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A comparison of the ForestMan AI software with the Heureka system regarding forest growth simulations and carbon calculations

(En jämförelse av programvaran ForestMan AI med Heureka-systemet avseende skogliga tillväxt- och kolberäkningar)

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Abstract

The purpose of this study is to evaluate the reliability of the forest growth simulations and carbon calculations of the ForestMan AI forest planning system. The ForestMan AI software is developed by and the property of Skogr Kaupa Group AB. ForestMan AI is based on the ProdMod model from SLU and carbon calculations according to methodologies recommended by the IPCC in Guidelines for National Greenhouse Gas Inventories reporting.

The Heureka system calculations are used as benchmark for the evaluation. Heureka is a planning system that has been developed over more than 20 years and has found extensive use in both research and among forest companies. The Heureka system calculations is used as the basis for evaluation since it can be considered state-of-the-art with respect to forest research and because it is also used for assessments for the Swedish reporting of greenhouse gas emissions.

The evaluation is based on the data from a forest estate in the Halland county. The estate encompasses 2.037 ha and has spruce as dominating species. It is, by and large, representative of forest in the region.

The evaluation shows ForestMan AI to perform growth projections and the associated carbon stock assessment to agree to a great extent. No major deviations between the outputs of the systems are identified.

The result of the study can be used as a basis for further development of standards for evaluating forest planning systems. Carbon as a commodity represents an emerging branch of forestry. Furthermore, it is the quantity to report by financial institutions and forest owners in Climate Benefit Analyses (CBA) mandated by the EU Taxonomy. Thus, it is crucial that different actors, SMEs (Small, Medium Enterprises) and others, are given access to research in various forms to meet the needs of this emerging branch of forestry.

The management of data for and computations with the Heureka system was done by Narayanan Subranian[a], checking data associated with the test property was done by Ulf Johansson[b], and the text was formulated by Ljusk Ola Eriksson[(].

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Sammanfattning

Syftet med denna studie är att utvärdera tillförlitligheten av simuleringar av tillväxt och kolberäkningar med ForestMan AI skogliga planeringssystemet. Programvaran ForestMan AI är utvecklad av och ägs av Skogr Kaupa Group AB. Den är baserad på ProdMod-modellen från SLU och koldioxidberäkningar enligt metoder från IPCC rörande riktlinjer för nationella växthusgasinventeringar.

Heureka-systemets beräkningar används som riktmärke för utvärderingen. Heureka är ett planeringssystem som utvecklats under mer än 20 år och har fått stor användning inom forskning och bland skogsföretag. Heureka-systemets beräkningar används som underlag för utvärdering eftersom det innehåller de senaste skogsforskningsresultaten och används för beräkningar för den nationella klimatrapporteringen.

Utvärderingen baseras på data från en skogsfastighet i Hallands län. Fastigheten omfattar 2 037 ha dominerad av gran. Fastigheten har skog som är rimligt representativ för regionen.

Utvärderingen visar att ForestMan AI tillväxtprognoser och tillhörande beräkning av kolförråd överensstämmer i stor utsträckning. Inga större avvikelser mellan systemens resultat kan identifieras.

Resultatet av studien kan förhoppningsvis användas som underlag för vidareutveckling av standarder för utvärdering av skogliga planeringssystem. Kol i skog representerar en framväxande gren av skogsbruket. Dessutom är det den kvantitet som finansinstitut och skogsägare ska rapportera i som ”Climate Benefit Analyses” enligt EU:s Taxonomi för miljömässigt hållbara investeringar. Det är därför avgörande att olika aktörer, små och medelstora företag och andra, ges tillgång till forskning i olika former för att kunna möta behoven hos denna nya verksamhet inom skogsbruket.

Hanteringen av data för och beräkningar med Heureka-systemet gjordes av Narayanan Subranian, data associerade med ForestMan AI-systemet levererades av Ulf Johansson, och texten har formulerats av Ljusk Ola Eriksson.

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Introduction

Forests fulfill several functions and deliver various ecosystem services (ES). One ES, which over the last decades has received increased attention, is climate mitigation. The capacity of forests to act as sinks, as well as to be the source of products that can store carbon and substitute materials based on fossil fuels, is well recognized. In Sweden, almost 50 million tons of CO_2e emissions per year are counteracted by some 35 million tons per year as forests sink and an additional amount of the same magnitude from product pools and product substitution.

One instrument to realize the potential of forests as carbon sinks is to pay forest owners for supplying the service (for Nordic examples, e.g. Guo, J. and Gong, P. 2017); Kangas, J. and Ollikainen, M. 2022)). Thus, forest owners are motivated to manage the forest such that carbon dioxide (CO_2) is removed from the atmosphere and stored as carbon in biomass and soil. In principle, the funding for payments could come from both governments, in order for them to fulfill national targets or comply with international agreements, and private capital, to receive offsets that serve as compensations for emissions elsewhere. Another motivation for private capital, and financial institutions in particular, is the need to prepare a Climate Benefit Analysis (CBA; EU 2020) of clients in order to make the investment eligible according to the EU Taxonomy (EU 2021; EU n.d.).

