Assessment of effects of afforestation on soil properties in Iceland, using Systems Analysis and System Dynamic methods

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ABSTRACT
Systems Analysis and System Dynamic methods were important in preparing model assessments in the AFFORNORD research programme in Iceland. In order to assess the combined effects of afforestation on soil chemistry and ground vegetation, existing models were adapted and new sub-models developed using the Learning Loop process and Group Modelling approach. This approach was necessary and successful as participants were directly involved and developed a shared ownership of the model and its results. The process resulted in a new type of assessment tool, the ForSAFE-VEG. The model was able to predict current soil conditions and biomass in Icelandic *Larix sibirica* plantations with good accuracy. First results from ForSAVE-VEG parameterization and simulations of long-term changes (150 years) in standing biomass, soil pH, soil organic matter, soil C/N ratio and ecosystem carbon sequestration are presented and discussed.

Keywords: Iceland, System Analysis, System Dynamics, Simulation, AFFORNORD, ForSAFE, afforestation

YFIRLIT
Mat á áhrifum skógrætar á jarðvegsþætti með aðferðarfræði kerfisgreiningar og kerfisaflfræði
Það reyndist afar vel að beita Kerfisgreiningu (e: System Analysis) og Kerfisaflfræði (e: System Dynamic) aðferðafræði þegar hermilíkan af áhrifum skógræktar á umhverisþætti var útbúið í norrænu rannsóknaverkefni (AFFORNORD). Til að útbúa trausta langtímaspá um áhrif skógræktar

á jarðvegsþætti og gróðurfar var eldri hermilíkönum af kolefnis- og næringarefnahringrásum í skóglendi breytt og bætt við þau nýjum ferlum. Þetta var gert með (Learning Loop process) e: Lærdómshringrás og (Group Modelling approach) e: samvinnu með hluthöfum. Nýtt hermilíkan af umhverfisáhrifum skógræktar varð til við þessa vinnu, ForSAFE-VEG. Hermilíkanið gat líkt eftir mældum breytingum í lífmassa lerkiskóga og jarðvegsþáttum. Fyrstu spár um langtímabreytingar (150 ár) á sýrustigi jarðvegs, kolefnisbindingu, lífrænu efni í jarðvegi og ofanjarðar eru kynntar og ræddar.

Lykilorð: Ísland, kerfisgreining, kerfisaflfræði, hermilíkön, AFFORNORD, ForSAFE, nýskógrækt

INTRODUCTION

Today, native birch woodlands and forests cover ca. 1300 km^2 in Iceland (Sigurdsson et al. 2007). Together, this amounts to only 1% of the total surface area of Iceland or 3% of the lowland area below 400 m a.s.l. It is, however, generally considered that ca. 90% of Iceland's forest and woodland cover has been lost since human colonization in the 9th century AD (Einarsson 1963, Þórarinsson 1961, Þorsteinsson 1973). This large-scale loss of forest cover has been explained by a combination of anthropogenic and natural factors, including human exploitation, volcanic episodes and harsher climatic conditions during the last millennia. The information about past forest cover comes from various sources, including, for example, pollen analysis studies, archeological findings, historical documents and bioclimatological information (Bergthórsson 1985, Hallsdóttir 1995, Kristinsson 1995). Bergthórsson (1985, 1996), used degree-days to estimate the maximum theoretical spread of common woodland species using historical temperature data from Iceland. Forest cover was further elaborated by Haraldsson & Ólafsdóttir (2003) and later by Jónsson (2005), where temperature data from the Greenland ice core (GRIP) was calibrated and used to simulate the total forest cover in Iceland during the Holocene period. The results about the actual forest and woodland cover in the 9th century have varied somewhat, but all studies show that large-scale deforestation has taken place in Iceland since human settlement began in the late ninth century.

The historical loss of woodland and forest cover in Iceland, together with low human population density, gives an almost unique opportunity for afforestation of treeless landscapes. These possibilities have recently been put in focus through the Kyoto protocol (UNFCCC 1998), which was ratified in Iceland in 2004. Iceland's present climate strategy includes increasing implementation of afforestation and revegetation of deforested and eroded areas in the near future (Umhverfisráduneytid 2007). In 1999, the Icelandic government decided to afforestate 5% of the Icelandic lowlands (below 400 m a.s.l.) within 40 years (Stjórnarráð Íslands 1999).This would about triple the forested area of Iceland, if all birch woodlands are also included as forests. To reach this target by 2040, the annual plantation rate needs to go from ca. 5 million trees to ca. 17 million trees.

The first forest plantation was established in Iceland in 1899. In 1990 planted or seeded stands of native birch and various imported species were estimated to cover 76 km^2 (Snorrason et al. 2005). In 2003, 82% of the forest plantations in Iceland were established using five tree species in the following order (Snorrason et al. 2005): Siberian larch (*Larix sibirica* L.), mountain birch (*Betula pubescens* Ehrh.), Sitka spruce (*Picea sitchensis* Carr.), lodgepole pine (*Pinus contorta* Douglas) and black cottonwood (*Populus trichocarpa* Torr.). In 2005, the total area of planted forests reached 300 km^2 (Sigurdsson et al. 2007). The annual planting has been increasing in recent years. It is, however, highly uncertain whether planting will increase to the necessary 15–18 million trees per year in the next few years to fulfil the goal of the Icelandic commitment.

Some of the oldest and largest planted areas are situated in Hallormstadur in eastern

Iceland, where there are extensive Siberian larch and mountain birch forests. Large-scale planting of larch first took place at this site in the 1950s. This area therefore affords one of the best possibilities to study how afforestation affects the environment.

As more emphasis was put on afforestation, some concern about the environmental effects of this activity was raised (Hilmarsson & Einarsson 2004, Þórhallsdóttir 2001, Usher 2002). Therefore the research project ICEWOODS was launched in 2002, which focused on the effects of afforestation on soil properties, carbon sequestration and biodiversity (Elmarsdottir et al. 2007, Sigurdsson et al. 2005). In 2004, a new Nordic project entitled "AFFORNORD – *Effects of afforestation on ecosystems, landscape and rural development"* was established (Halldorsson & Oddsdottir 2007). Together, these projects have greatly improved empirical data and knowledge of how afforestation affects ecosystem processes and structure. One of the goals of the AFFORNORD project was to develop modelling tools to apply in the planning phase of afforestation in Iceland to predict changes in the ecosystems, e.g. how forest production affects the biodiversity and soil conditions.

