Sustainability of forestry in Romania

Analysis using a dynamic simulation model; a case for public access to information on natural resources

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Abstract

There have been ample studies on the sustainability of Romanian forestry from a qualitative perspective. Quantitative studies on Romania's forests, however, have focused on either static analysis, or historical analysis. There have been no quantitative studies on the sustainability of Romanian forestry from a natural resource management standpoint. This research addresses the question of whether logging levels in Romania are sustainable, using a quantified dynamic simulation model. The results show that current levels of logging would lead to undesirable outcomes in the future, were they to be held at the same level. It also shows that, the levels of logging determined by actual forestry policies would be both sustainable, and lead to forest volume growth: a desirable outcome considering global carbon sequestration goals. The results indicate that early action to bring logging levels down to the level indicated by policies could have a large positive impact over the course of the next few decades. The relation between the model and the underlying data also showcases the importance of open data access on natural resources. Many parts of the model could be improved with open access to data, and inconsistencies in the data can more easily be brought to light. Solving these inconsistencies is important, as smart policies require an adequate understanding of both the actual state of the forests, as well as the rates of change that affect them.

Keywords: sustainability; forestry; Romanian forests; system dynamics; logging policy.

Acronyms

FAO	Food and Agriculture Organization of the United Nations
NFI	National Forest Inventory *(Inventarul Forestier Național)*
INCDS	The „Marin Drăcea" National Institute of Research and Development in Silviculture *(Institutul Național de Cercetare-Dezvoltare în Silvicultură „Marin Drăcea")*
NIS	National Institute of Statistics *(Institutul Național de Statistică)*
NFA	National Forest Administration – Romsilva *(Regia Națională a Pădurilor – Romsilva)*

1. Introduction

The Romanian forestry sector and forest resources are important at both the national and global level along many dimensions. At the national level, the forestry sector provides employment and contributes significantly to the economy (Abrudan et al., 2009; Bouriaud and Marzano, 2014). At the same time, the forests provide essential ecosystem services, and are critical for carbon sequestration for combatting climate change (Government of Romania, 2017b). The Carpathians in Romania are of outstanding importance for nature conservation (Soran et al., 2000; Stăncioiu, Abrudan and Dutca, 2010; Knorn et al., 2012), as Romania still has a lot of old-growth, primary forests that are important for biodiversity (Biriș and Veen, 2005; Knorn et al., 2013; Munteanu et al., 2016; Sabatini et al., 2018; Veen et al., 2010).

Though Romania has been confronting issues of forest management since 1895 (Leahu, 2001), it still faces challenges in the sustainable management of its forest resources. The challenges include the restitution of its forest resources to private owners (Ioras, 2002; Ioras and Abrudan, 2006; Măntescu and Vasile, 2009; Munteanu et al., 2016; Strîmbu, Hickey and Strîmbu, 2005), privatisation of the wood industry sector and changes in market demand of wood products (Ioras and Abrudan, 2006; Nichiforel and Schanz, 2009), the separation of competences across institutions (Abrudan et al. 2009), communication among many different stakeholders (Dragoi, Popa and Blujdea, 2011), the establishment of new institutions (Popa, Niță and Hălălișan, 2019), conflicting land use policies inhibiting afforestation efforts (Stăncioiu, Niță and Lazăr, 2018), illegal logging (Bouriaud, 2005; Knorn et al., 2012) and corruption (Bouriaud and Marzano, 2014).

The proper management of Romania's natural forest resources is therefore critical in order to ensure that the forests can sustainably fulfil their roles in climate and ecosystem regulation, biodiversity conservation, as well as continue contributing to human welfare. The National Forest Policy and Strategy, developed in 2000, and revised in 2005, stated the express policy of ensuring forest management according to the principles of sustainable management of natural resources (Abrudan et al. 2009). The current National Forest Strategy 2018-2027 (Romanian Government, 2017b) states that the overall vision is to have a "forestry industry [that] contributes to the well-being of people in an economically, socially and environmentally sustainable manner". Furthermore, the general objective of the current strategy is "the harmonization of the forest's functions with the present and future demands of Romanian society through the sustainable management of national forestry resources".

Though the legal provisions for sustainable forestry are set in place, there are indications that the application of these provisions have been far from adequate, both from the scientific community (Buliga and Nichiforel, 2019; Iojă et al., 2010; Knorn et al., 2013; Knorn et al., 2012) and from NGO's and investigative journalists (Agent Green 2018a, 2018b; Cernuta, 2019; Greenpeace 2012a; Greenpeace 2012b). The official values for the overall level of harvesting are themselves being questioned.

One of the most important tools for the sustainable management of Romania's forest resources is the National Forest Inventory – NFI (NFI, 2012b, 2019), for which two cycles have been completed so far (NFI 2012a, 2018). The NFI is the main data provider for reporting on indicators of sustainable forest management, under the umbrella of INCDS. Without it, management decisions at the national level would have no basis. Cernuta (2019), however, has pointed out some irregularities in the data, from which one of the conclusions that could be drawn is that the volume of wood available has been undervalued during the first cycle so that more could be harvested between the first and second cycles, while giving the appearance of sustainable logging levels. This seems all the more dangerous, since a yearly report on the state of Romania's forests (Romanian Government, 2015) claims the following (paraphrasing):

According to the National Institute of Statistics (NIS) the average volume of wood harvested yearly, legally, during the period 2008-2014, was 17.9 million cubic meters, while IFN measurements show that the volume of wood harvested yearly at the national level during this period was closer to 26.69 million cubic meters.

While studies on Romania's forestry sector have highlighted obstacles to sustainable forest management, no study so far has attempted to perform a national-level quantified analysis of the sustainability of logging levels. Given that government reports, NGO's, and investigative journalists all claim higher than allowed levels of logging, the present research aims to address the following question: *Are current levels of logging in Romania sustainable?* The question will be addressed from a natural resource management perspective, using a quantified dynamic simulation model.

2. Methodology and data

2.1 Methodology

Due to a number of factors, such as detail complexity and the dynamic behaviour in the observed system (e.g. changes in yield, age composition, logging levels), a causal dynamic simulation model is ideally suited for achieving the aim of gaining a holistic understanding over the problem (Sterman, 1988). Furthermore, causal dynamic simulation models are ideal laboratories for exploring the future impacts of current practices and to test different policies (Axelrod, 1997). The importance of using simulation modelling for sustainable forest management in particular is also well established (Peng, 2000; Pretzch, 2010; Shanin, Komarov and Bykhovets, 2012).

A stock and flow model based on the system dynamics methodology has been used for this research (de Gooyert, 2018; Forrester, 1968; Repenning, 2003; Richardson and Pugh, 1981; Sterman, 2000). Stock and flow models have been used to study a wide range of environmental/natural resource problems (Cavana and Ford, 2004; Ford, 2010), and they have been applied to the forestry sector as well (Dudley, 2004a; Dudley, 2004b; Jones, Seville and Meadows, 2002).

The boundaries of the system will be deemed to be sufficiently encompassing when the model will sufficiently reproduce the reference mode of behaviour (Barlas, 1996; Richardon and Pugh, 1981), implying an iterative model-building process. In our case, **the reference mode of behaviour is the timber yield of Romania's forests**.

A literature review has been conducted in order to determine the conceptual relationship between the system elements within a system dynamics framework (Forrester, 1968; Richardson and Pugh, 1981; Sterman, 2000). Supplementary interviews have been conducted with industry specialists in order to fill in the gaps in understanding from literature with real experience (Bryman and Bell, 2011; Forrester, 1992). Since there are qualitative data involved as well, a rigorous verification and reporting process must be applied to both the structure of the model, and the emerging behaviour (Barlas, 1996; Homer, 2012; Rahmandad and Sterman, 2012; Sterman, 1984, 2000).

2.2. Data

Secondary quantitative and qualitative data has been used for the creation of the model structure and for the representation of the historical behaviour. As mentioned before, the reference mode in question is the timber yield of Romanian forests. However, there is no single data series available to represent this value. Yield is estimated at the level of forest districts when their 10-year forest management plans are created. The silvicultural systems employed, as well as the maximum logging levels are also determined at the district level. For the purposes of this research, the aggregation of yield and logging values of each district would be desirable.

Data at this level of disaggregation, however, is not freely available. Furthermore, not all forests have forest management plans, while the implementation of the existing plans most often do not meet many technical and legal requirements (Buliga and Nichiforel, 2019). The values presented also do not account for illegal logging, organized excessive logging, or for errors in estimation by forestry officials: Bouriaud and Marzano (2014) point out that officials consistently underestimate both the quantity and the quality of the wood that is to be sold at auctions.[1]

Due to these obstacles, I have chosen to instead reconstruct the timber yield of Romania's forests from other data available at the national level, namely: forested areas, volume of standing wood, age composition of forests by area and volume, logging levels and growth estimates by age group. These data have been taken from FAO (2005, 2010, 2015), NFI (2012a, 2018), NIS (2019) and the Romanian Government (2006, 2007, 2008, 2009, 2010, 2011, 2012b, 2013, 2014, 2015, 2016, 2017a, 2018).

One measure of the confidence we may have in a model is the degree to which it is able to reproduce historical data (i.e. the reference mode) (Richardson and Pugh, 1981; Sterman, 2000). **While data on timber yield[2] is not publicly available, other historical data is available with which timber yield may be partially reconstructed.** We will therefore focus on a set of 32 reference modes composed of the other variables used:

[1] The reason given for the consistent underestimation by an interviewee during this research is that the officials often choose the lower bound of their estimation in order to avoid any complaints.

[2] Yield is defined as net growth of forests, not including logging.

1. Forest area by age group
2. Density of forests by age group
3. Volume of wood by age group – product of the first two
4. Overall wood growth
5. Overall wood loss

The starting year for the model is 2012. Though the reproduction of a reference mode over a longer time horizon would provide more confidence in the results of the model, this implies that the reference mode itself should reflect reality. There are four reasons why the starting year 2012 was selected:

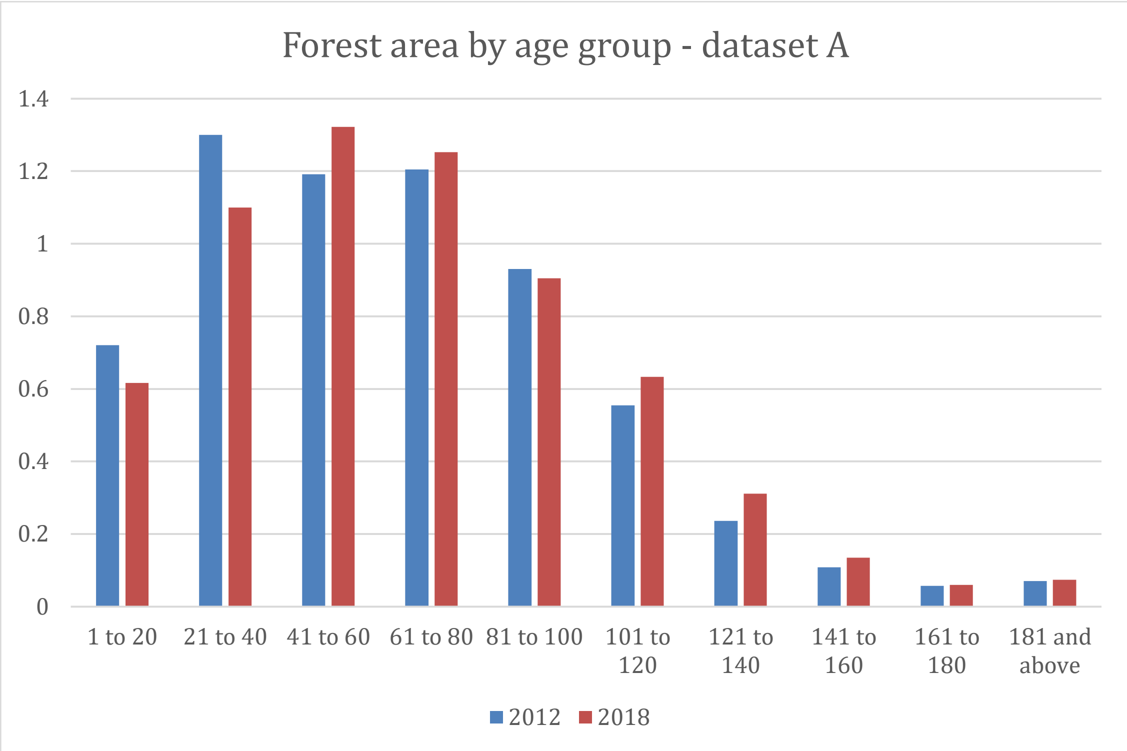
1. Before the first NFI cycle from 2012, the last forest inventory was completed in 1984 (NFI, 2019; Romanian Government, 2012a). The methodology with which that inventory was achieved is out-dated, and therefore it is difficult to compare the results of that inventory with the results from NFI.
2. The data available before 2012 is more aggregated, the last age population group specified being ‚age group 101 and above' instead of ‚age group 181 and above'. Extrapolating the data over an almost thirty year period is bound to produce errors, since there are too many unknowns, such as the age groups where harvest cuttings have occured in the past. Another challenge with extrapolation is having to account for shifts between age groups.
3. A number of drastic changes have occurred in the forestry sector over the last three decades. Since in its current stage the model is limited in its scope, it cannot represent the structural changes that have occurred in the forestry sector. It is therefore more accurate to start in 2012, where most of the changes have already taken place.
4. The ontology of forests within the model includes not only the area and the age, but also the volume of wood. This data is not publicly available before 2012, except for the aggregated value of 'total volume of wood'.

More precise results can therefore be achieved by relying only on the most recent data, since it is of higher quality, and fewer assumptions have to be made. Though the 2012 cycle of NFI (NFI, 2012a) would provide only one data point, the recently released 2018 cycle of NFI (NFI, 2018) provides the second data point necessary for the reference mode to be drawn for the period 2012-2018.

