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APPLICATION OF RESULTS OF AERIAL PHOTOGRAPH INTERPRETATION AND GEOGRAPHICAL INFORMATION SYSTEM FOR PLANNING IN FORESTRY

PRIMJENA REZULTATA INTERPRETACIJE AEROSNIMAKA I GEOGRAFSKOG INFORMACIJSKOG SUSTAVA ZA PLANIRANJE U ŠUMARSTVU

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The main aim of this work was to find a way to link all existing data, as well as data acquired by the interpretation of aerial photographs into a unique information source, and to generate new information as a basis for planning in forestry, by using the methods of a geographical information system (GIS). The research was carred out in the NP "Risnjak".

To accomplish this aim, it was necessary:

– to process the results of the interpretation of colour infrared (CIR) aerial photographs

– to make maps with various thematic contents

– to digitalize existing maps (pedologic, geologic, phytocenologic, economic)

– to organize databases

– to assign to each acquired layer an attribute data table (numerical and descriptive) by means of which it was possible to connect digitalized maps with tabular data

– to produce a digital terrain model (DTM) and to establish new layers (slope, exposure, etc.) based on it

– to incorporate newly acquired elements into the established GIS model and to connect them with the existing elements

– to analyze all acquired data (numerical and cartographical) at the same time per individual layer or per multilayer overlap

– to process statistically-obtained dependencies (exposure, slope, plant community, taxation elements, damage stage, etc.).

According to the set aim and trough the research carried out, certain results and knowledge were obtained about both the GIS-technology, as a tool for the realisation of the given objective, and the possibilities of the use of CIR aerial photograph interpretation and GIS for planning in forestry and for environment study.

The result of the research is the established GIS model for NP "Risnjak", which can be used in all future research and planning and also for the establishment of GISs for protected and other forest areas.

Key words: colour infrared (CIR) aerial photographs (Aps), photointerpretation, geographical information system (GIS), GIS model, National Park "Risnjak", digital terrain model (DTM), planning in forestry

INTRODUCTION
UVOD

Modern techniques and possibilities of data collection, processing and interpretation have a limited use in the forestry of Croatia. Most often, data are still collected on site and the existing maps are of uneven quality and accuracy, even with obsolete content. The forest is a living being in which birth, growth, development and death processes take place continuously, which are reflected on its aspect and status. Therefore, an up-to-date collection of data about its current status as well as on the changes occurring in it is necessary.

Forest management dates back to the first activities of man. By extending the area of his reach, man expanded his activities in nature, arranging his closer and broader neighbourhood, and thus he unconsciously planned in space (Meštrović 1984). Forest management requires data which describe forests in a dynamic way with respect to their status and spatial definition (Jordan and Erdle 1980). According to modern landscaping theory (Colby 1991), from the ecological and economic aspects of future development, forests are multipurpose surfaces which should be managed in way to be of use to all living beings (Probst and Crow 1991, Jacsman et al. 1991). Meštrović (1987) points out that forests are a very important segment of nature as a whole, and especially its protected sites, so when spatial plans for such sites are prepared or legal measures for their conservation, management, improvement and utilization are enacted, forests should be given special attention.

The planning concept in forestry involves an exchange of continuous processes with up-to-date databases and applications of GIS and existing software. In a well-established space management strategy, activities of planning and establishing an adequate control and decision-making system are of the greatest importance for each environment (Jukić 1994). Nowadays, it has become almost impossible to cover, maintain, interpret and analyze by classical methods such large amounts of data relating to the condition, quantity and distribution of phenomena and objects (in this particular case of forests) on the Earth's surface within a reasonable time period. Planning in forestry, similarly to other activities associated with nature and its resources, is closely connected with general progress and with the present attitude towards the environment in which we live (Meštrović et al. 1994).

On the basis of the foregoing, it can be concluded that forestry seeks a permanent inflow of information which can be ensured by remote sensing methods which would reduce the volume of in-situ data collection and provide advantages with regard to time and efficiency. Nowadays, photographs have become an indispensable tool in the study and monitoring of environmental status and changes. This refers in particular to colour infrared (CIR) aerial photographs (APs). By using the interpretation of aerial photographs, reliable statistical data for observed phenomena and objects can be assessed.

The data collected in this way offer a large amount of information used in many scientific and economic fields. The results of (aerial and satellite) photograph interpretation are most often shown in the form of thematic maps in which the spatial distribution of observed phenomena and objects, as well as their interrelations, are presented. Making such a map by the traditional terrestrial procedure requires time, effort and financial means, and once finished cannot be modified any more. A continuous inflow of new information (sudden and unexpected changes in the forest status) requires frequent modifications.