One issue associated with implementing payment schemes or CBA refers to the content of the forest management plan (FMP). The FMP should encompass a reliable projection of carbon stored in the forest. This demand relates to the ability of the forest owner to make forest plans that optimize the income stream from carbon payments and timber incomes. Likewise, a plan is needed for contracting parties, the forest owner and the investor, to make an agreement on terms of management that satisfies the requirements of a CBA.

Forest management plans (FMP) has been in use in Swedish forestry for more than half a century. It was, and still is, the main planning document for most forest owners, and a vital instrument for communication with service providers. With the introduction of the personal computer in the 80's, plans started to be developed into digital format. At the beginning, most software encompassed a 10 year period, just as the original paper plan. By time, several planning tools have extended the planning horizon to allow for long term planning, and integrated them with Geographic Information Systems (GIS). Today, it has become important to furnish the FMPs with methods that also provide reliable long-term assessments of carbon storage. Thus, reviewing tools such that governments, investors, and forest owners have access to reliable projections is imperative.

One planning tool with long-term planning capabilities is ForestMan AI. It is used by many forest owners in Sweden, ranging in size from more than a quarter million hectares to medium and small sized owners. The ForestMan software was acquired by Skogr Kaupa Group AB (SKG) in 2021 (Heberg & Dahlén, 2021). SKG initiated the development and implementation of new functionalities of their FMPs, enabling the management of other ES, including climate mitigation with a CBA module. Based upon the initial feedback from forest owners, the regulating banks, and the forest industry community, two issues became apparent. One is that there is still a knowledge gap between the requirements stipulated in the EU taxonomy regulation and the practical implementation. The other, and the subject of this study, is that there is a lack of evaluations of the accuracy of simplified carbon calculations, such as those proposed by SKG. The evaluation performed in this study only concerns the carbon content of living biomass, not soil carbon and litter.

With a grant provided by the Swedish Governmental Agency for Innovation Systems (Vinnova) the Swedish University of Agricultural Sciences (SLU) was given the task to validate forest growth simulations and carbon calculations of the ForestMan AI software. The evaluation is performed with the Heureka system (Wikström *et al.*, 2011) as benchmark. The Heureka system has been developed over a 20-year period at SLU and with continues input of research results. Being state-of-the-art and since Heureka is used for all of Sweden's National Inventory Reporting on LULUCF to the UNFCCC (Lundblad et al., 2023) it was considered the most appropriate instrument for evaluating the reliability of other planning systems.

Material and Methods

Growth models

ForestMan AI and Heureka share the same basic principle for growth estimation, i.e. they use empirical growth models in combination with allometric volume functions. A difference is that whereas Heureka growth and volume functions have single tree data as input, the growth models implemented in ForestMan AI use average stand data.

ForestMan AI uses the growth simulator ProdMod provided free of charge by SLU (Ekö & Ogemark, 1999). The growth and yield of established forest (dominant height > 7 m) is calculated by models for basal area growth (Ekö, 1985), natural mortality (Bengtsson, in Hägglund, 1981)., and ingrowth (Karlsson, in Hägglund, 1981). Volume is calculated with allometric volume functions (Ekö, 1985). Stand establishment is controlled by user input of plant species and numbers and with growth functions from 3 m height (Elfving, 1982).

The Heureka system is a series of software developed at SLU that allows the user to perform different analyses and management plans. The growth and yield of established forest (dominant height > ~7 m) is calculated by models for basal area growth, natural mortality, and ingrowth (Elfving, 2010). Volume is calculated with allometric volume functions (Brandel, 1990). Stand establishment follows default settings (Heureka föryngring (no date)).

Carbon Calculations

ForestMan AI is reporting forest carbon corresponding to Tier 3 according to the IPCC Guidelines for National Greenhouse Gas Inventories related to LULUCF (IPCC, 2003, 2006, 2019). The calculations cover living biomass of trees above and below ground for all living trees with a diameter > 8.0 cm and roots > 2.0 cm. ForestMan AI employs the standard equation recommended by IPCC (IPCC, 2003, s. Equation 3.2.2) as follows. Based upon forest stand site index (SI/H100), volume, and diameter at breast height provided in the forest management plan, the carbon stock of the total living biomass of trees, C_{tlb}, is calculated as

$$C_{tlb} = V_{IPCC} \times D \times BEF_2 \times (1+R) \times CF \qquad \text{Eq. 1}$$

where

- V_{IPCC} Merchantable growing stock volume. The forest volume (m^3ob = m^3sk in Swedish) converted into "merchantable volume" (m^3IPCC)
- D Basic wood density. By default according to Table 4.14 (IPCC, 2006, s. 4.71), (BDT/m3)
- BEF_2 Biomass expansion factor for conversion of merchantable volume to aboveground tree biomass (dimensionless)
- R Root-shoot ratio (dimensionless)
- CF Carbon Fraction of dry matter (default = 0.5), (tC/BDT)

For V_{IPCC}, a conversion factor of 0.964 is used (Gschwantner et al., 2019, s. Table 5). For BEF_2, the values in Table 1 are used ("All" referring to any species not in the other categories and calculated as the average BEF of the other species). The root-shoot ratio, R, is set to 0.25-0.30 depending on age of the stand.

