FORECASTING AND ESTIMATING ENVIRONMENTAL CHANGES ON A REGIONAL BASIS

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1. INTRODUCTION

During the 10 years of its existence IIASA traditionally accorded much attention to socio-environmental interaction processes. Considerable progress has been achieved in the implementation of the Balaton project and in the theory of water and air pollution.

The experience gained by IIASA in these fields provides a fundamental basis for the use of relevant techniques for tackling the existing problems of socio-environmental interaction. The prospects of socio-environmental interaction are nowadays regarded as one of the major problems facing the international community since many kinds of man's activities result in the deterioration of the environment. Deforestation, water and soil deterioration, and desertification have already reached a level that can no longer be ignored. Changes in the atmosphere, including changes in the ozone layer, the increasing concentration of CO_2 and acid rains, sea pollution, and toxic wastes, seriously endanger the sustainability of the environmental system.

The integration and the growing interdependence of modern society and the ecological components of the planet Earth determine the global character of the environment preservation problem. The importance of the latter is emphasized by the fact that nearly all of the existing industrial and agricultural technologies eventually cause environmental deterioration. Future technological development, therefore, should provide for the rational use of renewable resources and a transition towards sustainable socio-ecological interaction patterns.

The definition of an ideal socio-ecological system should be based on the comparative analysis of alternative policies of socio-ecological development. So far two approaches have been suggested in this respect. The first one is to formulate a scenario of socio-ecological development with regard to observed trends in history. The second is concerned with the use of modelling techniques to obtain the quantative estimates of the flow intensity between the various components of the environmental system and to define a set of alternative policies in quantative terms. Evidently the latter approach has more advantages.

The alternative case study involves the assessment of the projected outcomes of the alternative policies and selecting the best one among them, which serves as the basis for formulating a set of policy goals in terms of quantative measures and, more generally, for decision making.

The decision making procedures, however, cannot be fully formalized in view of the complexity of the socio-environmental system. It is therefore necessary to develop a man-machine system that would include an environmental model as a tool for policy analysis, and a team of experts that would analyze the projected outcomes of the alternative environmental policies and select the best one among them.

The modern theory of environmental modelling faces a serious dilemma. The models of the past which described the behaviour of the environment in qualitative terms, are nowadays often considered oversimplified. Considerable effort today is devoted to the development of a more detailed numerical model. However, a more complicated system has more degrees of freedom--a fact that has often been neglected by the proponents of the latter approach and causes additional difficulties from the point of view of verification and consistency of the model. A detailed model may prove to be a relevant tool for local analysis, but in a more general case the inaccuracy of the data may lead to a situation where the outcome of the model rather accounts for the cumulative errors in the data than for the actual regulations.

Actually, the problem we are facing is not <u>what</u> models to build, but rather <u>how</u> to build them and for what purpose. A model should adequately reflect the major properties and relations between the components of the ecological system to serve as an effective tool for policy analysis and practices.

Let us note that there exists a distinct relationship between the hierarchy of the processess within a given ecological system and the level of disaggregation and time scale of the relevant socio-environmental model. For instance, a decision to alter the watering schedule in agriculture could play a major role within a small region. The forecasting period in this case should be set equal to the vegetation period of crops (e.g., to one year), while the unit time interval within a model should be about one day since water absorption and distribution within the ecological system take about the same time. Evidently an adequate model, in this case, will have to be very detailed.

In contrast to this, climate changes may take centuries to become perceptable. Therefore, if we are to study the impacts that certain global changes may produce upon climate, be they long term or short term, we would have to consider a period as long as that.

We shall focus on the regional aspects of the socio-ecological changes. Our approach is based on the use of man-machine procedures for estimating and forecasting environmental changes, and implies the use of a simulation model that would reflect the effects of various changes within the socio-economic system upon the locked environment. Past experience in regional development shows that socio-economic changes usually take one to five years, while the corresponding environmental changes may take as long as 20 to 25 years. This is explained by the rates of change in the succession characteristics.

The simulation model must therefore adequately reflect the major trends in environmental characteristics at the regional level. It should also account for the interdependencies and the interactions between the environmental components and the response of the latter to pollution and other direct or indirect effects of economic activities (lumbering, agricultural land use, melioration, etc.). The intensities of response could be assessed as a function of investments in the relevant activity or given by the scenario.

