



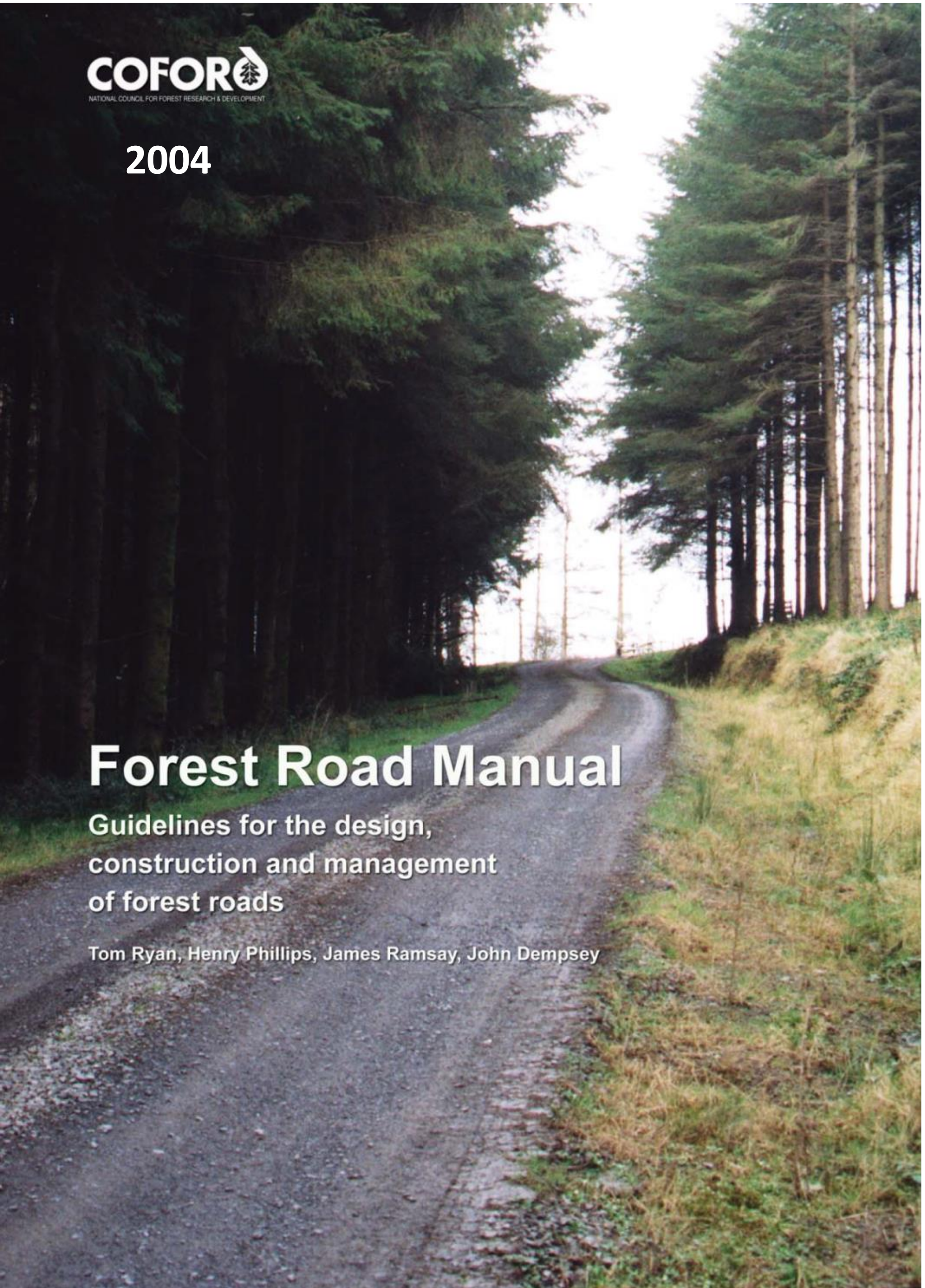
- Cut slopes greater than 2 to 3 m in height usually require a detailed geotechnical analysis.
- Situations that will warrant more in-depth analysis include:
  - Large cuts,
  - Cuts with irregular geometry,
  - Cuts with varying stratigraphy,
  - Cuts with high groundwater or seepage forces,
  - Cuts **involving soils with questionable strength**,
  - Cuts in old landslides or in formations known to be susceptible to land sliding.

Information required

Accurate cross sections showing topography,

- Proposed grade,
- Soil unit profiles,
- Unit weight and strength parameters (c’,ϕ’), (c,ϕ), or Su (depending on soil type and drainage and loading conditions) for each soil unit, and
- Location of the water table and flow characteristics.

Forest road planning



Great guidance on the www

Soil fertility

- Choose tree species and silvicultural systems that are well suited to the site and do not require continuing inputs of fertilisers
- Minimise the use of fertilisers and confine these to areas where analysis clearly shows management benefits, in accordance with a nutrient and soil management plan
- Plan any fertiliser applications to minimise the risks of nutrient loss (into water)
- Ensure the removal of forest products from the site, including non-timber products, does not deplete site fertility or soil carbon over the long term and maintains the site potential

Nutrient removal via stump harvesting

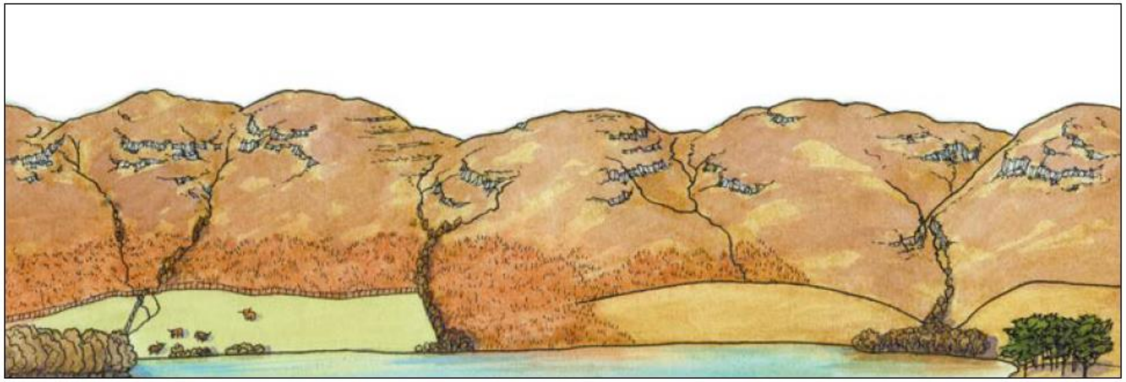
Is this practice acceptable <u>for the soil types involved</u>?

