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Adapting silvicultural management systems to urban forests

Klaus von Gadow

Institute of Forest Management, Georg-August-University, Göttingen, Germany

Abstract: An important objective of forest science today is to better serve the cultural and recreational needs of a growing urban population. Forests are complex open systems with multiple functions and to maintain credibility among the public, people in charge of the management of urban forests need to draw on the expertise of a variety of scientific disciplines, not only the humanities, but increasingly also the forest engineering and forest biological sciences. The multi-disciplinary character of forest research can be utilized to achieve a more effective interface between science and politics.
The objective of the paper is to present a system for silvicultural management of forests within urban landscapes. The system includes three elements:
1. *Forest Options Planning*, using suitable tools for generating and evaluating silvicultural management options;
2. *Management Demonstration and Referencing,* based on a network of managed and unmanaged field plots;
3. *Silvicultural Event Analysis*, involving preventative evaluation of silvicultural activities based on event-oriented resource assessment.
It is concluded that, considering their social and cultural importance, the forests within the growing urban landscapes are hardly receiving the scientific attention they deserve.

Key words: Urban forest planning, multi-objective optimization

Introduction

The theoretical basis for sustainable forest management was established during the early 19th century in Europe by scientists representing a variety of disciplines. A number of basic principles were developed, including Hundeshagen's (1826) *Normality Theory* which is still being used in commercial forestry for analysing the complex relationship between tree growth, state of the resource and the level of harvesting in rotation management systems. Faustmann (1849) developed a *Discounted Cash Flow Theory* for evaluating different silvicultural treatment options which is also still widely used today. The importance of forest growth research was also recognized during the 19th century (Pressler 1865).

After the second world war, scientific activity in the areas of forest growth, forest assessment and forest decision support was increasingly influenced by publications which originated outside Central Europe, mainly in North America, in some countries of the Southern Hemisphere and in Northern Europe where commercial forestry plays an important role. Thus the old scientific discipline *Forest Management* experienced a revitalization during the past two decades. This flourish-

Address for correspondence: Klaus von Gadow, Institut für Waldinventur und Waldwachstum, Georg-August-Universität, Büsgenweg 5, 37077 Göttingen, Germany.
E-mail: kgadow@gwdg.de

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ing after a century of a rather subdued existence may be attributed to the new need for an integrating discipline capable of utilizing the accumulation of data and detail, and of counteracting the process of increasing scientific fragmentation (Humboldt 1845, p. 81). Most important were the contributions in the area of forestry-related operations research, a field of investigation which has hardly received any attention in Central Europe. The objectives of forest management today are numerous and often contradictory. Using traditional silviculture, forest political aspirations are difficult to implement. The demands of a more well-educated public require a level of sophistication of silvicultural management that cannot be achieved with practical experience alone.

In the past, forest science has been focussing mainly on sustainable management of wooded landscapes in rural settings. Studies relating to urban forests and trees have been numerous, but limited mostly to small-scale applied research at the municipal level. Nevertheless, forest management is increasingly characterized by a rejection of "*mechanistic*" models in favour of "*organic*" ones where forests are seen as complex open systems fulfilling a variety of functions (Kennedy et al. 1995; Fähser 1998).

An important task of the scientific discipline known as *forest management* is to develop tools for making accessible to practical silviculture at least some of the wealth of information that is available within an increasingly specialized and fragmented scientific landscape. For this reason it is useful when the research efforts are not restricted to solving specific problems. Research is also concerned with the development of principles and concepts that can be used to guide data collection and general scientific activity. This objective is especially relevant for "integrating disciplines", such as *silviculture* or *forest management*.