2. THE SIMULATION MODEL

According to Vernadzky (1) an ecosystem may be characterized in terms of its seven major components, namely, energy, air, water, soil, plants, animals and reducent (destructors). Any current state of a given ecosystem, as well as changes within it, may be therefore described quantitatively as a function of the states of these components and the relations between them. This consideration opens the way for designing an integrated model of ecological development of the region, provided that the estimates of the states of the ecological components at any point of time within the scope of the model are known.

We have suggested a method for constructing the integrated indicators that describe the current states of the seven environmental components listed above, using the conventional indicators accepted in geography, soil science, hydrology, etc. These parameters were then used as the basis for the socio-environmental interaction model designed at the All-Union Research Institute for Systems Studies (VNIISI)(2,3).

There are many ways, in which the socio-economic system affects the ecosystem and its components, including agricultural land use, fertilizers, pesticides, industrial use of air and water supplies, destruction and/or artificial cultivation of various plants and animals. However, the most important anthropogenic factor influencing the ecosystem is pollution which, in a general case, includes both chemical wastes and solid particles. The model, therefore, should include pollution as a major variable affecting all the other components of the ecosystem both in terms of its level and rate of change. On the other hand, any comprehensive study of ecological evolution would be incomplete without some reference to the public efforts aimed at maintaining and improving the environmental conditions.

We shall illustrate the operation of the VNIISI model in terms of a diagram (see Figure 1).

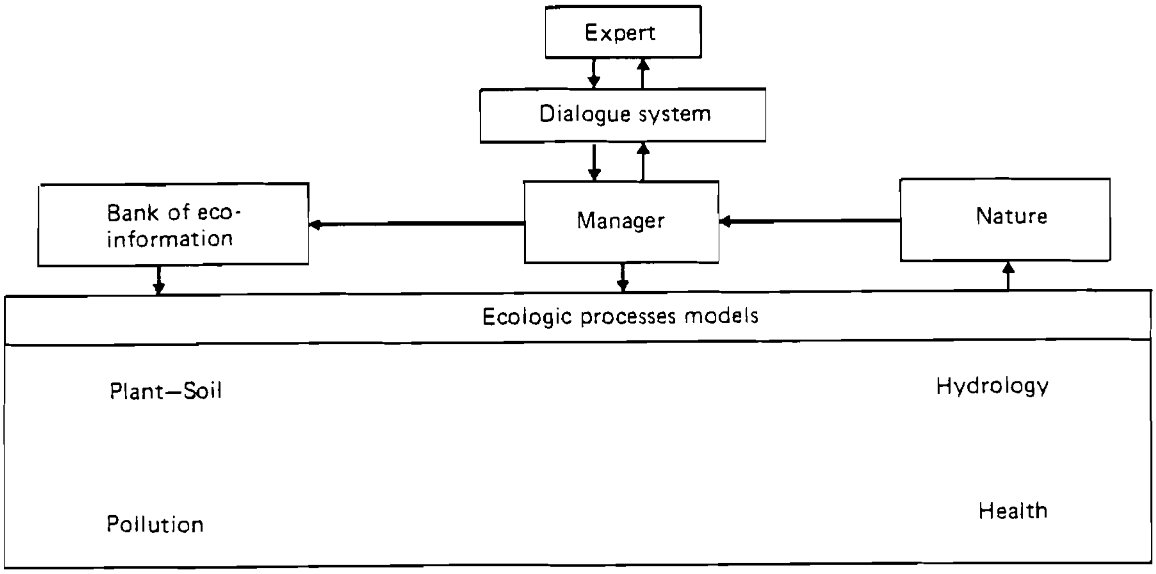


Figure 1. Structure of the system.