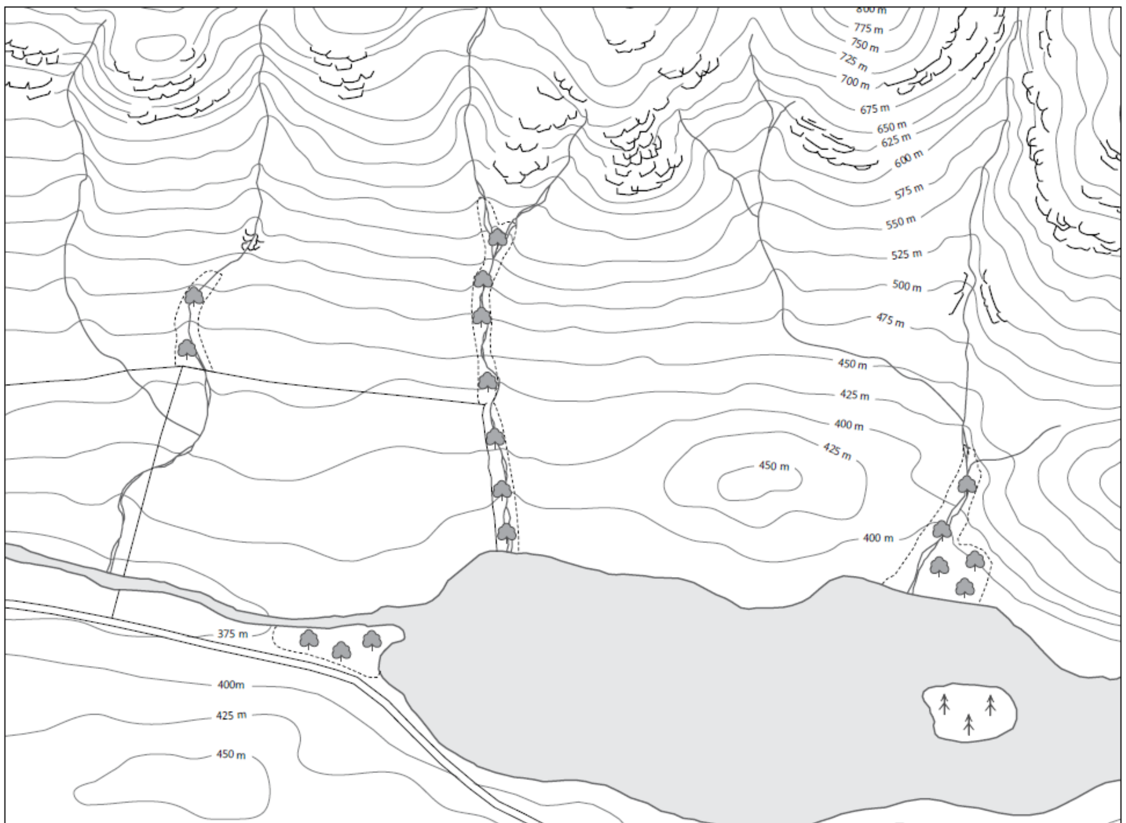
What about:

- Nutrient removal/balance?
- Soil removal?
- Soil disturbance?
- Soil erosion?

Also relevant for litter raking and brash baling

Forest planning – ‘Forests on rolling hills’