The modelling tool chosen for this was ForSAFE, which is an integrated soil-chemistry-forest ecosystem model that dynamically simulates forest production (Belyazid 2006, Wallman et al. 2005). The building of the ForSAFE model was initially supported by the ASTA and SUFOR programs (Sverdrup et al. 2002), and the model was directed at answering questions related to changes in boreal forest ecosystems under changing trends of atmospheric deposition (Belyazid 2006). In parallel, the model was extended with the VEG module to make up the ForSAFE-VEG module, also within the framework of the ASTA project (Sverdrup et al. 2007). Since ForSAFE and its extension, the VEG module, is a recently developed modelling tool it needed adjustments for Icelandic conditions. The Icelandic conditions can be considered as "extreme", where the soil conditions do not follow the classical stratification of podsols.

Icelandic soils are of volcanic type (Andosols) and have unique properties regarding sequestering of carbon and nitrogen with time (Oskarsson et al. 2004). Icelandic andosols are homogeneous in character due to the unique soil formation processes. Apart from soil genesis by decaying plant material two other processes are involved: 1) tephra and post-glacial silt material are deposited onto the soil by wind transport, 2) erosion features called *rofabards* (Arnalds et al. 1997) are deposited onto the soil by wind transport. The chemical properties of the Icelandic Andosols required changes in the fundamental modules of ForSAFE that dealt with chemical weathering of minerals. Adjustments in the model concerning tree growth and the accumulation of carbon had to be made. It was therefore decided to hold several group sessions with the stakeholder experts in Iceland to determine how the model could be improved to incorporate the changes necessary to produce output and simulations that could be interpreted and that would increase the validity of the output.

The main goal of this paper is to describe how the Group Modelling approach was used to modify and develop new sub-models for the process-based simulation model, ForSAFE-VEG. The second goal is to publish the first results from the new modified assessment tool ForSAFE-VEG for long-term changes in soil pH, soil organic matter, standing biomass and the C/N ratio in afforestation areas in eastern Iceland.

MATERIALS AND METHODS

Because the problems outlined in the AFFORNORD programme involved both very different disciplines and research foci and needed knowledge from all of these to be integrated, a participatory, iterative and adaptive method was chosen. In order to prepare for simulations of soil, forest and vegetation development, several methods and steps were adopted for the overall process:

1. Systems Analysis and System Dynamic

approach to define the task, goal and proper tools.
2. The learning Loop process and Group Model Building to develop the necessary knowledge together with stakeholder experts.
3. A Delphi method for parameterization with subsequent iterative adjustment.
4. Computer programming to make the knowledge numerically executable.
5. A case study to focus the effort into a real world setting.
6. Group Model Building to convert simulation outputs to understandable results and policies.
7. Development and inclusion of new submodels in the existing integrated model ForSAFE.

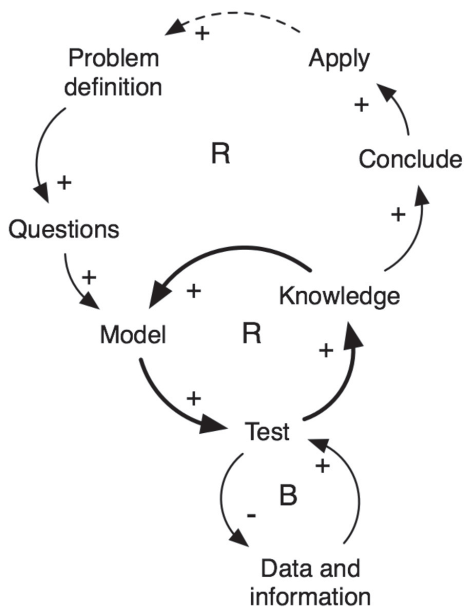

Figure 1. The Learning Loop process is iterative and serves as a "roadmap" towards understanding the problem. It assists the group in understanding and analysing where the group is situated in the development process, from problem definition to developing questions about which models are created and tested. Knowledge is gained from the testing of the data and information available and enables correction or redesigning of the models. When sufficient testing is completed conclusions can be drawn using the models.

8. Field validation by testing the integrated ForSAFE-VEG model on data from two Icelandic ICEWOODS sites.

The System Analysis engineering method as defined first (Walker et al. 1923) and the System Dynamic method (Forrester 1961) are combined into a specific modelling method under the name Learning Loop process (Haraldsson 2005, Haraldsson & Sverdrup 2004). The Learning Loop process is based upon several practices and methods that are both rooted in the participatory approach of Group Model Building (Vennix 1996), which includes the Stakeholder Management procedures elaborated by Maani & Cavana (2000) and Maani & Maharaj (2004), and as well as the Delphi approach (Adler & Ziglio 1995). The Learning Loop process is a roadmap towards understanding the problem. It assists stakeholders in the participatory process in analysing where the group is situated in the learning process of developing an understanding of the complexity and the crucial structural arrangement of the problem. The Learning Loop process guides development from conceptual diagramming towards building simulation in an iterative fashion where the qualitative structure is tested in the number domain (Figure 1). Qualitative structures are expressed through Causal Loop Diagrams (CLD), which enable understanding of cause and effect (Haraldsson & Sverdrup 2004). The CLD variables either illustrate change in the same direction (indicated with a "plus") or change in opposite direction (indicated with a "minus") (Figure 1).

For the Icelandic case studies, the Learning Loop process was iterative and operational, and whenever theoretical reasoning or evaluation of available experimental data was not possible, empirical relationships or approximations were used. Conjectures according to the "best available expert estimate" were adopted (through the Delphi method), regardless of whether proven or not, when information was lacking. The main approach was to use responses to individual factors and let these communicate through feedbacks, using model structures in order to reconstruct the integrated ecosystem responses. The ultimate objective was a predictive model for ground vegetation dynamics in terrestrial ecosystems which could assume the complexity of causality structures and feedback loops and include land management changes. After definition of the model in terms of Causal Loop Diagrams (CLD), Stock-and-Flow Diagrams (SFD), equations, calculation sequences and diagrams, the ForSAFE-VEG model was integrated into the executable code in FORTRAN.