When analysing forest age distribution, irreconcilable differences were observed between the data from yearly governmental reports on the one hand, and the data from NFI on the other.[3] Two separate datasets have therefore been developed:

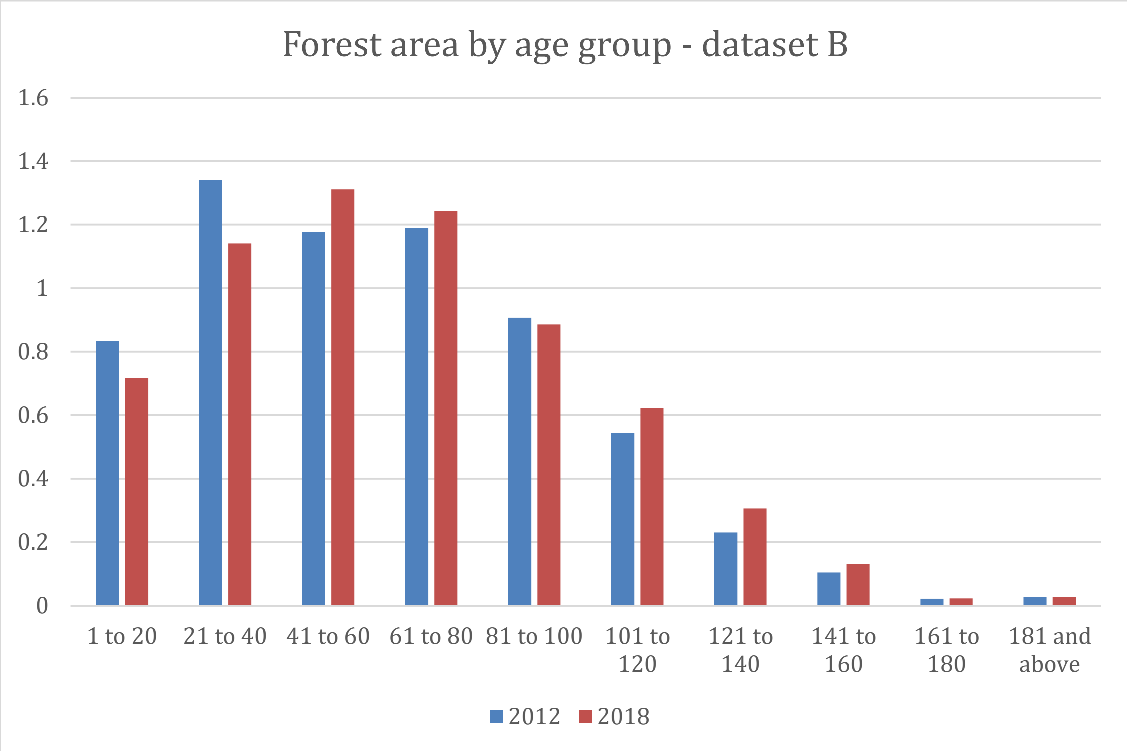
- Dataset A relies primarily on data from the National Forest Inventory, but relies on yearly governmental reports for forest age distribution data.
- Dataset B relies only on data from the National Forest Inventory.

Two distinct sets of reference modes are thus obtained from the two datasets.[4]

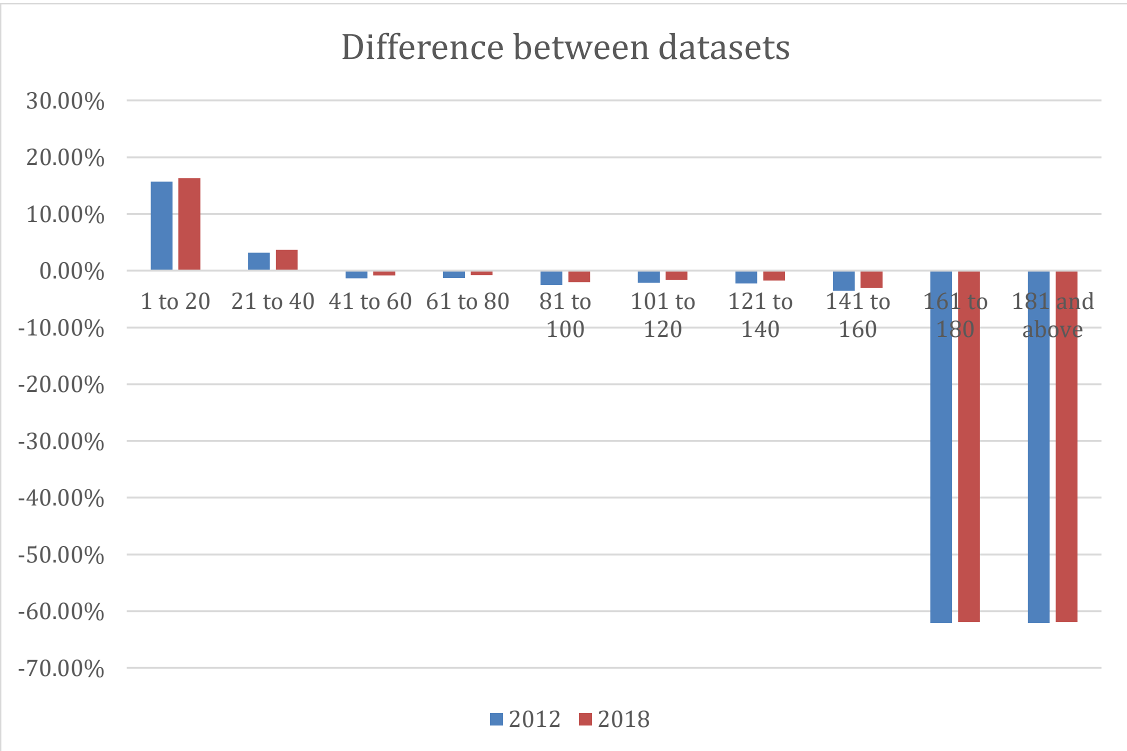


Graph 1 –Forest area by age group – A. Units in million hectares.

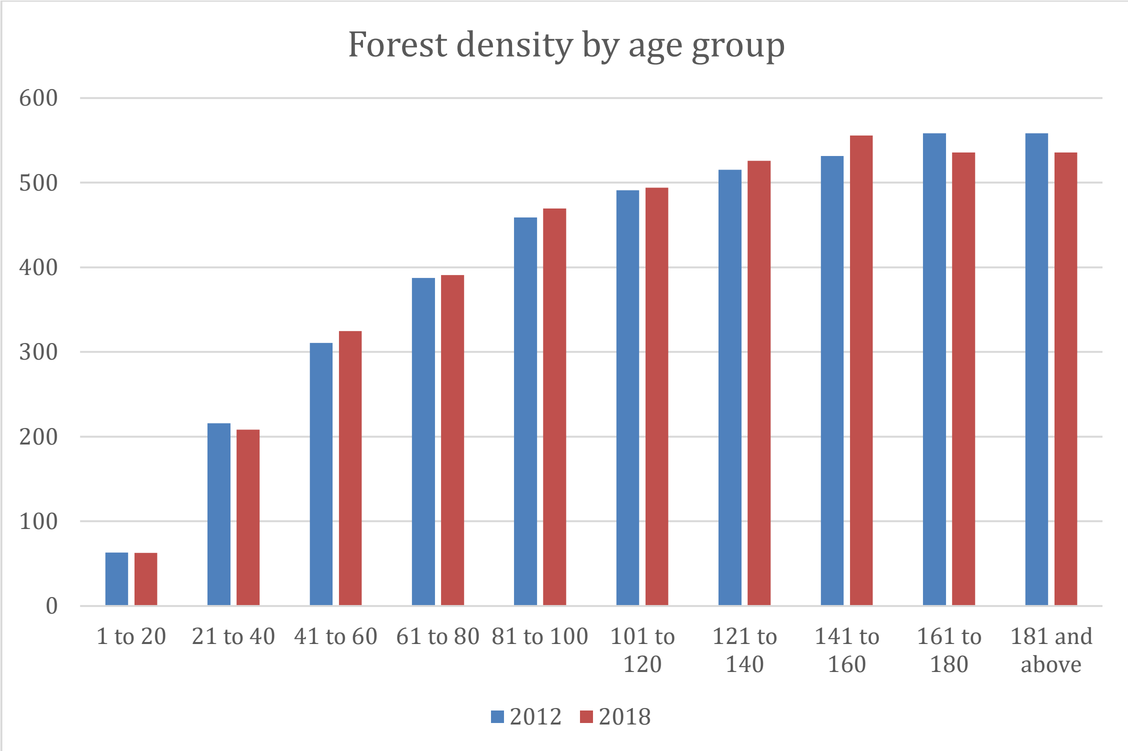
[3] Neither the Ministry of Environment, nor NFI has responded to queries about these inconsistencies.
[4] Details on how the two sets of reference modes were obtained can be found in Appendix B and C.



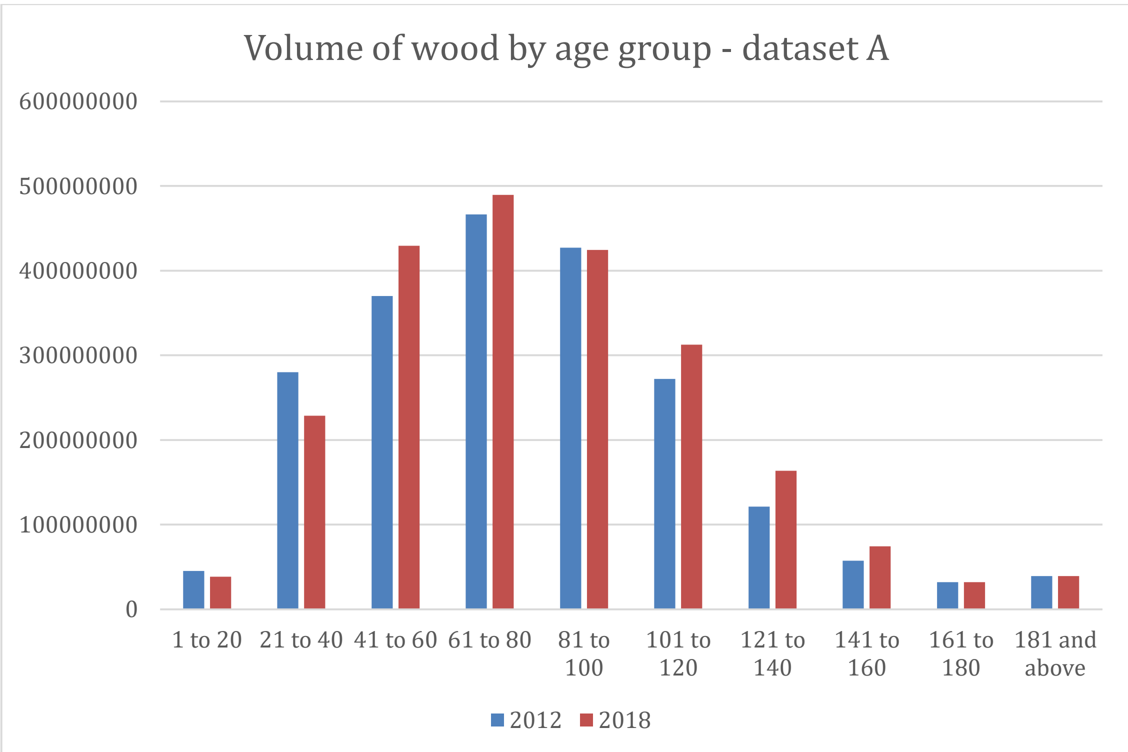
Graph 2 – Forest area by age group - B. Units in million hectares.



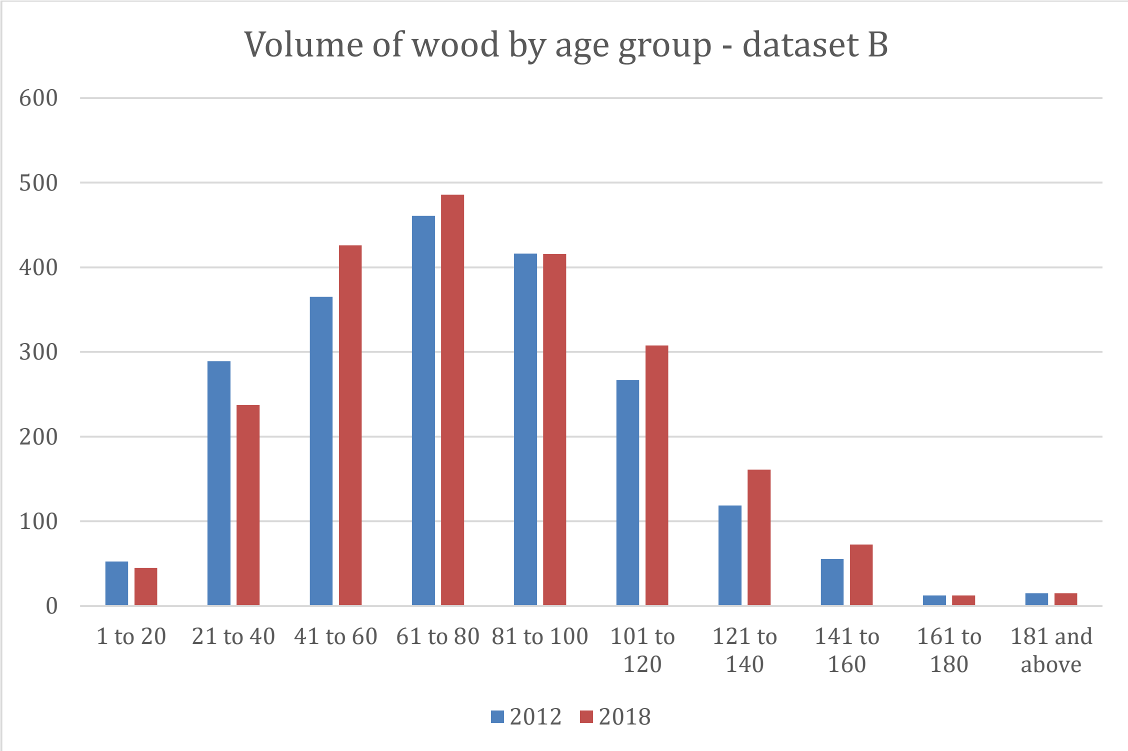
Graph 3 – Comparison of forest area by age group dataset B to dataset A.



Graph 4 – Forest density. Units in m³/hectares.



Graph 5 – Volume of wood – A. Units in million cubic meters.



Graph 6 – Volume of wood – B. Units in million cubic meters.

Carcea and Dissescu (2014), FAO (2012) and Schuck *et al.* (2002) have been consulted for the correct understanding and translation of the terminology across Romanian and English.

3. Model structure

The ontology of forests in the model is limited by the data publicly available. In this case, it contains the area, the age and the density of the forests.

3.1. Area

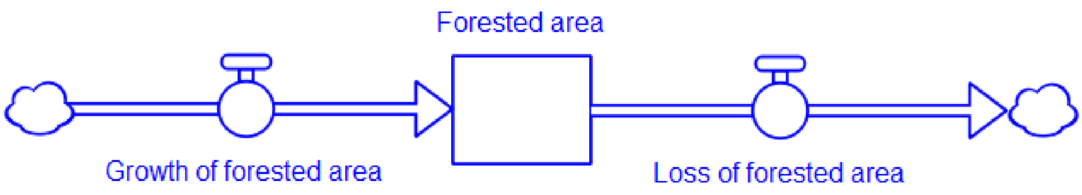


Figure 1 – Forested area.