The procedure is as follows. First, the decision maker (or a team of experts) specifies the task in terms consistent with the vocabulary of the system indicating the location and the size of the area as well as the scenario version. This input information is then translated into the computer command language and transmitted to the Manager system (a specialized monitoring system). The purpose of the Manager is to locate the specified region, to select the relevant data from the bank of ecoinformation where it is stored, and to transmit this (along with the values of the equations parameters) to the individual sectors of the model. The Manager also carries out the necessary adjustment and verification procedures to fit the sectors of the model to the regional data. The next step is to link the individual sectors of the model into an integrated regional model. This task is also performed by the Manager. The resulting environmental model is then run and its output is transmitted through the Manager system into the dialogue system. This information is then processed and presented in a convenient form for use by the decision maker.

Further steps involve direct interaction of the decision maker with the environmental model. Each question/answer iteration takes about 1-1.5 minutes of the CPU time on the PDP 11-70 computer. The adjustment of the system to a new region usually takes 10 to 30 minutes depending upon the ecological properties of the region in question and the level of disaggregation adopted in the specification of the initial scenario.

The relationships included in the model to describe the ecological processes are ordinary differential equations which reflect the dynamics and the major links between the macroecological parameters. Some insight into the kind of relationship included in the model is offered by the flow diagram (see Figure 2) which represents a condensed version of the soil-plant sector (4).

The package of computer programs (created at VNIISI) may find application for selecting land development policies for areas 10^4 km^2 and more or less uniform soil and climate characteristics within the area over the previous decades.

The scope of the model covers both the direct and indirect effects of economic activity upon the environment. Changes associated with socio-economic development (which are considered in the model) include changes in the amount of biomass caused by lumbering, harvesting, forest cultivation, etc. Also to be considered are pollution (industrial wastes and soil water deterioration caused by the application of fertilizers in agriculture) and improvements in the quality of soil (associated with the use of fertilizers, etc.).

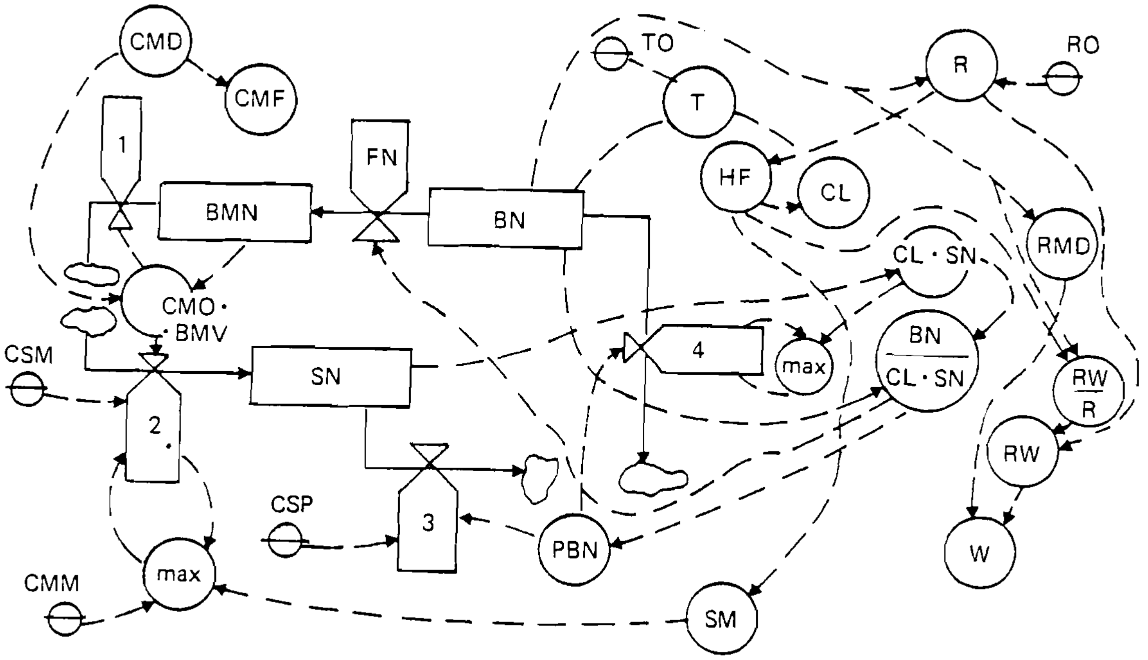


Figure 2. Flow diagram of the soil-plant subsector of the environment model (BN - biomass, SN - soil, BMN - mortmass).