Table 1. BEF_2 values used in Eq. 1

Species	Parameter
Scots pine	1.216
Norway spruce	1.432
Broadleaves	1.542
All	1.379

Heureka estimates carbon content for all trees and includes roots with a diameter greater than 2 mm (Heureka, no date). Calculations are made with the biomass regression equations developed by Marklund (1988) for above ground biomass, and Petersson (1999) for below ground biomass of trees with dominant height above 7 m. Smaller trees are estimated with models developed by Claesson, Sahlén and Lundmark (2001). The assessment is based on single tree data from the growth prediction.

Forest management simulation

The evaluation is based on two forest management simulations, undisturbed growth (UG) and today's forestry (TF). The TF simulation should correspond to business-as-usual (BAU) management. Thus, it is a kind of management that will cover most of applications of ForestMan AI to forest properties. To normalize the simulations with ForestMan AI and Heureka, the harvests of the TF simulations should over time be the same as net growth. The primary purpose of the GU simulation is to test the calculations without the potential difference in implementing forest management actions in ForestMan AI and Heureka, respectively. Together, the TF and GU simulations would make it possible to infer conclusions regarding the properties of ForestMan AI *vs*. those of Heureka.

In ForestMan AI different management scenarios can be simulated by the use of management templates (*SE:* skötselmallar). Each management template defines the main activities to be performed in the forest stand to achieve a certain goal and strategy. These activities are described in Strategic Activity Plans (SAP). The standard strategic activity plan for the TF simulation includes parameters and considerations such as legal cutting restrictions, best practices and optimum economic returns to the forest owner given current average market conditions.

The TF simulation with Heureka corresponds to the BAU scenario developed by the Swedish Forest Agency in the latest national forest impact analysis, SKA 22 (Skogsstyrelsen, 2022). The parameters are set to reflect current management of forest owners. The TF simulation utilized the Heureka sub-system RegWise (Heureka RegWise, no date). The UG scenario was implemented and run with the Heureka sub-system PlanWise (Heureka PlanWise, no date). Both sub-systems use the same functions for growth and carbon calculations.

Forest data

The forest belongs to a forest property close to the Tönnersjö municipaly in eastern Halland county (for reasons of data and business integrity, the name and exact location of the estate is not disclosed). The productive forest area is 2,037 ha. It is dominated by spruce (81%), with minor volumes of pine (6%) and deciduous species (13%). The average stocking is 180 m^3ob and the average age is 42 years, with minor areas older than 60 years Figure 1(a). The property is productive with most of the area dominated by spruce of high site index Figure 1(b).

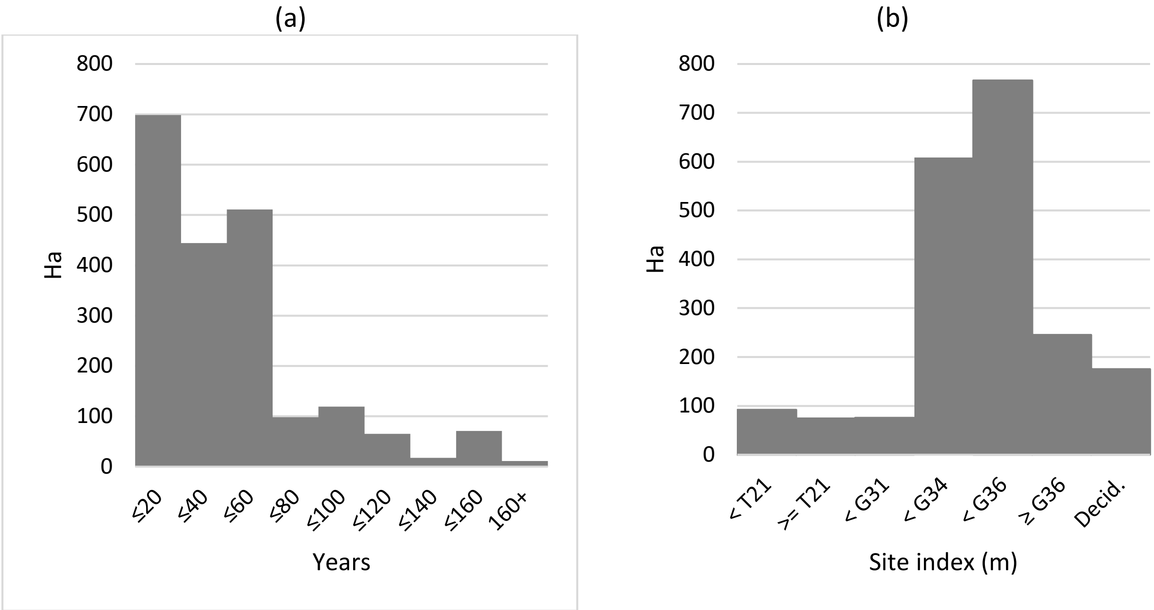


Figure 1. Age class distribution (a) and site index distribution (b).

Data for the simulations was accessed from the ForestMan AI database. Since ForestMan AI data is not wholly compatible with data requirements of Heureka, like vegetation type, they were set to default values in Heureka. ForestMan AI data is stand averages whereas Heureka operates with single tree data (see section Growth models). Heureka transfers stand average data into a diameter distribution based in Weibull functions. There is no guarantee that the calculated distribution coincides with the actual distribution.

Results

In the presentation of results, FMAI is used for ForestMan AI and Ha for Heureka in figures. As before, UG is used for undisturbed growth simulation and TF for today's forest management simulation. Results are presented for the entire forest holding of standing volume and carbon in biomass.