The entire area of forest may be represented as a stock (see above). Growth of forested areas leads to an increase of the value of the stock, while loss of forested areas leads to a decrease of the value of the stock. Increase may be due to afforestation, reforestation, or natural forestland growth through the spreading of seeds (Grebner, Bettinger and Siri, 2013). Loss, on the other hand, may be due to deforestation, natural disasters, or natural shifts in forest life cycles ((Grebner, Bettinger and Siri, 2013).

Mathematically, we could describe this simple system as:

$$F_{a_t} = \int_{t_0}^{t} (G_a - L_a)dt + F_{a_0}$$

Equation 1

Where F_{a_t} is 'forested area at time t', G_a is the 'rate of growth of forested area', L_a is the 'rate of loss of forested area' and F_{a_0} is the 'forested area at time 0'. The model computes the above equation as an Euler integration, and all further equations will be documented in this manner (Richardson and Pugh, 1981, Sterman, 2000):

$$F_{a_t} = F_{a_{t-1}} + dt(G_{a_{t-1}} - L_{a_{t-1}})$$

Equation 2

Where dt is now a computational 'timestep', and $F_{a_{t-1}}$ is the 'forested area one timestep before time t', $G_{a_{t-1}}$ is the 'rate of growth of forested area one timestep before time t', and $L_{a_{t-1}}$ is the 'rate of loss of forested area one timestep before time t'. The timestep used in the model is 1/8, meaning that there are eight calculations performed for every year of the simulation run.

3.2. Age

In order to include the age of the forest in its ontology, the system from figure 1 must be extended to become an aging chain (Sterman, 2000). As can be seen in figure 2 below, the stock of forested area has been disaggregated into ten stocks. The first nine stocks describe age groups of twenty, while the last stock in the aging chain describes all forests above the age of 180.

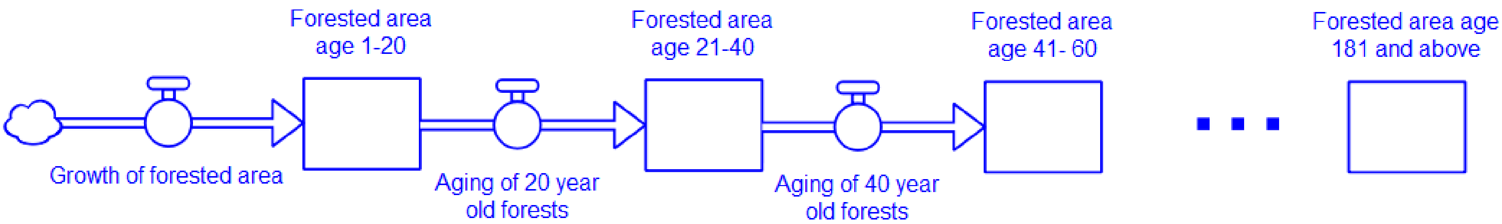


Figure 2 – Forested area by age group – homogenous stocks.

One error in this representation is that stocks represent homogenous groups, meaning that any individual hectare is equally likely to leave the stock at any given time. For our purposes, however, we need to differentiate the oldest forests from each given stock. One possible workaround is to have a separate stock for every year, though this would result conveyor[5]. As can be seen in the visual representation of the stocks below (figure 3), they are no longer homogenous, but are divided into 'slats'. As a unit of forest enters a stock, it then moves from one slat to the next, taking exactly '20 years' to emerge from the other side. An exception is the final stock, which does not require heterogeneous representation, as it is the final stock in the aging chain.

[5] See the following link for the documentation on conveyors: https://www.iseesystems.com/resources/help/v1-8/Default.htm#08-Reference/05-Computational_Details/Conveyors.htm?Highlight=conveyor

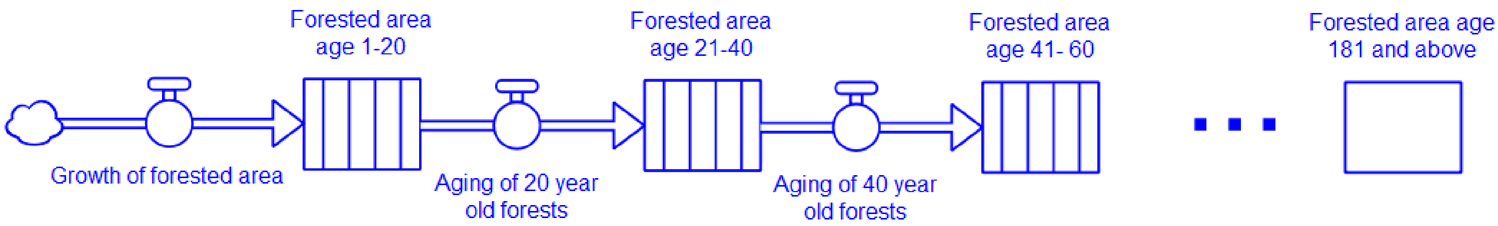


Figure 3 – Forested area by age group – conveyor stocks.

Equation 2 still applies in this case, but the meaning of the variables differ slightly: F_a can represent any given stock in the chain, for instance 'forested area age 21-40'. In this case, G_a represents 'aging of 20 year old forests' and L_a represents 'aging of 40 year old forests'. The loss of area from one stock (L_a) becomes the growth for the next stock (G_a). The rates of change, or flows, may be described in the following manner:

$$L_{a_t} = F_{a_{t-1}}[1]$$

Equation 3

Where L_{a_t} is the 'loss of forested area at time t' and $F_{a_{t-1}}[1]$ is the 'stock of forested area one timestep before time t residing in the first slat'. The number of slats equals the 'transit time' divided by the timestep. In our case, the transit time is the size of the age group, 20, and the timestep is 1/8, meaning that each conveyor contains 160 slats. Whatever forested area resides in a stock at time t will therefore pass on to the next stock within 160 timesteps.

3.3. Volume and density

By expanding the ontology of the forests to include volume of wood as well, we can track the evolution of growth and include logging into the model as well. This is achieved through the implementation of a coflow (Sterman, 2000). As the forest area ages, the volume of wood belonging to that area flows through an aging chain of its own. The aging of the volume of wood is defined through the aging of the area itself. The initial volume of wood in each stock is calculated based on forest density data per age group from NFI (2012a). The quantity of wood that is carried from one stock to the next is defined both through the average density of the specific forest age group, as well as the initial density of the oldest trees from that age group.

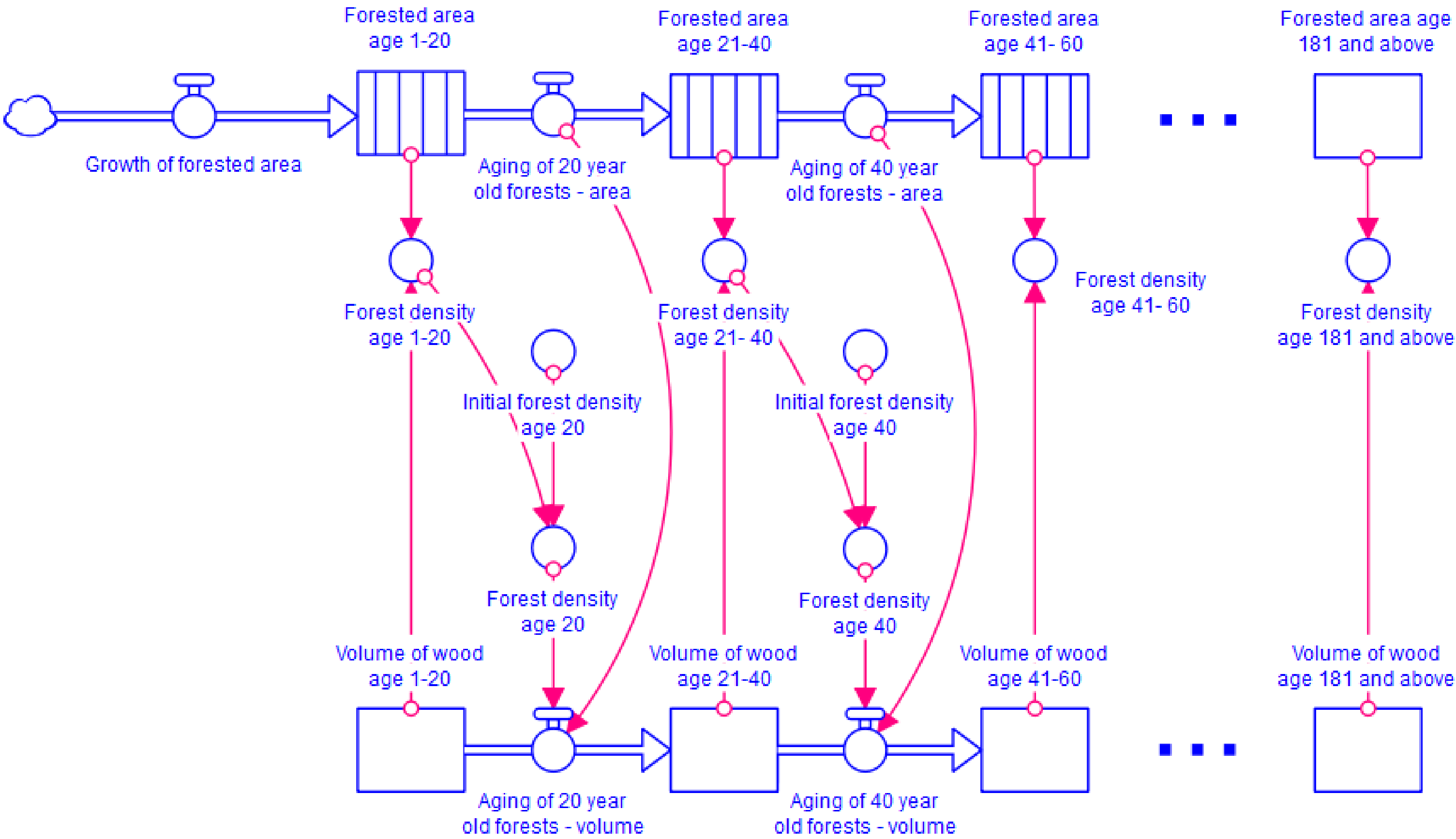
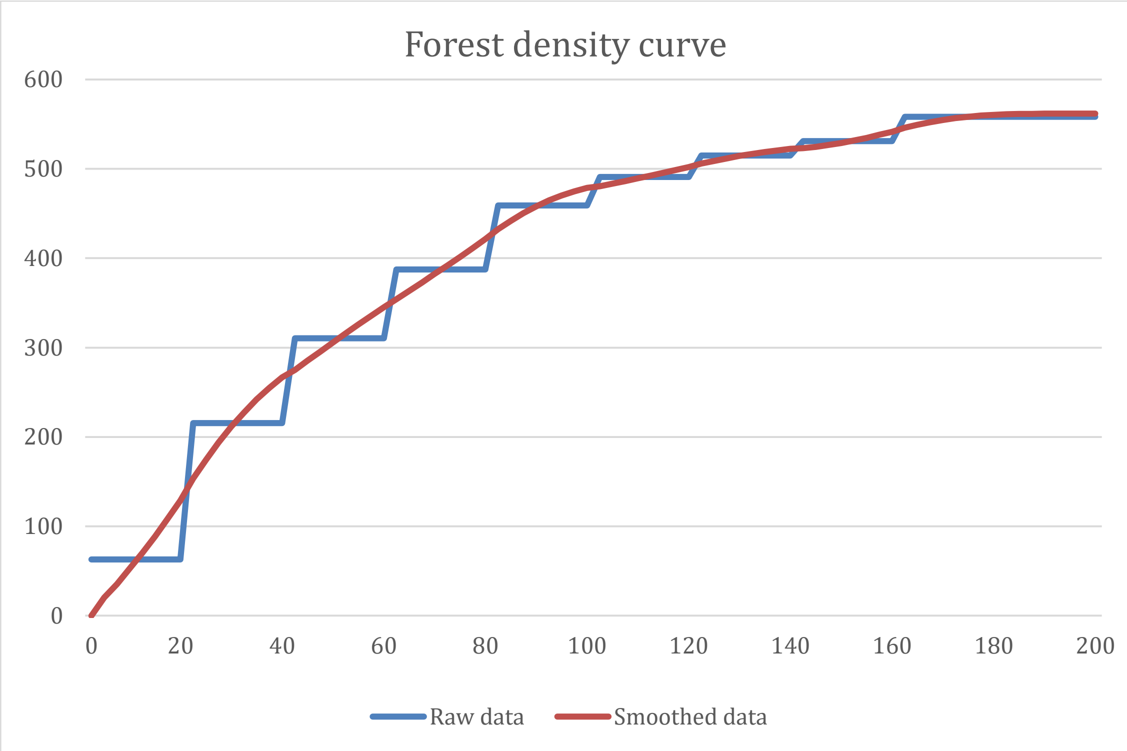


Figure 4 – Volume and density.

$$F_{v_t} = F_{v_{t-1}} + dt\left(G_{v_{t-1}} - L_{v_{t-1}}\right)$$
$$L_{v_t} = F_{do_t} * L_{a_t}$$
$$F_{do_t} = F_{do_0} * F_{da_t}$$
$$F_{da_t} = \frac{F_{v_t}}{F_{a_t}}$$

Equation 4

Where F_{v_t} is the ‘volume of wood at time t’, $G_{v_{t-1}}$ is the ‘aging of wood from the previous stock one timestep before time t, $L_{v_{t-1}}$ is the ‘aging of wood from current stock one timestep before time t, F_{do_t} is the ‘forest density of oldest trees from current stock at time t’, F_{do_0} is the ‘initial forest density of oldest trees from current stock’, and F_{da_t} is the ‘average forest density of the current stock at time t’. The L_v of one stock becomes the G_v for the next stock. As can be seen from the equations, the density of the oldest trees changes proportionally to the density of the entire age group. The initial density is taken from the NFI (2012a), and can be seen in the graph 5 below (smoothed data is used):



Graph 7 – Forest density. Units in m^3/ha.