Urban forests and green spaces are in the public eye. All kinds of tree-related events, such as planting or felling, are often discussed in public and reported by the media. Therefore, urban woodland management should be based on scientifically sound principles, conform to acceptable silvicultural practice, and be transparent to the public. These objectives can be met if silvicultural options are compared and evaluated, if silvicultural management is visibly and understandably demonstrated in the field, and if the management activities can be continuously monitored on a short and long-term basis. Such a silvicultural management system was developed at the *Institute of Forest Management* at the University of Göttingen in Germany. It embraces three elements known as *Forest Options Planning*, a *Management Demonstration and Referencing* strategy and a system for preventative evaluation of silvicultural activities known as *Silvicultural Event Analysis*.

Presentation of developed methods

Forest options planning

Social sustainability calls, among other things, for decision processes which are democratic and fair. In an urban environment, all citizens may be regarded as decision-makers. Participatory planning and group decision-making are ways to get acceptance and commitment to forestry planning (Pukkala et al. 1995). The objectives of participatory planning require tools that are transparent and easy to use, and that are especially designed to support a negotiation process and to assist in reaching widely acceptable decisions relating to the management of trees and forests. Such a tool is the so-called Forest options model which assumes that an urban forested landscape is an aggregation of spatially defined land parcels of varying size and form. Each parcel is characterized by a specific tree population with a given species and size distribution. The Forest Options model is based on the premise that not one, but a variety of silvicultural options are potentially available for each land parcel. Each option is characterized by a specific succession of silvicultural treatments and natural developments and has a value which reflects citizen preferences.

The number of possible silvicultural options depends on the length of the planning period and the number of classes defining silvicultural operations. This number may be very high. For example, if a stand may be either thinned or not thinned in n successive years, then there are $2^{(n+1)}$ possible combinations of silvicultural events. Usually, however, foresters specify that a silvicultural operation takes place in exactly k of the n years. Furthermore, let us assume that at least j years have to elapse between successive silvicultural events. Then the number of possible combinations of silvicultural events is equal to $\binom{n-(k-1)\cdot j}{k}$. Obviously, the number of possible treatment options increases with increasing structural diversity.

A scenario for the urban landscape as a whole is a specific combination of silvicultural options in all the individual land parcels. It is possible to compare the different scenarios and to identify the more desirable ones. This concept is easy to understand. It also provides an excellent basis for incorporating knowledge from the different scientific disciplines. The goal is to maximize or minimize an objective function $max\ \mathbf{Z} = \mathbf{c}'\mathbf{x}$, subject to constraints relating to a variety of required outputs $\mathbf{Vx} = \mathbf{b}$. Details about this method have been published before (Gadow & Puumalainen 2000). The final objective is to provide a map of silvicultural operations for management and a list of activities to facilitate implementation of the processes of negotiation and participatory planning.

Management demonstration and referencing

As the name implies, the purpose of a *management demonstration and referencing* strategy is to demonstrate acceptable silvicultural practice in the field and to provide a reference to unmanaged areas. Management demonstration and referencing is based on a system of managed and unmanaged field plots. The managed field plots are used for education and demonstration of acceptable silvicultural practice. Based on the work by Nöllenheidt (2000; Böckmann & Hüsing 1999), a *management demonstration plot* (*MDP*) represents the core area within a management demonstration forest (Fig. 1). Identical in design, a *management referencing plot (MRP)* is located within a forest area which is withdrawn from management. The objective is to provide comparative data for demonstrating the "closeness" between managed areas and their unmanaged counterparts.

As mentioned before, the design and measurements of *MDP*'s and *MRP*'s are identical. Plot sizes varying between $\frac{1}{4}$ and $\frac{1}{2}$ hectare have been used, depending on the density and development stage of the forest. This information makes it possible to provide detailed information about the species and size distributions and the spatial structure. The plots are permanently marked and assigned to forest stands that are of particular interest or importance. They are particularly useful for education and training because the effects of a specific silvicultural manipulation can be made transparent in the field by an analysis of the modifications of forest density and structure (species, size and spatial distributions).