The Icelandic case study

The Icelandic case study (ICEWOODS) was located on the eastern shores of Lake Lagarfljót in eastern Iceland (Figure 2). The case study was a joint project of the Agricultural University of Iceland, Icelandic Forest Research and Icelandic Institute of Natural History. Within the project, the modelling exercise using the ForSAFE-VEG model (Figure 3) was initiated with the following objectives:

1. Predict forest production and carbon sequestration in aboveground biomass.
2. Predict the fate of soil stocks of carbon and nitrogen as well as explain observations that are apparently counter-intuitive.
3. Assess and predict long-term changes in soil pH because of vegetative change.
4. Assess possible changes in ground vegetation composition.
5. Assess possible changes in fauna and fungi.

The modelling exercise objectives were designed to help understand and connect the experimental results from the project, and make future predictions at the study site. In this paper, we focus mainly on the methodological work behind the modelling exercise and present only early results relating to the first three goals, namely standing biomass changes, the C/N ratio, the soil carbon stock and the long-term changes in the soil pH. Further description of the ICEWOODS case study can be found in Elmarsdottir et al. (2007). Other results from the case study can be found in, e.g., Sigurdsson et al. (2005), Bjarnadottir & Sigurdsson (2007a, 2007b), Elmarsdottir & Magnusson (2007), Gudleifsson (2007), Eyjolfsdottir (2007), Halldorsson & Oddsdottir (2007), Olafsson & Ingimarsdottir (2007). Other modelling results are presented in Belyazid et al. (2007).

The ForSAFE-VEG (Figure 3) model was not originally adapted to the site conditions of the Icelandic case study. Therefore various adaptations needed to be completed for the model to be able to tackle the objectives stated above. Three main model changes were identified:

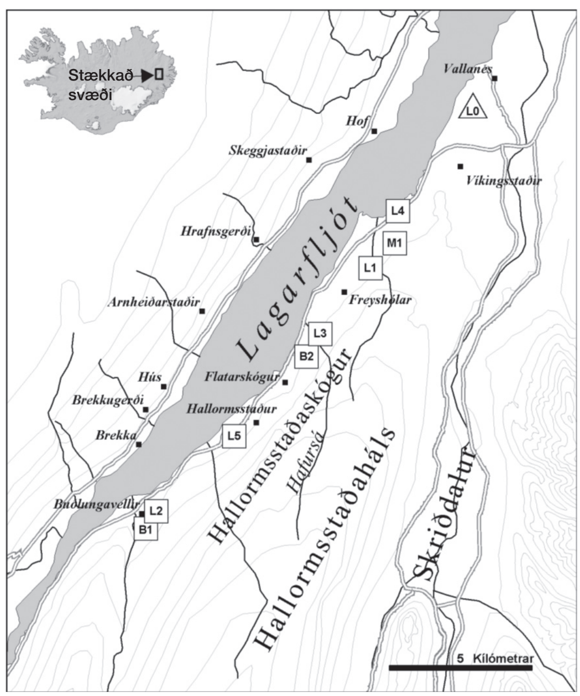

Figure 2. The Icelandic case study took place at Skógar in the Fljótsdalshérad District in eastern Iceland. L0-L5 are 10-51 year old stands of *Larix sibirica*, B1 og B2 are 15 and >100 year old stands of *Betula pubescens*, M1 is grazed heathland, comparable to the afforested sites. (Map: Bjarki Thór Kjartansson)

1. Parameterization of input to the growth module within ForSAFE for *Larix* as the dominant planted tree species at the site, see (Belyazid et al. 2006, Wallman et al. 2005).
2. Inclusion of a sub-module for the development of a grass production model for open land, representing the mass fluxes at the site before trees are introduced (Belyazid et al., manuscript).
3. Selection of indicator plant species and parameterization of the species responses to the composition drivers in the model, see (Belyazid 2006, Sverdrup et al. 2007).

The parameterization for *Larix* growth (point 1) was based on the PnET model (Aber & Federer 1992), which also forms the basis of the growth module in ForSAFE. Goodale et al. (1998) carried out parameterization of PnET to different tree species and that work was used for *Larix* in the Icelandic case.

The model improvements required for the second point involved a conceptual modification of the CLD model (Figure 4). While the model was constructed and used with the assumption that the growth of ground vegetation had little impact on the soil chemistry in managed boreal production forests under the ASTA and the SUFOR programmes, it became clear that this assumption did not hold in the case of the Icelandic study. The double arrows in Figure 4 were developed under the Icelandic exercise to account for the substantial and decisive effects of the ground vegetation on the soil chemistry and the build-up of the soil organic matter pool. This required a revision of the model processes, and once the conceptual basis for the growth, uptake and litter fall processes related to the ground vegetation was

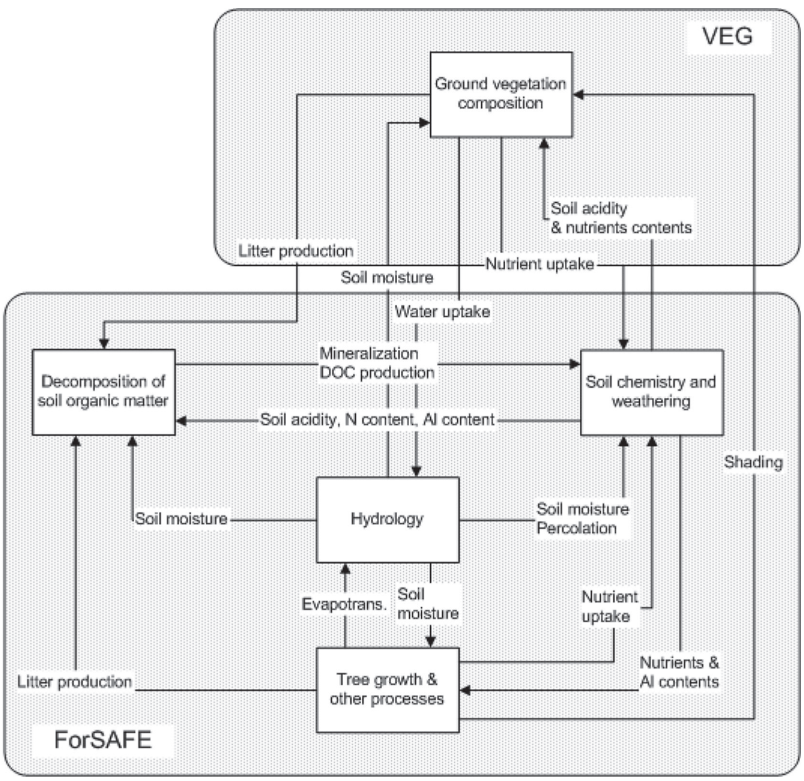

Figure 3. The ForSAFE model incorporates the processes of tree growth, soil chemistry, decomposition and hydrology. The model is extended with the VEG module to include the growth and composition of the ground vegetation (Adapted from Belyazid 2006).

