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An Algorithm for Simulation of Forest Management Decisions in the Global Forest Model

An algorithm for decision making on forest management in the Global Forest Model (G4M) is developed. The algorithm provides harvesting of a specified amount of wood in countries. Adequateness of the algorithm is demonstrated on example of Ukraine, Poland, Byelorussia and Russia.

Introduction

Climate extreme events the people are facing the last decade more and more often [1] are associated with human induced climate change [2]. Mitigation of climate change requires substantial reduction of greenhouse gas emissions to the atmosphere, as well as sequestration of carbon dioxide (one of the most influential greenhouse gas) in ecosystems. *Reduction of emissions from deforestation and forest degradation* (REDD) is expected to be included in the next climate agreement, in particular REDD was considered at the recent climate change negotiations in Copenhagen in 2009 [3].

There is a need for a model allowing simulation of different forest management options and corresponding carbon flows in order to assess effectiveness of forest management mitigation options. In contrast to local scale models we propose a global model assuring similar accounting approach across countries and thus making the countries comparable.

We improved the Global Forest Model (G4M), which has been developed at the International Institute for Applied Systems Analysis for assessing policies aimed at reduction of deforestation and stimulation of afforestation [4], [5]. We supplied G4M with a forest management module¹ and an algorithm simulating decision making on forest management to satisfy wood demand.

The objective of this paper is to develop an algorithm for simulation of forest management decisions that allow production of demanded amount of wood for usage in the Global Forest Model.

Structure of the global forest model

The G4M is a geographically explicit agent-based model that simulates decisions made by virtual land owners on deforestation and afforestation taking into account profitability of forestry and agriculture. Considered version of the model operates on a regular grid of $0,5 \times 0,5$ decimal degree². Forest parameters in each cell are initialized using global geographic datasets – the forest area with *global landcover* (GLC 2000), forest biomass with a product obtained from FAO data, agriculture suitability, protected land where land-use-change is not allowed, etc. The land use change decisions are estimated for each grid-cell [6].

¹ The forest management module is developed by Georg Kindermann, International Institute for Applied Systems Analysis, Austria.

² In fact the resolution depends on input data resolution and computational resources.

Deforestation occurs if price of agricultural land (that mimics the net present value of agriculture) together with profit from selling wood obtained from clearing the forest is greater than the *net present value* (NPV) of forestry. On opposite, afforestation occurs if there is land that can be afforested, the environmental conditions are suitable and the forestry NPV is greater than the price of agricultural land [6].

By giving a value to the carbon stored in existing forests or accumulated in planted forests, e.g. carbon tax for lost carbon in case of deforestation or payments for carbon accumulated additionally in forest ecosystem in case of a/re-fforestation we can increase forestry NPV and thus stimulate forest owners to decrease deforestation and increase afforestation [5], [6].

The model is widely used for evaluation of policies aimed at reduction of deforestation and forest degradation (REDD) on global, regional [4] or country scale [5].

Forest management module

The forest management module simulates forestry on a scale of forest. It contains a generic forest growth function, allows creation of a forest with specified environmental and management parameters (growth function parameters, *mean annual increment* for a normal forest¹ – MAI, *stocking degree* – SD, *rotation length* – RL, thinning, harvest losses, forest area and age structure information). Forest is represented with a set of forest plots of $(N = RL + 1)$ N age classes (one year step) and of different area as specified in the age structure information derived from country forestry statistics. If the age structure is not specified the forest management module creates a normal forest. The forest management module provides thinning and harvest according to the specified parameters bringing forest to “normal” state gradually. The forest management module also determines RL that is optimal for getting maximal mean annual increment and *maximal* sustainable harvest every year (RL_{MAI}), *getting maximal biomass* (RL_{maxBm}), or *keep current biomass* (RL_{Bm}) for particular growth conditions (MAI) and management type (SD and thinning).

Simulation of forest management decision-making

In each grid cell where MAI and land area are greater than zero, and environmental conditions are suitable for growing forest, two virtual forests are created using the forest management module – an existing forest, which matches observed aboveground biomass (C_{ab} modeled with C_{fmab}) and forest area, and a new forest with zero area that probably will be planted during the simulation (fig. 1).