Growth Simulations

The development of the standing volume for the simulations is depicted in Figure 2. The absolute values of the two systems follow each other. The Heureka growth falls behind natural mortality after ca 100 years, meaning that standing volume will start to decrease. This does not occur with FMAI even after 150 years.

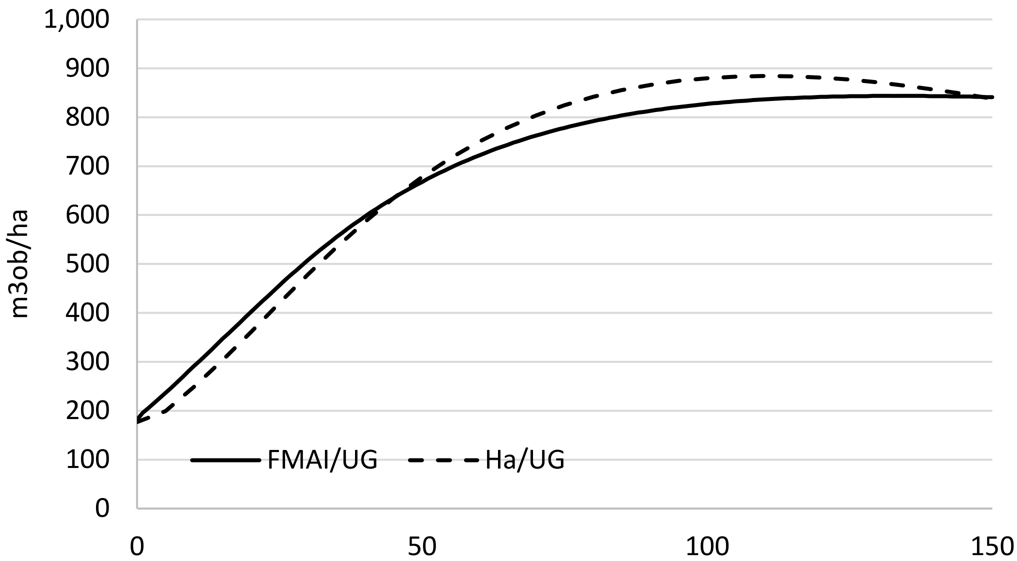


Figure 2. Standing volume under management UG for Forestman (FMAI) and Heureka (Ha)

Under TF management, standing volume should stay at about current value. This management principle is reflected in Figure 3(a). If one takes account of harvests being allocated earlier in time with FMAI than with Heureka, we can observe that the standing volume of the two systems coincides at about 200 m^3ob ha-^{1} over a period of at least 100 years. The harvests (accumulated) that regulate the development of standing volume are almost the same over the first ca 70 year, after which they are slightly higher with Heureka (Figure 3(b)). At the end of the planning horizon, Heureka harvests about 2 m^3ob ha^{-1} y^{-1} more than FMAI, 10.9 compared to 8.9.

