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Integrated Modeling Approaches and System Dynamics in Education related to Sustainable Resource Management, Forestry, and Land use Management

Experiences and Perspectives at the School of Forestry and Resource Management, Technische Universität München, Germany

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Abstract

The School of Forest Science and Resource Management at Technische Universität München, Germany offers two different streams of education. The traditional stream is education in forest science (BSc, MSc, Diploma), which traditionally qualifies forest and related enterprise managers and scientists. The other stream is the 2001-founded international master course in Sustainable Resource Management (SRM), which qualifies managers or consultants who have to deal with interdisciplinary problems in resource management worldwide.

With the SRM program, the organisers put more emphasis in education on teaching systems thinking and practice system dynamics skills to increase the number of qualified academics in this field. Thus, resource management and forestry education included and improved system dynamics (SD) and modeling issues in their curricula. The goal is to improve the student's systems thinking skills to enable them applying resource management and foresty in their home countries highly based on systems principles.

This paper describes the structure of the courses and demonstrates, which aspects of SD, modelling and models are currently used for which purpose in these fields of education. In our experience up to now, students appreciate these issues and are interested in more SD and modelling related courses. We also observe typical misunderstandings among the students concerning the meaning of stocks and flows and the role of simulation software.
Our main conclusions and future perspectives are, that by providing high-quality lectures in SD-related issues we should try to raise the student's demand for getting more subjects presented in an SD context, which in turn should stepwise increase the supply. As especially the SRM students are a very international group, we hope to be multiplicators for systems thinking worldwide.

Keywords: Education, Systems Thinking, System Dynamics, Integrated Modelling, Resource Management, Forestry, Sustainability.

1 Introduction

Despite the widely accepted systemic quality of many issues in natural resource management and land use planning, the widespread application of systems thinking, integrated systems modelling, and system dynamics in these fields' research and education activities is nowadays not well developed, and particularly in German speaking countries far beyond its inherent possibilities. Moreover, the awareness of the value of theory and application of system dynamics in forest science, forest management practice, and in forestry related regional planning issues is by far not adequately recognised. One reason seems to be the fact that systems thinking and multi-disciplinary model building is mostly absent in the regular universities' education programs. Astonishing is that this matter of fact also applies to other fields of science like engineering sciences (Nadtke 2003) or social sciences (Repenning 2003). Even in forest science and forestry, with its long tradition in observing the forest as complex ecosystem and in developing a wide range of modelling approaches (Mies 1998), integrated modelling at the landscape level and above is at the beginning and is seen as the challenge of the near future (Chertov et al. 1999). Integrated modelling implies a great potential in combination with the central paradigm of the concept of sustainability in the use of forest resources that has been coined by German foresters like Hans Carl v. Carlowitz (1713), J. Ch. Hundeshagen (1828), and Georg Ludwig Hartig (1820), and Heinrich Cotta, who 1811 established worldwide the first school of forestry in Tharandt, Saxony. Sustainability is still the self-evident red thread of today's professional forestry education. Furthermore, forest management in general has a long tradition in long-term thinking and interdisciplinary approaches in both science and practical management that are of particular value in all related fields of resource management.
Based on these considerations the idea for a new integrative and international Master of Science Programme was born and developed at the School of Forest Science and Resource Management at the Technische Universität München in Freising, Germany. By pooling expertise from the School of Forest Science, at place for the classical forestry education, completed with expertise from teachers of other faculties of the University and from external experts, the School managed to compile an interdisciplinary spectrum of courses, which, in the end, have one common goal: training of skills required for achieving sustainability in real-world resource systems. As a result, the International Master of Science (MSc) Programme in 'Sustainable Resource

Management' (SRM) was implemented at the Technische Universität München in 2001. Furthermore, the organisers took the opportunity to offer special courses that deal in particular with systems thinking, systems analysis and system dynamics with the goal to put these kinds of knowledge and skills at the centre of the education. In the following chapters we will discuss the structure of the SRM program and the traditional education at the school in relation to system thinking and system dynamics. We will give a short overview which kind of system dynamics models are currently in use and which are available for various educational purposes in future. Finally, we will share our first years' experiences with the students' attitudes regarding System Dynamics and express our plans we have for the future.

2 The courses

2.1 Sustainable Resource Management (SRM)

The general objective of the international MSc program is to prepare students, who already possess an eligible academic degree, for professional work in the various fields of resource management that addresses all kinds of natural resources like water, air, soil, plants, and wildlife as well as land use management and human resources.

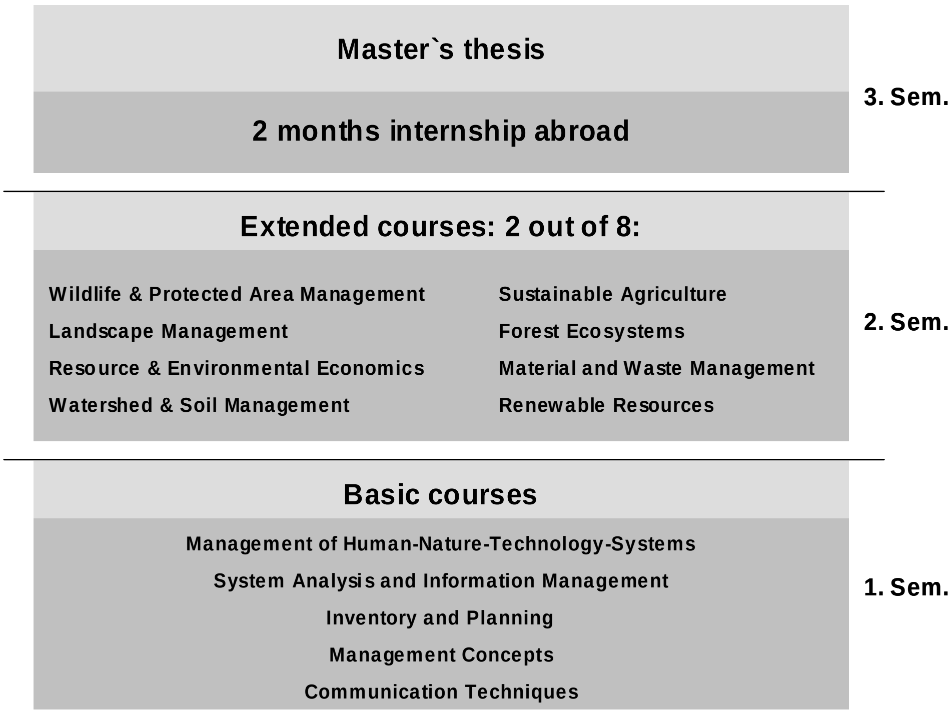

Fig. 1. Structure of the MSc course Sustainable Resource Management (SRM) at the School of Forest Science and Resource Management, Technische Universität München.

This requires an interdisciplinary and integrated teaching programme that provides the systemic understanding and skilful application of important concepts, tools, and techniques in resource management including important 'soft' skills for professionals like rhetoric, conflict management and moderation. These special management skills will increase the capabilities of the Graduates to solve natural and human resource problems in their own way and appropriate to their own cultural and natural environment. The goal is that graduates learn to design and implement management regimes for sustaining high-productivity use to meet real human needs in that way that it is done sufficiently and reliably, efficiently and appropriately, justly and enjoyably. Moreover, the education in this program takes the students beyond the boundaries of the traditional disciplines such as forestry and agriculture.