A medium-scale new mixed conifer and broadleaved forest

From https://www.forestry.gov.uk/ukfs/planning

Essential information

Rock and rankers

Shallow peat over podzol

Podzol

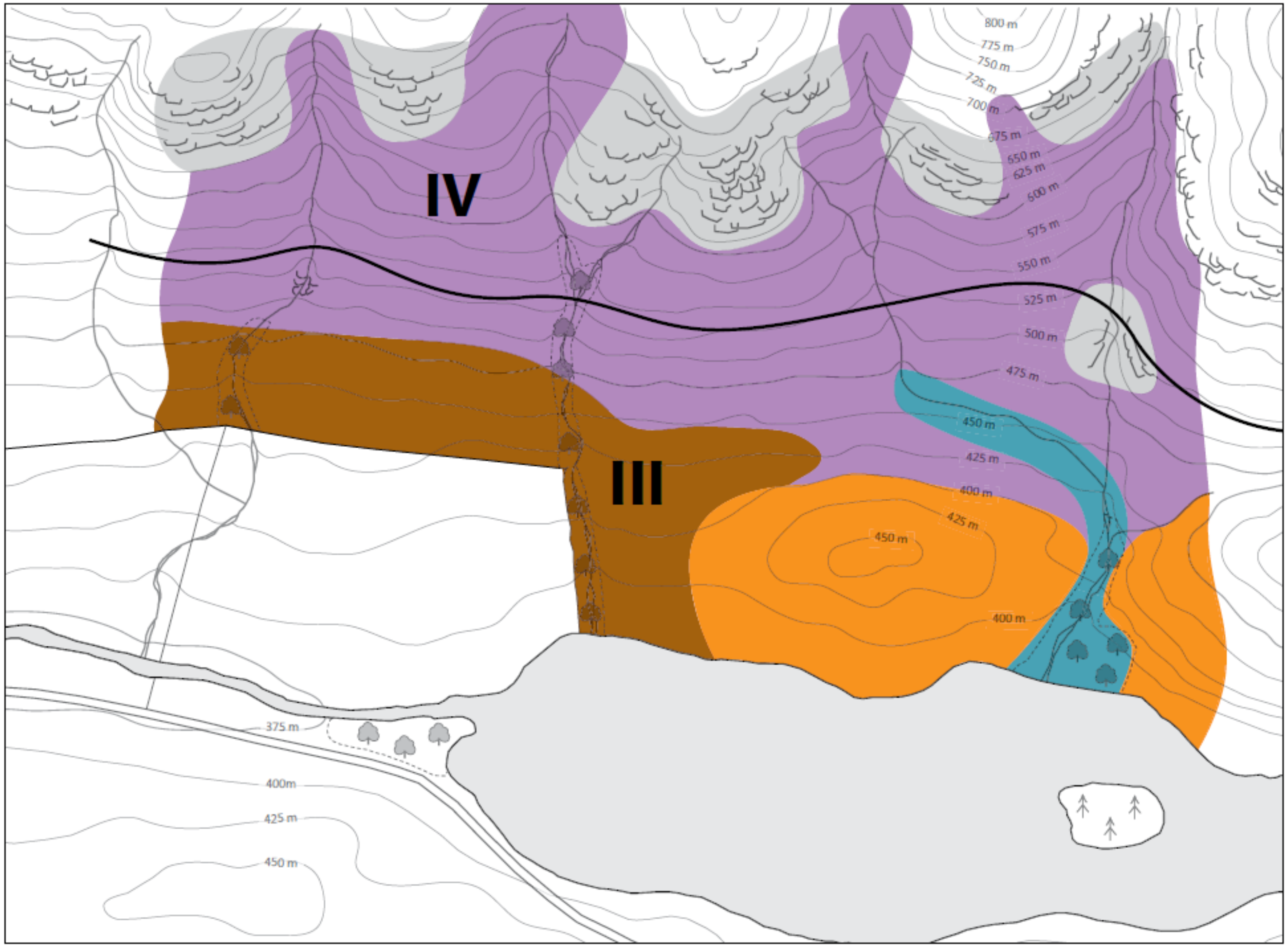
Upland brown earth

Surface water gley

Mid-slope boundary

IV Windthrow hazard class

Soil map

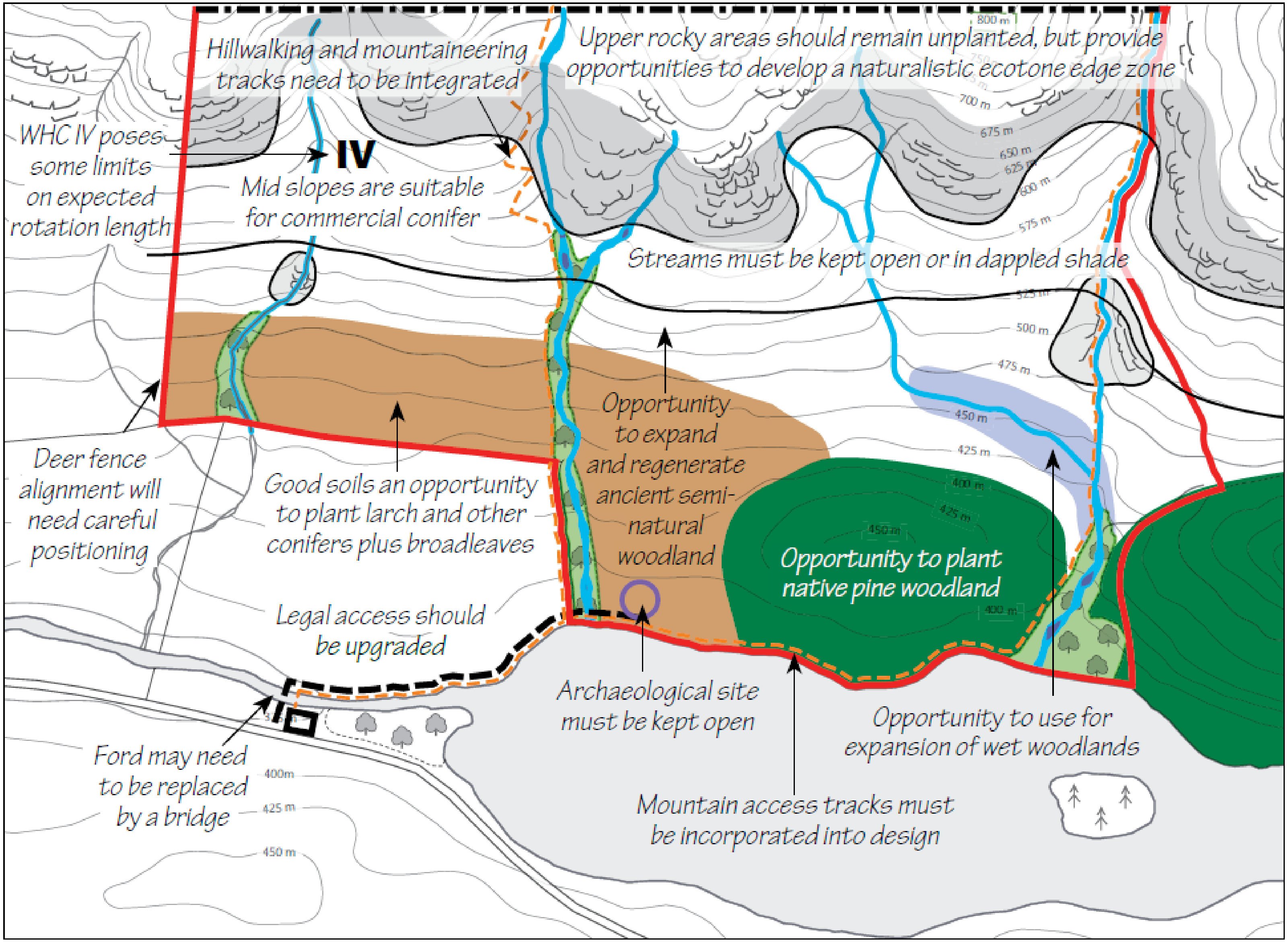


Constraints and opportunities analysis

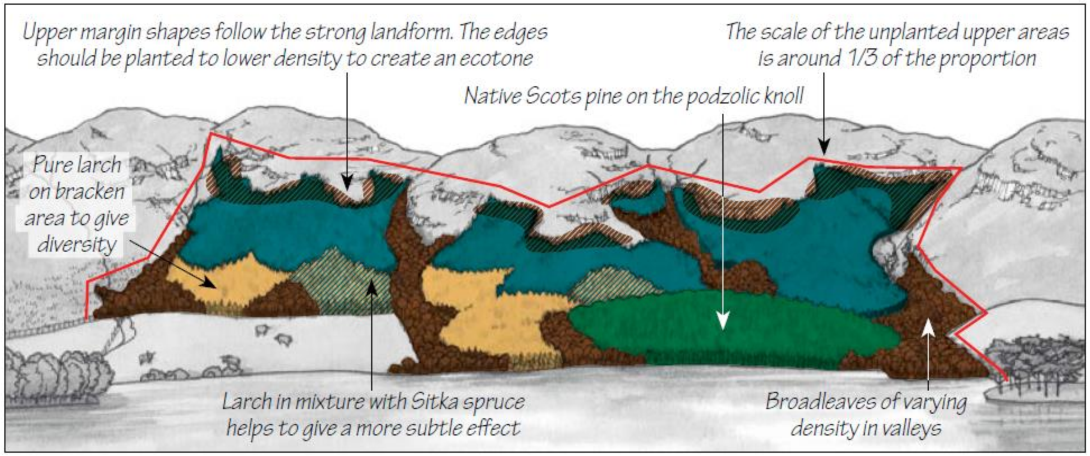
Factor	Constraint	Opportunity
Soils	Upper elevation areas have thin and infertile soils	The better soils allow for more species choice at lower elevations
Windthrow hazard	Upper elevations have potentially higher windthrow hazard and may be uneconomic to plant with productive species	In areas of higher wind hazard class either retain as open ground or in appropriate conditions establish native woodland
Historic environment	Sites must be identified and kept clear	To protect and incorporate them into the open space network of the design
Trails and paths	They may be disrupted by woodland management activities Where they cross the deer fence these areas will be vulnerable to deer incursion	To maintain trails and paths through both open space and through the forest to enhance and diversify the user experience
Deer management	Deer numbers and current management practices mean that a deer fence is needed The visual impact of the fence must be accounted for	To develop and maintain the open areas within the fence as ungrazed habitat
Water	The many streams must be kept open Stream crossings by roads may be a problem	To create valuable riparian habitats

Also: Timber extraction, protected species/biodiversity, landscape

Constraints and opportunities – plan



Planting plan



Deer fence
Sitka spruce
Larch
Native Scots pine and birch
Sitka/larch mix
Native broadleaves
Upper margin ecotone area

Soil protection - conclusions

- Forest soils need protection under production forestry
- Forestry authorities should put in place a range of measures to protect forest soils
- Technical guidance on soil protection must be developed. This must include input from civil engineering and drainage expertise
- Knowledge of soil type is essential for effective soil protection
- Soil protection is best achieved by generating a positive ethos for protection based on an understanding of soil/forest sustainability
- Nevertheless, good site supervision and inspection (monitoring) are vital during and after sensitive forest operations. A risk-based approach is useful.