3.4. Growth

The volume of wood from each stock in its aging chain changes not only due to the shift in age distribution of the forest area, but also due to the growth of the forests within each stock as well. The inclusion of growth results in the system seen in figure 5 below:

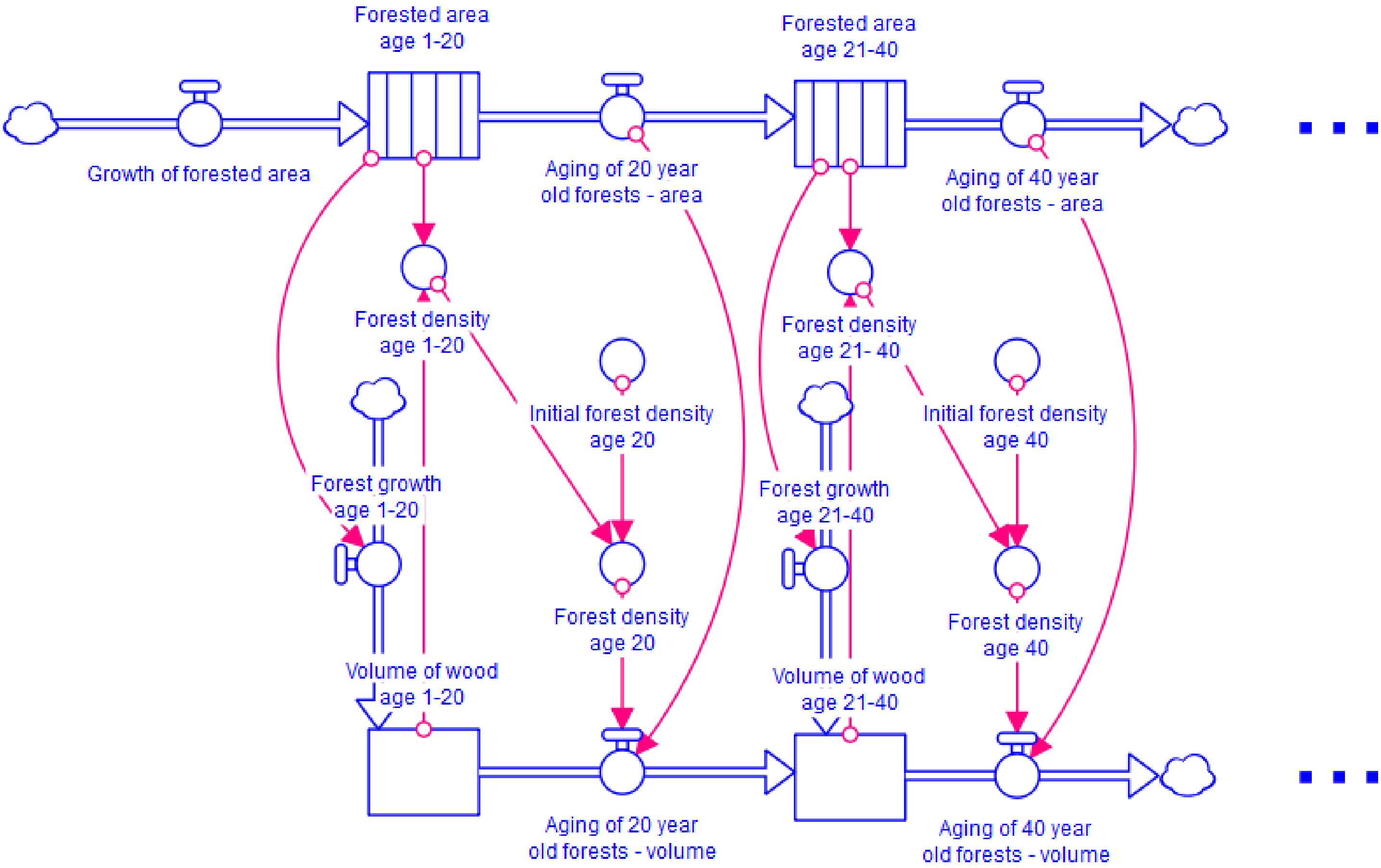


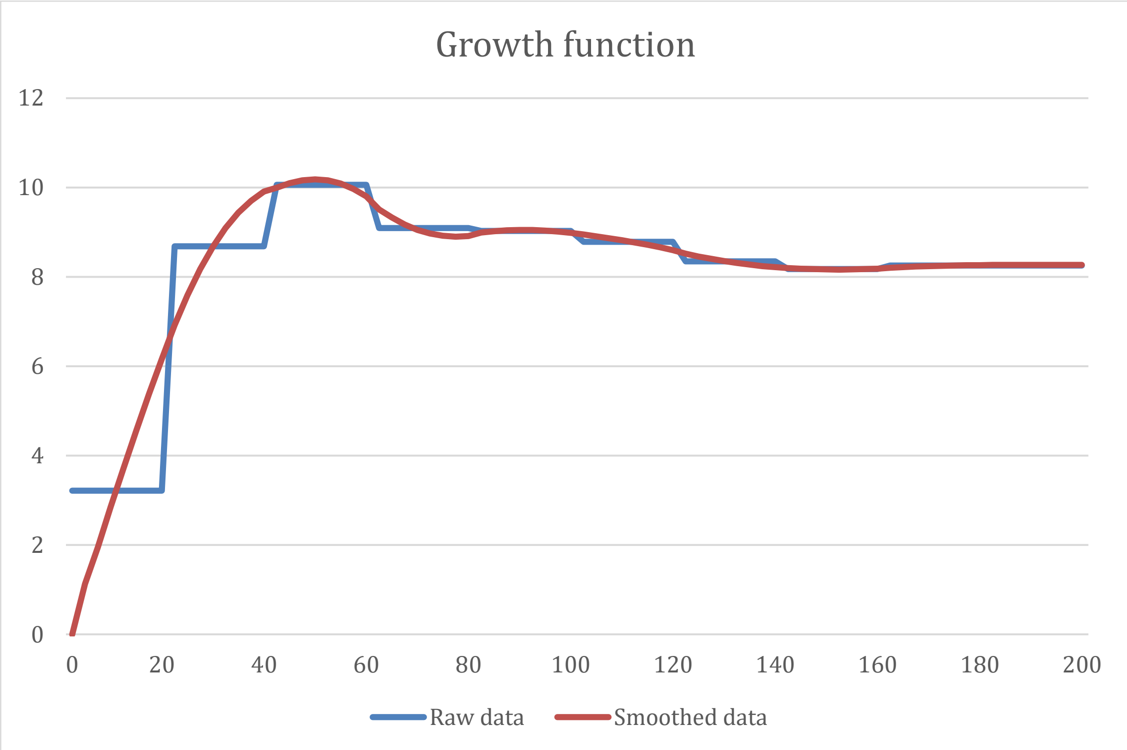
Figure 5 – Growth.

The equation for the stock of volume of wood now changes to include forest growth as well. Additionally, the forest growth is defined by a nonlinear growth function, estimated based on national-level forest growth data from NFI (2018).

$$F_{v_t} = F_{v_{t-1}} + dt\left(F_{g_{t-1}} + G_{v_{t-1}} - L_{v_{t-1}}\right)$$
$$G_{f_t} = f(F_{a_t})$$

Equation 5

Where $F_{g_{t-1}}$ is 'forest growth one timestep before time t' and $f(F_{a_t})$ is the 'growth function of the forested area at time t'. A graphical form of the function can be seen in graph 6 below.



Graph 8 – Growth function. Units in m^3/ha/year.

3.5. Extraction and regeneration

The structure is finalized with the addition of extraction[6] and regeneration. Depending on the silvicultural system employed, the extraction of the wood from the forest may lead to a reclassification of the forest area in question to the age group 1-20[7]. Forest regeneration is therefore defined in the model a new growth cycle on an area where extraction has occurred. All other forest area growth, be it due to afforestation or the natural spread of forests, is contained as an exogenous variable in 'Growth of forested area'[8].

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[6] Extraction contains not only loss of wood through logging, but also through natural means, be they windfalls, pests or old age. Due to this simplification, the final age group along the aging chain, namely forests aged 181 and above, cannot grow above a threshhold density derived from the forest density data from NFI, 2012a. This is in order to avoid situations where the density of the forest grows to infinity under conditions of low logging levels..

[7] The base value in the model for the fraction of

[8] For 2012-2018 historical data has been used. Beyond 2018, the assumption is that the forest area will continue growing with the average growth rate since 1990.

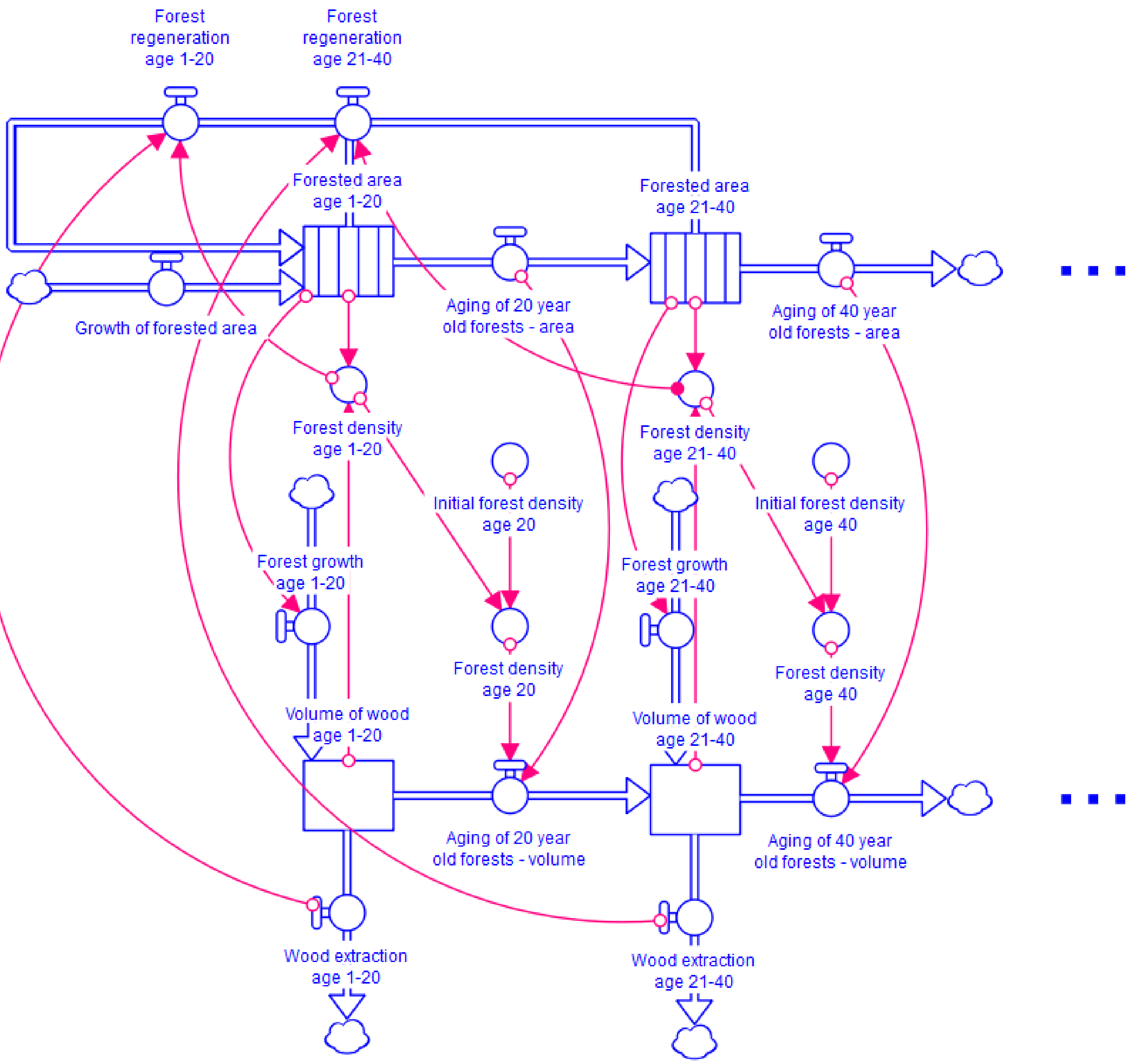


Figure 6 – Extraction and regeneration.

The final equations for the stocks of forested areas and volumes and wood are:

$$F_{v_t} = F_{v_{t-1}} + dt\left(F_{g_{t-1}} - F_{e_{t-1}} + G_{v_{t-1}} - L_{v_{t-1}}\right)$$
$$F_{a_t} = F_{a_{t-1}} + dt\left(G_{a_{t-1}} - L_{a_{t-1}} - F_{r_{t-1}}\right)$$
$$F_{r_t} = F_{e_t} * F_{da_t}$$

Equation 6

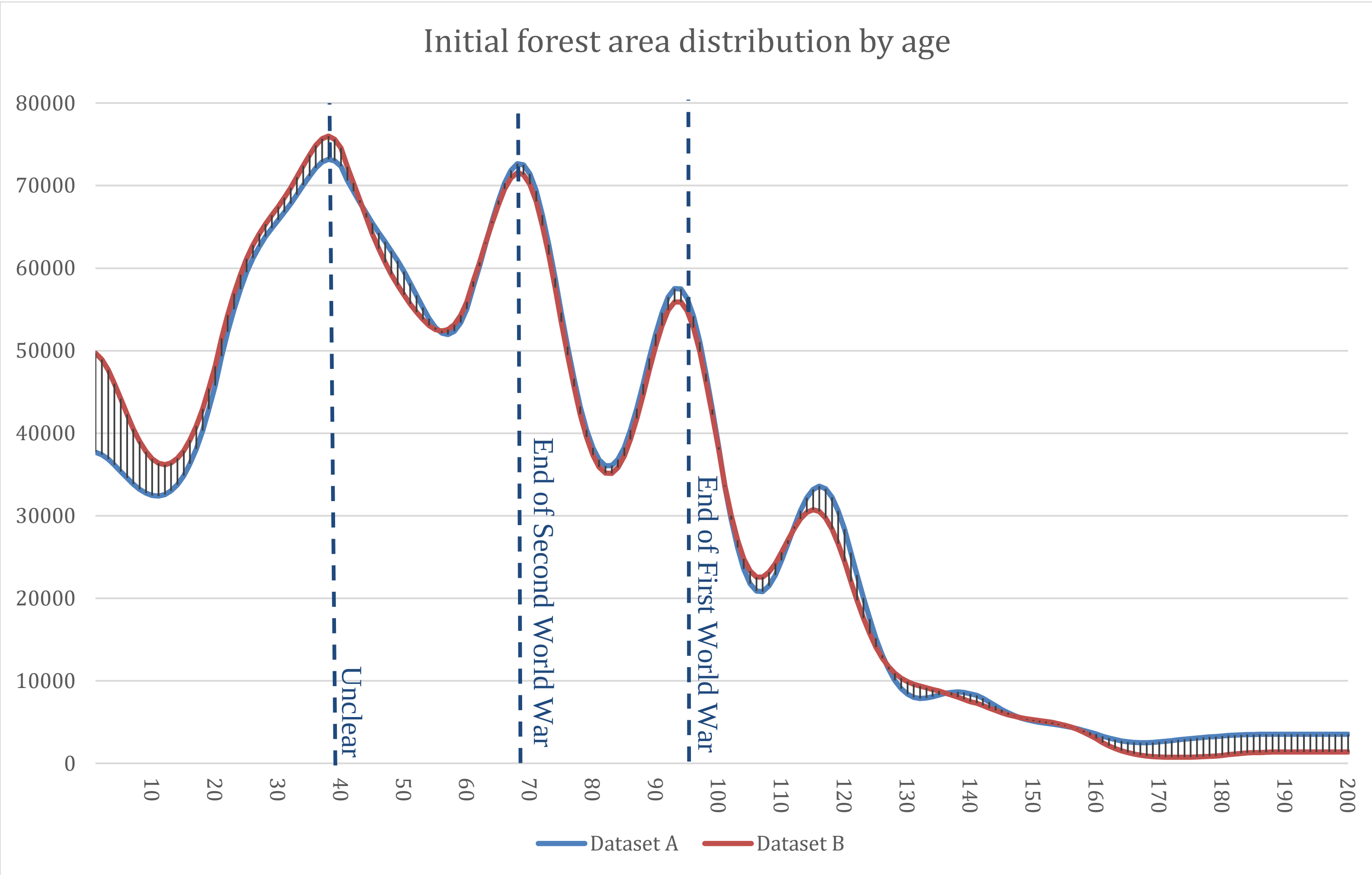
Where $F_{e_{t-1}}$ is the ‘wood extraction one timestep before time t’, and $F_{r_{t-1}}$ is ‘regeneration of forested area one timestep before time t’. Exceptions to these equations are the first and last stocks in the aging chain for forested areas. The sum of F_r from all stocks is added as an additional inflow to the first stock[9]. Meanwhile, the last stock does not feature L_a.