The MSc program is designed for 3 semesters (Figure 1). If required, the students can participate in an optional preparatory course which provides orientation and add-on language skills. The first semester requires the attendance in a series of five basic courses dealing with concepts and techniques of resource management. These courses include a) Management of Human-Nature-Technology-Systems, b) System Analysis and Information Management, c) Inventory and Planning, d) Management Concepts, and e) Communication Techniques. During the second semester the students have to chose two elective fields out of eight fields of specialisation which are a) Wildlife and Protected Area Management, b) Landscape Management, c) Resource and Environmental Economics, d) Watershed and Soil Management, e) Sustainable Agriculture, f) Management and Protection of Forest Ecosystems, g) Material and Waste Management, and h) Renewable Resources. The third semester is dedicated to prepare the master thesis. The programme is accompanied by field trips and case studies, and it includes an internship in another than the student's home country.

Starting with about 20 students from 6 countries in the first year, 76 new students from more than 40 countries in the second year, the MSc-Programme reached its full capacity with about 80 international beginning students in the third year, which seems to confirm the attractiveness of the concept and the lectures.
In three lectures of the MSc-Program the students directly get in touch with SD and integrated modelling: a) "Introduction to Sustainable Resource Management", b) "Systems Analysis and Model Building", and c) "Forest Growth for Resource Managers".

2.1.1 Lecture "Introduction to Sustainable Resource Management"

The lecture "Introduction to Sustainable Resource Management", as main part of the basic course "Management of Human-Nature-Technology-Systems", is designed to be the "red thread" through the whole master course in order to provide basic and theoretical knowledge as well as coherence. Therefore, the aim of the lecture is to define the most important perceptions of sustainable resource management, to show typical properties of biological, social, and technical systems, their combinations and interactions. The lecture ends up discussing examples for actual interdisciplinary problems of resource management and the corresponding efforts to find sustainable solutions.
Each topic is represented by the university's expert scientists and by external experts. One key issue of this lecture is to communicate the value of systems thinking, system dynamics and systems analysis as appropriate tools for a comprehensive interdisciplinary understanding and handling of complex systems that will result in better management strategies for real-world-systems. We intend to provide the basis to qualify our students to be managers or consultants able to solve interdisciplinary problems in the context of sustainable use of natural, human and technological systems.

The goal is to improve the student's systems thinking skills to enable them applying resource management in their home countries based on systems principles. This shall contribute to a wise management of resources for the benefit of future generations as well as the present one and that they produce high yields sustainably. We strive for deepening their understanding of system theory and system thinking, the relationships between structure and long-term behaviour of resources, teach the principles of relationships between stocks and flows, the concepts of feedback, non-linearity and delay. In addition, we introduce important tools and methods, such as causal-loop and stock-and-flow diagrams, and emphasise the role and importance of simulation models in the SD context.

2.1.2 Lecture "Systems Analysis and Model Building"

This lecture is designed to amplify and to consolidate the basic knowledge from the systems dynamics part of the lecture "Introduction to Sustainable Resource Management". The lecture defines the most important perceptions of systems analysis and model building. The value of models in practical decision support and in the process of scientific cognition is discussed as well as examples of different model types for different purposes.

A very important part of this lecture is to delineate the path of abstraction leading from a real system to a mathematical model and its implementation as a simulation tool. STELLA turned out to be our choice as teaching aid for this task. The university's computer laboratory provides computers with a STELLA campus installation that offers students unlimited access to this tool. We give lectures to guide the students how to operate the software. By this way, STELLA is intensively used to explain the most important generic system structures, their typical dynamics and their occurrence in actual biological, social, technical and psychological systems. The exercises with the software shall enable and encourage the students to experiment with self-constructed models. As a part of the examination, students get an assignment to analyse a story containing a dynamic problem and find approaches for solutions using STELLA.

2.1.3 Lecture "Forest Growth for Resource Managers"

As mentioned above, advanced SRM students have to choose two fields of specialisation. One of these fields is called "Management and Protection of Forest Ecosystems". Here we communicate the basic static and dynamic properties of forest ecosystems, and the most important sustainable forest management concepts on landscape level or above to future decision-makers.

The lecture "forest growth" offered by the chair of forest yield science is a part of this elective field. It teaches driving forces and biological laws of forest growth, how to steer forest growth, and how to transform it into specific forest products.

2.2 Bachelor, Master, Diploma in Forest Science

The classical and traditional qualification offered by the school is the education in Forest Science on different levels: Bachelor, Master, and Diploma. Traditionally, its main focus is to educate forest managers on enterprise or larger level (> ~5.000 ha) and forest scientists of all specialisations. In the past decades, the study programmes have been revised several times to adapt to changing needs; the last revision has been done in 2000. Nevertheless, this education has always necessarily been very comprehensive, as forest managers have to act all along in the biological, technical and human dimension at the same time. Here we identify the greatest potential benefit of systems thinking and SD in education. This recently attracts very different kinds of students. Contrarily to the situation ten and more years ago, most of the today students don't want to work in classical forestry from the beginning of their studies but chose to study forest science anyway, because they feel to be qualified for a large variety of professions from applied ecology to pedagogics.

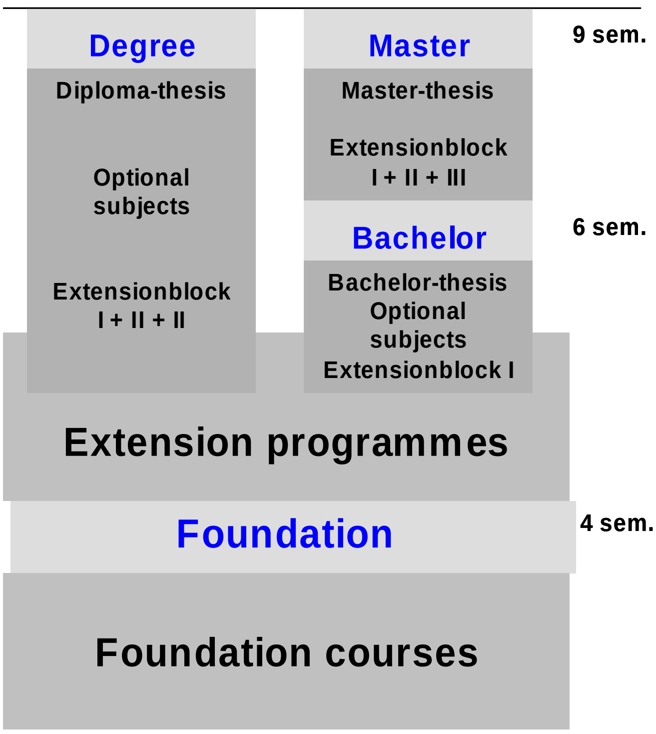

Fig. 2. Structure of the Forestry Education at the School of Forest Science and Resource Management, Technische Universität München. Degree: Diplom-Forstingenieur (Univ.) in Forest Science, Bachelor of Science (BSc) in Forest Science, Master of Science (MSc) in Forest and Wood Science.

Depending of the degree aimed at, the study programme in forestry is designed for 9 semesters (fig. 2). The first four semesters consist of the foundation courses, which deal with a) general basics of natural and social sciences, b) natural-scientific, and c) social-scientific basics of forest science, and d) basic aspects of forest production and technology in forestry. From the fifth to the sixth semester, we operate obligatory extension programmes, where the knowledge from the foundation courses b) to d) is deepened in order to reach a professional level. Parts of the sixth semester are already open for students to choose extension blocks from a large range of possibilities, such as International Forestry, Nature Protection, Land Use Planning, Dynamics and Management of Population, Forest Enterprise Management, Geographical Information Systems, Methods of Wood Science and many more. Depending of the degree one or three extension blocks have to be chosen and a thesis has to be prepared. There is also room for attending optional subjects. Regularly the education is finished within 9 semesters (Master, Diploma) or 6 semesters (bachelor) respectively (Figure 2).