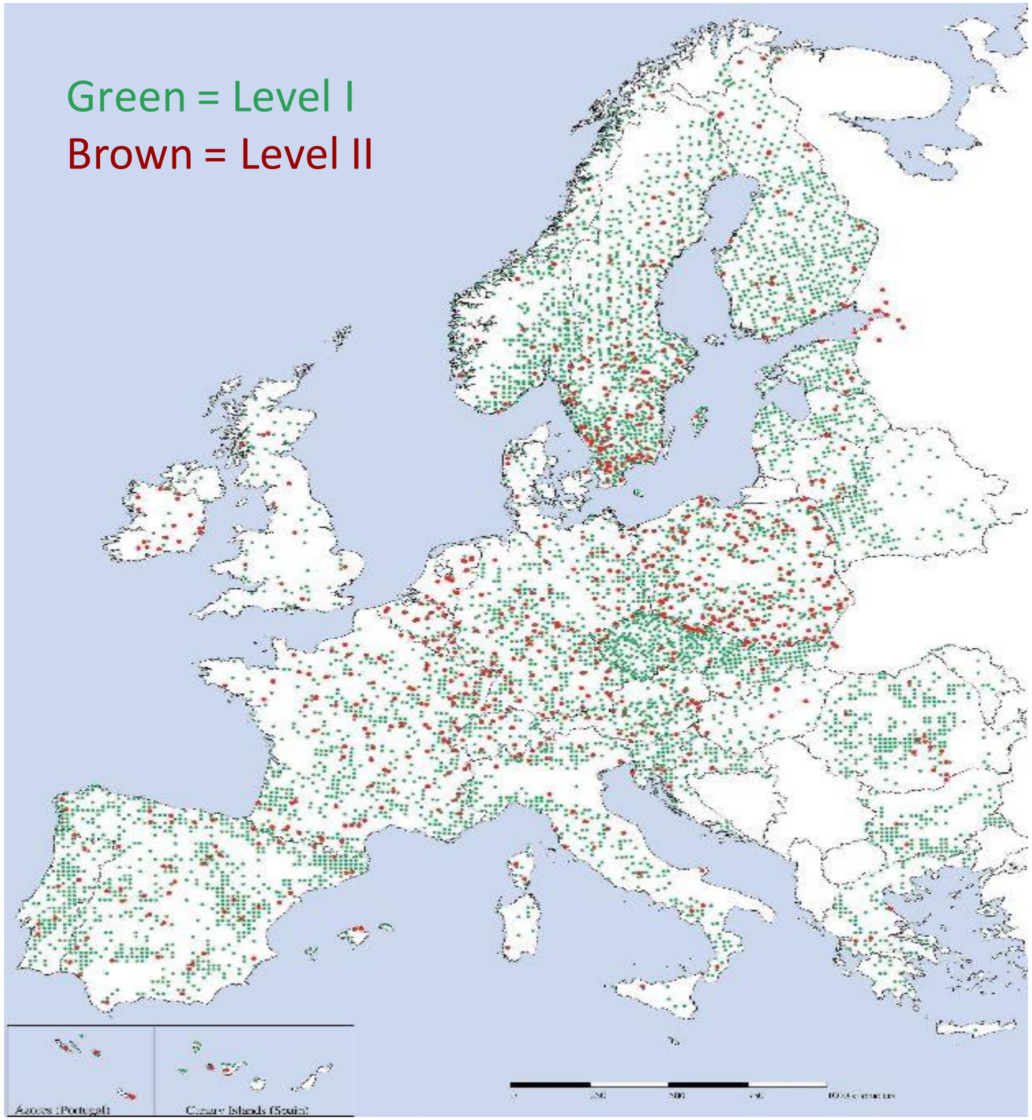
Why? Many reasons

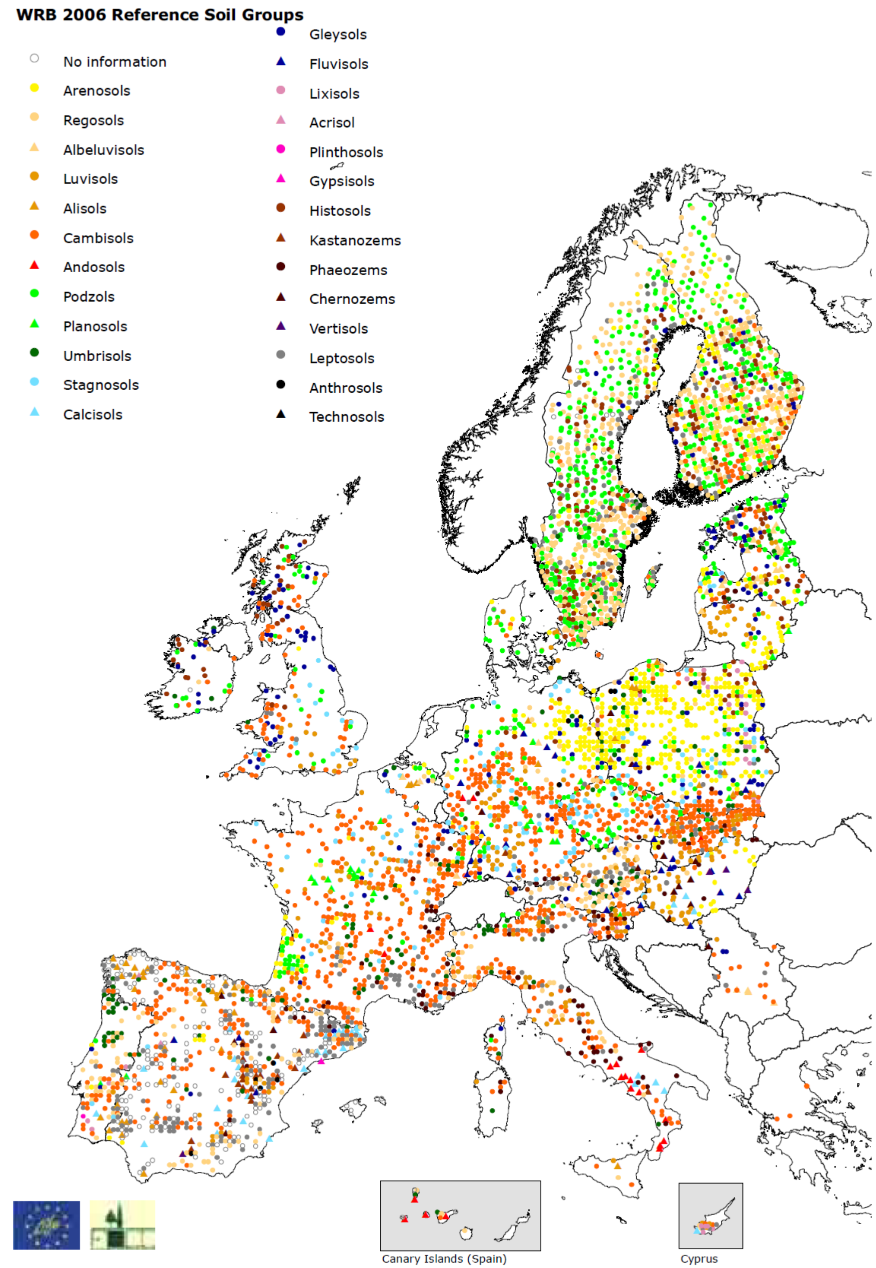
- For international reporting (e.g. Forest Europe, GFRA, UNECE ICP Forests)
- For national reporting (various drivers in forest, and outside it, e.g. environmental monitoring)
- **To verify compliance with SFM or certification**
- **To provide basis for management planning and intervention**
- To support foresight and other strategic policy activities
- To support scientific research (pure, applied)

Forest Europe Criteria and Indicators

Number	Indicator	Full text
1.4	Forest carbon	Carbon stock and carbon stock changes in forest biomass, forest soils and in harvested wood products
2.2	Soil condition	Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types
2.5	Forest land degradation	Trends in forest land degradation
4.5	Deadwood	Volume of standing deadwood and of lying deadwood on forest and other wooded land
5.1	Protective forests – soil, water and other ecosystem functions – infrastructure and managed natural resources	Area of forest and other wooded land designated to prevent soil erosion, preserve water resources, maintain other protective functions, protect infrastructure and managed natural resources against natural hazards

Extensive and Intensive forest monitoring networks – ICP forests Level I and II





Map 3. Geographical distribution of the WRB 2006 Reference Soil Groups on the BioSoil+ Level I and II plots

Soil sampling – a skilled task






Environmental Monitoring and Assessment (2005) **111:** 149–172
DOI: 10.1007/s10661-005-8219-0

SAMPLING THE SOIL IN LONG-TERM FOREST PLOTS: THE IMPLICATIONS OF SPATIAL VARIATION

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Environ Monit Assess (2009) 158:67–76
DOI 10.1007/s10661-008-0565-2

Spatial variation in soil carbon in the organic layer of managed boreal forest soil—implications for sampling design

Petteri Muukkonen · Margareeta Häkkinen · Raisa Mäkipää

How many soil samples do we need?