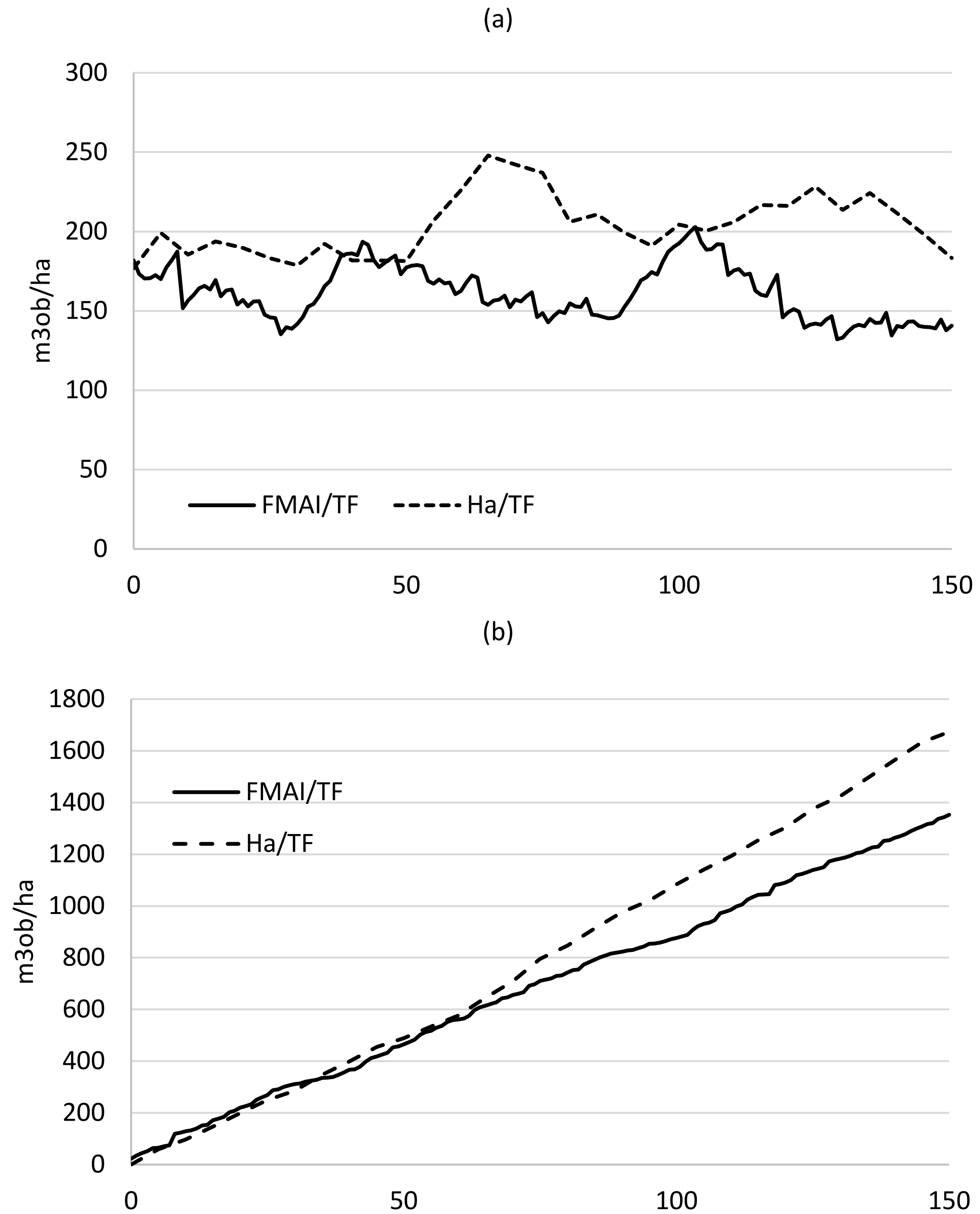
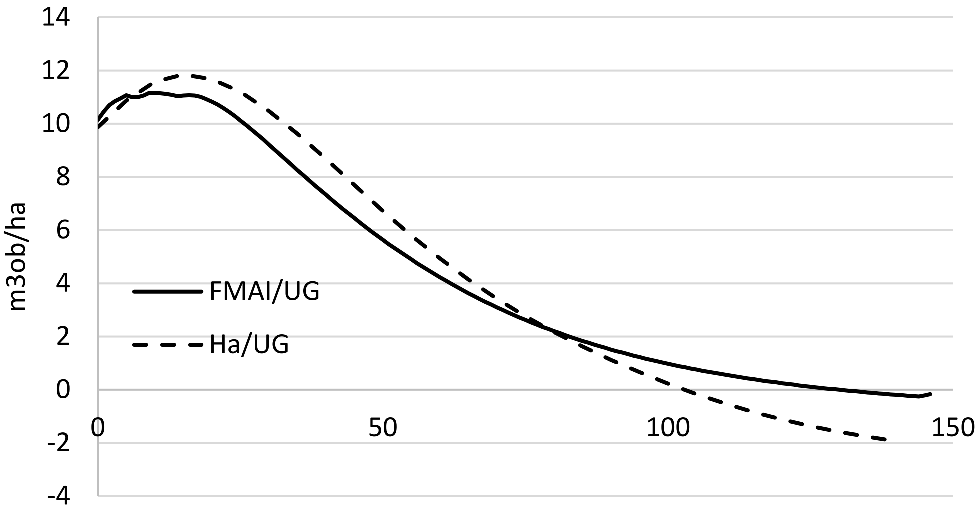


Figure 3. Standing volume (a) and accumulated harvest (b) under management TF for FMAI and Heureka

What is depicted regarding standing volume for GU and TF simulations (for TF, in combination of harvest) is reproduced in graphs showing increment. Under UG, over the first ca 80 years, increment is slightly higher with Heureka, except for the first ca 15 years (Figure 4(a)). A small difference in initial stocking, 182 m3ob ha-1 for FMAI compared to 177 compared to Heureka, in combination with the larger increment during the first years, explain why the stocking level is larger with FAMI for more than 50 years (Figure 2).

Under TF, growth appears larger with Heureka than FMAI. One can note that the larger the difference in stocking level between Heureka and FMAI, the larger the difference in growth (cf. Figure 3(a) with Figure 4(b)).

(a)



(b)