The only policy introduced to the model is to extract wood from older forests when it is not available in younger forests. Thus, for any amount of wood not available for extraction from forests aged 1-100, the amount is spread out evenly across forests aged 101 and above. For any amount of wood not available for extraction from forests aged 101-140, the amount is spread out evenly across forests aged 141 and above. And for any amount of wood not available for extraction from forests aged 141-180, it is to be extracted from forests aged 181 and above.

[9] Though it may seem redundant at first to have F_r as both an outflow from and an inflow to the stock 'Forested area age 1-20', inflows and outflows are treated differently in the case of conveyors. The inflow is always added to the very last slate (newest element) in the conveyor, while the outflow is calculated as a percentage leak across all slates.

4. Model results and analysis

4.1. Reproducing historical data for 2012-2018



Graph 9 – 2012 forest age distribution indicated by model. Units in hectares on y axis, and years on x axis.

The original data on the age distribution of forest areas in 2012 from Graph 1 and Graph 2 has been first smoothed, and then weighted in such a way as to reproduce as closely as possible the age distributions in 2018. The resulting age distributions can be seen above. The overall shapes remain the same, and the absolute values diverge mostly at the two ends of the spectrum, as was also indicated in Graph 3. There are three substantial peaks in the curve which have been highlighted. Two of these can be explained by the land-use changes brought upon by the First and Second World Wars (Munteanu et al., 2016). The cause for the peak of 40-year-old forests is, however, unclear. Munteanu *et al.* (2016) point out that harvesting occurred over much larger territories during the 60's than during the 90's, and the silvicultural systems employed at the time could also have contributed to a large spike in forest regeneration during the 70's. This explanation is not entirely satisfactory, however, since historical data indicates that harvesting levels were higher before the second and third peak than before the first peak, yet the first peak is larger than the second and third peaks. Furthermore, the model run showed a relatively high deviation from historical data for the age group 1-20 for both datasets. Deviation in one age group also affects the level of confidence in the accuracy of the results from neighbouring age groups, as errors bleed from one age group to the next – i.e. solving the deviation of one group will cause deviation in the next group.

Age group	Dataset A - Smoothed		Dataset B - Smoothed	
	Deviation in hectares	**Percentage deviation**	**Deviation in hectares**	**Percentage deviation**
1-20	-53272	8.644%	-91623	12.783%
21-40	-1636	0.149%	-563	0.049%
41-60	-16936	1.281%	-7003	0.534%
61-80	-8565	0.684%	-790	0.064%
81-100	6648	0.735%	4715	0.532%
101-120	17063	2.697%	33809	5.431%
121-140	60130	19.303%	46082	15.057%
141-160	252	0.187%	-185	0.142%
161-180	2273	3.786%	17115	74.852%
181 and above	-5958	8.118%	-1556	5.568%
Average deviation	**17273**	**4.558%**	**20344**	**11.501%**
Average deviation – except age group 161-180			**20703**	**4.462%**

Table 1 – Deviation from historical data of base run– area by age group in 2018.

Nevertheless, the model was able to replicate the historical data for forest area age distribution change (See Graph 1 and Graph 2) with a percentage deviation of less than 5%, except for age group 161-180, where there is a percentage deviation. It is, however, a small deviation in absolute terms, as excluding the age group from the calculation of the average decreases percentage deviation and increases deviation in absolute terms. The overall forest area is the same as historical data indicates.

Age group	Dataset A - Smoothed		Dataset B - Smoothed	
	Deviation in m^3/ha	**Percentage deviation**	**Deviation in m^3/ha**	**Percentage deviation**
1-20	-8	13.235%	-4	6.672%
21-40	-1	0.269%	0.4	0.170%
41-60	4	1.213%	-2	0.489%
61-80	3	0.669%	1	0.378%
81-100	-4	0.763%	-3	0.674%
101-120	-13	2.683%	-20	4.113%
121-140	-84	15.995%	-69	13.163%
141-160	-4	0.749%	-1	0.256%
161-180	-19	3.587%	-227	42.455%
181 and above	47	8.803%	32	6.055%
Average deviation	**18**	**4.797%**	**36**	**7.442%**
Average deviation – except age group 161-180			**15**	**3.552%**

Table 2 – Deviation from historical data of base run– forest density by age group in 2018.

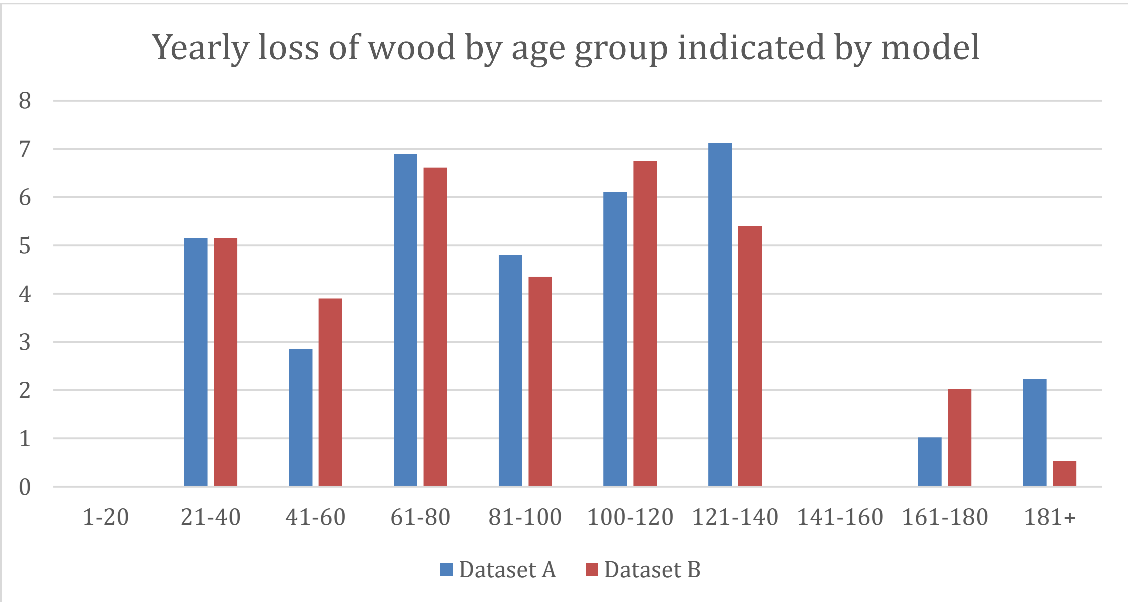
In the case of forest density, the replication of the historical data (See Graph 4) is similar, as can be seen when comparing Tables 1 and 2. Deviations of over 5% can be seen in age group 1-20, 121-140, and 181 and above. In the case of dataset B, there is a large deviation in the case of forest density as well.

Age group	Dataset A - Smoothed		Dataset B - Smoothed	
	Deviation in 1000 m^3	Percentage deviation	Deviation in 1000 m^3	Percentage deviation
1-20	-7984	20.735%	-8331	18.60%
21-40	-955	0.418%	286	0.12%
41-60	-359	0.084%	-4345	1.02%
61-80	-93	0.019%	1525	0.31%
81-100	-141	0.033%	-604	0.15%
101-120	-184	0.059%	3365	1.09%
121-140	361	0.221%	-141	0.09%
141-160	-420	0.563%	-288	0.40%
161-180	20	0.063%	76	0.62%
181 and above	-12	0.030%	22	0.15%
Average deviation	**1053**	**2.222%**	**1898**	**2.26%**

Table 3 – Deviation from historical data of base run- volume of wood by age group in 2018.

The reproduction of the data for volume shows a different story. Here, only the data for age group 1-20 is reproduced with a deviation of over 5%, while the rest is close to 0%. This is due to the fact that the extraction levels were adjusted in such a way as to match the reference mode. This was not possible for age group 1-20, since even 0 extraction yielded values that were too low.

Overall, there is an average deviation of 5.463% across the 30 reference modes of behaviour, and only 3.641% when not counting the results of age group 161-180 from dataset B for area and density. This level of historical data reproduction across 30 reference modes is satisfactory in terms of model validation.



Graph 10 – Loss of wood indicated by model. Units in million cubic meters/year.

The historical data on volume has been matched closely with the wood loss values from Graph 10 above. These values contain both wood extraction through logging, as well as wood loss through natural means, such as windfalls, pests or old age.

Interestingly, age the data for age group 141-160 was reproduced with an average deviation of 0.382%, and the model indicates that these forests have suffered from no wood loss, either from logging of from natural means. If the allegations from Cernuta, 2019 regarding the tampering of the NFI data are to be believed, perhaps this finding serves as an indication as to which age groups were tampered with, since it is unlikely that no logging has occurred within this specific age group.

Table 4 also shows the overall wood loss values for the period 2012-2018, and their deviation from NFI data, which shows 36.42 million m^3/year on average for the period 2012-2018.[10]

Age group	**Dataset A - Smoothed**	**Dataset B - Smoothed**
Average loss between 2012 and 2018 – in million m^3/year	36.18	34.725
Deviation	**7.422%**	**3.102%**

Table 4 – Deviation from historical data on wood loss – average for period 2012-2018.

Finally, model has also been able to replicate overall forest growth for the period 2012-2018. The growth value indicated by NFI is 54.20 million m^3/year.[11]

Age group	**Dataset A - Smoothed**	**Dataset B - Smoothed**
Average yield between 2012 and 2018 – in million m^3/year	54.84	54.42
Deviation	**1.178%**	**0.053%**

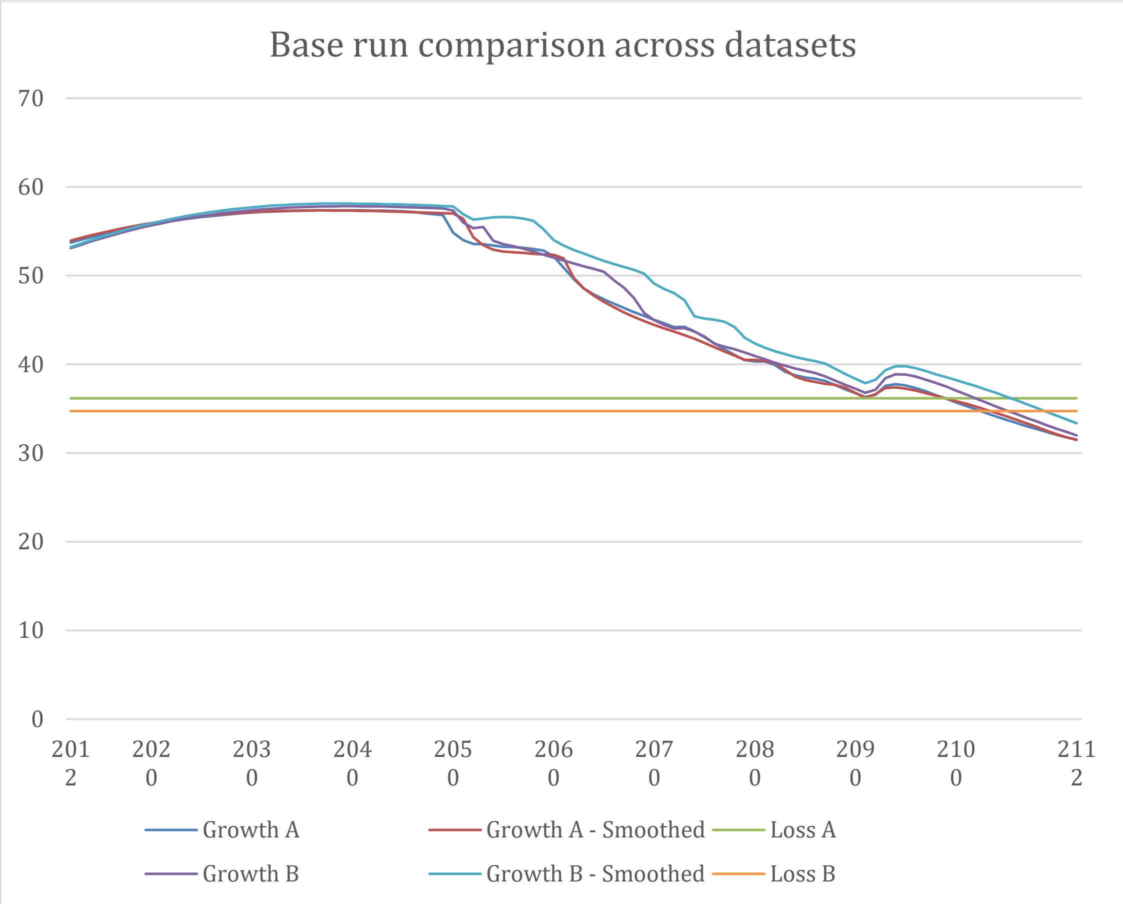
Table 5 – Deviation from historical data on wood growth– average for period 2012-2018.