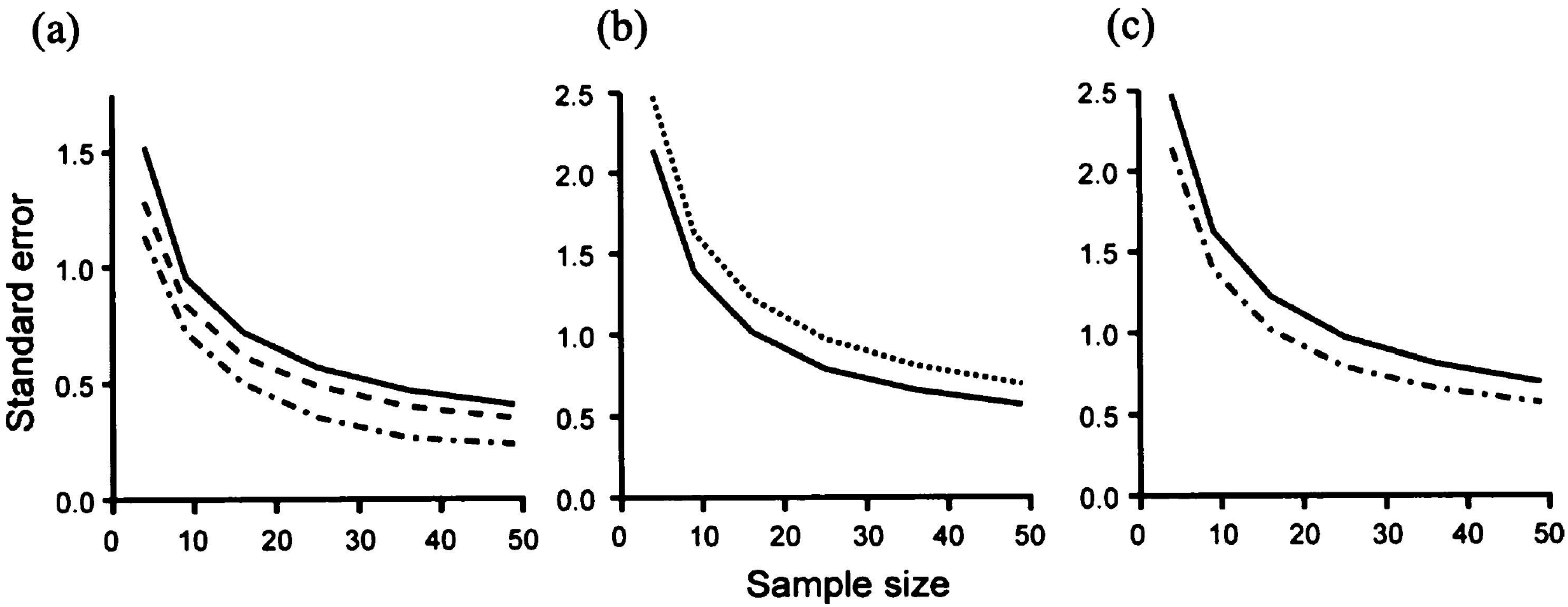


Figure 6. Graphs of standard error against sample size for bulking for (a) Savernake, (b) Rannoch and (c) Coalburn. The lines represent: ——— depth 1, - - - - - - depth 2, ·–· -·-·- depth 3, and ······ the classical standard error.

From Kirwan *et al*. (2005)

United States
Department of
Agriculture

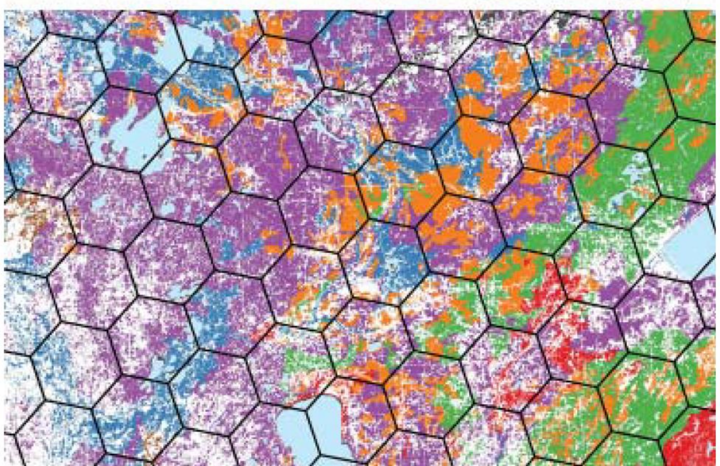
Forest Service

North Central Research Station

General Technical Report NC-258

Soils as an Indicator of Forest Health: A Guide to the Collection, Analysis, and Interpretation of Soil Indicator Data in the Forest Inventory and Analysis Program

Katherine P. O'Neill, Michael C. Amacher, and Charles H. Perry



2005

Forest soil indicators

Physical indicators
e.g. for erosion, disturbance, compaction
Chemical indicators
e.g. soil pH, organic matter content, carbon, nitrogen
Biological indicators
e.g. soil enzymes, microbial biomass

ICP Forests

LRTAP
Long-range Transboundary Air Pollution

United Nations Economic Commission for Europe (UNECE)

Convention on Long-range Transboundary Air Pollution (CLRTAP)

International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)

MANUAL

on

methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests

Revision 2016

Programme Co-ordinating Centre of ICP Forests

Johann Heinrich von Thünen Institute
Institute of Forest Ecosystems
Alfred-Möller-Strasse 1, Haus 41/42
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www.icp-forests.org/Manual.htm

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UNECE ICP Forests Programme Co-ordinating Centre (ed.), 2016: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute of Forest Ecosystems, Eberswalde. [http://www.icp-forests.org/Manual.htm]

Chemical and physical properties

Type of parameter	Key parameters	Layer	Relevance
Carbon and nitrogen	C_{tot}, N_{tot}, (Carbonates)	Organic	Forest nutrition, atmospheric N deposition, climate change
		Mineral	Forest nutrition (0-20 cm), C- & N stocks (0-80 cm)
Nutrients	Total P, Ca, Mg, K, Mn	Organic	Atmospheric deposition of basic cations, stock of macronutrients
		Mineral	Weathering rates, critical loads of acidity, stock of macronutrients
Acidity, Exchange characteristics	pH, Carbonates, CEC, BS, Exchangeable cations, Exchangeable Acidity	Organic	Buffering acid input, acidification status
	pH, Carbonates, CEC, BS, Exchangeable cations, Exchangeable Acidity, Al_{ox}, Fe_{ox}	Mineral	
Heavy metals	Pb, Cu, Zn, Cd, Cr, Ni, Hg	Organic	Atmospheric metal deposition
		Mineral	Atmospheric metal deposition, calculation critical loads (0-20 cm), deficiency of oligo elements
Physical soil parameters	Particle size distribution and soil texture	Mineral	Profile description and soil classification, estimation of plant available water, nutrient exchange capacity
	Organic layer mass	Organic	Calculation of stocks
	Bulk density of the fine earth (BD_{fe}) and the coarse fragment content	Mineral	Calculation of stocks, nutrient supply to plants, index for compaction
	Soil Water Retention Characteristic (SWRC)	Organic Mineral	Water balance models, nutrient fluxes, estimation of soil porosity

Soil protection factor

- Organic matter
- Fertility
- Acidification
- Contamination
- Disturbance
- Compaction

From ICP Forests soil manual

Quantitative soil physical measurement

Penetration resistance

Bulk density

$$\frac{M}{V} = D$$

Soil compaction

- Soil physical properties are not conventionally monitored in a way that facilitates national reporting.
- Changes in soil bulk density are usually measured on a site-specific basis.
- More quantitative measurements of compaction using techniques such as cone penetrometer or shear strength estimates are sensitive to variations in soil moisture content, complicating comparison of data collected on different sampling dates or in different regions.
- Current measurements of compaction <u>are based primarily on visual estimates of compacted area.</u> [However] subsurface compaction … may not be readily visible to field crews and may be under-reported. In addition, measurements do not reflect the degree or intensity of compaction.