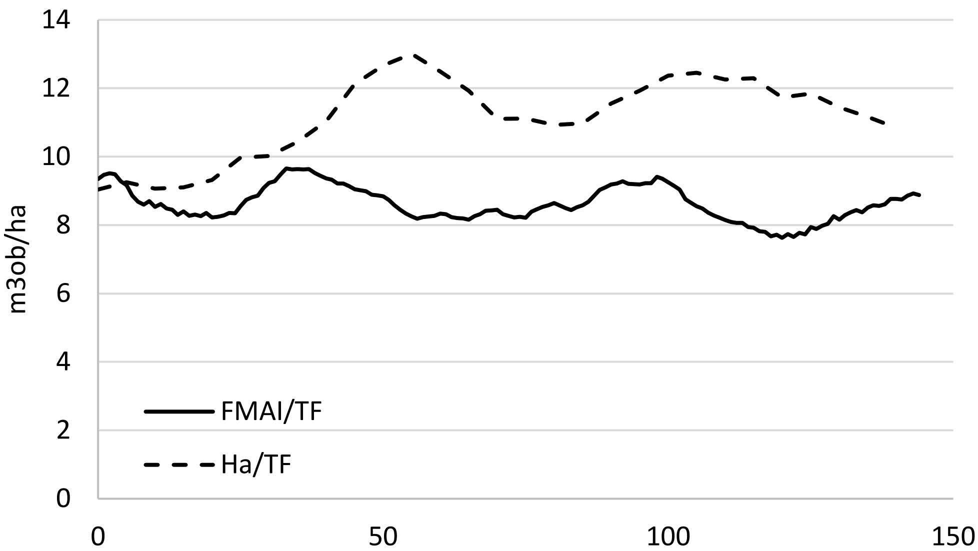
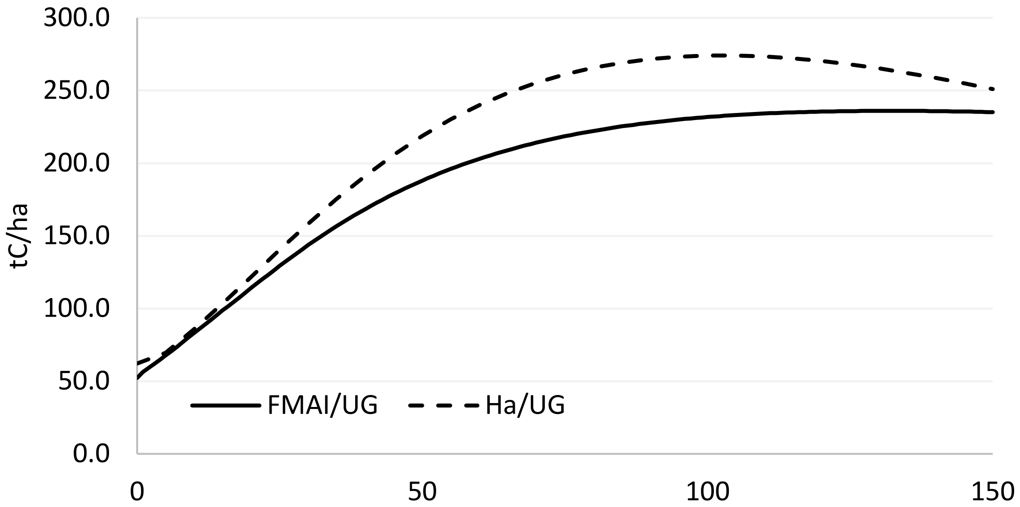


Figure 4. Increment under management UG (a) and TF (b). (To avoid differences due to different formulas, increment is here calculated as I(t) = V(t) – V(t-1)+ H(t-1), where I(t) is increment during the period between t-1 and t, V(t) is standing volume at time t, and H(t) harvest at time t. Heureka calculation is based on 5-year periods and FMAI on running 5-year averages.)

Carbon assessment

Carbon content in biomass follows the trajectories of standing volume under UG as well as under TF (Figure 5(a) and (b)). What is different for carbon compared to standing volume is that the difference between FMAI and Heureka is bigger. This is due to different relationship between a unit of standing volume and a unit of carbon (see Figure 6).

(a)



(b)

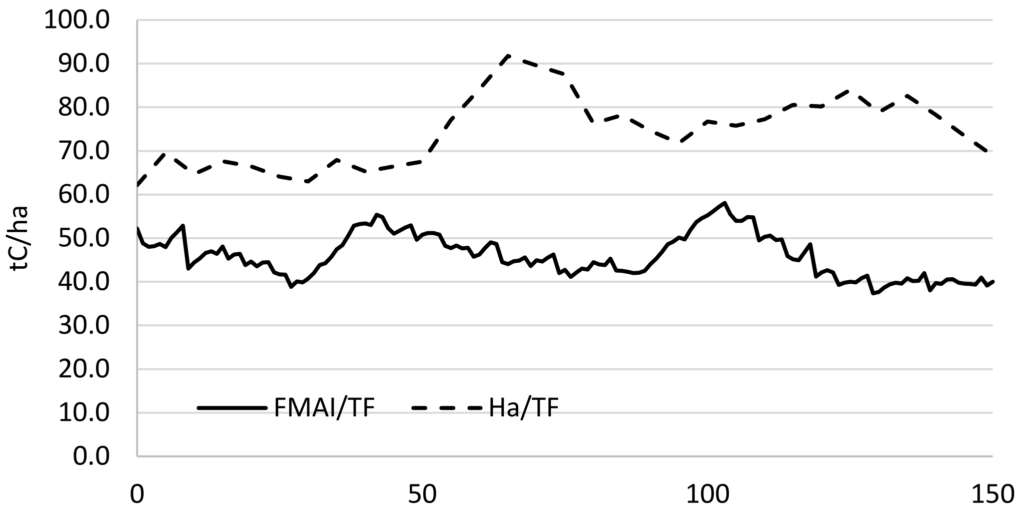
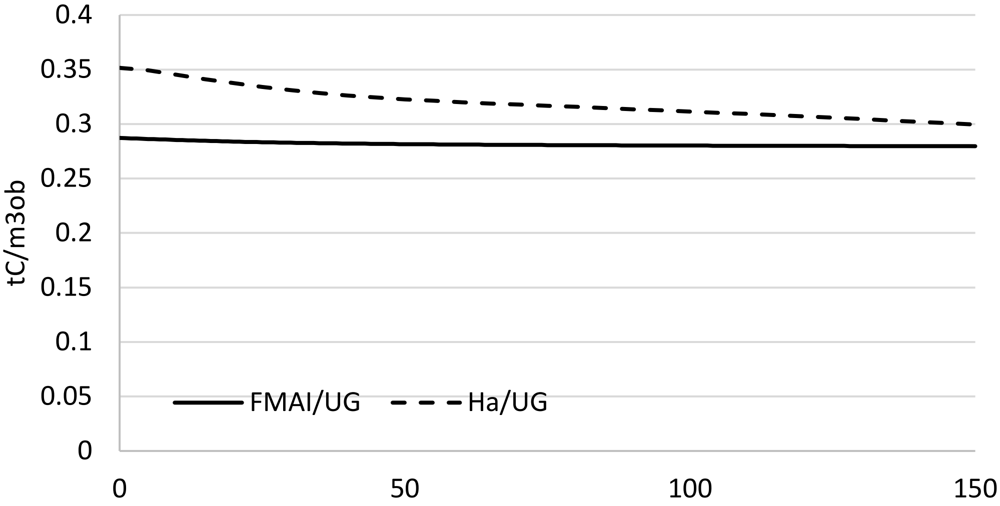