The deviation for dataset A is higher for both overall loss and growth. This is unsurprising, however, since all of the data for dataset B was based on NFI data, and the overall loss and yield values come from that same data source. Considering that most of the historical data for forest area by age group, forest density by age group, forest volume by age group, as well as the historical data of overall wood loss and growth were reproduced with a deviation of less than 5%, the indicated future behaviour of the model can be analysed with a higher degree of confidence.

[10] The actual value is 36.42 million, but the NFI uses the international definition for forested areas, while the Romanian government uses a different definition. Only areas that meet the national definition are included in the National Forest Fund and managed accordingly. The value of 58.62 million has therefore been adjusted proportionally to the forested area according to the national definition. See Annex A for detailed explanation of the definitions.

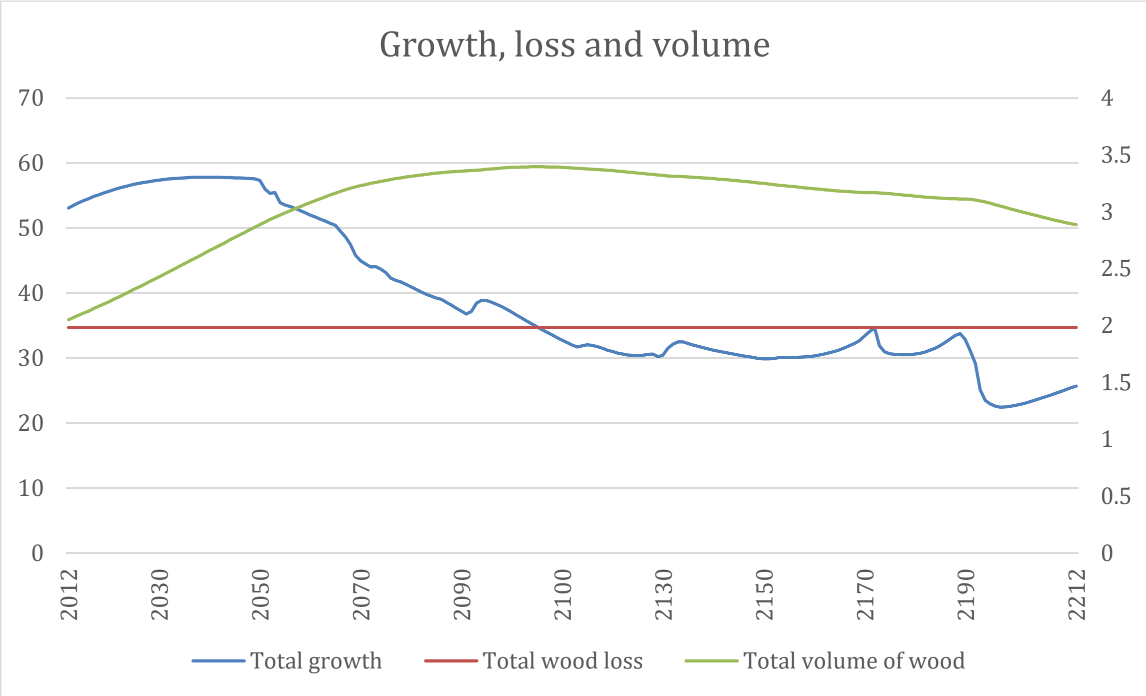
[11] See footnote 9 above. Actual value is 58.62 million.

4.2.Base run



Graph 11- Base run. Units in million m³/year.

The above graph shows the base run results over a 100 year period for yield. As it can be seen, the overall trend is the same across both datasets, whether smoothed or not. While smoothing the dataset may be important for replicating short-term data on age distributions, the graph shows that it is not important when calculating the long-term dynamics of overall yield. More importantly, however, it can be seen that growth drops below loss in every case, should current loss rates continue.



Graph 12 – Base run. Units in million m³/year on left axis for growth and loss; Billion m³ for volume on right axis. Results for model run dataset B (raw data).

Over an even longer time horizon, growth will not grow back to higher levels than loss (Graph 12). Furthermore, since this behaviour leads to overall younger forests, and therefore less volume of standing wood, and less carbon sequestration (among other things, such as diminished ecological functions, damaged aesthetic or spiritual values), the potential impact is quite severe.

4.3. Sensitivity analysis within range of uncertainty

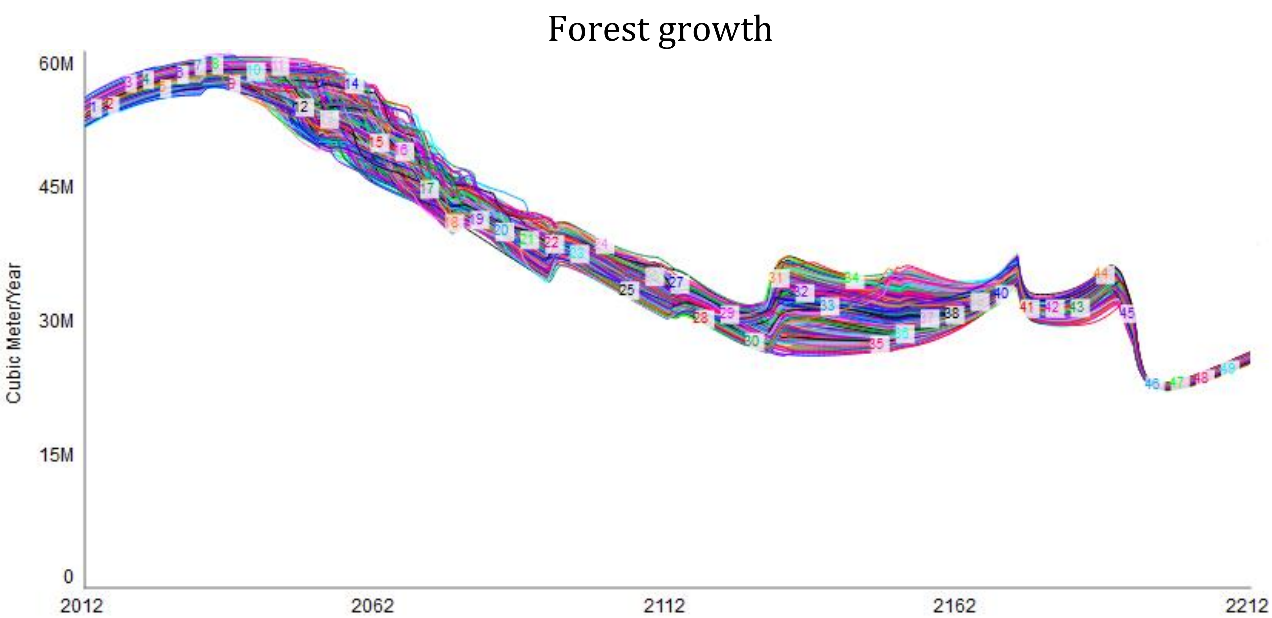
The base run of the model would indicate that the current logging rates are not sustainable. However, there is uncertainty related to the data on forest area, density, as well as the growth function. To account for this uncertainty, sensitivity analysis using Latin Hypercube sampling with 500 runs has been conducted across the range of uncertainty.[12]

[12] Seed number 44444.

The range of uncertainty across the variables is based on the statistical margins of error reported in NFI (2012a, 2018).

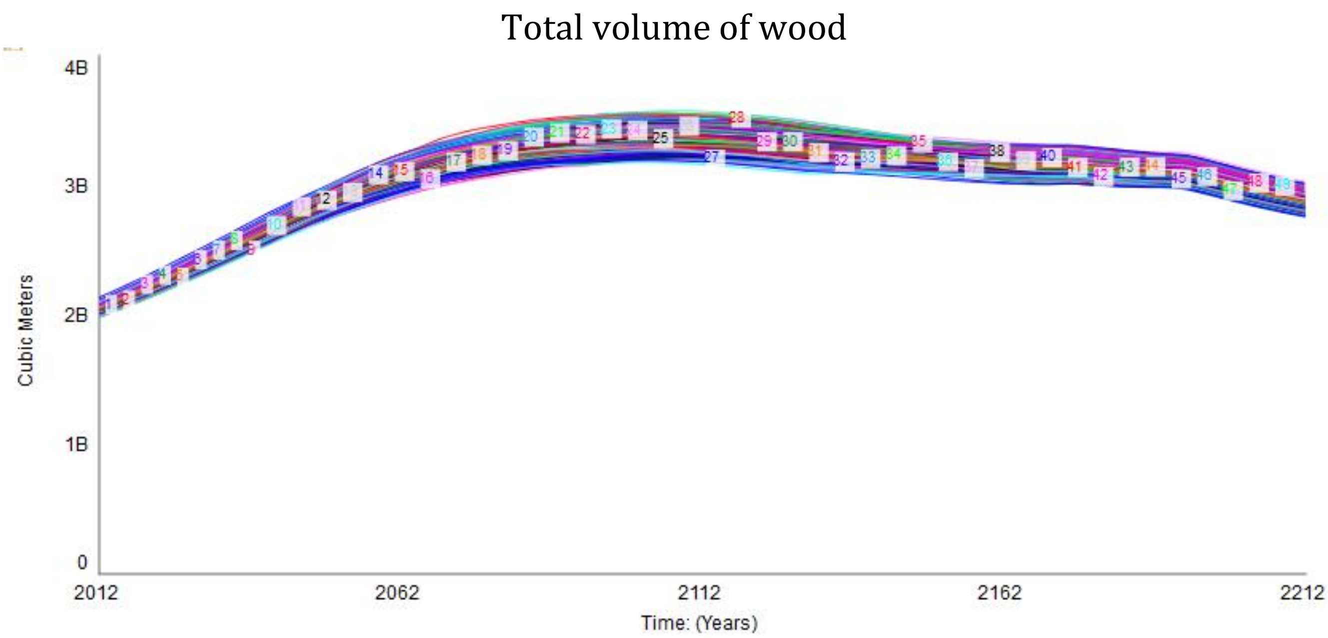
Age group	Forest area	Forest density	Forest growth
1-20	4.93%	5.44%	3.22%
21-40	4.16%	2.45%	2.53%
41-60	4.53%	2.09%	2.87%
61-80	4.66%	2.13%	2.34%
81-100	5.37%	2.38%	2.52%
101-120	7.04%	3.11%	2.86%
121-140	10.44%	4.38%	3.97%
141-160	16.89%	7.66%	5.57%
161-180	26.13%	10.21%	6.99%
181+	26.13%	10.21%	6.99%

Table 6 – Margins of error for variables. Source: NFI (2012a, 2018).



Graph 13 – Latin Hypercube test – dataset B (raw data – not smoothed).

As can be seen in Graph 13, though there is quite some divergence in terms of values at certain points in time, such as between 2012 and 2062, or 2112 and 2162, the overall trend remains the same. In fact, towards the end of the model run there is a striking convergence of values around a single point. The results of the Latin Hypercube test for the total volume of wood show something similar (Graph 14 below). Though there is some divergence in the values, the overall trend remains the same for all runs – growth, then decrease of overall volume.



Graph 14 – Latin Hypercube test – dataset B (raw data – not smoothed).

The result of the sensitivity runs further reinforces the level of confidence we may have in the results of the model, as the model overall behaviour of the model is not sensitive to the statistical margins of error reported in NFI (2012a, 2018).

4.4. Scenario runs

Though the total levels of yearly loss of wood is documented, the actual level of logging is not publicly available, even though INCDS does have this data within their National Forest Inventory.

It is difficult to assess how much of the total loss can be attributed to logging without a significant expansion of the model to separate natural losses from logging. According to the Romanian Government (2015), the NFI reported findings of logging of 26.69 million m^3/year for the period 2008-2014. Assuming that this rate has held steady for the period 2014-2018, this would mean that 76% of wood loss is attributable to logging, and the rest is through natural causes.

It is important to mention, however, that the average maximum planned harvest for the period 2008-2014 was 20.25 million cubic meters per year (Romanian Government, 2009, 2010, 2011, 2012, 2013, 2014, 2015), based on the sum of all forest management plans. Of the 20.25 maximum planned harvest, an average of 17.8 million cubic meters were officially reported. This still leaves 8.89 million m^3/year of unreported harvesting during that period. **This means that for every cubic meter of wood reported, there is**

an extra 0.5 cubic meter of unreported wood that is extracted from Romania's forests. Cernuta, 2019, estimates that this ratio could have grown as high as 1:1 recently. A few scenario runs are therefore required in order to understand, on the one hand, the potential outcome of such high logging levels, and on the other hand to understand the suitability of the actual policies in place – the maximum planned harvest at the national level.

	LOGGING LEVEL	LOSS DUE TO NATURAL CAUSES	TOTAL LOSS
SCENARIO 1	36.5 million m^3/year	8 million m^3/year	44.5 million m^3/year
SCENARIO 2	20.25 million m^3/year	8 million m^3/year	28.25 million m^3/year

The results of the base run have already been shown in section 4.2. The base run implies a logging level of 26.69 million m^3 and loss due to natural causes of 8 million m^3/year.

Scenario 1 is the 'worst case scenario' and assumes that:

1. The average level of loss due to natural causes will continue to be that from the period 2012-2018.
2. The average level of reported logging will continue to be that from 2012-2017 (Romanian Government; 2013, 2014, 2015, 2016, 2017a, 2018).
3. In addition, for every m^3 of reported logging, there will be m^3 of unreported logging.