Silvicultural event analysis

It would be useful if the activities of forest resource assessment and silvicultural monitoring could be combined. This objective may be achieved by timing the assessment so that it coincides with a silvicultural event. *Silvicultural event sampling* is a method designed to monitor management activity. Most resource inventories assess the entire growing stock (which may soon change as a result of a harvest operation) or the growing stock remaining after a harvest (to evaluate the damage done by harvesting operations). Silvicultural event sampling captures stand data immediately after marking the trees, but before the marked trees are removed. Thus, silvicultural event sampling provides data about management-induced changes which can be used to evaluate a particular silvicultural activity.

The dynamic development of an urban forested landscape embraces a great variety of changes resulting from silvicultural activity (Fig. 1). An effective mechanism for maintaining control over management activities is a method known as *Silvicultural Event Analysis*. Silvicultural Event Analysis evaluates events such as tree planting and harvesting. It involves a variety of disciplines and a definition of acceptable management practice. Events may be evaluated in terms of changes in forest density (maximum removal of biomass), forest structure (site-species match; size distributions) and forest value (recreation value; log quality).

Silvicultural Event Analysis is preventative. The planned silvicultural modifications are evaluated before being implemented. Most important in a managed forest are the harvest events, which are often carried out at regular intervals. Harvest decisions are normative and intrinsically fuzzy. The fuzzy character of a thinning is exemplified by vague expressions (*high* thinning, *low* thinning), by the personalized nature of the decisions and by the fact that exact measurements of tree attributes are usually not available. The removal of a tree modifies the spatial distribution of the temperature and radiation regime and thus influences a variety of biogeochemical processes. An important element of urban forest management are guidelines defining acceptable manage-

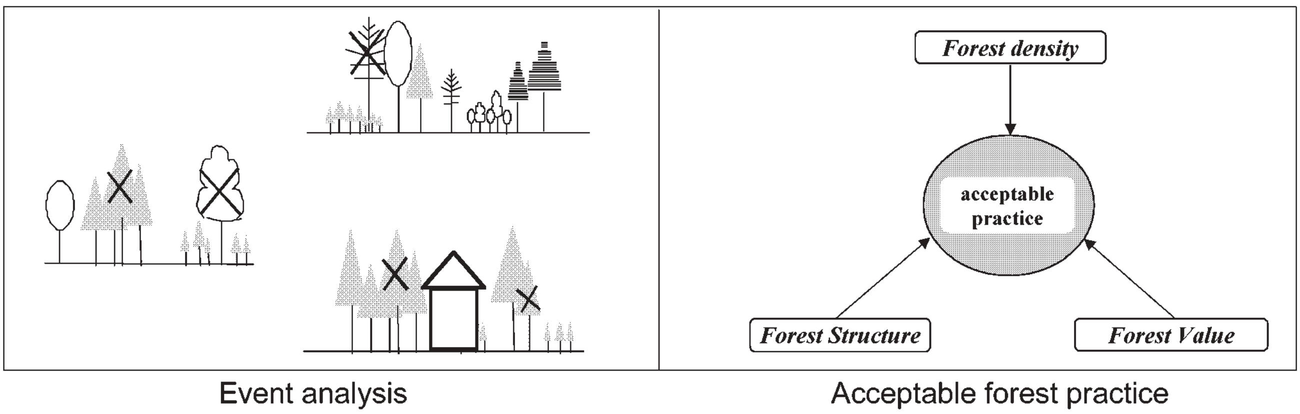

Fig. 1. Silvicultural event analysis is a mechanism for maintaining control over management activities, especially tree removals. A necessary basis for the analysis is a definition of acceptable management practice.

ment practice The *acceptable-management-practices*-concept makes it possible to apply existing experience from various scientific disciplines, and to consider current thinking among municipal governments, non-governmental organisations and other interest groups.