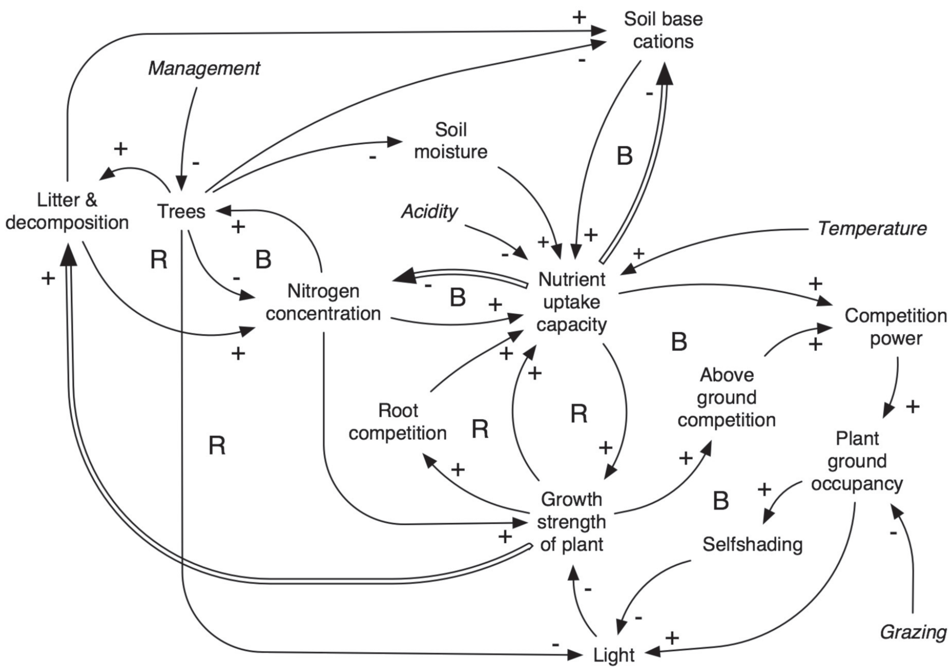

Figure 4. CLD for the vegetation change process in ForSAFE-VEG as developed during the SUFOR and the ASTA programmes and further developed in the AFFORNORD programme. Processes that feed back in the same direction are called reinforced processes (indicated with R) since they amplify the condition. Similarly, the processes that feed back to give a change in the opposite direction (indicated with B) balance out (dampen) a condition.

clarified, the model was recoded (Belyazid et al., manuscript). The result became a fully integrated vegetation-soil system, where the effect of the ground vegetation is not assumed to be negligible but is fully included in the model calculations (Figure 4).

The third required addition to the model (point 3) concerned the identification of indicator ground vegetation species and the parameterization of their responses to the drivers used in the model. This process was carried out in close cooperation with Icelandic ecologists based on the example of a similar table developed for Swedish forest ecosystems (Belyazid 2006, Sverdrup et al. 2007).

All three of the improvements to the model described above were carried out through a close collaboration between the field experts and the modellers. This process required numerous iterations through the learning loop, and because of the diversity of the knowledge involved, Group Modelling played a central role. The procedures related to these developments are described in detail below.

The Group Modelling process

The Group Modelling sessions were important for clarifying the issues and questions as well as for defining the vegetation model and deriving the parameterization. The Group Modelling procedure can be summarized into four phases (Haraldsson 2005) that were adapted for the ForSAFE-VEG development:

I. *The definition phase:* Discussions on the research problem and identification of system analysis tasks take place. Stakeholders and problem owners are invited to participate to acquire information on system symptoms and define the problem boundaries. Experts are also invited to participate and then to leave the process when their particular knowledge of the problem has been utilized. The understanding generated during the Group Modelling sessions is used to design new experiments to increase the understanding of detailed processes within the problem being studied. Asking the right questions helps in identifying how the symptoms are manifested in the problem structure. The hypothesis and the study goals are identified. Information on system symptoms is acquired and the system boundaries are defined. Participants ask the relevant questions (developing a hypothesis) and design the first structures (through CLDs). Several iterations of the Learning Loop are made.

II. *The clarification phase:* Conceptual models are created using graphic representations of the problem. In this phase both CLDs and SFDs are used as search and construction tools, iteratively back-and-forth. From the CLD all coupled differential equations are derived. Eventually, enough understanding can be generated to provide the documentation basis for translation into a computer simulation tool by which the system feedbacks can be analysed dynamically in time and space. If information from new experiments or experiences initiated by this ongoing process becomes available, it can immediately be used for improving the understanding of the system processes and improving the CLDs and SFDs. Eventually, enough understanding can be generated to provide the documentation basis for translation into a computer simulation tool, allowing the system feedbacks to be analysed dynamically. In our case this was used to adapt an already existing model (ForSAFE) to accommodate the vegetation assessment that was important to the question.

III. *The confirmation phase:* This is the verification of the system structure. There is a breakthrough in understanding, both realization of what the "right" question is and what the key components relevant to the question are. The system boundaries as well as assumptions and limitations of the study are definitely set. The study is concluded when the research questions are answered and validated and uncertainty is documented. Stakeholders and problem owners document the results and new questions generated from the modelling.

IV. *The implementation phase:* Policies and tools are developed and implemented from the new research findings. The true performance of the model is measured and experience gained in this phase is used to develop questions for further research.

According to Haraldsson (2005), a thoroughly planned project which involves careful documentation through all steps will enhance the understanding of the behaviour of the problem, thus leading to discoveries of mechanisms that otherwise would have been overlooked. There were several results of the development process for ForSafe. Several sessions were held with stakeholders for each of the development steps. The ForSAFE-VEG development team used results from each meeting as a basis for their own homework, to test the new knowledge and to introduce it to the participants in the following session on the new model setup. The four phases enabled a focused development process since the stakeholders could understand why particular knowledge was introduced to them (Table 1).