The model may be used to forecast the level of pollution and environmental conditions in terms of the integrated characteristics of environmental components. It may also find application in estimating the long term trends in the evolution of soil characteristics in the areas of agricultural land use, changes in crop productivity crop output per area unit) associated with climate and soil quality changes. The forecasting properties of the model were tested in a series of expert forecasts devoted to the evolution of the steep and forest ecosystem. It has also recieved practical approbation for selecting a policy for forest rehabilitation in the areas cleared by fire.

A number of improvements that were recently introduced into the model are aimed at enhancing the scope of the model to cover northern regions, steppes, deserts and semi-deserts, mountainous areas of medium height, projections of the load upon the water supply system, assessment of the ecological effects of land use (soil erosion, saltening/desaltening, etc.).

3. FOREST REHABILITATION POLICIES: A CASE STUDY

The use of modern technologies is producing dramatic changes in forestry by substantially reducing the duration of the forest rehabilitation period. The surprising results achieved in this field are, to a large extent, due to the use of fertilizers.

We have made an attempt to apply our model for projecting the possible outcomes of this technological substitution in the case of the south-western regions of Siberia.

The time horizont was chosen so as to cover the whole period of forest rehabilitation from undergrowth to full ripeness (e.g. when the stock of wood reaches the highest bonitet specified for local conditions).

Considered were the following policy options:

1. Forest regeneration in the areas cleared by fire;
2. Forest regeneration in the clear cut areas;
3. Forest regeneration in the clear cut areas--application of 10 kg of conventional fertilizers per hectare per year;
4. Forest regeneration in the clear cut areas--application of 10 kg of conventional fertilizers per hectare per year within a period of the most intensive growth of biomass;
5. Same as in 4, but implanting 5 year old trees in the clear cut areas.

Figures 3 and 4 present the biomass supply curves (metric tons of biomass per hectare), for options 3 and 5 the maximum outcome is provided by the (5) scenario. The associated reduction of the rehabilitation period as compared with the conventional policy (option 2) is 49 years. A shift to the optimal rehabilitation regime in the region under consideration would imply 35-37 years of fertilization. Though these time requirements

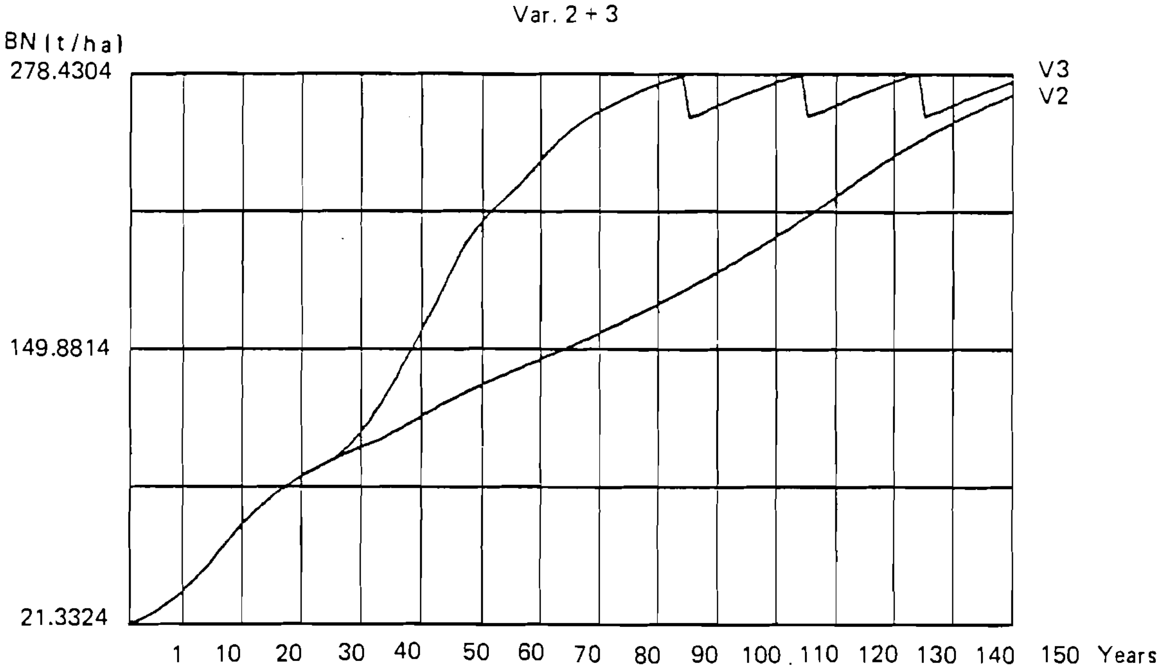


Figure 3. Rehabilitation of the forest.