(from 'Soils as an Indicator of Forest Health')

Soil erosion

Quantitative strategic forest *soil* monitoring of soil erosion is not possible

Qualitative evaluation of soil erosion can be attempted during forest inventories

4.6 Data and Model Limitations

Because erosion estimates are made on the basis of modeled results, analysis of this indicator is necessarily limited by the assumptions of these models. It is also important to recognize that soils vary naturally in terms of their potential for soil erosion and their ability to tolerate these soil losses. For this reason, aggregate estimates of soil erosion have little meaning in and of themselves.

Soil disturbance

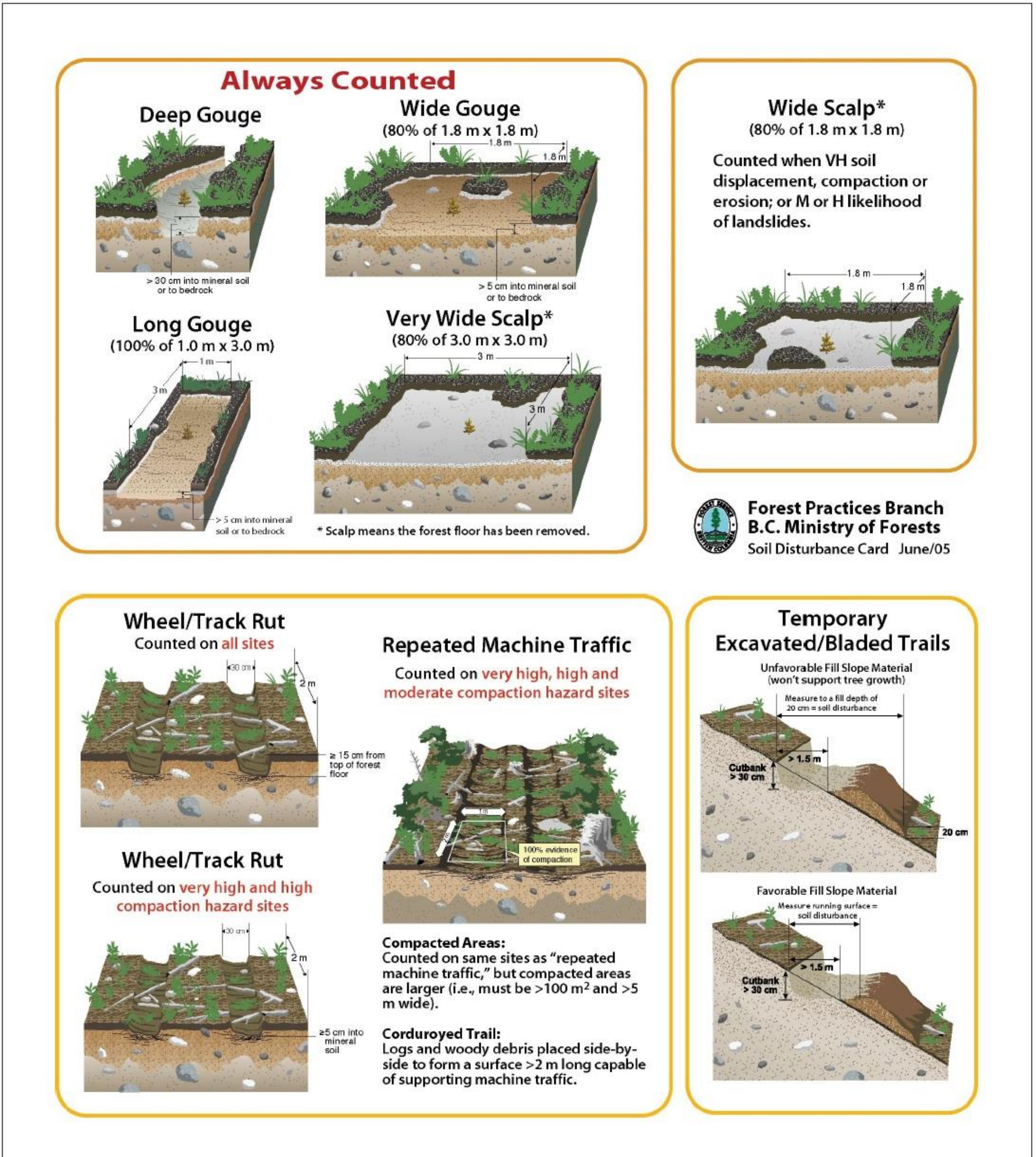


Fig. 1. Field card showing disturbance types counted under B.C. Forest Practices Code and Forest and Range Practices Act.

From Curran et al. (2007)

Soil disturbance

Code	Title	Description
0	Undisturbed	Litter horizon undisturbed
1	Forest floor disturbance	Disturbance of the forest floor, but no exposure of underlying mineral soil
2	Shallow soil disturbance	a) forest floor removed and mineral soil exposed
		b) less than 5 cm mineral soil deposited on forest floor
3	Deep soil disturbance	a) mixing of mineral soil evident
		b) more than 5 cm of mineral soil deposited on forest floor