Model inputs

The major inputs to the project were the objectives of the ICEWOODS case study and the AFFORNORD programme, namely, to predict the changes in ground vegetation and soil stocks of carbon and nitrogen following afforestation in Iceland, Norway, Denmark and Sweden.

Table 1. An overview of the Group Modelling process for developing the new integrated ForSAFE-VEG for Iceland.

Steps	Description
I. Definition	Defining problems and key questions for the ground vegetation change process in Iceland compared to Scandinavia.
II. Clarification	Clarifying key processes for ground vegetation species and response functions for the Icelandic settings in the ForSAFE-VEG model.
III. Confirmation	Confirming parameterization of the Icelandic ground vegetation species through comparison of comparable Swedish test sites.
IV. Implementation	Implementing the new integrated knowledge of the combined ground vegetation species model for ForSAFE-VEG. Running simulation and validating the Icelandic test sites.

RESULTS

The Group Modelling process and the development of the new modified Assessment Tool

The result of the Group Modelling process is the iteratively adapted method, derived through actual testing on the AFFORNORD project. A total of 11 Group Modelling sessions were held in both Iceland and Sweden between November 2004 and early 2007 for the ForSAFE-VEG development for Iceland. The early development focused on parameterization and the plant selection list, and work during and after 2006 focused on developing the grass primary production module. The number of meetings for the project grew iteratively in response to the needs for defining, understanding and undertaking the different tasks. The total number of meetings was necessary in order to answer the questions pertaining to the Icelandic sites and to perform the necessary simulation runs. The results of the Group Modelling sessions with participants from ICEWOODS and AFFORNORD can be categorized according to the four phases (Figure 5):

Definition- phase 1: The overall task and question for the VEG model development defined. Overall modifications and adaptation of the ForSAFE-VEG discussed. A general outline for the vegetation model for ForSafe was adopted and modifications discussed. A proposal for the vegetation change mechanism

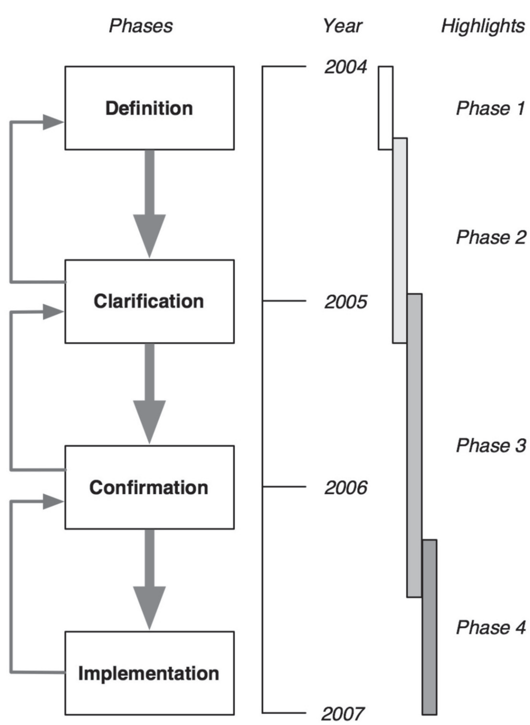

Figure 5. The 11 Group Modelling sessions went through the four phases (Definition, Clarification, Confirmation and Implementation) iteratively during the period 2004-2007. The final implementation phase was the accurate test runs for the Icelandic sites.

Table 2. The coefficients a0, k+, k-, w+.w- are parameters of the nitrogen response curve, kbc/al gives the coefficients of the aluminium response, kbc of the response to calcium, kph the response to soil pH. Wmin, Wtop, Wmax are parameters of the soil moisture function, Tmin, Ttop,Tmax of the temperature function, Lmin, Lmax for the light response, h(m) is effective shading height, z is rooting depth class, kP the coefficients for the phosphorus response and kG for the response to grazing. Years gives the delay time based on plant survival age. For further explanation see Sverdrup et al. (2007).