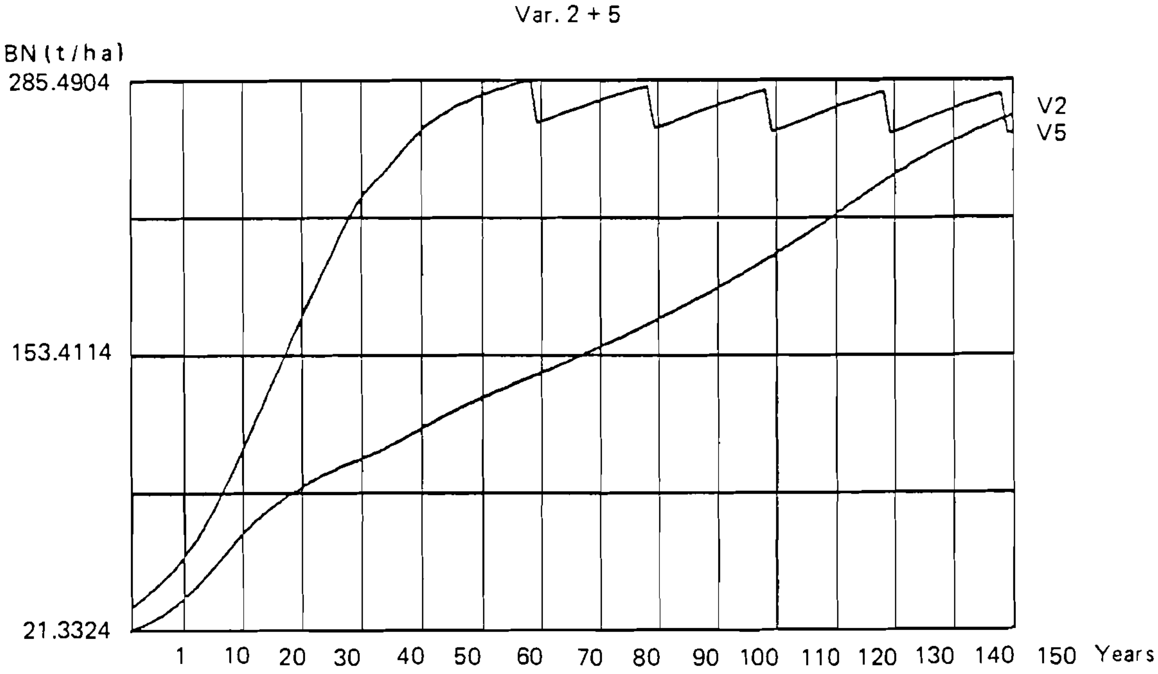


Figure 4. Rehabilitation of the forest.

may seem impressive, it should be kept in mind that fertilization is performed only once a year and, if agricultural aircraft are used, would cost about 3 rubles per hectare.

To conclude, let us note that it is essential that the fertilization schedule in the forest covered areas should provide additional nutrients during the period of the most intensive growth of vegetation. If the same amount of fertilizers were used in, say, the successive period, the duration of the rehabilitation period might be significantly greater.

4. ON THE IMPLICATIONS OF ACID RAIN

Another case study was devoted to the negative effects of acid rain on the forest ecosystem in the northern regions of Europe. The data on the SO_2 concentration in the lower layers of atmosphere is not readily available because the regime of acid precipitation (especially in the areas located some distance away from the sources of the SO_2) has not yet been adequately studied. Therefore, we had to restrict our analysis to the possible impacts of direct absorption of SO_2 into the soil. Since the annual rate of SO_2 penetration into the soil (in the areas clustered around the SO_2 sources) is about 150 kg per hectare, we have set the average rate of the SO_2 penetration at 40 kg per hectare.