Before the last revision of the study programme in 2000, the numbers of beginning students oscillated around 50 per year. Since 2000, the beginning student numbers steadily increased from 48 in 2000 to 100 in 2003. Issues related to modeling and SD are directly dealt with in the lecture “Forest yield Science”.

Lecture “Forest Yield Science”

In the framework of the classical forestry education, the Chair of Forest Yield Science offers a lecture called “Forest Yield Science”. Its purposes and contents are similar to the lecture forest growth offered in the resource management framework, but the knowledge communicated here is much more detailed as it is aimed at qualifying people who directly have to manage a forest. The lecture consists of two parts, where the first belongs to the foundation courses and the second to the extension programmes.

It focuses on understanding which driving forces and biological patterns produce the typical dynamics of single trees and forest stands. Furthermore, we instruct, how, in quantitative terms, these dynamics can be influenced by silvicultural management. As forest growth models play an important role in this context, students learn to know, which main types of such models are existing, which purposes they are serving, how they work, and how they can be constructed. In a practical part of the lecture, students perform management scenario simulations for different forest stands with the forest growth simulator SILVA (Pretzsch et al. 2001), where they learn to handle such a model in practice, and at the same time deepen their understanding of forest dynamics.

3 Available models

3.1 Models currently in use

3.1.1 Simple model games for teaching important system archetypes

In the practical part of the lecture Systems Analysis and Model-Building, students learn to know some of the very important system archetypes by practice modelling in the STELLA environment. We start with exponential growth and asymptotic decay, proceed to their interactions, which leads to s-shaped growth and overshoot and collapse patterns. Furthermore we introduce system structures producing oscillation and main chains. When introducing a system archetype, we always try to connect it to a very striking example, e.g. exponential growth is developed by example of a bacteria population starting to grow with –for the time being- unlimited resources. When the typical process-generating pattern has been made clear, we show, again by examples, that basically the same structures generate the same process in very different real world systems, from biology to economics to psychology. E.g. for many students it seems to be a new perplexing insight, that constant relative growth rates for economy –as postulated by most politicians- are absolutely impossible on the long run, as this would mean unlimited exponential growth.

When these subjects have been understood by the students, they are already able to solve somewhat larger problems on their own. As a part of the examination they have to do an assignment, where a resource management problem is presented as a story; in the story, there is always a client, who has the problem, and the student act as the consultant. The story has to be analysed carefully in order to identify the important structures of the system. Then, it must be step-by-step transformed into a model using STELLA. This model must be used to answer some questions related to dynamic problems. Finally, the students have to write a short report for the client, where they have to express their own view of the problem and show possible solutions.

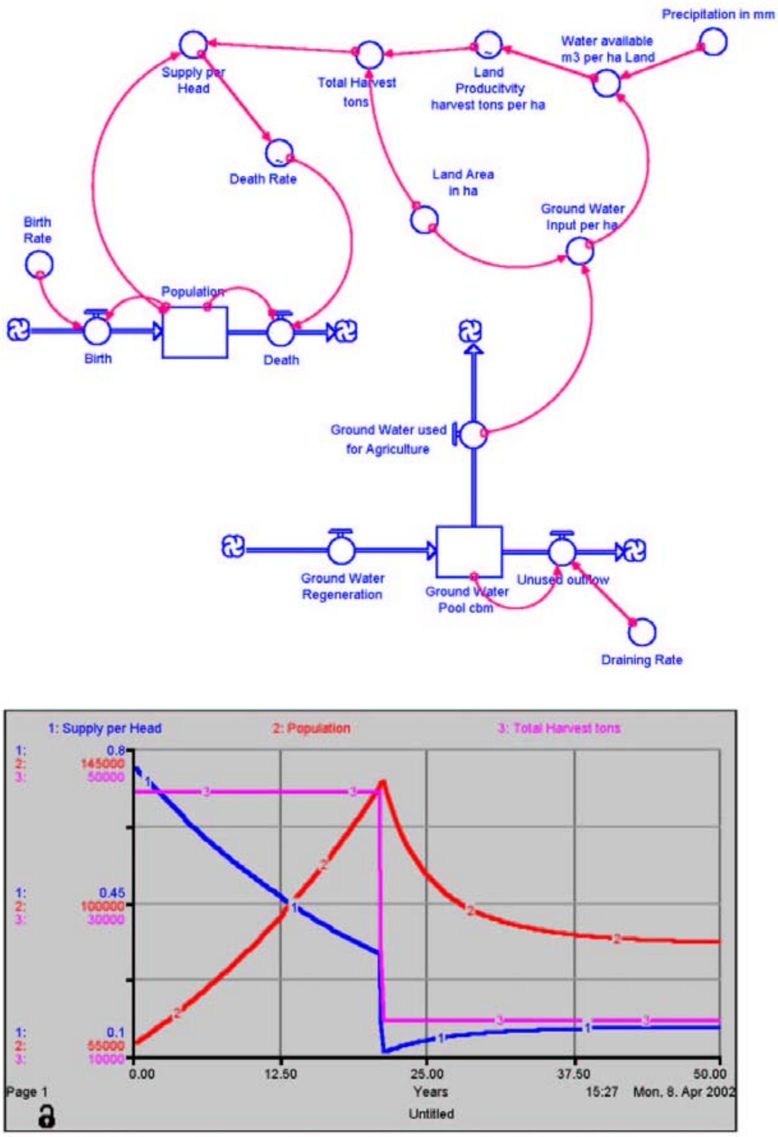

Fig. 3. Constructing a model for population dynamics in the fictive country Nabakoumaland as a task of examination in Systems Analysis. In the scenario shown, unwise use of ground water resources causes first exponential population growth, then a drastic breakdown due to famine.

As an example, the 2001 story introduced king Nabakouma III, absolute ruler of a fictitious small and poor country in Africa. Nabakouma III wants to enhance prosperity and welfare for his country and people by utilising a newly discovered underground water reservoir for large-scale irrigation of their fields. World bank announced financial support, but demands a professional advisory report. With an appropriate model (Figure 3), one can show, that only a very thought-out water management regime together with birth control policies can improve life conditions and prevent a catastrophic overshoot and collapse pattern in the population dynamics.

3.1.2 Normal Forest Model NORMFOR

In the Lecture 'Forest Growth' for the SRM students learn about the so-called 'normal forest model', and we developed the STELLA-based model NORMFOR to demonstrate the idea of the 'normal forest', its typical dynamics and the possibilities to move a real forest towards the ideal state of 'normality'.