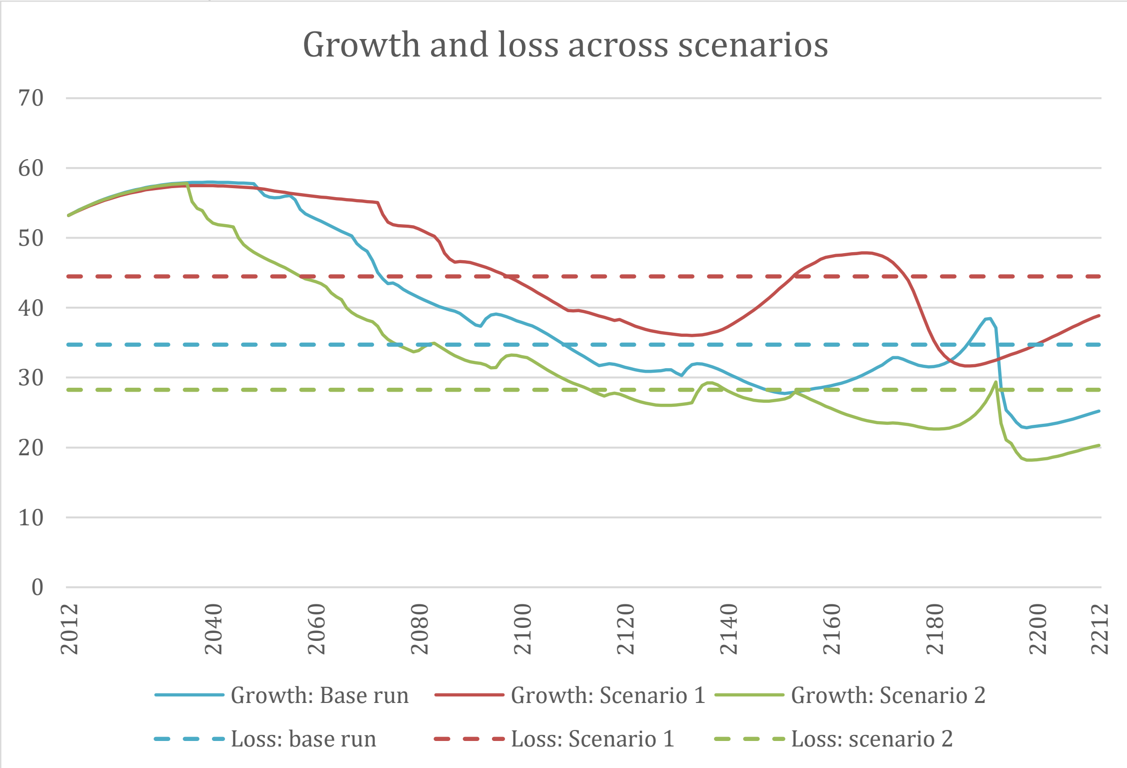
Scenario 2 is the 'best case scenario' and assumes that:

1. The average level of loss due to natural causes will continue to be that from the period 2012-2018.
2. The average level of logging will stay at the average of 20.25 million planned harvest starting.

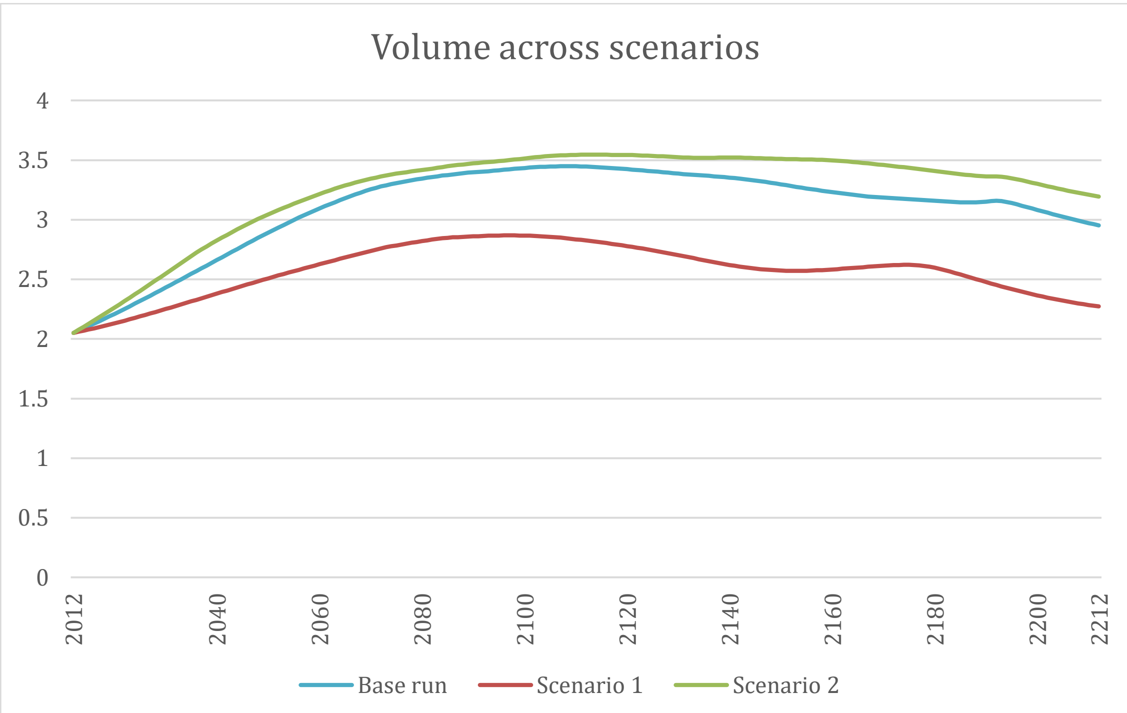
The results[13] from Graph 15 and Graph 16 indicate that high levels of logging lead to a higher growth level as well, since younger forests grow faster, as shown in the growth function from Graph 8. However, the increased growth rate is not sufficient to compensate for the increase logging that takes places, since the overall volume of wood is much lower in Scenario 1 compared to the base run, and slightly higher in Scenario 2 than in the base run. Furthermore, the higher the level of logging, the sooner the growth level drops below the loss level. One conclusion to be drawn from this is that the sooner action is taken to redress logging levels, the greater the impact will be. This is especially visible when comparing the results for total volume of wood: in the year 2050, Scenario

[13] From Dataset B – Smoothed.

1 shows 2.5 billion m^3, while Scenario 2 shows 3 billion m^3. In terms of carbon sequestration alone, this would mean a difference of 0.5 billion tonnes of CO_2. Considering that the yearly CO_2 emissions of Romania have been at around 70 million tonnes/year lately (Source: UNDS), this implies that the correct implementation of Romania's forestry policies could completely neutralize 7 years' worth of emissions (current level) by 2050.



Graph 15 – Scenarios: growth and loss. Units in million m^3/year.

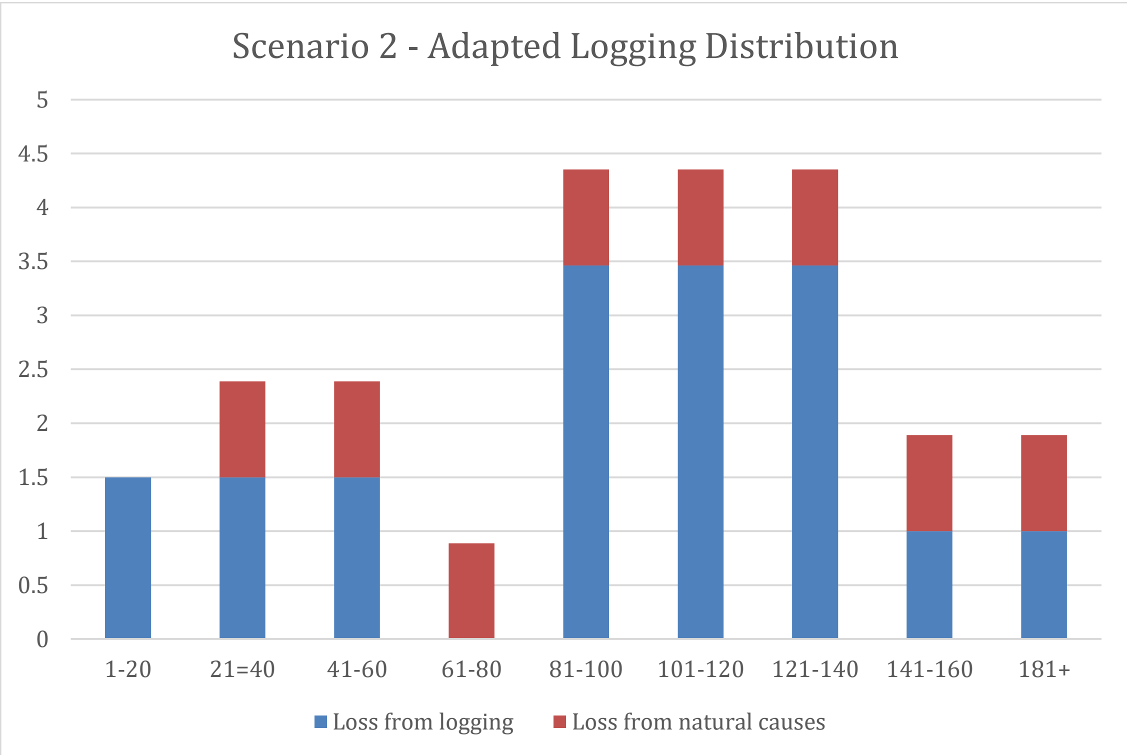


Graph 16 – Scenarios: volume. Units in billion m^3.

Even though Scenario 2's loss value is based on the maximum allowable yearly harvest, the model indicates that not even this level of logging is sustainable, since the volume of wood will start dropping in the long run, albeit first it will reach higher levels sooner.

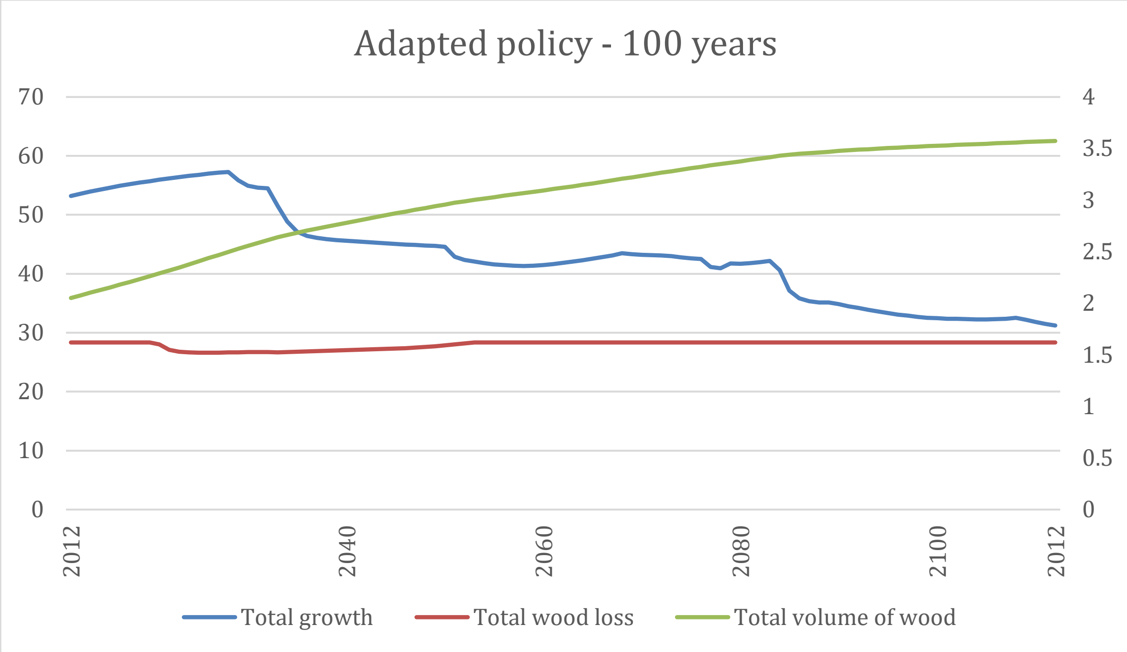
4.5 Policy run

An adaptation of Scenario 2 may lead to sustainable logging, while still harvesting the same amount of wood, with a different logging distribution than in the simulation run described above. An adapted version of Scenario 2 features the same overall level of logging, but with the following distribution.



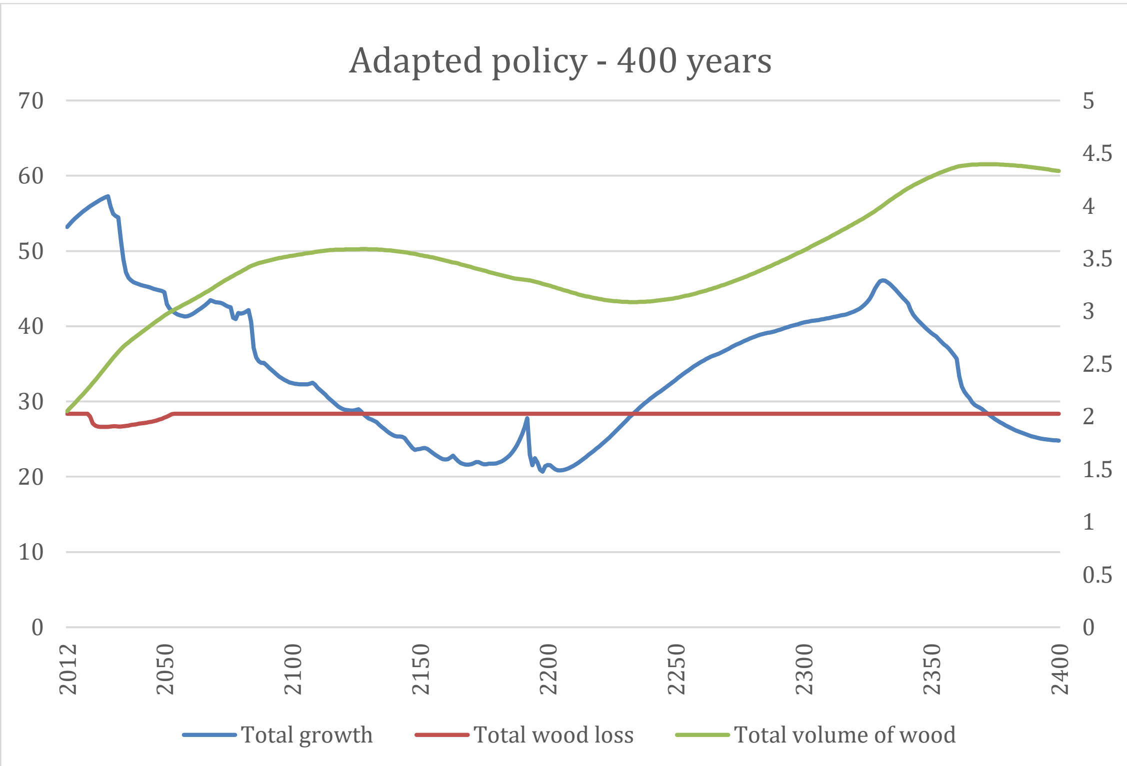
Graph 17 – Adapted logging distribution. Units in million m^3/year.

Furthermore, the simulation run has been changed to assume that no cuttings from the age group 1-60 leads to regeneration (Figure 6). This is assuming that all of the cuttings are thinnings that are part of silvicultural measure employed. Wood obtained through thinnings is referred to as 'secondary product', since the main purpose of thinning is not to obtain wood, but to allow more room for other trees to grow faster. The value of 4.5 million m^3 was determined based on data from Romanian Government (2018a), which indicates indicates up to 4.4 million m^3 of secondary products harvested in 2017. The following results are thus obtained.