Figure 5 represents the life cycle of a mixed forest, growing in loam soils and of that in the areas subject to acid rain. In the latter case, there is a 6% decrease in the amount of biomass and an 8% decrease in soil fertility by the end of the simulation period. However, to get a more precise picture of the damage caused by acid rain, one has to account for the deterioration of the quality of biomass, in which case the loss would be about 8% (soil deterioration not included).

In the case of the coniferous forest (Figure 6), the results obtained are very similar to the previous case. However, in case of the lime stone areas (Figure 7) the negative affects of acid rain were minor. This can be explained by the fact that the alkaline matrix roks neutralize the SO_2, thus preventing forest damage.

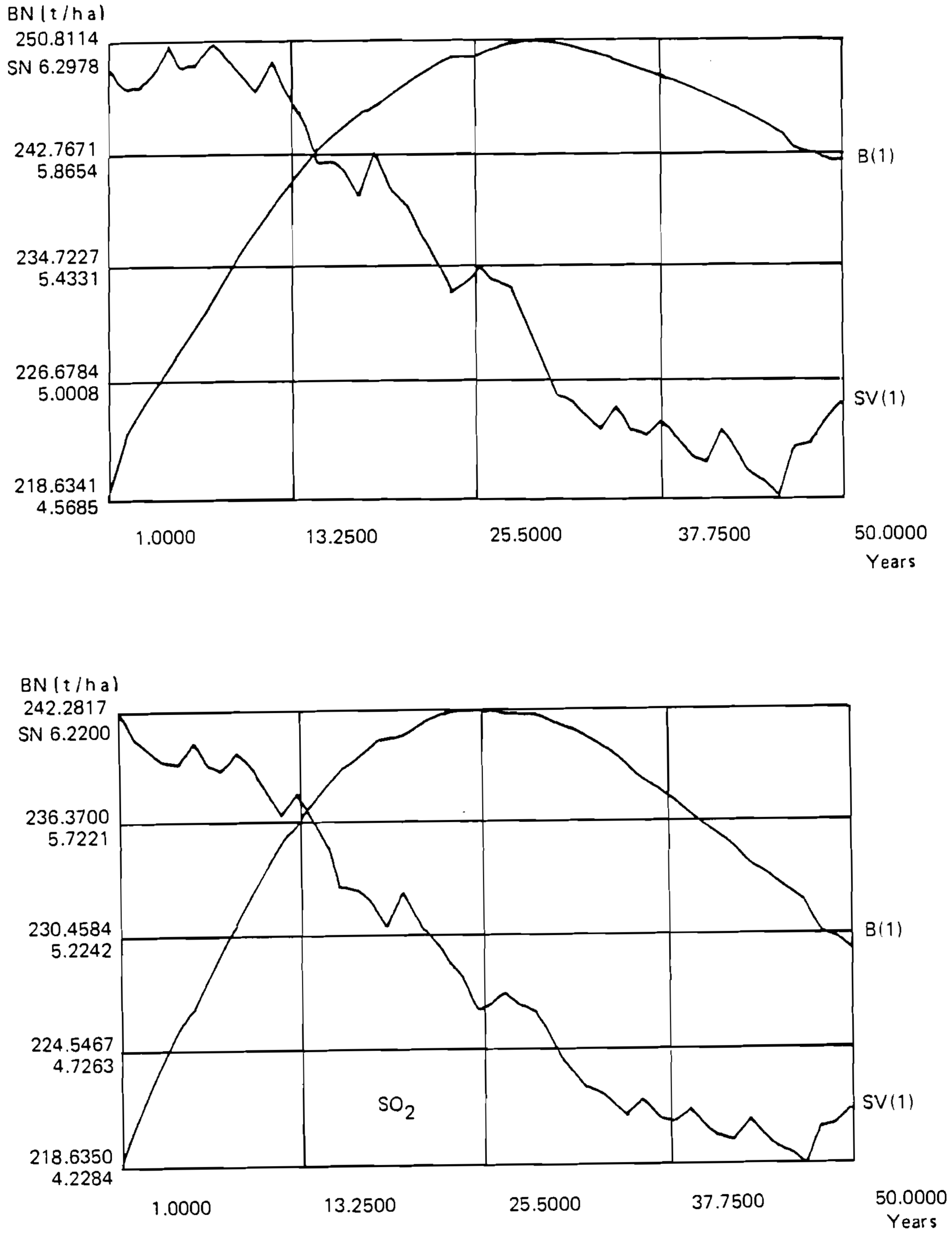


Figure 5. Mixed forest, loam soils.