Figure 5. Carbon assessments under management UG (a) and TF (b).

Figure 6 shows that Heureka calculates with a higher grade of carbon per m^3ob than FMAI. One can note that in the case of TF (Figure 6(b)), the quote is constant, whereas it is slightly decreasing with Heureka under UG (Figure 6(a)). Why the quote is reduced with Heureka, if it has to do with a change of average density from changed species composition or has some other cause, has not been investigated; the prolongation of the growth prediction goes beyond what can be supported by empirical data.

(a)



(b)

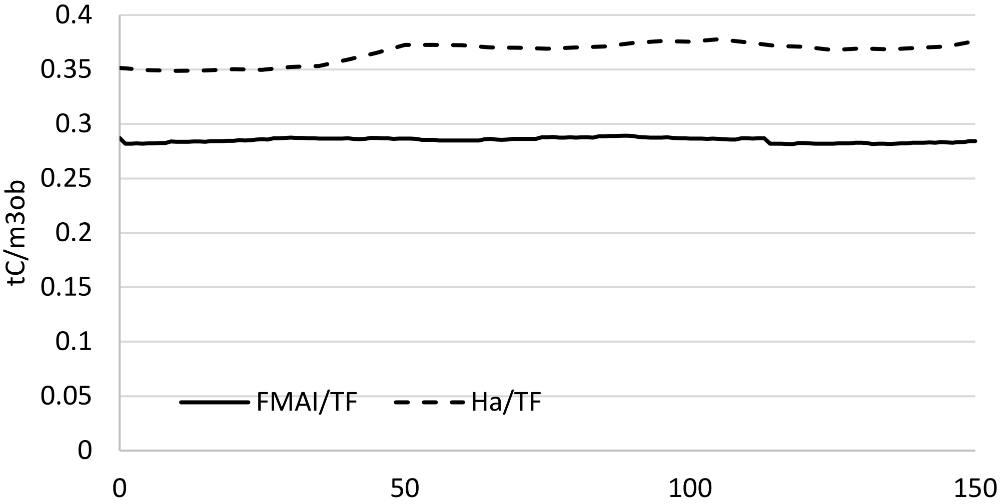


Figure 6. The relation between carbon and standing forest in terms of tC to m^3ob under management UG (a) and TF (b).

Discussion

Analysis of simulations

The discussion will take the growth projection as starting point. Unless growth is reasonably well in in agreement with the Heureka benchmark, the carbon assessment will not be either. Starting with the undisturbed growth simulation (UG), it is possible to conclude that the two simulations agree for the first ca 100 years. The prolongation of the growth further, for an estate with the current age and site index distributions, represents a considerable extrapolation compared to the underlying empirical data basis for the models.

Turning to the today's management (TF) simulation it also shows a high degree of agreement. That net growth does not deviate considerably implies that the regeneration of new forest after final felling has about the same properties.

Given that ProdMod is the basis for growth projections, it should not a come as a surprise that simulations with the same data and the same management system agree. The systems use the same kind of growth models, i.e. empirical growth functions that predict basal area growth, ingrowth and natural mortality regulate the number of stems and basal area, and they have allometric volume calculation. Furthermore, they are both based on analysis of National Forest inventory data, albeit from different years of inventory.

There are still growth deviations of the TF simulation. The growth rate is higher with Heureka than with ForestMan AI. Over certain periods does Heureka hold larger volumes (see Figure 3(a)). This will a cause for growth to be larger for Heureka. Another cause for deviation is the lack of coherence of the set of input data needed for the two systems. It is basically impossible to say whether data gathered specifically for Heureka (single tree data, vegetation type etc.) would make the growth predictions agree more or less than they do in this study. Another possible explanation is the general growth level of the underlying NFI data. The data behind ProdMod is older (NFI plots 1973-1977) than the data for Heureka (NFI plots 1988-1992). This could result in lower growth given the long standing trend of increased growth of Swedish forests.