Graph 18 – Adapted logging distribution. Units in billion m^3 on right axis, million m^3/year on left axis.

The above graph shows that over a 100 year period, the level of overall level of logging may be sustainable, even with such a crude adjustment to the logging distribution as in Graph 17.[14] This becomes more apparent when running the simulation over a very long time horizon.



Graph 19 – Adapted logging distribution. Units in billion m^3 on right axis, million m^3/year on left axis.

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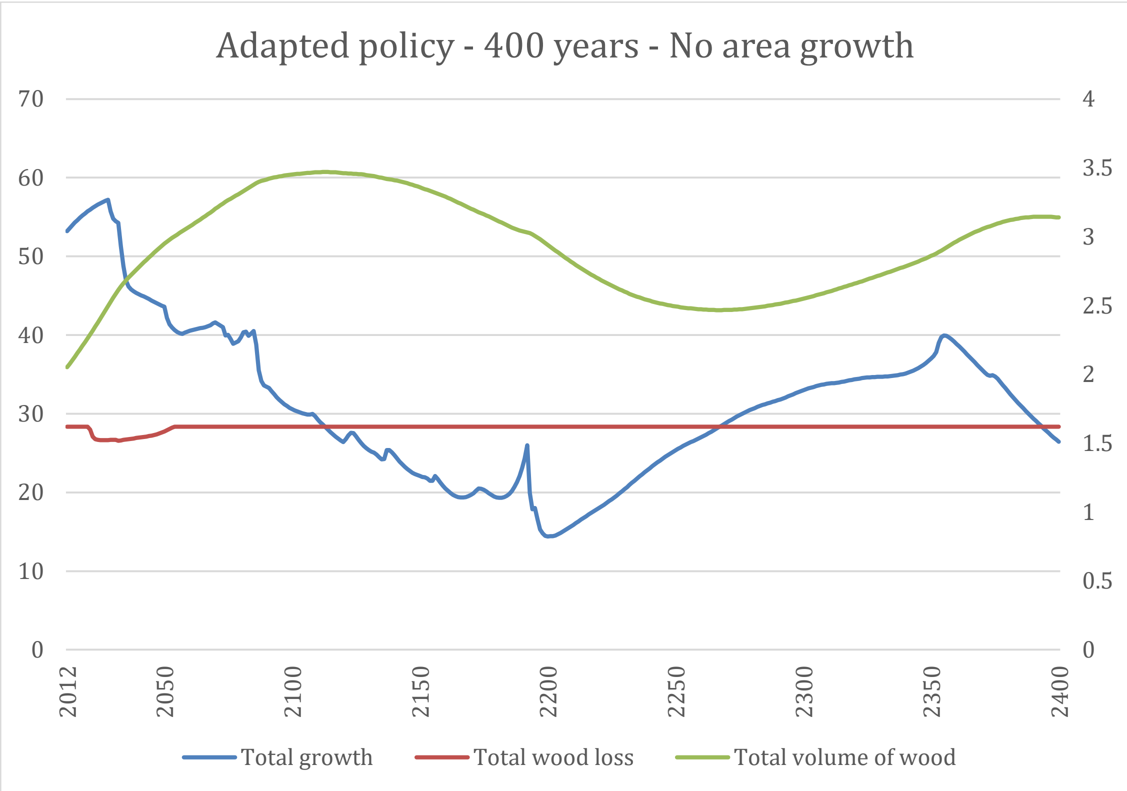
[14] The slight drop in logging levels at the beginning of the simulation run is due to the policy described in section 3.5 still being implemented.

One possibly confounding factor here is that the total forested area continues to grow in the simulation run from Graph 19, even though the official stance of Romania, by law, is to have 9 million hectares of forested land by 2050 (Romanian Parliament, 2016), while the run from Graph 19 reaches 8.5 million by 2400. In order to see the effect of forested land area growth on the results, a separate run has been made without any land growth after 2018.



Graph 20 – Adapted logging distribution. Units in billion m^3 on right axis, million m^3/year on left axis.

As it can be seen, the overall trend is the same, even with no forested area growth, though the oscillatory nature of total volume is undesirable in both cases. These simulation runs indicate that **the overall level of logging established through forestry policies is most likely to be sustainable.** A smartly adapted logging policy, carefully selecting from which age group to harvest, is likely able to harvest this natural resource sustainably, without causing such oscillatory patterns through time.

5. Discussion

5.1. Limitations

The model used to arrive at the results described in section 4 faces a number of limitations, and these should be taken into account when considering the results. The following are the most important limitations identified by the author, though there may certainly be more:

I. Logging and loss due to natural causes (decay) are not differentiated

Though some estimations have been made in Section 4.4, the model structure does not differentiate between different types of loss. One reason for this is that precise logging values are not publicly available, and some guesswork is require, even though, as previously mentioned, this information is known by INCDS:

The estimation of the total amount of wood harvested from terrains with forest vegetation is presently based on the yearly statistical reports submitted by forest districts extraction companies. The measurements performed on the permanent sample surfaces of NFI, including stumps, will allow for the precise estimation of the quantity of wood harvested from terrains with forest vegetation. (NFI, 2019)

An even bigger problem caused by this limitation is that the decay rate is static, unlike the growth rate, which is dynamic and dependent on the age composition of the forests. The decay rate should also certainly depend at least on the age composition of the forests. In fact, both the growth and decay rates could further be improved by making them dependent on forest density as well: higher density slows growth until maximum density is reached, whereupon growth will equal decay and lead to homeostasis in old-growth forests – the final successional stage (Grebner, Bettinger and Siry, 2013). While there is no data on the average decay rate of forests by age group available publicly, the decay rate could be reconstructed based on research on forest growth dynamics by species in Romania. To do this, however, the ontology of the forest must be expanded to include species differentiation as well.

II. Species are not differentiated

While NFI (2012a, 2018) does contain data on species composition, it is impossible to know the age distribution by species. For example, data on the area and density of beech forests is available, but the datasets do not specify the age distribution of beech forests separately, only the total average age distribution of forests. Upon reviewing the measurement methodology of the National Forest Inventory (NFI, 2012b), however, it becomes apparent that this information too is available to INCDS, or at least could be calculated based on the disaggregated measurement data.

III. Forest regeneration process not clear

A rough estimate has been made as to how loss of wood affects the age distribution of forested areas (Section 3.5.). This estimate, however, does not account for the nature of silvicultural interventions at different age groups (see Section 4.4.). It also does not account for the differences between the way in which logging and decay processes affect regeneration processes (though, as mentioned before, logging and decay processes themselves must first be differentiated).

There are also two assumptions built into the model structure that do not always reflect reality. Firstly, all forest land begins to regenerate without any delay. While this might be so in the case of properly executed silvicultural systems, it might not be so in the case of improperly executed ones, or in the case of illegal logging. Secondly, the model assumes that all forest land will regenerate, and does not account for the possibility of soil degradation which would inhibit regeneration. While land use change (and hence, deforestation), must always be compensated for through an equal or greater amount of afforestation (Romanian Parliament, 2016), this does no guarantee that all forested areas that are cleared will regenerate without some sort of additional intervention.

While NFI (2012b) describes the measurement methodology, it does not describe how the classifications are made based on the measurements. This is important to know when determining how silvicultural different silvicultural systems actually affect the forest age classifications of the National Forest Inventory.

IV. The maximum density of forests is not well defined

A rough estimate has been made on the maximum forest density[15]. The maximum density, however, should be a result of the growth and decay dynamics of forests. Improving those aspects of the model structure should help overcome this limitation as well. Overcoming this limitation is important, as sensitivity analysis included in Annex D has revealed that model results are sensitive to this parameter, though the overall trend remains the same.

[15] A sensitivity analysis of this parameter has been included in Annex D.

V. Private and public land is not differentiated

This limitation is perhaps the least important one at this stage, since ownership does not affect natural processes. Furthermore, the Forestry Code applies the same stringent rules upon public and private forest management (Romanian Parliament, 2016). In fact, one of the complaints from private forest owners is that the Forestry Code is too stringent (Buliga and Nichiforel, 2019).

VI. All forest areas are open for logging

Some forest areas in Romania are protected to different extents. Logging in such forests is either restricted or prohibited. In order to more accurately estimate sustainable logging levels, these forests must be represented separately within the model. The effect of this limitation on the results of the base run, however, should be limited. Firstly, because of the many cases of forest disturbances in natural and national parks, and secondly because of the increased fraction of the implementation of so-called ‘conservation cuttings’.

5.2. Main takeaways

The present research demonstrates, first and foremost, the potential of the use of simulation models in studying forestry sustainability. System dynamics specifically allow for the ontology of forests within the model to be adapted to the data available. Expanding the ontology, however, would allow for more detailed policies to be tested, rather than the crude ones presented here.

Secondly, the model results indicate that the potential impacts of correctly applying current forestry policies are significant. It is therefore imperative to correctly assess the sources of forest loss, and how much each source contributes to the overall loss level. It can then be determined which courses of action can bring down the overall level of logging closer to the levels indicated by official policies fastest.

One possible lever is increasing the effectiveness of the Forest Inspectorates. A study by Popa, Niță and Hălălișan (2019) point out that the effectiveness of new institutions is affected by the engagement of their employees. Their study indicates that, although the employees of the recently created Forest Inspectorates have a positive attitude and adopt positive subjective norms towards performing the required engagement in law enforcement effort, factors such as unsuitable training, improper planning & management, unsuitable legislation and even **unavailable information** limit their perceived power in performing the required engagement in their work.

Another source of excess logging is that officials consistently underestimate both the quantity and the quality of the wood that is to be sold at auctions (Bouriaud and Marzano, 2014). Romsilva itself states in its management plan for 2016-2020 that one of their main priorities is the professionalization of their staff, as it has been assessed that many staff members lack the desired level of training and knowledge. Solving this issue could not only reduce the level of excess logging, but also prevent economic losses in the long-run. Another reason for the consistent underestimation, given during an interview for this research, is that the quantity and quality of wood is measured 13 times in Romania. [16] Once would think that multiple measurements ensure accuracy. What happens instead, is that responsibility is diluted, and no one is held accountable.

Several authors point out that a necessary policy for sustainable forestry at the national level is the implementation of financial compensation schemes for owners of protected areas (Stăncioiu, Abrudan and Dutca, 2010). Though these financial compensation schemes are part of the Forestry Code (Romanian Parliament, 2016), they have never been implemented. The implementation of such a policy would lead to a further decrease of excess logging. Using disaggregated NFI data, one could identify the amount of excess logging across all protected areas. A cost-benefit analysis can then be made to identify how to prioritize the implementation of this policy compared to other ones.

Securing funding at the European level for the research of virgin forests, and guaranteeing their strict protection, would also contribute to a decrease of excess logging. Such research would prove to be valuable at a global level as well:

The remaining virgin forests of temperate Europe are an inexhaustible source of ecological information about biodiversity, structure, natural processes and overall functioning of undisturbed forest ecosystems. Their research will reveal information which can be used for ecological restoration of man-made forests which are degraded through intensive forestry practices over the last centuries. - Veen et al. (2010)

The proper conservation of protected areas also faces legislative challenges:

…cuttings in old-growth forests are predominantly in accordance with forest management plans, legal harvesting activities are obviously responsible for their diminishment. Protected areas, including recent expansions under the Natura 2000 framework, do not safeguard these forests as originally envisioned. Biodiversity and

[16] For comparison's sake, in Austria it is only measured once.

specifically protected area governance continue to face serious challenges with respect to their ability to safeguard old-growth forests. – Knorn et al. (2013)

Though virgin forest are protected by law, if a local villager were to fell one tree from that forest for use as firewood, the entire forest is no longer considered to be a virgin forest by law, and is therefore opened for logging activities.

The third takeaway of this research and its results is the power of data. Had these aggregated results not been published, the sustainability of Romanian forestry could not have been quantified even to this extent. Lack of transparency has been a consistent problem in the Romanian public sector, even until the present day. This research is not the first one to point out the importance of public access to information.

Lack of information about forest change was also pointed out as worrisome by Knorn et al. (2012), due to its importance to the conservation of old-growth, primary forests, biodiversity, and large mammal habitats. Several existing research projects, such as the one by Munteanu et al. (2016), could be significantly improved with more disaggregated information. And, as mentioned above, even the Forest Inspectorate suffers from lack of information.

5.3. Future research

Beyond what has been presented in the ‘Limitations’ section, the present model may serve as a basis for other future research possibilities as well. One possibility is to include forestry economics aspects, or ecological function aspects as well. Thus it would be possible to broaden the research scope beyond the natural resource management perspective. On the demand side, economic aspects could include firewood demand, demand for construction material or demand for furniture. On the supply side, economic aspects could include the way in which species, wood quality, or the diameter of the felled tree affects the price.

Another possibility is to combine this model with GIS analysis, using Corine Land Cover data, among others. Combining with GIS analysis would also enable more serious research into land use change.

Finally, expanding the logging policy section would permit more detailed analysis of the logging policies that would allow for desirable forest age distribution patterns.

6. Conclusions

The question that this thesis addressed using a dynamic simulation model: *Are current levels of logging in Romania sustainable?* Though the model indicates that the natural resources provided by Romania's forests will not be depleted, the overall yield and volume of Romania's forests is set to drop, even under the assumption of continuous forest area growth. This is the case for both the optimistic and pessimistic assumed levels of logging.

The model also indicates, however, that current forestry policies, so long as they are properly implemented, are very likely to be sustainable on the long run, while also leading to a growing stock of standing wood. This behaviour is the most desirable one, as it would lead to a fulfilment of economic needs, while also contributing to carbon sequestration, a higher fulfilment of ecological functions, and biodiversity preservation.

Many parts of the model could be improved with greater access to data concerning the natural resources of the country. Open access to data on Romania's forests can lead to valuable research concerning the effectiveness and sustainability of current and future natural resource management policies. The use of computer simulation models can aid in the discovery of inconsistencies in data. Clean and consistent datasets would, in turn, increase the confidence of public policy-makers in the results of dynamic simulation models.

Finally, open access to data on natural resources is a question of moral principles. After all, as Romania's National Forestry Strategy states: *In Romania, this relationship [between forest and man] is marked by a history filled with moments when "the forest was a brother to Romanians", as is often described in literature*[17]. (Romanian Government, 2017b) It is therefore the duty of the Romanian government to not inhibit, but rather facilitate Romanians to return the favour, and care for the forests.

[17] Author's translation.

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