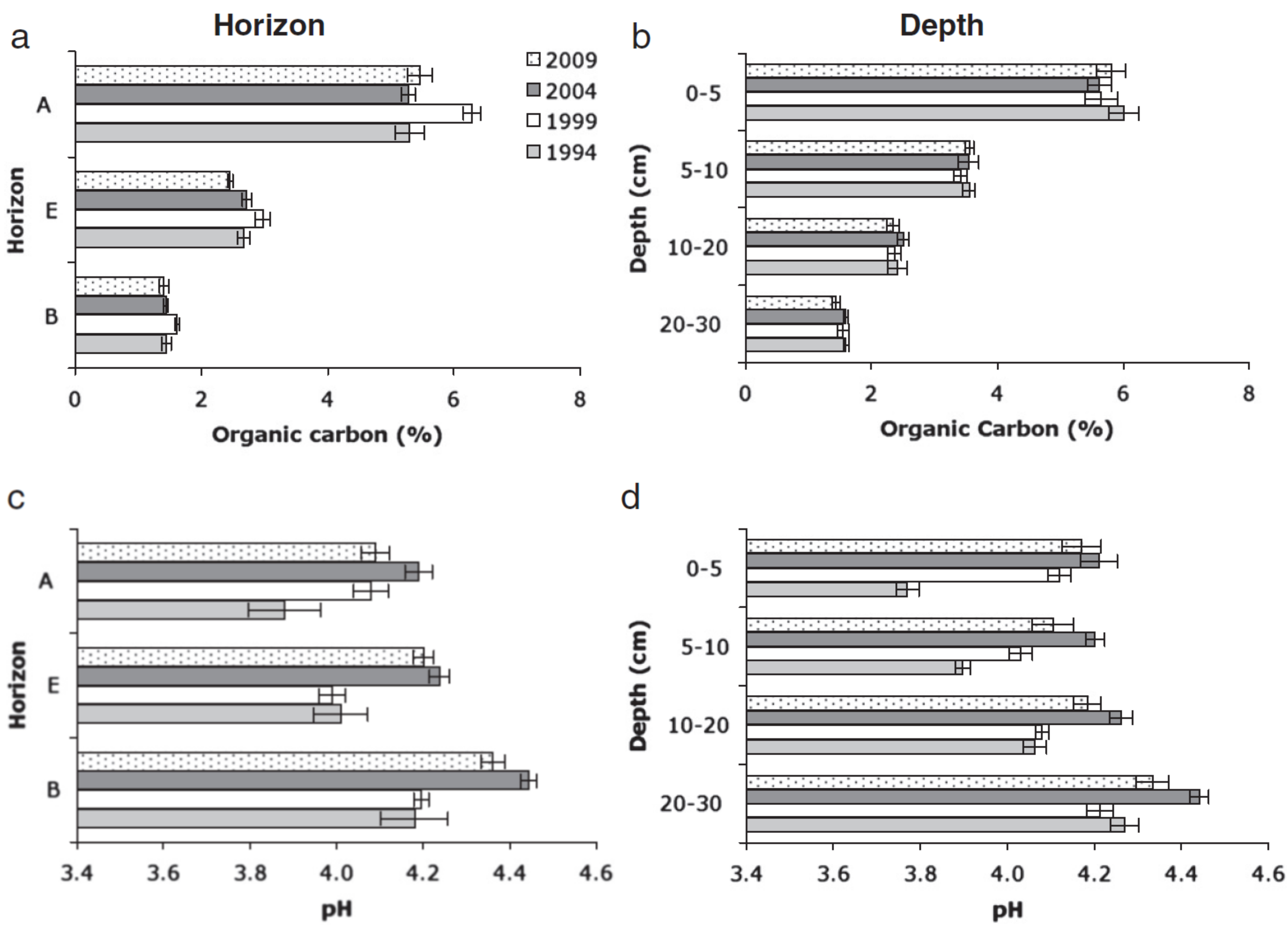
After Bockheim et al. (1975)

Limitations to data

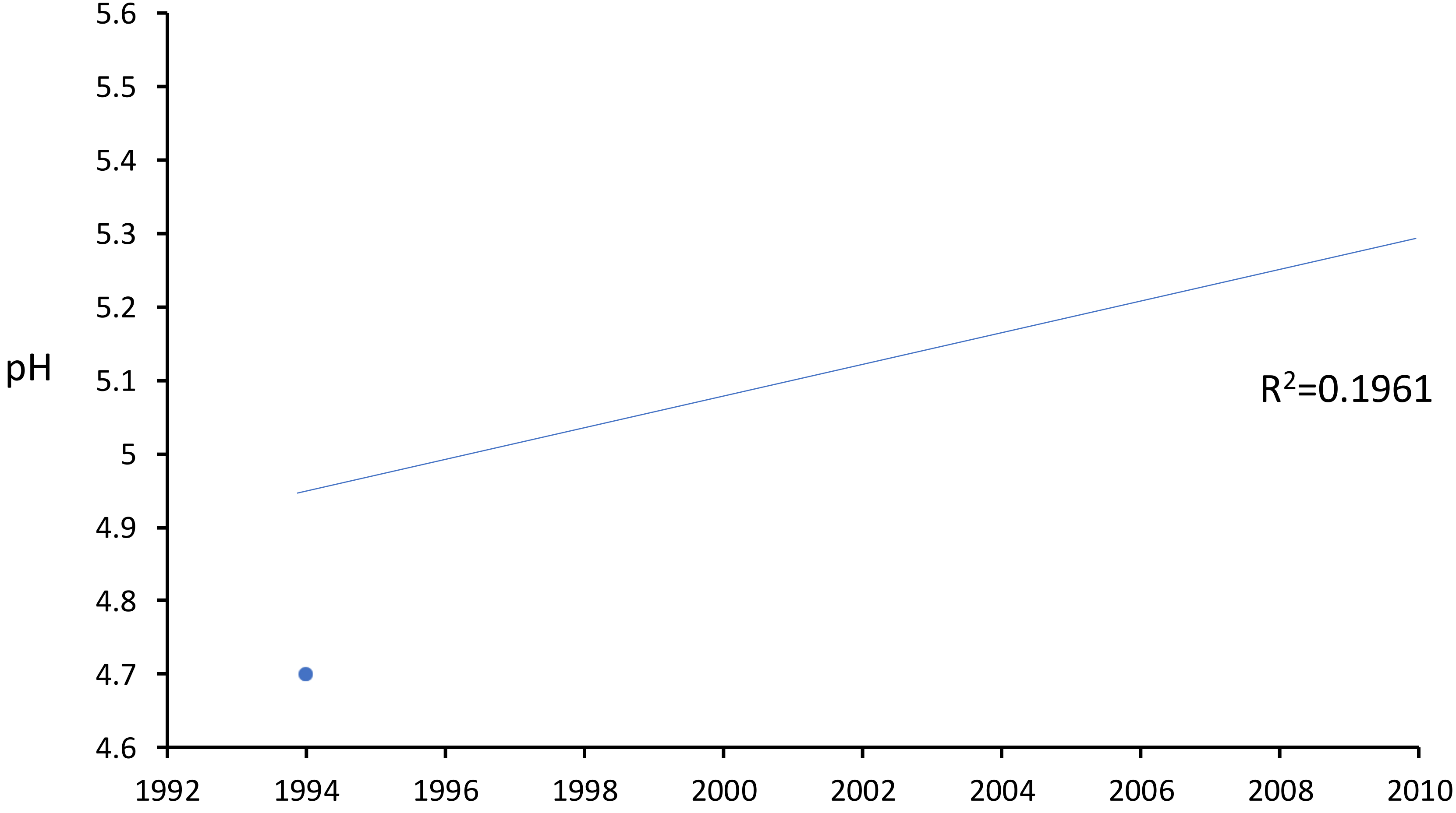
- Soil chemical and physical properties can be highly variable in the field and are expensive to analyse
- So interpretation of soil chemical data is confounded by spatial variability within the plot
- Depending upon the soil type, both the number of samples and the methods used in collecting these samples may vary between plots, complicating compilation and estimation procedures
- Soil samples reflect conditions at depth collected
- Shallow samples are more responsive to disturbance
- Samples may be needed from the entire rooting zone

(from 'Soils as an Indicator of Forest Health')

UK ECN soil monitoring study



Detecting trends in soil chemistry



Soil pH; B horizon, Alice Holt

Trigger values

- Very few soil chemistry measurements generate information that can be used actively in forest management.
- Measurement values will be dependent upon underlying soil type and nature of silviculture undertaken, especially species grown.
- Also difficult to detect a clear ‘signal’ amongst the ‘noise’ due to spatial and temporal variation.
- The Ca/Al ratio or base cation : Al ratio in soil solution is the most established indicator in relation to tree root, and thus forest ecosystem health.
- A Ca/Al ratio <1 is suggests damaging soil chemistry for tree fine root health and survival (although different values are available for different species).