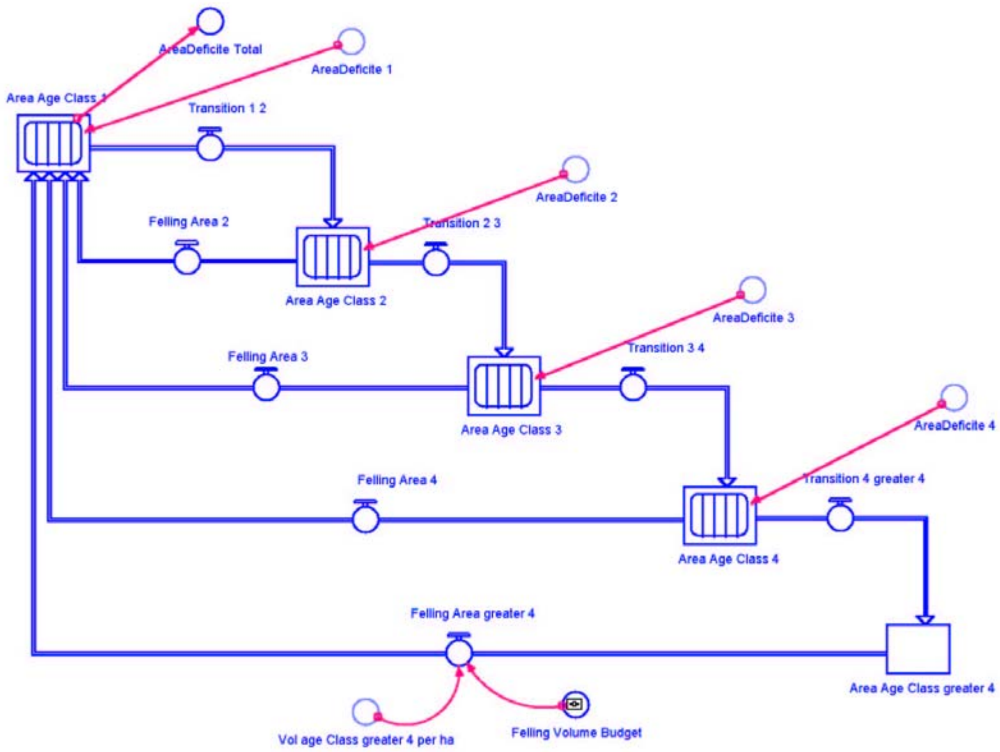

Fig. 4. Main structure of the Normal Forest Model NORMFOR. Stocks represent the areas occupied by respective forest age classes, flows represent the sequential transition of forest areas from age class to age class and the sudden transition to age class 1, when an area is clearcut and replanted. Note that most converters are 'ghosts'; their calculation is not shown in this diagram.

The 'normal forest model' is a mental model, every professional forester carries in his/her mind. In its basic form it had been invented and already formulated mathematically by Hundeshagen (1826) and Heyer (1841). It still forms the backbone of sustainable forest management worldwide. A 'normal forest' is a forest in a larger area, which is in an ideal state of perfection under sustainable management in the strictest sense (Assmann 1961, Ostmaston 1968, Speidel 1972). This ideal state is a dynamic equilibrium where the forest delivers continuously the same yield in terms of quality and amount. Annual increment, growing stock, annual harvest, yield and expense are constant. Forest scientists developed many indices, which quantify the deviation of 'normality' for an actual forest. In addition, a whole set of indicators is available -and obligatorily used by foresters- which are used to derive a felling budget which moves a forest from its present state nearer towards normality. In practice, this is an iterative

process, which is often disturbed by unforeseeable events. Thus, true normality is never reached, but the normal forest model guarantees, that this exemplary state of perfection never gets out of scope.
In the model, a normal forest is defined as a set of forest stands, where each stand age is represented on the same area. Each year, the oldest stand is always cut and immediately replanted. In this idealised forest, Except for age, everything else, like tree species, site conditions, etc., is the same and constant over time.
In NORMFOR, each area covered by a forest at a special age (class) is represented by a stock. These stocks are sequentially connected by flows, which force the transition of areas in higher age classes as time passes by. Each age class has a certain wood volume per unit area, so, transition of an area from one age class to another is connected with an accumulation of wood on this area. When wood on a certain area is harvested, this area is considered as to be replanted and will be shifted to the youngest age class (Figure 4).
Timber harvest is defined by an annual felling budget, which expresses the timber volume to be cut. Cutting starts at the oldest age class and will –sequentially- affect younger age classes, when this is necessary to reach the felling budget.
For the sake of simplicity, the parameters of NORMFOR are set on values, which approximately reflect the dynamics of tropical or subtropical short rotation plantation tree species, such as certain eucalypts. The model includes four age classes each covering a span of five years and one age class, which contains everything older. The whole model forest area amounts to about 100 ha.

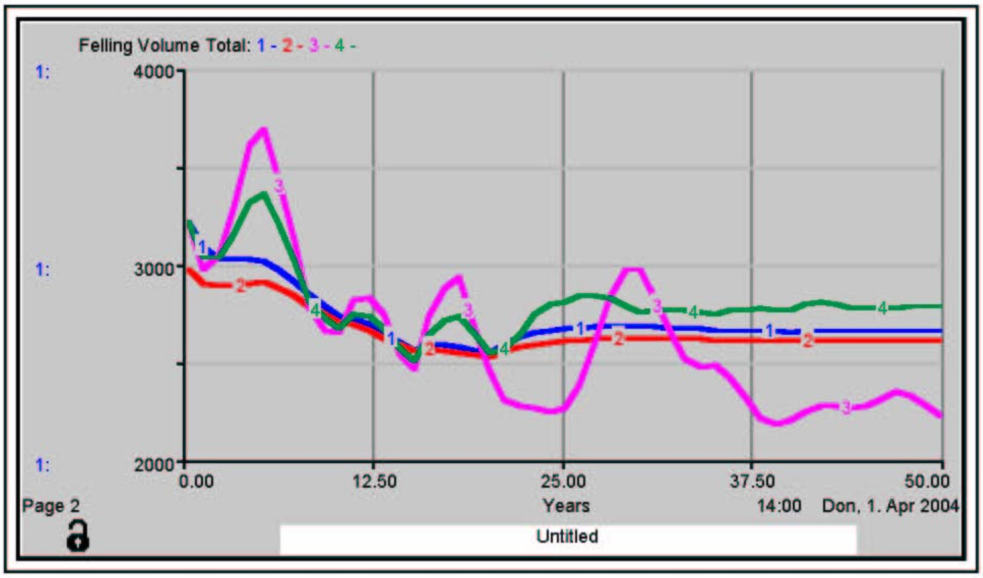

Fig. 5. Scenario runs with the Normal Forest Model NORMFOR. Development of felled timber volume in a virtual forest enterprise controled by different felling budget indicators. Although adjusted for aiming at the same equilibrium point each indicator produces a different level of steady state.

Before running the model, the user must define the start frequency distribution of the age classes and a constant annual felling budget. After some time, the forest will reach normality, but its key parameters, annual volume increment and total standing wood volume will stabilise on very different levels. As an alternative to setting a constant felling budget, the model user can also choose one of five common forestry felling

budget indicators (cf. Speidel 1972) to be applied iteratively at each time step. These indicators use different methods to calculate a felling budget based on information about the forest, e.g. total standing wood volume, current and past wood increment, desired time period to achieve normality. It can be demonstrated, that the different indicators don't perform equally well depending of the start situation (Figure 5). While each of the indicators finally leads to a normal forest, the desired normal standing and regularly felled timber volume and increment level are often missed significantly.
While, classically, the normal forest model is being taught as a set of mathematical equations, its main consequences can be made clear more quickly via simulating with NORMFOR. The strength of the model is, that it is a valuable teaching aid to put across the core concept of sustainable forest management worldwide. Understanding this concept is absolutely essential for resource managers, when they are concerned with forestry issues.

3.1.3 Forest Growth Simulator SILVA

The forest growth simulator SILVA (Pretzsch et al. 2001) is a tool, which allows to simulate forest development for mixed and pure, even- and uneven-aged forest stands under a large variety of silvicultural concepts. When the first version of the model was constructed end of the 1980s, the main purpose was to support forest management decisions from the point of view of multi-criterial sustainability, but we increasingly recognized SILVA as an ideal tool for teaching forest dynamics and its feedback structures with management issues.