Discussions

The forest options model

The *forest options model* is based on accepted theory, using a range of effective techniques for finding satisfactory or optimal solutions, including mixed integer programming, simulated annealing and tabu search (Öhman & Eriksson 1999). Solutions may be established which simultaneously implement economic objectives and environmental constraints. The basic structure and the solution techniques are well established. An example of a series of maps showing the location of silvicultural operations in different planning periods, was presented by Chen & Gadow (2002). They used the method of *Simulated Annealing* and a two-component objective function (Net present value and even flow of activities). The main challenge when using this approach, is to generate realistic silvicultural options and to use objective functions reflecting urban political objectives.

As mentioned before, the forest options model has been successfully applied in many countries, in a range of forest types and under varying environmental conditions (see for example Torres Rojo & Brodie 1990; Murray & Church 1995; Bettinger et al. 1997; Öhman & Eriksson 1999; Gadow & Puumalainen 2000). The results show that better use could be made of the unique interdisciplinary character of forest science to quantify the complex relationships between silvicultural activity and natural processes. An advantage of the Forest Options Model is the fact that it is highly suitable for integrating science into the planning process, that it can be applied in any forest type and management strategy, that it combines stand level objectives and forest level constraints and that it facilitates participatory planning. Applications in urban environments are lacking, however.

Management demonstration and referencing

The *management referencing* concept is part of the silvicultural management strategy applied in the municipal forests of Lübeck and Göttingen (Fähser 1995; 1998) while the *management demonstration* concept is being used in German State Forests (Böckmann & Hüsing 1999). Nöllenheidt (2000) presented a study in which different plot designs were compared. Based on the comparison, he proposed a design where the *management demonstration plot* represents the core area within a management demonstration forest (Fig. 2). All the diameters, heights and position coordinates of all trees within the plots were measured.

As demonstrated by Roschak (1998), a *management demonstration and referencing plot* may be used to obtain empirical data about forest dynamics. The resulting forest and tree models provide the basis for silvi-

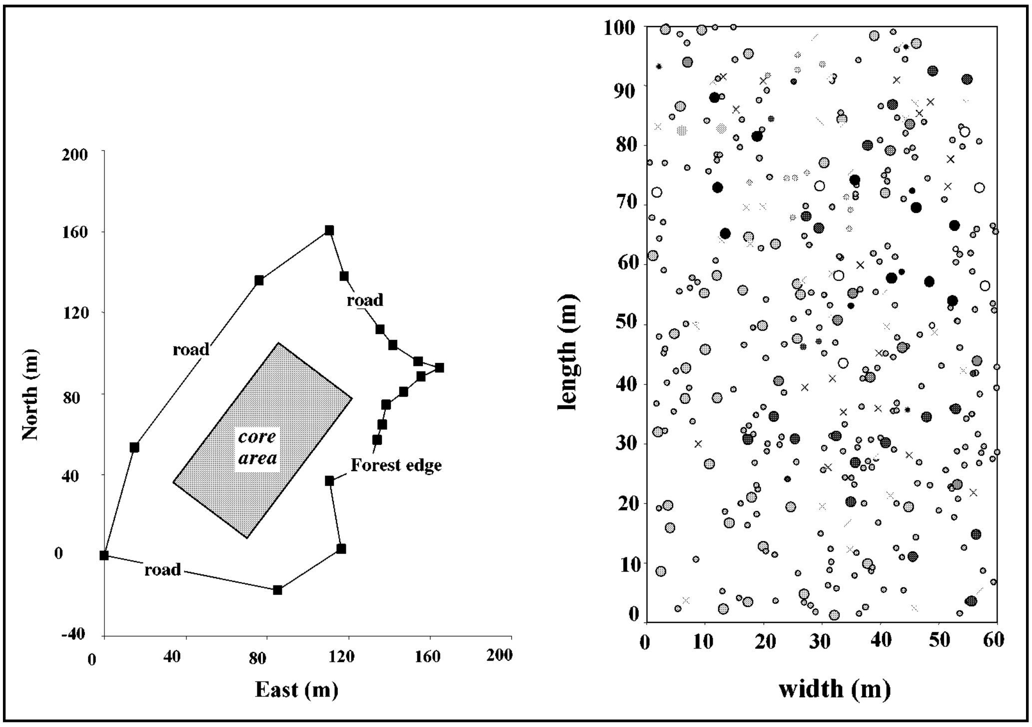

Fig. 2. Example of a management demonstration or referencing plot representing the core area within a management demonstration forest (left); the spatial distribution of the trees of different species and dimensions within the core area is shown on the right (crosses represent locations of harvested trees).