Latin name	years	a0	k+	w+	k-	w-	kbc/al	kbc	kph	Wmin	Wtop	Wmax	Tmin	Ttop	Tmax	Lmin	Lmax	h(m)	z	kP	kG
Cladonia lichen	20	1	0,01	1	0,003	3	0,07	0	1050	-0,2	0,05	0,25	-2,5	5,5	13,5	500	2500	0,05	0	0,1	0,67
Hylocomium	20	1	0,05	1	1000	0	0,07	1,50E+05	1050	0,05	0,15	0,35	-1	7	15	100	5000	0,02	0	3	0
Racomitrium	20	1	0,1	1	1000	0	0,07	1,50E+05	1050	0,05	0,15	0,35	-2	5	13,5	875	3500	0,05	0	1	0
Calluna vulgaris	30	1,4	0,2	1	3	3	0,2	0	3000	-0,25	0,15	0,4	-1	7	15	500	5000	0,25	2	1	0,67
Empetrum nigrum	15	1,6	0,03	1	0,003	3	0,2	1,50E+05	3000	-0,2	0,1	0,4	-1,5	6,5	14	750	5000	0,1	1	1	0
Vaccinium myrtillus	10	1,6	0,1	1	0,1	3	0,1	0	1500	-0,1	0,15	0,5	-1	5	11	250	2500	0,3	1	1	2,3
Vaccinium vitis-idea	15	1,6	0,03	1	0,003	3	0,35	0	5250	-0,2	0,1	0,45	-1,5	4,5	10,5	500	4000	0,15	1	1	0,67
Agrostis capillaris	5	1	0,5	2	1000	0	0,2	0	3,00E+03	0,05	0,15	0,5	3	11	19	750	4000	0,25	2	3	2,3
Alopecurus prat	5	2	2	2	1000	0	1,2	0	1,80E+04	0,05	0,15	0,5	5	13	20	1000	4000	0,25	2	3	2,3
Deschampsia caespitosa	5	1	0,5	2	1000	0	0,2	0	3,00E+03	0,15	0,35	0,6	3	11	19	1000	5000	0,35	2	3	0
Deschampsia flexuosa	5	1	0,05	2	1000	0	0,13	0	1950	0,05	0,15	0,3	-1	7	15	250	3000	0,2	2	3	2,3
Carex vaginata	7	1	0,1	2	1000	0	0,3	0	5,00E+03	0,1	0,2	0,25	1	9	12	250	2500	0,3	3	1	9
Festuca ovina	10	1,5	5	2	10	1	0,1	0	1,50E+03	-0,1	0,2	0,6	-1	7	15	1500	5000	0,1	1	1	2,3
Nardus stricta	10	1,2	0,05	2	10	1	0,2	1,50E+05	3,00E+03	0,15	0,25	0,4	0	8	16	1500	5000	0,15	2	1	0
Poa pratensis	5	1	20	2	1000	0	8	0	1,20E+05	0,05	0,1	0,2	4	12	25	1250	5000	0,4	2	3	9
Poa sylvatica	5	1	10	2	1000	0	8	0	1,20E+05	0,05	0,1	0,2	2	10	20	1250	5000	0,4	2	1	9
Poa glauca	5	1	10	2	1000	0	8	0	1,20E+05	0,05	0,1	0,2	1	8	17	1250	5000	0,4	2	1	9
Dryopteria filix-mas	20	1	0,5	2	1000	0	2	0	3,00E+04	0,1	0,3	0,5	3	11	16	150	2500	0,5	2	1	2,3
Pteridium aquilinum	20	1	0,5	2	1000	0	0,2	0	3,00E+03	0,05	0,2	0,3	2	8	18	750	3250	0,7	2	1	0
Antennaria docia	5	1	0,01	2	1000	0	0,1	0	1500	0,05	0,1	0,2	0	6	12	2000	5500	0,01	1	1	0
Alchemilla alpina	10	1	0,3	2	1000	0	1	0	1,50E+05	0,1	0,2	0,25	1	9	12	500	3000	0,1	2	1	0,67
Dryas octopetala	30	1	0,1	2	1000	0	2	0	3,00E+05	0,05	0,25	0,6	-1,5	6,5	12	1250	5000	0,07	3	1	0
Equisetum prat	10	1	0,5	2	1000	0	0,5	0	9,00E+03	0,1	0,17	0,3	0	8	16	250	3500	0,2	3	1	0,67
Galium verum	3	1	5	2	1000	0	1,2	0	1,80E+04	0,1	0,25	0,4	3	11	19	250	5000	0,15	1	1	0,67
Geranium sylvaticum	3	1	1	2	1000	0	1,8	0	2,70E+04	0,15	0,25	0,4	2	10	14	500	3000	0,5	2	1	9
Rumex acetosa	5	1	0,1	2	1000	0	1	0	1,50E+04	0,1	0,25	0,4	2	10	18	1000	5000	0,3	2	1	0
Thymus praecox	15	1	0,03	2	1000	0	0,1	0	1,50E+03	0,05	0,17	0,3	-1,5	6,5	12	750	5000	0,1	1	1	2,3
Trientalis europaea	2	1	0,5	2	10	1	0,2	0	3,00E+03	0,1	0,2	0,4	2	10	18	250	3000	0,15	1	1	0,67
Trifolium repens	5	1	1	0	1000	0	1,3	0	19500	0,2	0,35	0,4	5	12	18	1250	5500	0,3	2	1	32
Betula	60	1	1	2	100	1	0,25	0	4000	0,15	0,45	0,9	2	12	17	1000	2000	0,2	2	1	9
Salix lanata	30	1	0,5	1	0,1	3	0,6	0	10000	0,05	0,35	0,6	-1	3	7	750	4000	0,8	2	1	2,3
Salix phyllicifolia	30	1	2	2	1000	0	0,5	0	9000	0,2	0,4	0,6	2	10	18	750	4000	1	2	1	9
	Delay	N-parameters					Acidity			Water			Temperature			Light		Height	Rooting	Phosphorus	Grazing
		Pollution								**Climate**						**Competition**					

was developed as well as addition of a new grass module. The foundation was made for a Collembolan/soil microfauna sub-module to ForSAFE

Confirmation- phase 2: The local application sites were chosen and in-depth discussions and revision of model principles carried out. Revisions and additions made to the plant selection list as well as parameterization of vegetation responses and climatic factors for Iceland. Furthermore parameterization of Icelandic soil chemical properties.

Clarification- phase 3: All causal links used and vegetation response parameters and coefficient databases were verified, tested and confirmed for Iceland with specialized experts during Group Modelling sessions.

Implementation- phase 4: Trial runs and sensitivity analyses with the confirmed structure and parameterization were conducted and compared to both Icelandic and Swedish sites. First results from ForSAFE-VEG were presented for the Hallormstadur site.

The CLD (Figure 4) was taken up, thoroughly discussed and revised through Delphi processing. Substantial revisions and additions were made to the initial plant selection list as well as parameterization (Table 2). One of the major results that carried into the follow-up programmes after AFFORNORD was made during the clarification phase where the Icelandic plant selection list was developed. Substantial revisions and additions were made to the initial plant selection list as well as parameterization (Table 2). The group process progressed until the end of the AFFORNORD programme in 2006 and the results were carried on into the Swiss and the Danish follow-up programmes.

Predictions by the new modified assessment tool for the Icelandic case study

The preparations of ForSAFE-VEG through the interactive Group Modelling process resulted in a new assessment tool that was specifically parameterised for Icelandic conditions. The first modelling runs with the current parameterization showed the following results. A *Larix* stand planted in 1951, having three relatively mild thinnings during 1971, 1985 and 1995, should have accumulated ca. 7000 g m^2 of wood in 2005. This was a slight underestimation of the measured data from the Hallormsstadur *Larix sibirica* stand planted in 1951 (Figure 6). We assume that no further thinnings will take place in the *Larix* stand during the next 95 years and it will not be harvested. The *Larix sibirica* will continue to have relatively high production during the next 30-40 years, reaching 11,500 g m^{-2} standing biomass in 2052. Adding 50 years to the rotation only increased the total standing biomass to13,000 g m^{-2} (Figure 6).