Regarding the assessment of carbon, there are differences. They refer primarily to the relation between carbon to standing volume. The lower value for ForestMan AI should, to a greater or lesser extent, be a consequence of the minimum diameter for below ground roots, 2.0 cm for ForestMan AI and 0.2 cm for Heureka. The differences could be referred to the values of the expansion factors applied in Eq. 1. The quote is constant throughout the simulation with both systems. Thus, changing one of the expansion factors could in principle make the assessments almost identical. One could also discuss how important the differences are. In real world situations, it is likely that what matters is the difference of carbon content between periods, which makes the absolute level less critical. Another aspect on carbon calculation is that Heureka exhibits more flexibility as to the state of the forest, as indicated by the reduction of the quote of carbon to stem volume overtime for the undisturbed growth simulation (see Figure 6(a)). However, as noted before, when the change of the quote becomes more pronounced (ca 100 years for start of simulation), the state of the forest is beyond the empirical basis of the models.

Would it be advisable, or even necessary, to gain more material for the evaluation? This could involve more estates or it could be based on analyses of different strata of the current estate. However, on may question the cost efficiency of expanding the investigations. Looking for deviations in more detail of the data of the current estate is problematic. Specific forest management actions are not always, and would often not be, simulated in the same stand at the same time. Attaining such synchronization of actions is technically difficult. Thus, it would be difficult to detect “clean” examples of apparent deviations of growth projections. Inspecting more estates, and again looking for similarities and differences over a larger set of stands, can be questioned from fact that the current implementation appears to function reasonably well. Due to the similarity of growth projections of the two systems it's not likely that you would find deviations under other conditions with application of the same management system.

What could be of interest to study further is the implementation of other management systems, like continuous cover forestry. However, the empirical basis for simulating this kind of alternative management systems is limited. This goes for the growth models in ProdMod as well as in Heureka.

One item that would require further study is dead organic matter and soil carbon in case it is included as basis for carbon assessments. It is more difficult to estimate than biomass regarding all parts of the calculation, i.e. initial stock, litter fall, and decay. Among other factors, not covered by this study, are growth adjustment parameters, like breeding effects and climate change impact. Breeding effects from improved plant material is fairly well known. Climate change effects are notoriously difficult to project. This is so not only because climate change as such is uncertain. Even if there was a good assessment of climate change, the effects in terms of different risk factors, such as draught, wild fire and storm, would still be uncertain.

To sum up, there is no indication that the growth projection and the associated carbon stock assessment of ForestMan AI would not be reliable when compared to Heureka calculations. This does not mean that there is a guarantee that they are reliable when compared to what actually may happen. That is, however, nothing that the Heureka system can guarantee either.

Future development

Based on the experiences of this project, the following suggestions are made in pursuit of improved planning of forests for climate mitigation that could support forest owner, investors, and society at large. This is all the more important considering the responsibilities put on financial institutions and forest owners perform CBA following the EU taxonomy (EU, 2020).

It would help stakeholders, and in particular investors, if a licensing system for carbon assessment could be established. A carbon licensed forest planning system would fulfill minimum requirements for reliability covering relevant stand conditions and management systems. Since the Heureka system is, and have the necessary infrastructure to stay, state-of-the-art, an owner of a planning system could bench mark against a given set of archetypical stand types or estates. Furthermore, since the IPCC method embodied in Eq. 1 appears to give satisfactory assessments of biomass carbon, it could represent, with given parameters, the standard for translating stem volume to carbon.

Carbon as a commodity represents an emerging branch of forestry. It highlights and accentuates the need to improve the science-based transparency, integration, and collaboration between the research community and the private sector. Enhancing and streamlining access to research for SMEs and the start-up community would enable advancement and innovation for the many actors of this domain. Major improvements are:

- Availability of different kinds of publications. Several central references are restricted to printed reports and found in the archives of university libraries. Examples of such research, of importance for development and review of models for this study, are (Marklund, 1988) and (Ekö, 1985). Digitizing older research related to forest growth simulations and carbon calculations would facilitate development work of SMEs active in this area. This is relevant also for other sources of research relating to other types of applications (timber, bioenergy, etc.), but still highly relevant in new applications for ecosystem services (carbon, biodiversity, recreation and scenic values etc.).

- Open source code. Adaptation and implementation of research results into practical implementations can be made more effective and rapid by the inclusion of models, equations, algorithms, and source code when publishing research reports. To publish and document code at repositories like GitHub should be made part of good research procedure. An example where open source code could make a difference, if made available, is the Heureka research program. A large part of research belonging to forestry in general is coded for use in the Heureka system. Currently, neither descriptions of the models nor the code are publicly available. Specific to the ForesstMan AI, the source code for ProdMod and ProdMod2, would make further development possible.
- Open source data. Access to relevant forest and climate related data is identified as cumbersome. Larger research programs such as Digital Forest are in practice restricted to larger corporations, universities, and government agencies. Making research data, like silvicultural trials and National Forest Inventory plots, available in repositories destined for this purpose is urgent.

Conclusions

The evaluation of ForestMan AI with the Heureka system output as benchmark shows ForestMan AI to perform growth projections and the associated carbon stock assessments of adequate quality. No major deviations between the output of the systems can be identified.

This fact highlights the need to develop solutions based upon solid scientific-based research as the foundation for any decision support system. The experiences gained in the project of system development and evaluation indicate that much would be gained by making research, whether in the form of publications, code or data, publicly available to the many SMEs driving the advancement of this area.

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