cultural decision-making. They are developed from empirical data which may be obtained in field experiments. Considering the time horizon, three types of trials have been used. *Permanent growth trials* are established and remeasured, usually at regular intervals, for long periods of time, resulting in high maintenance cost and long wait for data. *Temporary plots* may provide a quick solution in a situation were nothing is known about forest dynamics. They are measured only once, but cover a wide range of ages and growing sites, assuming some "normal" or representative silviculture. This method has been used extensively during the 19th century (see, for example Kramer 1988, p. 97; Assmann 1953; Wenk et al. 1990 p. 116). The main limitation of the temporary plots is the fact that they do not provide information about change rates. Thus, most of the contemporary modelling techniques cannot be applied. *Interval plots*, measured twice and spread over a range of growing sites, development stages and silvicultural treatment categories, combine the advantages of the permanent plot, – change information, – and the temporary designs, minimum wait for data. The interval between two successive measurements should be sufficiently long to absorb the short-term effects of abnormal climatic extremes.

Silvicultural event analysis

For several years, *silvicultural event analysis* has been an integral part of the curriculum at the Forestry Faculty in Göttingen, Germany. The basic analysis, involving silvicultural modifications of forest structure and growing stock value, is complemented by an evaluation of the effects of a particular harvest operation on the soil conditions, the genetic structure of the tree population and the forest climate, drawing on the specific expertise of the departments of Soil Science, Forest Genetics, Forest Zoology and Bioclimatology. Obviously, the usefulness of the analysis increases with increasing uncertainty of management and complexity of decision-making. Therefore, the method is specifically appropriate in uneven-aged, multi-species forests managed in the selection system.

The basic data about a particular silvicultural event are obtained by systematic grid sampling, using fixed or variable radius circular plots. The assessment, known as *silvicultural event sampling*, takes place after the trees have been marked for removal and before they are cut. In this way it is possible to simultaneously produce information about the population of trees before the silvicultural event, about the removed trees and about the trees remaining after the event. The silvicultural event sampling, complemented by soil measurements, sampling of genetic material, and radiation measurements, thus provides data about the management-induced changes, which can be used in a *silvicultural event analysis*.

S*ilvicultural event analysis* has not yet been practiced outside the University. Based on the student comments and the positive feedback from the various disciplines which are taking part, the method appears to be a promising alternative to the classical techniques of forest assessment, which are not event-oriented, but are scheduled to take place at fixed time intervals and which are not holistic, but focused on timber variables. Based on the premise that there is a growing need for a more transparent management of forested ecosystems and green spaces in the urbanised societies, applications of s*ilvicultural event analysis* would probably be appropriate in the urban environment.

Conclusions

As the rate of urbanisation continues to increase, there is a growing need for the establishment and maintenance of forested ecosystems and green spaces in the urbanised societies, especially in Europe and North America, and urban forestry research has become an important feature of forest and tree research. Projects are mostly in the area of forest policy and the social sciences. Examples are Schmithüsen et al. (1997) overview dealing with the forestry perceptions and attitudes of citizens in Germany, Austria and Switzerland; an overview for the Scandinavian and Baltic countries compiled by Sander & Randrup (1998); a review of urban forestry planning and management in Great Britain (Johnston & Rushton 1999) and a review of urban forestry research in Europe (Konijnendijk et al. 2000). Among the various disciplines (Landscape Ecology, Landscape Architecture, Biology, Botany, Pathology, Environmental Science) the scientists most frequently involved were forest scientists, closely followed by horticulturists. The main emphasis in urban forestry research has been on policy-making and planning and the increasing role of public participation and conflict management in which the social sciences have played a major role (Konijnendijk 1999). The unique multi-disciplinary character of forest research can be utilized to achieve a more effective interface between science and politics.