The ForSAVE-VEG also simulated an increase in carbon stock in the top 10 cm soil layer following afforestation, leading to an increase in the soil C/N ratio (Figure 7). This increase was predicted to be at maximum in ca. 2010, when soil the C stock was predicted to be ca. 2100 g

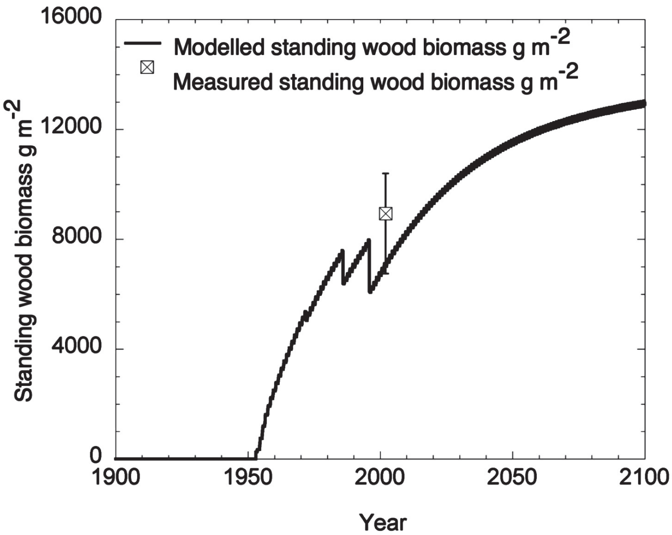

Figure 6. Simulated increase in standing woody biomass during 150 years after plantation by *Larix sibirica* in eastern Iceland by the ForSAFE-VEG model. Also plotted is the actual standing biomass (mean and standard deviation) in one 53 year old *Larix* stand.

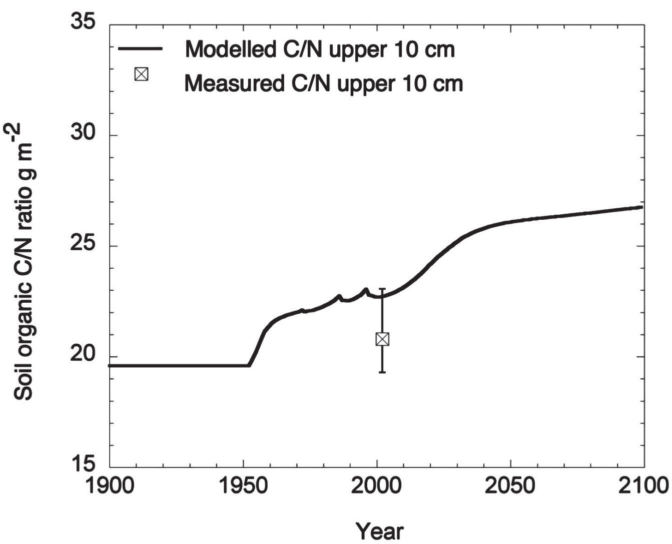

Figure 7. Simulated change in soil C/N ratio during 150 years after plantation by *Larix sibirica* in eastern Iceland by the ForSAFE-VEG model. Also plotted is the actual measured soil C/N ratio (mean and standard deviation), excluding root C, in one 53 year old *Larix* stand.

m^{-2} higher than before afforestation (Figure 8). During the following 90 years the soil C stock was predicted to slowly decrease and be 1,450 g C m^{-2} higher in the year 2100 than in 1951.

It should be noted that when compared to measured data, the ForSAVE-VEG slightly overestimated both the measured soil C stock and the C/N ratio in the 53 year old *Larix* stand (Figure 7 and 8). This was partly because the soil tree-root carbon stock was not included in the measured data.

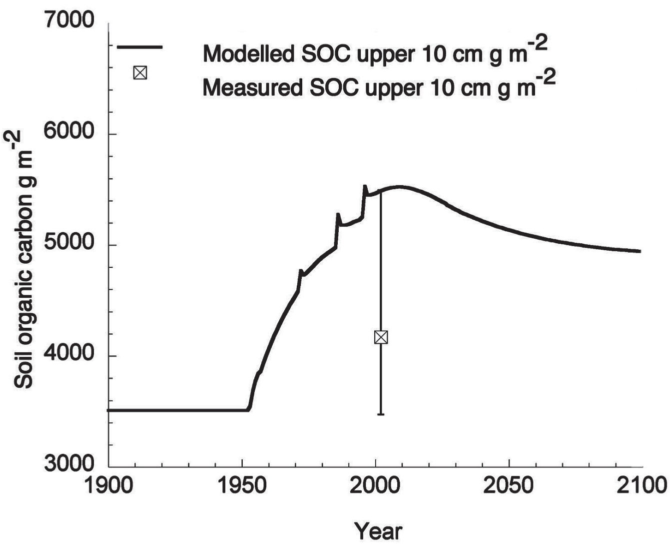

Figure 8. Simulated change in soil carbon stock during 150 years after plantation by *Larix sibirica* in eastern Iceland by the ForSAFE-VEG model. Also plotted is the actual measured soil carbon, excluding root C (mean and standard deviation) in one 53 year old *Larix stand*.

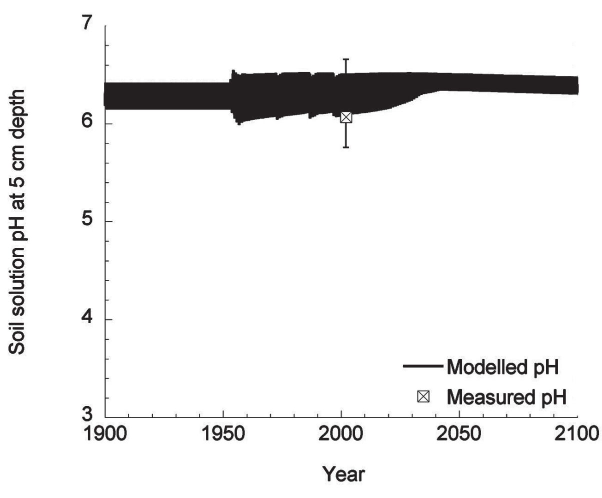

Figure 9. Simulated change in soil pH during 150 years after plantation by *Larix sibirica* in eastern Iceland by the ForSAFE-VEG model. Also plotted is the actual measured soil pH (mean and standard deviation) in one 53 year old Larix stand.

ForSAVE-VEG predicted a slight decrease in soil pH following afforestation due to more cation uptake and a higher input of organic matter (Figure 9). The predicted pH and the actual measured pH in the 53 year old *Larix* sibirica stand overlapped, with a minimum pH of ca. 6.0. The model predicted that the minimum pH would occur relatively early after plantation, when the trees have the highest growth rates and take up most nutrients from the soil (Figure 9). Then the soil pH slowly increased again, with some dips when input of organic matter peaked, such as at thinnings. The model further predicted that as the planted forests became older and their productivity decreased, the minimum soil pH became higher than it was in the grassland soils.