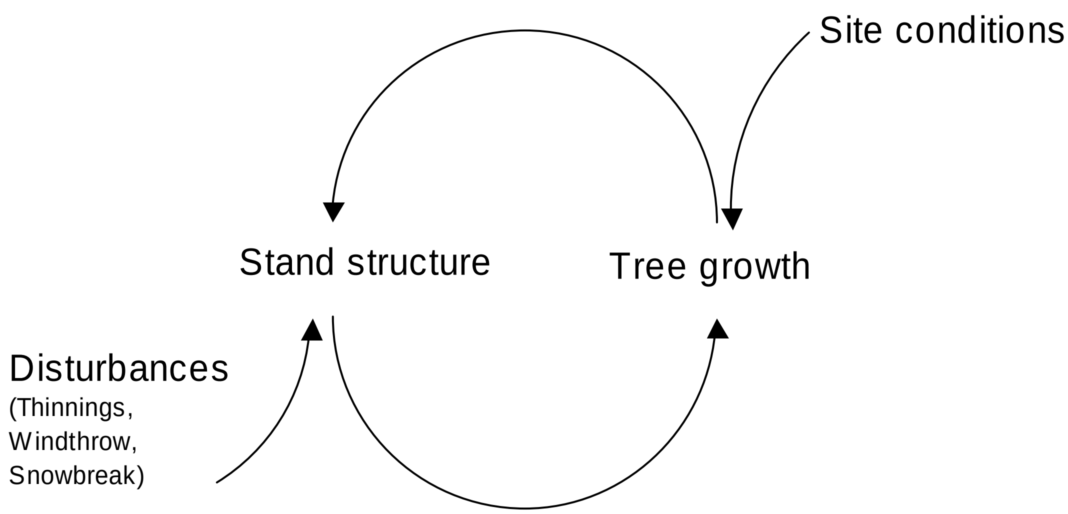

Fig. 6. Coarse cause effect-structure of the forest growth simulator SILVA.

In the simulator a forest stand is a set of single trees whose coexistence is modelled as a spatial-temporal dynamic system. Compared to traditional tools, already the coarse cause-effect-structure of SILVA (Figure 6) is based on an enlarged dynamic understanding of forests. Thus, the increment of a tree results from the site conditions, the present state of the tree, expressed through crown dimensions, and the spatial structure of the stand, expressed by the three-dimensional space utilisation of the single trees. This stand structure results in a specific spatial growth constellation for each single tree, which more or less reduces its growth. Changes of this structure, due to

thinnings, growth or mortality, consequently change growth constellations and therefore have a significant impact on the further development of the trees, the stand and its structure. Figure 7 illustrates the sequence of steps in a simulation run with SILVA.
Forest stands are dynamic systems, which are steered by strong feedback effects. Exactly these feedback mechanisms are utilised by foresters when they remove trees in order to steer the development of the remaining stand and to generate revenues. As SILVA explicitly models these feedbacks, the simulator has proven to be a very effective tool for simulating the dynamic response of forests to a large variety of management scenarios.

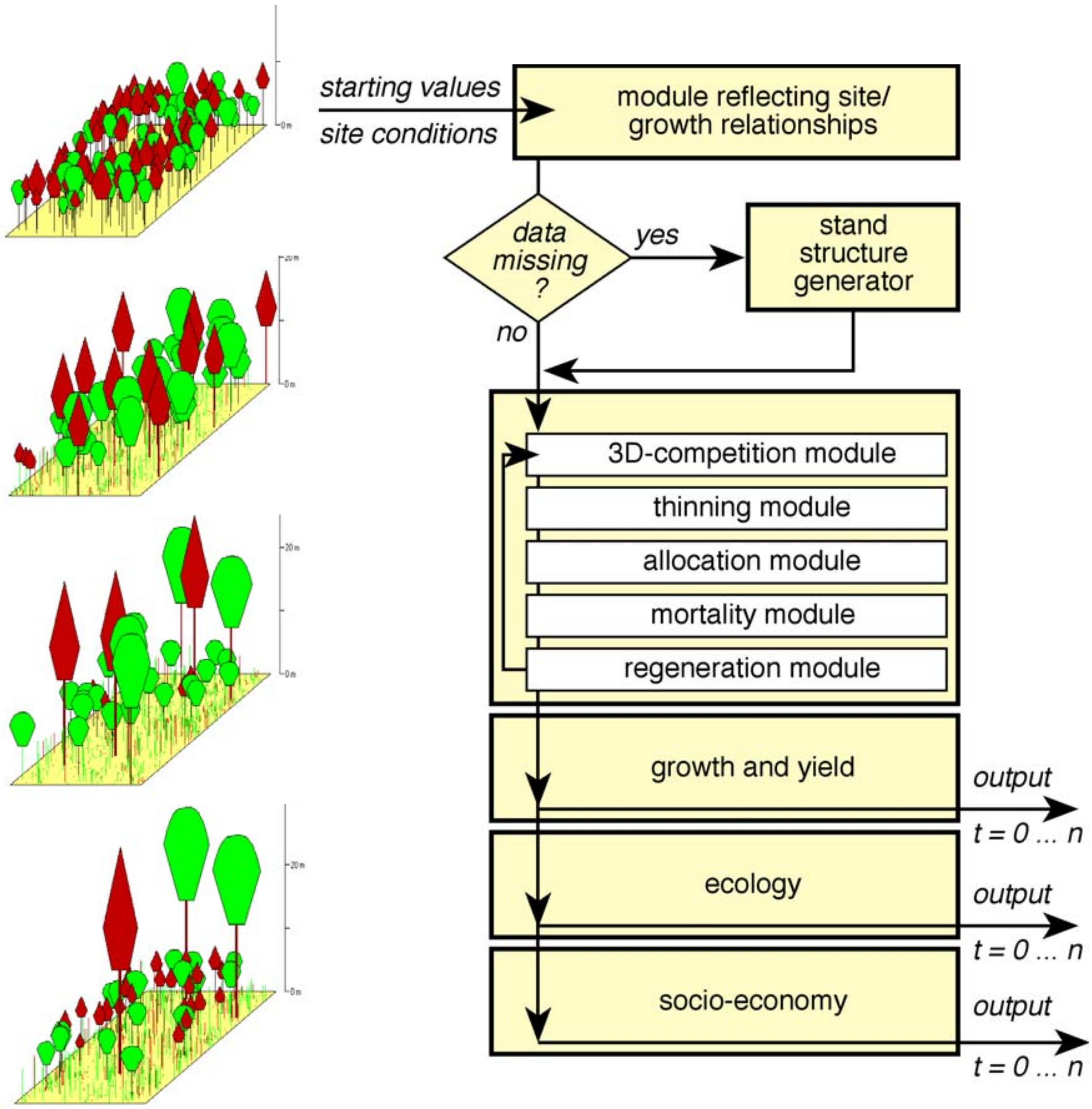

Fig. 7. Forest growth simulator SILVA: flow-chart (right) and forest stand development simulated over 100 years (left).