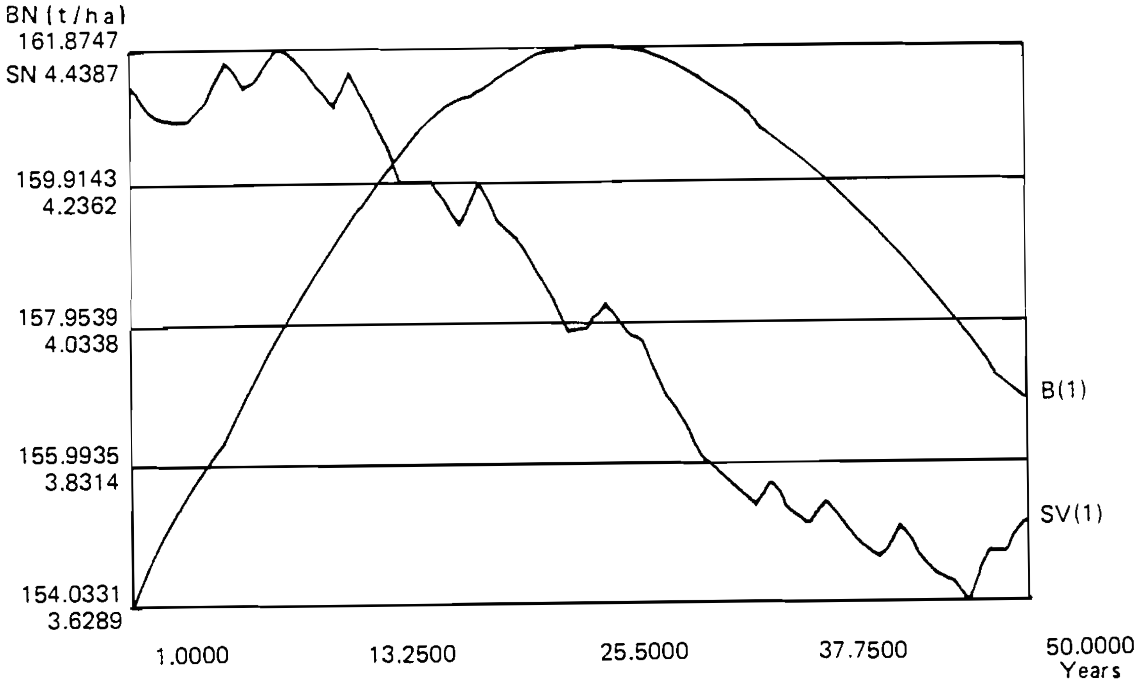
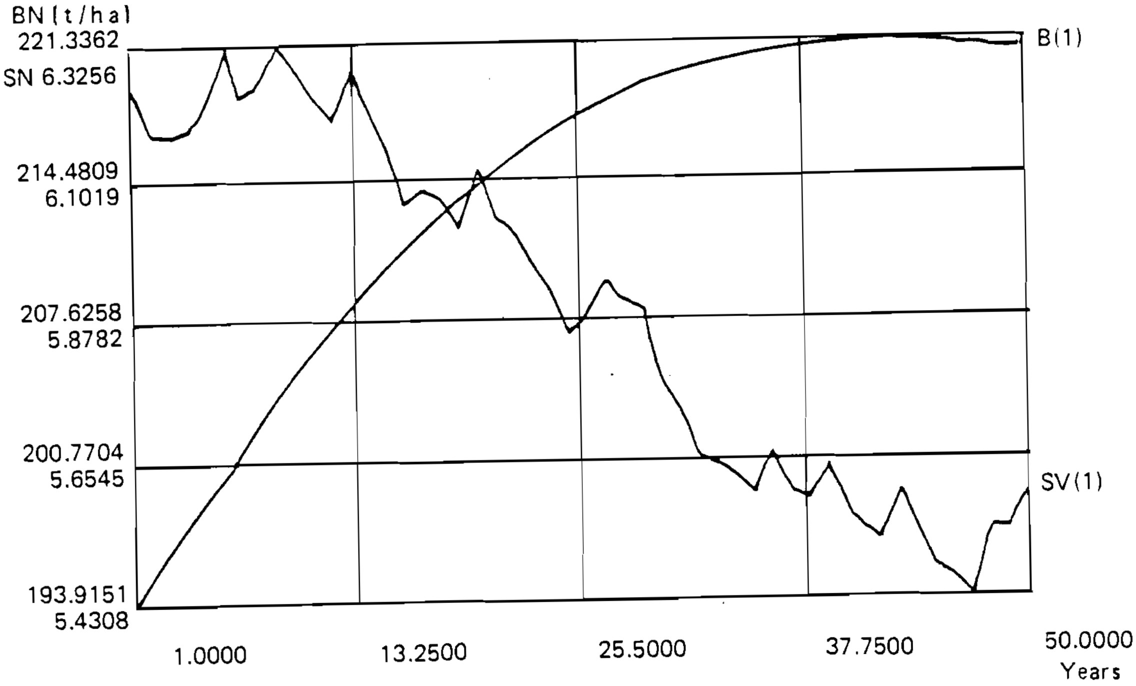