Forest soil microbiological indicators

Category	Potential microbial indicators of soil quality
Microbial biomass	Direct counts; Muramic acid; Ergosterol; Fumigation – incubation; Substrate-induced respiration; Phospholipids; C and N; Biomass C/total organic carbon
Soil enzymes	Dehydrogenase; Phosphatase; Arylsulfatase; Arginine
Activity measurements	Respiration; qCO_2
Microbial community structure	Sole-carbon source utilization; Phospholipids; Nucleic acids: whole population DNA amplification of specific genes by PCR
Indicator organisms/process	Nitrifying bacteria/nitrification

from Staddon *et al.* (1999)

Alternatives to 'field-based' soil monitoring

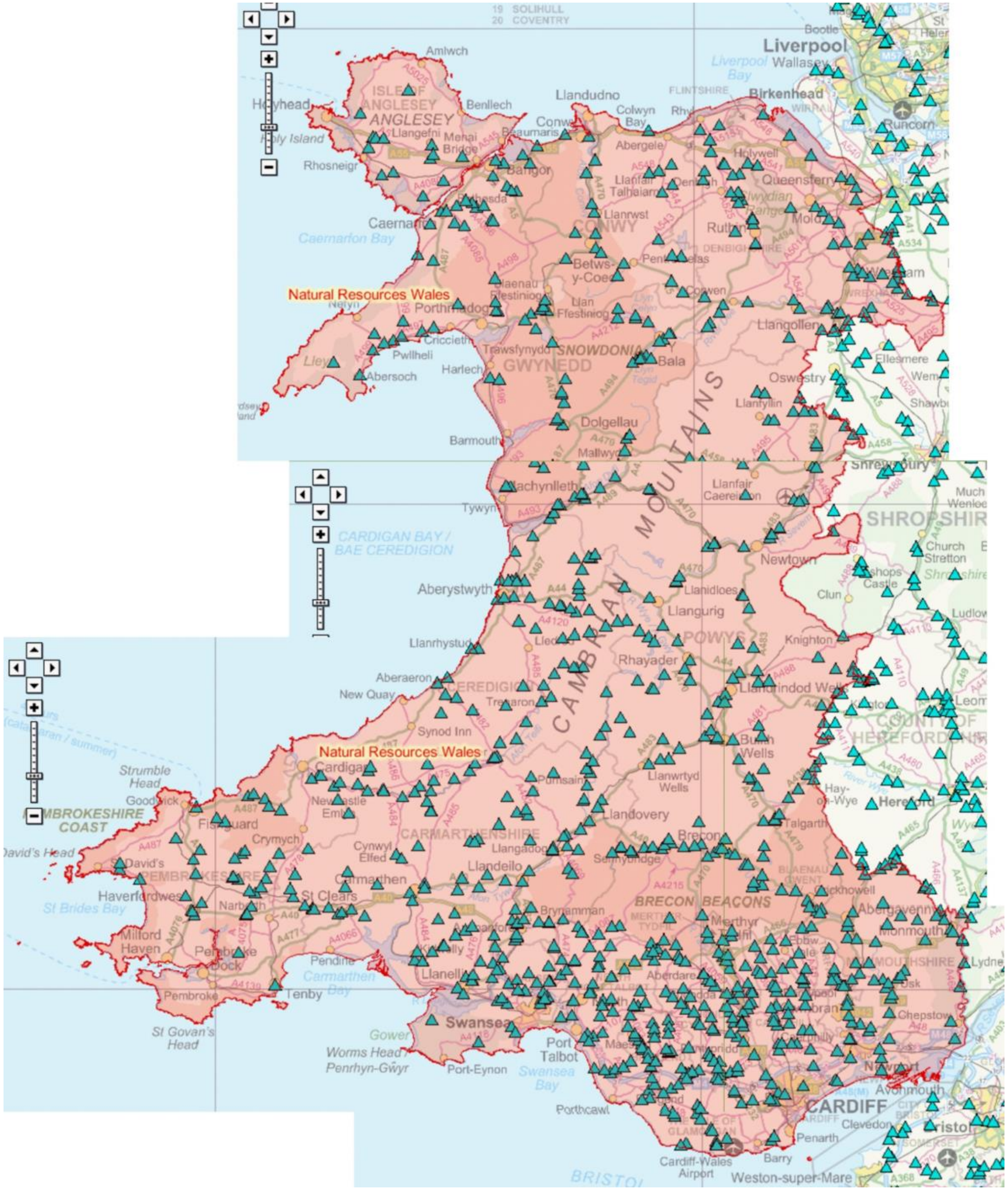
Headline indicators
1. Area under forest/woodland
1.1. Area of forest/woodland on specific soil types
1.2. Area of forest/woodland on brownfield land
1.3. New planting (ex agricultural land)
1.4. Area with FSC or other certification
1.5. Area supported by state management intervention via grants etc
1.6. Areas of forest managed as Natura 2000 sites
Surrogate indicators
2.1. Forest productivity by compartment
2.2. Foliar analysis (for soil fertility)
2.3. Stream sediment via colour/turbidity (for soil erosion)
2.4. Forest industry fertilizer and pesticide use (gross quantities)
2.5. Ground vegetation
Awareness indicators
3.1. Uptake of 'Forests and Soil Guidelines' and other soil-related publications
3.2. Number of hits/downloads to/from the appropriate website on soil-related material

From Moffat (2003)

Foliar sampling & analysis

Table 1. Deficient and optimum foliar nutrient concentrations for young stand of Sitka and Norway spruce during the dormant season, as unit oven-dry weight. Modified from Everard (1973), Leaf (1973), Binns et al. (1980), Taylor (1991) and Savill et al. (1997).

Element	Unit	Deficient	Marginal	Satisfactory
N	g/kg	<12	12–15	>15
P	g/kg	<1.2	1.2–1.8	>1.8
K	g/kg	3–5	5–7	>7
Ca	g/kg	<0.5	0.7–1	1–2
Mg	g/kg	<0.3	0.3–0.7	>0.7
S	g/kg	<0.9	0.9–1.5	>1.5
Fe	mg/kg	<20	20–50	>50
Cu	mg/kg	<2.5	2.5–4	>4
Zn	mg/kg	<9	9–15	>15
Mn	mg/kg	<4	4–25	>25
B	mg/kg	<5	5–20	>20



River water quality - monitoring stations in Wales

Water turbidity can be used as a surrogate indicator for soil erosion

Soil monitoring - conclusions

- Forest soil health/condition is best assessed using a combination of traditional chemical and physical measures taken from permanent, unfenced, monitoring plots
- Organic matter (carbon) content, bulk density, pH or Ca/Al are perhaps most important measures
- Due to the complexity of forest soils and ecosystems, interpretation of indicators should be undertaken by forest production and ecosystem scientists familiar with the wide range of services and benefits forests provide
- Despite the attractiveness of utilising biological component of forest soils as indicators of soil health, they require further development before they can be reliably used
- Soil indicators developed for other landscapes should not be used for forest soils without critical evaluation

Overall conclusions

1. Promotion of a culture of soil protection as an integral part of SFM the best way to minimise damage to soil.
2. Many instruments available but co-ordination and leadership essential.
3. Most soil damage is preventable and avoided by effective (and modern) forest planning and operation supervision.
4. Monitoring soil quality/condition will support soil protection and can prevent soil damage.
5. However, a programme of repeated soil measurements is expensive and at risk of future closure. Better to embed soil evaluation in existing programmes if possible.
6. Evaluation of soil information is a skilled task and should be part of an overall assessment of forest health.

Thank you for your attention

Any questions?

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