SILVA is no so-called mechanistic model, which explains tree growth starting at the level of physiology. Single-tree growth in SILVA is described as the change of dendrometrical variables as diameter in breast height, total height, crown diameter and length. The driving variables are highly aggregated; such as there is e.g. a single index for soil water supply. Competition among trees is described by geometrical methods. The growth equations driving the model are fitted empirically based on a unique data set from long-term research plots partly covering a time span of more than 100 years. Nevertheless, biological plausibility never came out of view when formulating the model equations. The input data needed for using the model is constrained to information, which is accessible for forest managers from their standard site classification or regular inventory. The output covers a large range of information covering timber production as well as economic and ecologic issues (Biber and Weyerhaeuser 1998, Pommerening et al. 2000). Thus, the simulator provides information and generates results, which can be used to assess sustainability from a multi-criteria point of view. The simulator is not limited to small forest areas. Data from large-scale sample forest inventories can be used to perform scenario calculations on large regional level (e.g. Biber et al. 2001). Due to the broad range of information provided by SILVA and due to its biological plausibility, it has played a key role in the interdisciplinary sector study "German Forest Sector under Global Change" (Lindner and Cramer 2002, Pretzsch and Ďurský 2002)
Students come in touch with SILVA mainly in the courses related to forest science, where they intensively work with the model. But we also present SILVA as an example for a management-related dynamic model in the lectures 'systems analysis' and 'introduction to sustainable resource management'.

3.2 Models considered for future application

The models shown in the following chapter are readily available and can in our opinion contribute to a great deal to transporting problem-specific and SD related knowledge. In the framework of UNESCO's 'Man and Biosphere MAB' program and national research activities in the 1970s and 1980s some of the integrated projects incorporated model-building activities, which aimed in the construction of large integrated, socio-economic, ecological models. From these activities and additionally from international trainings courses, mostly organised from the German Foundation for International Development (formerly DSE and nowadays INWENT), a remarkable set system dynamic models have been developed. Most of these models are described in research reports, technical reports, scientific papers and other media, at least a complete documentation of the source code is available (e.g. Grossmann et al. 1993). These models are of particular value for the system dynamics knowledge and model base and in particular for education from various points of view. Firstly, they represent important examples of applications of system dynamics models of real-world systems at regional or community level; secondly they principally allow a review of the predictive capabilities of the models as time progresses and the modelled real systems evolved; thirdly they embody the state-of-the-art in system dynamics modelling of that time that seems to be of equal importance nowadays. Fourthly, they are valuable teaching and learning models to get acquainted with more complex models than the small ones usually supplied with system dynamics tutorial material. Mostly, it is necessary to transform the models into up-to-date simulation environments like STELLA, which is a good training for beginners and advanced modellers.

From this pool the following models were selected for introduction in this paper:

Proto – National Model with Extended Forest Sector (Grossmann 1994)
The model depicts the interaction between a national economy and the forest sector (Figure 8).

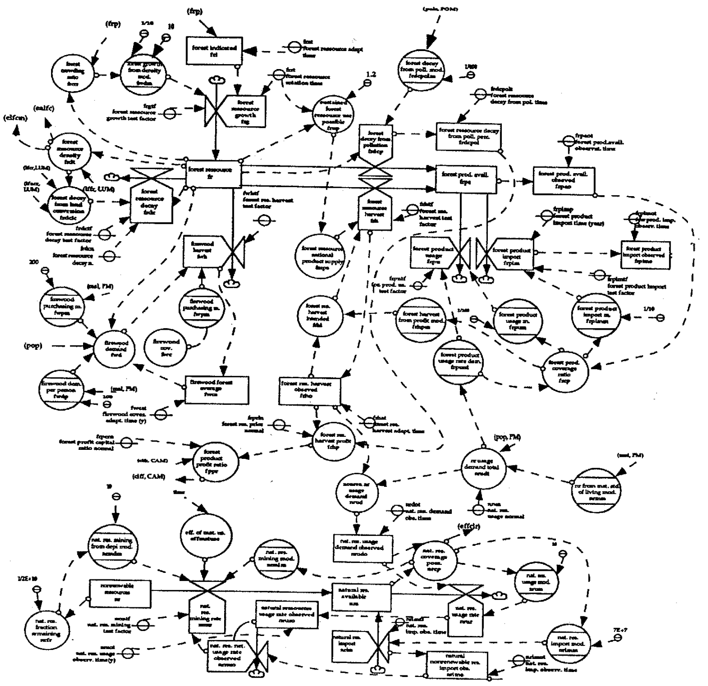

Fig. 8. Stock-and-flow diagram of the forest sector part of the model Proto. This model is completely documented (Grossmann et al. 1993).

It also includes a renewable and a non-renewable resource sector, a sector with four land use categories, a food sector (as energy equivalent), an economy sector, and a pollution sector. Although, it had been applied and modified by other groups, nowadays, it would need considerable adaptations to new insights in e.g. economical development. Nevertheless, it is well suited for training purposes and as a starting point for modelling similar problems.

SECENG - Forest Damage by Secondary Pollutants (Grossmann 1991)
The model deals with the problem of forest die-back caused by secondary pollutants and it explores the most probable reasons for this phenomenon. It reproduces the impacts of secondary pollutants in synergistic combination with SO2 and NOx studied in the area of the 'Rosalia Lehrforst', a forest demonstration centre of the BOKU - University of Natural Resources and Applied Life Sciences, Vienna, Austria. The model contains the stock and flow structures for pollutants (NOx, SOx, VOC), biomass of the forest stand, and biomass of the tree foliage (Figure 9). Damage is modelled as total impact by pollutants affecting foliage biomass. The model was linked to risk maps for forest damage produces with geographic information systems (GIS) to compare model results with field data. This approach has been applied in other projects (cf. Grossmann and Schaller 1986).

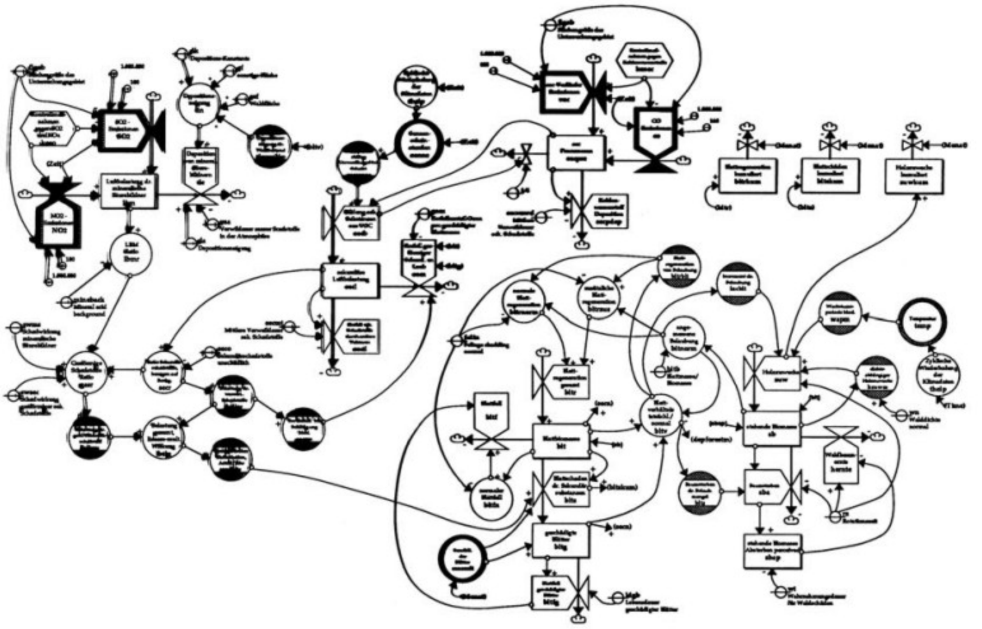

Fig. 9. Stock-and-flow diagram of SECENG. This model is completely documented (Grossmann et al. 1993) but not transferred to up-to-date modelling environments yet.