Figure 6. Coniferous forest, loam soils.



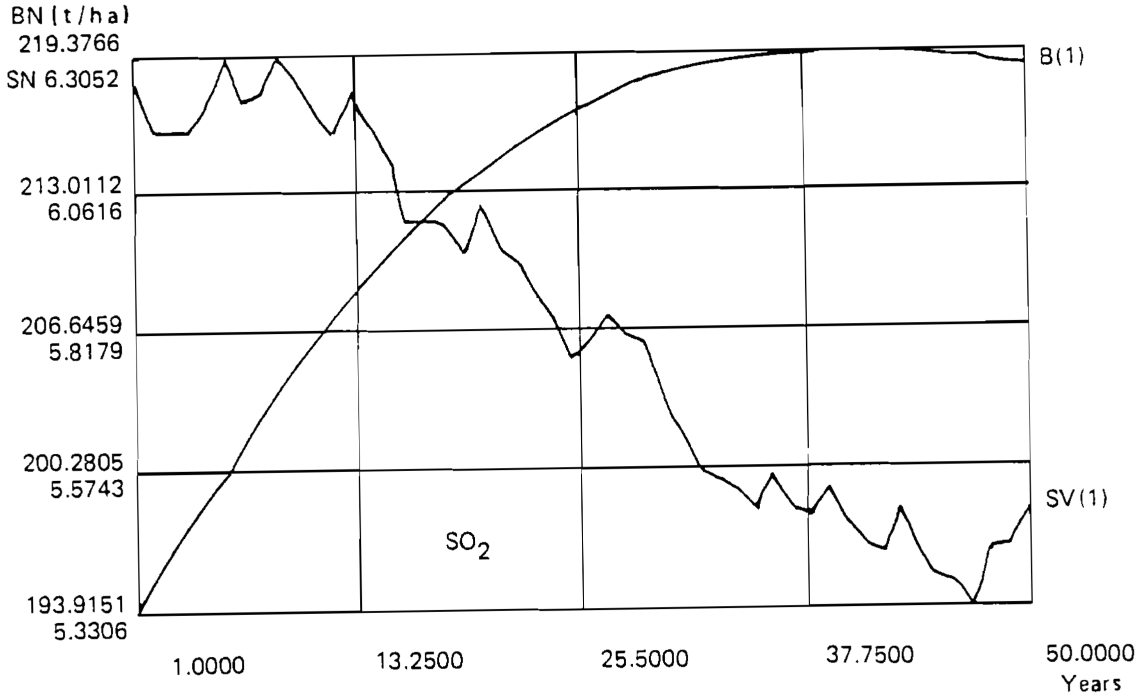


Figure 7. Coniferous forest, lime soils.

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