DISCUSSION

Preparation of the new modified assessment tool and the Group Modelling process

The commitment of the AFFORNORD and ASTA programme participants resulted in a high degree of shared ownership in the whole process which will prepare the acceptance of the results even if these should turn out to be counter-intuitive. The advantages and lessons learned from the process can be summarized as follows:

• The AFFORNORD and invited Swedish participants from the ASTA programme were comfortable with the modelling approach. They were directly involved in the process and had participated in defining it and thus had a direct ownership in the model. The participants understood that the computerized model is only a numerical picture of the mental model they jointly drew on paper and numerous blackboards.

- The parameterization was a direct result of the work of the participants, as the authors of this study had no way to do the model parameterizations alone.
- Several test runs at the proxy sites were available for assessment by the AFFORNORD participants for evaluation of their own success of parameterization.
- The dual group modelling process shared between the Swedish partners and AFFORNORD enhanced the process by providing a larger experience base and the opportunity to exploit the very large overlap in problem focus and scope, even though particular objectives of the partners were sometimes different.
- The group agreed upon a CLD of the basic process and generated a consensus on the parameterization and established field sites for assessment.
- The group accepted the assumption and limitations of the modelling tool developed into ForSAFE-VEG.
- In the process of developing group modelling as a tool, the ForSAFE modelling of biogeochemistry and biodiversity for Hallormstadur appeared as a by-product.

Predictions by the new modified assessment tool for the Icelandic case study

ForSAFE-VEG was able to predict current soil conditions and biomass with a relatively good accuracy, which showed that the first parameterization effort for the Icelandic sites was successful.

The growth of *Larix* sp. is characterized by intense development in the first 15-35 years, faster than most conifers, followed by slower growth as the forest matures (Bauger 1985). Although both height growth and volume production can be impressive during the juvenile phase, the increment declines over time. This pattern was relatively accurately simulated by the ForSAVE-VEG model.

There was an apparent difference in the temporal patterns of the soil C stock and soil C/N ratio (Figures 6 and 8). As forest stands became older the soil C stock started to decrease again, due to the lower production related to decomposition. The simulated C/N ratio, however, continued to increase all through the rotation. The latter increase was mostly because more and more of available soil N became locked in the standing biomass of the forest. This could indicate that the high production of the *Larix sibirica* can possibly lead to a reduction in available soil N. Care must be taken when such sites are harvested to see that nutrients are returned to the soil. This can partly be done by leaving branches and tops at the site at harvest.

The ForSAVE-VEG model predicted a long-term accumulation of carbon both in soil and aboveground following afforestation by *Larix sibirica* in eastern Iceland. When soil carbon was converted to soil CO_2 sequestration, this amounted to ca. 77 t CO_2 ha^{-1} in 2010 and 53 t CO_2 ha^{-1} in 2100. When woody biomass was similarly converted to CO_2 sequestration, it amounted to ca. 156 t CO_2 ha^{-1} in 2010 and 248 t CO_2 ha^{-1} in 2100. The average annual ecosystem CO_2 sequestration rate (wood and soil) was predicted to be 4.9 t CO_2 ha^{-1} year^{-1} in the *Larix sibirica* stand during the first 50 years after plantation. These sequestration rates are in the same range as found by measurements in *Larix sibirica* stands of similar age in northern and eastern Iceland (Snorrason et al. 2002). It is also similar to the mean annual sequestration rates of 4.4 t CO_2 ha^{-1} year^{-1} used in national estimates of carbon sequestration by afforestation (Sigurdsson et al. 2007).

When a longer rotation, or 150 years, was used the mean annual ecosystem sequestration rate dropped to 2.0 t CO_2 ha^{-1} year^{-1} over the whole rotation, due to both lower productivity of older forests and the slight reduction in soil carbon due to less input of organic matter. This result highlights how important it is to be careful when CO_2 sequestration potentials are presented as they are always very sensitive to the rotation length chosen.

Some ecologists have advocated the idea that coniferous plantations in Iceland will greatly acidify the soil and therefore have large environmental effects (e.g. Þórhallsdóttir 2001). Higher productivity in an ecosystem should always bring a slight reduction in the surface water and topsoil pH, due to a higher base cation uptake from the soil and a greater input of decomposing organic matter (Cannell et al. 1999). It is, however, not until soil pH falls below 5.0 that problems with a deficiency or unavailability of plant nutrients, such as phosphorus, calcium, molybdenum and boron, start for most vascular plants (Smithson et al. 2002). An extreme soil pH of below 4.5 can lead to toxicities when elements such as aluminium increase their solubility to concentrations that may kill some vascular plants and soil invertebrate populations or salmonid fish in nearby catchments (Kreiser et al. 1990). As noted by Cannell et al. (1999) this should not be taken as a general response of the trees alone. Such effects occur where the region has appreciable concentrations of air-borne pollutants (high acid deposition) and base-poor soils overlying rocks with few weathered minerals, such as granite. That the adverse effects of coniferous trees on soil pH in Denmark and Germany have been mainly an indirect effect of high air pollution load has been further proved by Rothe et al. (2002) and Gundersen et al. (2006).

Neither the simulated soil pH nor the measured data from the 53 year old *Larix sibirica* plantation in eastern Iceland seem to indicate that acidification will be substantial in Icelandic volcanic soils (Andosols). This prediction is also in accordance with empirical data from other Icelandic studies where soil pH under forest plantations of different coniferous species has been measured (Sigurdardottir 2000, Sigurdsson et al. 2005). It has been noted that soil invertebrates, such as earthworms, sensitive to reductions in soil pH are common in coniferous plantations in Iceland (Gudleifsson 2007). Further, it has been found that changes in ground vegetation of planted forests are more strongly related to changes in light availability than soil pH (Sigurdsson et al. 2005). Both these observations support the conclusion that soil acidification is not a substantial problem in coniferous plantations in Iceland.

The initial runs by the ForSAVE-VEG model, presented here, give good hopes that the model may be applicable over different forest types and geographical areas and may therefore be a valuable tool for studying the environmental impact of afforestation in Iceland.

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