Agroforestry Village Community in Gebang, Java, Indonesia (Grossmann 1998)
The purpose of the model is to simulate the agroforestry scheme of a village community in the long run with respect to food production, income from forestry, and development of the village population. Therefore, the model allows assessing the sustainability of different types of agroforestry systems and of population policies. Figure 10 shows the Meta-structure of the model and the interactions that have been established between the following sectors: forestry, agricultural crops, commercial fruit and wood production, population, income, and food demand and supply. Figure 11 shows the results of a scenario run with the agroforestry model.

4 Experiences

At the end of each semester the students give their opinion about the quality and relevance of the lectures. The students' response shows that the lectures and courses teaching systems thinking and systems analysis belonged to the ones that are most appreciated. In general, we experience our students to be very open-minded for SD and modelling issues. Many are very interested and try to keep on track with SD also beyond the normal lectures and consider its methods as important tools in their coming professional career. Some resource management students already started their master's thesis addressing problems that require SD application. Not surprisingly, students generally like STELLA as a valuable and useful tool, which allows to construct executable computer simulation models and test ideas without being too familiar to the inherent mathematics. Also, from the teacher's point of view this tools allows us to interest far more persons for modelling and SD than we could reach with a pure difference-equation-based teaching concept.

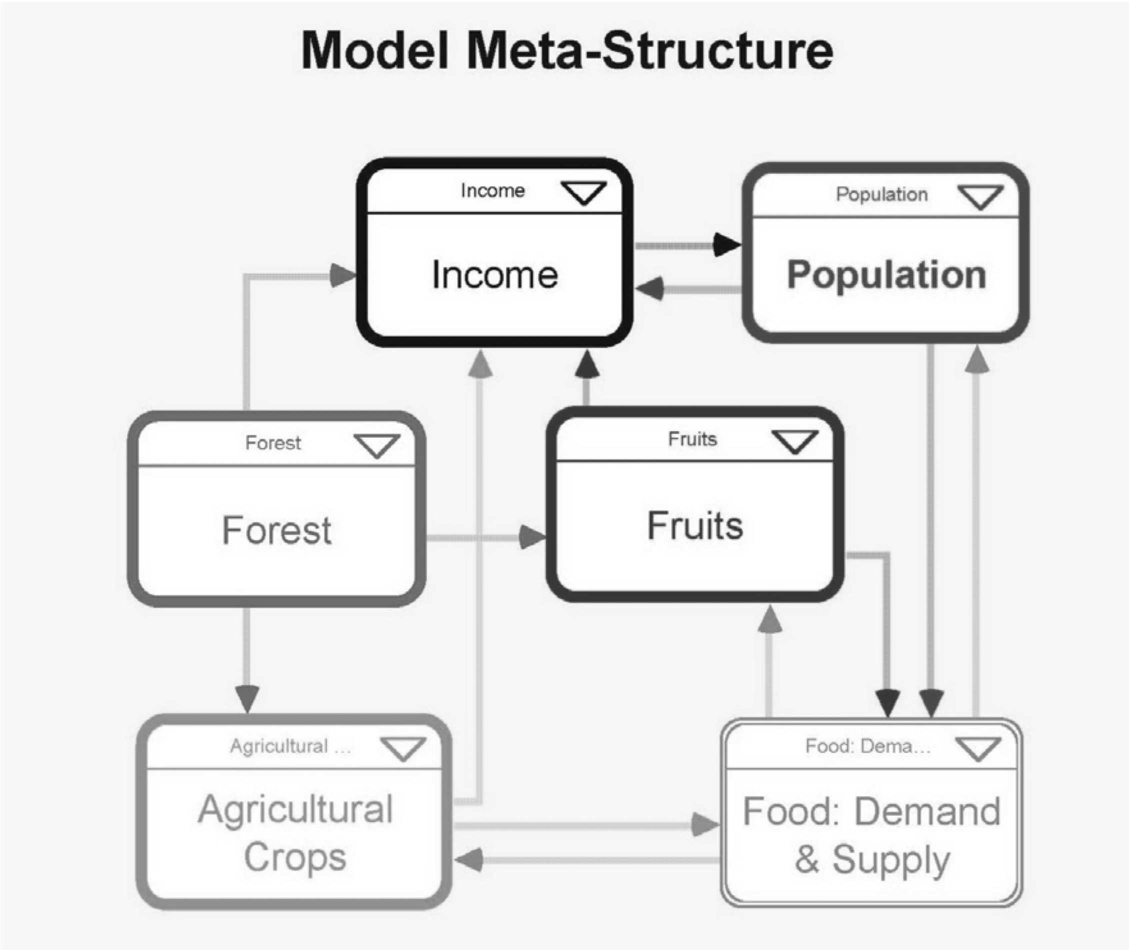

Fig. 10. The sector structure of the Agroforestry Village Community model prepared with the software STELLA.

However, the apparent easiness of handling models with STELLA often conceals two common misunderstandings among students. Although repeatedly instructed and highlighted in the lessons, when revising the exams, which include similar questions as proposed by Booth Sweeney and Sterman (2000) and Sterman (2002) as ‘Bathtub Dynamics Tasks’, we find out, that there is also a considerable lack in understanding the basic concept of stocks and flows in a considerable portion of the students. The results correspond well with the experiences published by Booth Sweeney and Sterman (2000). In winter semester 2003/2004 only 34 out of 68 examinees gave fully correct answers to the bathtub task presented in figure 12 (see also figure 13). Regarding ‘Bathtub Dynamics’ we plan to apply the same tasks and procedures as proposed by Booth Sweeney and Sterman to test our future students. As the test group is very heterogeneous, we hope to contribute a very interesting sample to the Bathtub Research (cf. Kapmeier 2004)

Another misunderstanding often heard when discussing with students, is the opinion, that the ability to operate STELLA already makes a professional modeller and problem-solver, while we try put across, that such software is nothing less but nothing more than a very helpful tool. Despite such misunderstandings of some students, we experience a rising demand for SD issues from highly motivated students, who consider to do their master thesis using SD methods. As personal resources are limited, we cannot satisfy the accelerating demand at the moment by only the small number of modellers, which is currently teaching them. Due to the high degree of interdisciplinary in forestry, we see a great potential to enlarge the group that applies SD and modeling methods in their special field of teaching.

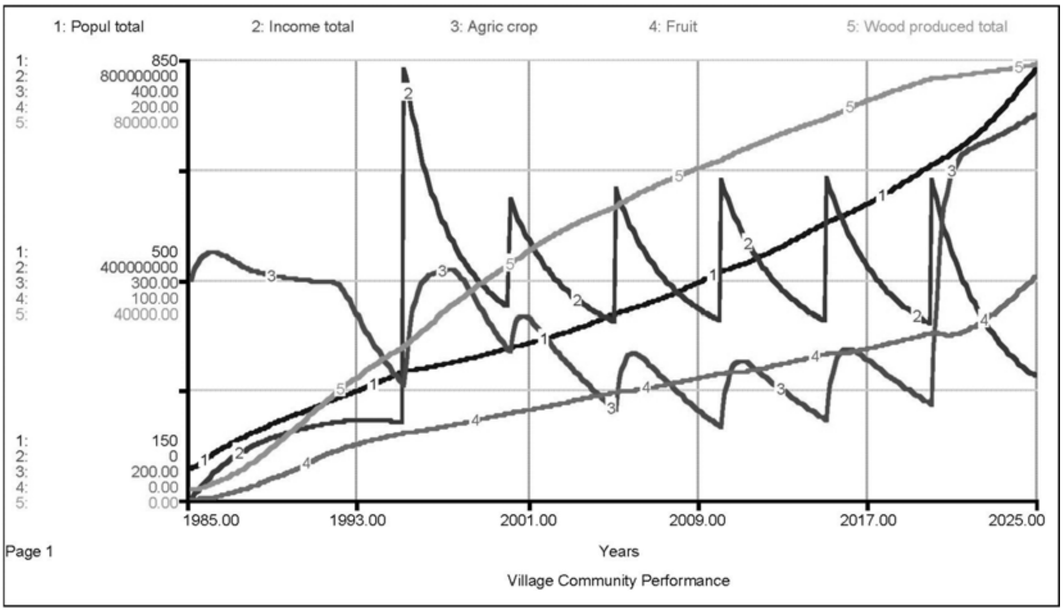

Fig. 11. Performance of the agroforestry village community with high birth rate policy.