Silvicultural management in urban areas presents numerous challenges not experienced in a rural setting. Whether we think about cultural vs ecological conservation in Cape Town's *Newlands Forest* on the slope of Table Mountain (Gosling 2002) or in Vancouver's *Stanley Park*, or about optimum silvicultural management in Berlin's 29 000 ha municipal forest, the objectives of forest management are numerous and often contradictory. Forest political aspirations are complex and difficult to implement using traditional silviculture. The demands of a public which is increasingly acquainted with forestry and silvicultural methods require a high level of sophistication of forest management which cannot be achieved with practical experience alone. Integrated approaches are called for, which are capable of utilizing the accumulation of detailed information from a variety of scientific disciplines. The useful contributions today are provided by developments in the area of forestry-related operations research, a field of investigation which has received much attention during the past 20 years, mostly in Northern Europe and in North America.

Successful implementation of a silvicultural management system requires operational objectives and a practical concept for implementing the objectives. The concept includes suitable methods of resource assessment and description, operational planning and management control. To save costs, resource assessment and continuous monitoring could be combined. It is not necessary to use technical jargon when describing aspects of forest density or structure or when explaining a silvicultural program to a layperson. Descriptions of forest state and descriptions of manipulations of a forest that are easy to understand are especially important to people in an urban environment who place a high value on the natural resources that are within easy reach.

New forest planning tools which could be used to advantage in the urban environment aim to produce predictions, alternatives, and answers to *what-if* questions. These tools are used for sensitivity analysis, allowing flexible interaction with a given process by changing the decision criteria and the problem formulation. Consequently, there is a need to provide a range of decision support tools for addressing particular issues, such as tree species selection, genetic structure modifications resulting from selective tree removals; facilitating tree root and crown development by specific removals. The *Forest options model* presented in this paper is based on accepted theory, uses effective search techniques and is capable of finding solutions which simultaneously implement economic, social and environmental objectives. The major challenge when using the forest options model is the specification of realistic treatment options and accurate estimation of model coefficients. This tool can then generate a favorable environment for integrating knowledge from different disciplines.

A silvicultural operation may reduce forest density and modify the spatial structure, species composition and value of the standing crop. *Silvicultural event analysis* is a method designed to monitor management activity. The concept requires that forest assessments coincide with silvicultural events. The assessment takes place after the trees have been marked for removal and before they are removed. Through appropriate timing, the activities of resource assessment and management control can thus be very effectively combined. Sound solutions must be developed for specific conversion problems (Spellmann 1998). Forest development is inherently uncertain and management needs to be adaptive. Adaptive management is facilitated by *silvicultural event analysis* involving regular quantitative evaluation of management activities. The resulting experience can be used to improve the treatment specifications in the Forest options model.

Forested landscapes in urban areas are complex open systems with multiple functions. Understanding the dynamics of these systems is a prerequisite for sound management. Consequently, the assessment, analysis and planning of urban forested landscapes is a challenging task requiring multi-disciplinary approaches. Studies dealing with climate change and biodiversity are featuring prominently in forest and tree research today. These problem areas are addressed by long-term forest ecosystems research projects, such as the Sustainable Forest Management in Southern Sweden (SUFOR) or the Sonderforschungsbereich 299 of the German Science Foundation 'Land use concepts for peripheral regions'. The science of Forest Management has developed tools to ensure that the findings generated by such projects can be utilized by practical management. Useful means to achieve this transfer are the *forest options model*, the *management demonstration and referencing* concept and the method of *silvicultural event analysis*.

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