A set of forest parameters is initialized iteratively using geographically explicit or country specific information. Increment is determined using a map of potential net primary production and translated into MAI. MAI was scaled at country level to match MCPFE (The Ministerial Conference on the Protection of Forests in Europe) data. Age structure and stocking degree are used as additional information for adjusting MAI. If stocking degree of forest modeled with a given age structure (country average) in a cell is greater than 1,05, age structure of the modeled forest is shifted iteratively by a few age classes towards older forest. If stocking degree of forest modeled in a cell is smaller than 0,5, age structure of the modeled forest is shifted iteratively by a few age classes towards younger forest. It is required that the shifts are symmetrical to keep country average age structure close to statistical value. If the age structure shift distribution within a country is skewed towards older forest, the country's average MAI is increased iteratively. If the age structure shift distribution within a country is skewed towards younger forest, country MAI is decreased iteratively.

¹ Forest which consists of forest plots of all age classes (up to RL) of equal area.

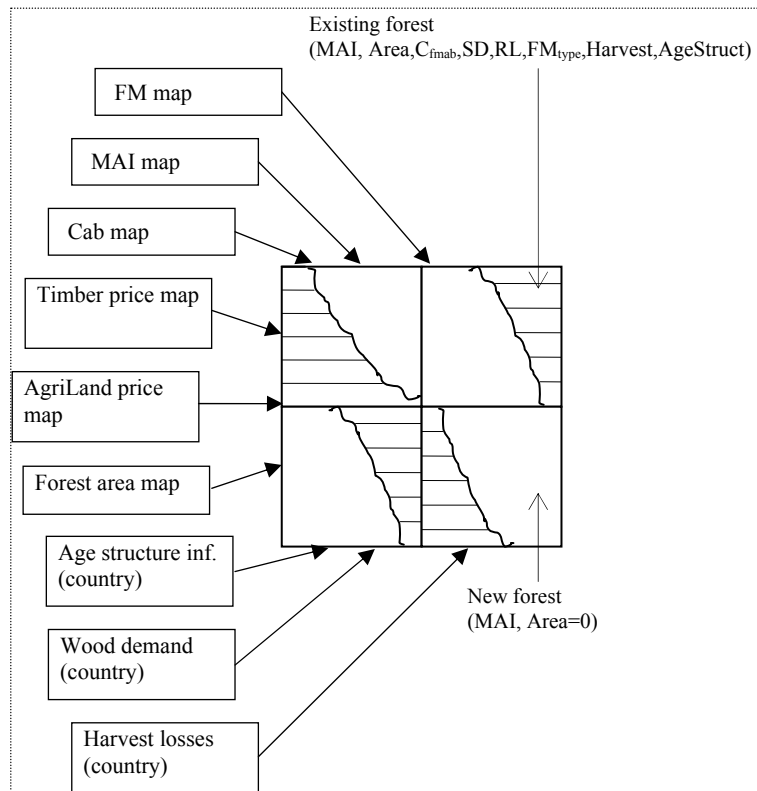


Figure 1 – Initialization of virtual forests in the grid cells

In case of non-uniform age structure stocking degree is determined as a relation of modeled biomass to the observed biomass. If age structure information is not available, stocking degree is set to one.

Six *forest management types* (FM_{type}) that influence further forest management decisions are identified:

$$FM_{type} = \begin{cases} -2, & \text{if } FM_{map} = 0 \wedge MAI \leq \overline{MAI} \wedge NPV_{For} \leq NPV_{Agri} \\ -1, & \text{if } FM_{map} = 0 \wedge MAI \leq \overline{MAI} \wedge NPV_{For} > NPV_{Agri} \\ 0, & \text{if } FM_{map} = 0 \wedge MAI > \overline{MAI} \\ 1, & \text{if } FM_{map} = 1 \wedge MAI \leq \overline{MAI} \wedge NPV_{For} \leq NPV_{Agri} \\ 2, & \text{if } FM_{map} = 1 \wedge MAI \leq \overline{MAI} \wedge NPV_{For} > NPV_{Agri} \\ 3, & \text{if } FM_{map} = 1 \wedge MAI > \overline{MAI} \end{cases}$$

In the above expression FM_{map}^1 is a map indicating that a particular cell contains managed or unmanaged forest, NPV_{For} and NPV_{Agri} are net present values of forestry and agriculture respectively. \overline{MAI} is average mean annual increment in country considered.