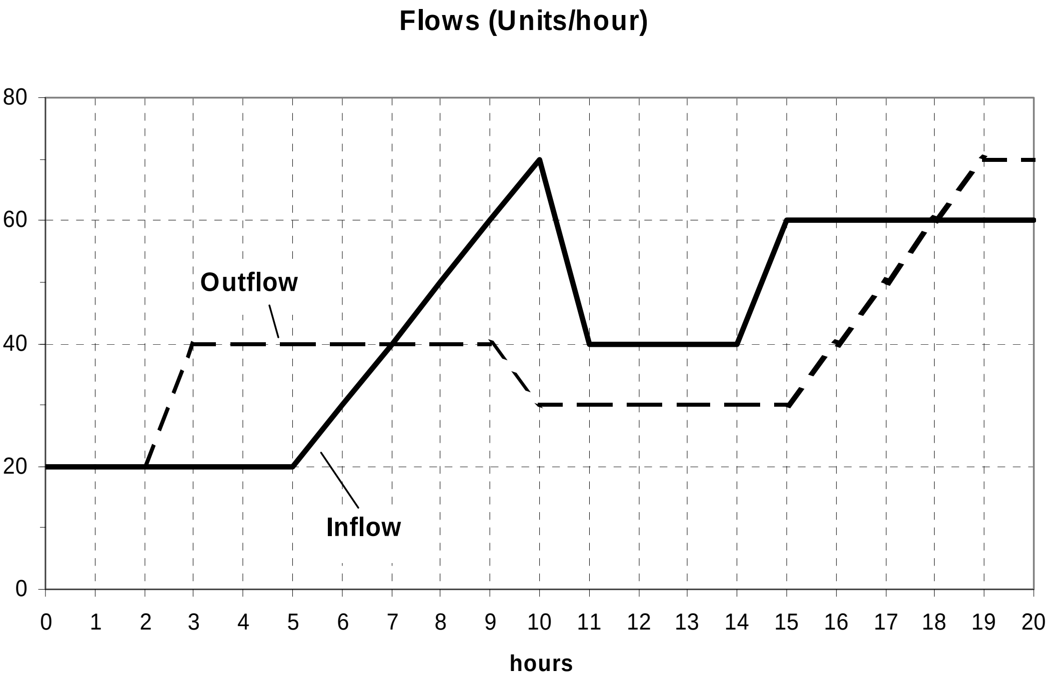

Fig 12: 'Bathtub Task' used in an exam in winter semester 2003/2004: Consider a stock with an inflow and an outflow. Calculate and draw the values of the stock for each time step. The initial value of the stock is 100 units.

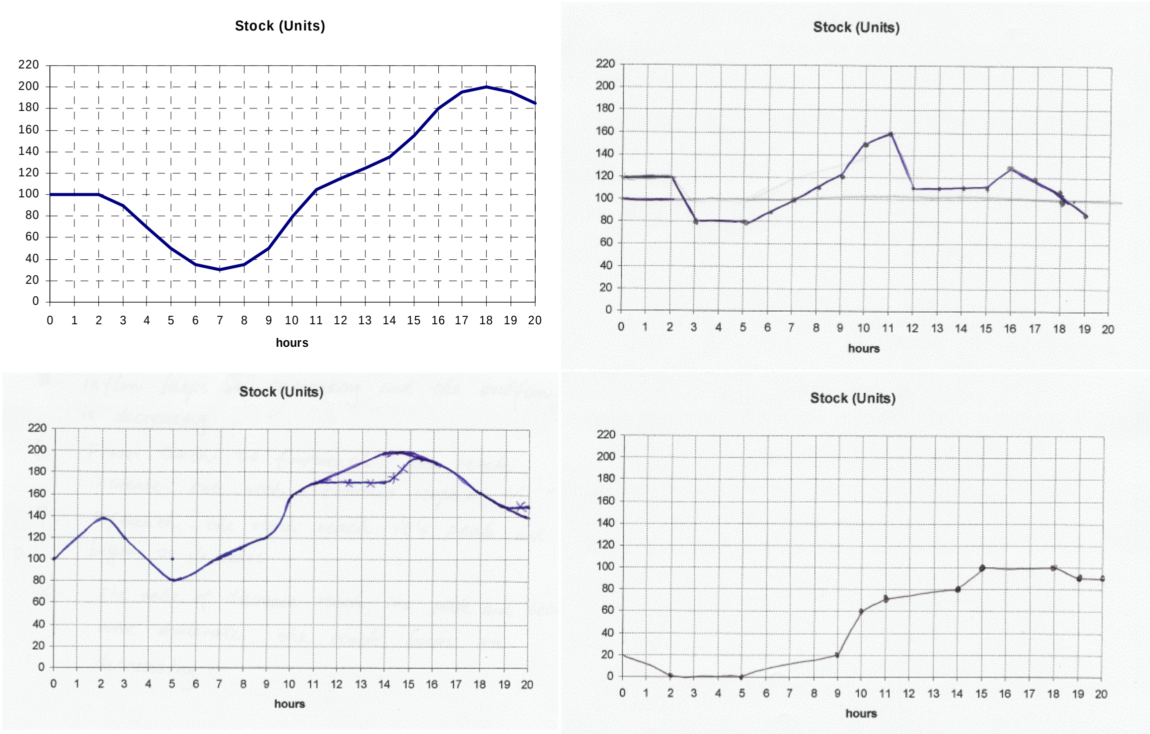

Fig. 13: Typical student’s responses to the bathtub task given in Fig. 12. Top left is the correct solution, the other solutions are errorneous.

5 Conclusions

The concept to put a strong emphasis on systems thinking and system dynamics into the education of the international MSc program for Sustainable Resource Management seems to be a successful strategy as other international MSc programs at the University, which also started in 2001, could not gain the same popularity and student enrolments as SRM. From our point of view, SD and integrated modeling are very valuable tools for the students and also for the later professionals. We see many promising possibilities and also the need for extending its application in teaching at our school, in forestry as well as in resource management. Clearly, progress can be only made step by step. We are neither competent to teach all subjects -we can only show obvious and possible interdisciplinary links- nor would our teaching time budget allow for that.

We are rather counting on a market process: our teaching must simply be very good in order to raise student’s demand for getting more in contact with SD and related modeling in other subjects. This should, on the long run, have effect on the supply side. A promising step has just been done: the bachelor programme in forestry is currently being revised and a whole teaching module has been dedicated to Systems Analysis and Modelling, partly due to the successful implementation of systems thinking and system dynamics in the SRM programme. We also hope, that, on the long run, our efforts contribute to increase the international community of highly qualified systems thinkers and system dynamicists. We see ourselves at the beginning of a promising process and would appreciate to get advice and support from the System Dynamics Community.

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