Forests with $FM_{type} > 0$ are used for wood production (are managed). Rotation length of managed forests is set to RL_{MAI} , RL_{Bm} or RL_{maxBm} depending on whether wood harvest within a country is smaller, equal or greater than domestic wood demand (RL_{MAI} allows

¹ Derived from FAO data by Georg Kindermann, International Institute for Applied Systems Analysis (Austria).

maximal annual sustainable harvest and usually is the shortest considered rotation, RL_{Bm} allows keeping current biomass in forest, RL_{maxBm} allows accumulation of biomass in forest and usually is the longest considered rotation). If RL_{Bm} is smaller than RL_{MAI} we use RL_{MAI} to avoid transition effect resulting in temporal decrease of harvest even if the rotation length is changed to RL_{MAI} .

Every simulation year all cells are processed one by one. In the input file, which contains data for each grid cell, the cells are sorted by countries, then descending by MAI, amount of carbon in aboveground biomass, forest area, population density and agriculture suitability. Thus productive forests of larger area and closer to populated places are processed first. Harvested wood in a cell is a sum of final harvest, pre-final harvest (thinning) and wood obtained from deforestation. A sum of harvested wood in a country is compared to domestic demand in the country. If demand is greater than supply by more than 2 %, rotation length of forest in cells (that belong to the considered country) is decreased to RL_{MAI} one by one until demand is satisfied. If after processing all cells in the country, demand is still greater than supply by 2 %, unmanaged forest ($FM_{type} \leq 0$) is turned to managed ($FM_{type} > 0$), cells with population > 0 or $FM_{type} = 0$ and -1 are taken first.

If harvest in a country is greater than demand by 2 % rotation length of less productive forests ($0 < FM_{type} < 3$) is increased gradually (five-year time step) up to RL_{maxBm} . If after processing all cells in the country, harvest is still greater than demand by 3 %, RL of forests in the country with $FM_{type} > 0$ is increased gradually up to RL_{maxBm} until the 3 % threshold is reached. Forest management type is changed to unmanaged if the supply-demand difference is more than 5 % after the previous iterations ($FM_{type}: 1, 2 \rightarrow -2, -1$) or if the difference is still higher than 5 % productive forests are affected as well ($FM_{type} 3 \rightarrow 0$).

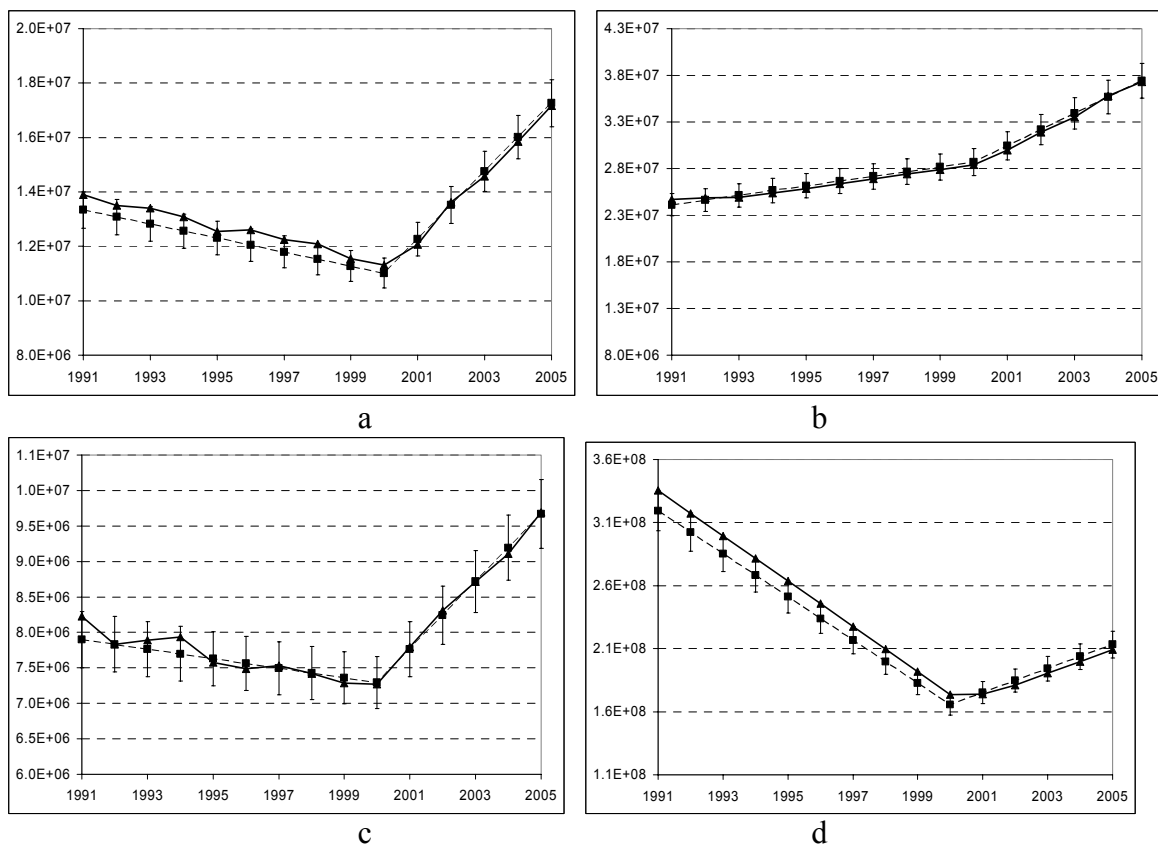


Figure 2 – Wood production in Ukraine (a), Poland (b), Byelorussia (c) and Russia (d) in 1990 – 2005 according to the FAO statistics (rectangles) with 5 % errorbar and simulated harvest (triangles)

In order to follow expansion of populated cells we check every ten years at the beginning of forest management adjustment whether harvest deviates from demand by more than $\pm 12\%$. If harvest is greater than demand by 12% and recently depopulated cell contains managed forest, the forest is turned to unmanaged. The forest management type is changed as well ($FM_{type}: 1, 2, 3 \rightarrow -2, -1, 0$). If harvest is smaller than demand by 12% and recently populated cell contains unmanaged forest, the forest is turned to managed (used). The forest management type is changed respectively ($FM_{type}: -2, -1, 0 \rightarrow 1, 2, 3$).

We applied the algorithm for simulating forest management decisions for getting statistical wood harvest in 1990 – 2005 in Ukraine (fig. 2a) and neighbor countries – Poland (fig. 2b), Byelorussia (fig. 2c) and Russia (fig. 2d). The maximal difference between modeled and statistical data is 5% . Increasing wood harvest is modeled with higher precision – maximal difference on upward parts of the graphs is less than 2% . In general, the harvest initialized by the algorithm matches the statistical data very well.

Conclusions

The algorithm considered in the paper allows simulation of decision making on forest management on a forest scale that leads to production of specified amount of wood on a country scale. If the input data on domestic wood production statistics, deforestation rate and forest resources are consistent the simulation of forest management decisions using the algorithm is plausible. The Global Forest Model supplied with the forest management module and the algorithm can be used for a versatile REDD policy assessment.

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Алгоритм для імітаційного моделювання рішень щодо лісокористування в глобальній моделі лісу

Розроблен алгоритм прийняття рішень щодо лісокористування в глобальній моделі лісу (G4M). Алгоритм забезпечує заготовлюванню заданої кількості деревини по країнах. Продемонстровано адекватність алгоритму на прикладі України, Польщі, Білорусі та Росії.

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Алгоритм для имитационного моделирования решений относительно лесопользования в глобальной модели леса

Разработан алгоритм принятия решений относительно лесопользования в глобальной модели леса (G4M). Алгоритм обеспечивает заготовление заданного количества древесины по странам. Продемонстрирована адекватность алгоритма на примере Украины, Польши, Белоруссии и России.

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