A large amount and variety of data, changed ecological conditions and the necessity of spatial analysis call for the use of geographic information system (GIS) technology. This technology facilitates:

- electronic computer supported automatic cartography,
- receipt, storing, search, maintenance, updating, analysis, statistical processing and printing in various forms of a large number and variety of data,
- collection and storage of spatial information in the digital (quantitative) form, that makes possible objective analyses of spatial data,
- acquisition of new cartographic contents by various overlapping methods or by statistical processing of numerical and descriptive data.

In the present disturbed ecological conditions, this allows continuous monitoring of the forest status by take place, as well as timely and correct decision making in its management. It can therefore be concluded that the key position in supporting deliberate planning and decision making in forestry is occupied by GIS.

Forest management, i.e. planning in forestry involves decision making on several criteria, some of which are associated with quality and quantity data, others with weather conditions, and the third types are defined in space. A GIS has proved to be a technology which, by its possibilities, connects all three of the above-mentioned groups of criteria and, by its results, supports planning (Martinić 1993).

Planning, as one of the basic components of forest management, is the preoccupation of many specialists. There are four requirements of modern planning: technology which allows interactive work in the graphic environment, organized data thematic banks, computer equipment, and the knowledge and experience of an expert who can connect the possibilities of technology and the expected benefits.

Unlike the past planning method, GIS technology, supported by computer and remote sensing, makes possible a completely new approach in planning. This so-called "continuous" planning includes a change monitoring system which assumes permanent data updating with the changes which occur within a certain time period.

Such knowledge encourages many scientists to develop their own planning methodologies, i.e. various approaches in task accomplishment and in the use of methods and techniques within the planning system. In such an approach to the problem using GIS technology, the expert is relieved of routine work (mapping by hand, establishing new layers from the existing ones etc.), consequently leaving him more time for decision making in space management, namely planning, and offering new possibilities for research.

AIM OF RESEARCH
CILJ ISTRAŽIVANJA

INTERPRETATION OF AERIAL PHOTOGRAPHS AND GIS IN FORESTRY
INTERPRETACIJA AEROSNIMAKA I GIS U ŠUMARSTVU

Photogrammetry, namely photointerpretation as a method for the collection of necessary data on the space or geometrical characteristics of a certain area, is particularly suitable for use in a GIS. The GIS is based on the idea that every datum on the Earth's surface or its cover is to be geocoded, namely, linked up with terrestrial coordinates, which allow for faster and more precise handling of a large number of data and offer a better performance of such spatial analyses which until now has been impossible.

The results of aerial photograph interpretation can be presented in the form of maps, diagrams or tables and directly incorporated into a GIS as one of the layers (Benko et al. 1993, Kušan and Kalafadžić 1993), provided, however, that these data are previously vectorized, because vector model is more adapted to supporting the graphical mode. Most often the results of aerial photograph interpretation are presented in the form of thematic maps showing the spatial distribution of phenomena and objects on the Earth's surface, as well as their relationship.

The input of various thematic contents obtained by aerial (satellite) photointerpretation considerably increases the amount of information on forests, which eventually allows for reliable and timely decision-making. Aerial photographs are primary sources of information for many inventories and for planning in modern forest management (Reutebuch 1987).

The first application of photogrammetry in forestry, and where most experience has been gained, has been in forest management. In the last few decades, forestry photogrammetry has become a reality. According to Tomašegović (1987), it is the information system which provides basic data and methods for a fast, inexpensive and reliable synoptical identification of environment elements relevant for forestry (ground relief, vegetation, water systems, roads, etc.).

During the 1980s and in the early 1990s many papers were written dealing with the use, accuracy and efficiency of remote sensing and GIS in forestry (Kalafadžić 1984, 1987, Kušan et al. 1992a, Kalafadžić and Kušan 1993, Posarić 1993).

The ever-increasing application of GIS technology, i.e. the possibilities to use digital data, brought an important change into the process of making decisions concerning space. GIS not only created a new dimension in cartography, but opened new fields and pushed forward borders in a number of other fields, such as natural resource and infrastructure system planning and management (Smyrnew 1990).

Efficient management and planning require reliable information for forest surface mapping, growing stock inventories, assessment of forest decline and health, etc., and the collection of such information can be rationalized and made less costly by using the interpretation of aerial or satellite photographs (Kalafadžić and Kušan 1993).

In the 1980s, forest mapping based on aerial photographs became the usual operational practice in developed and developing countries (Jano 1986, Stellingwerf 1986). Most often, forest mapping is done simultaneously with a forest inventory and since aerial photographs allow for a stand data collection in which these data are spatially defined, the use of aerial photographs for forest inventory and for mapping has necessarily become a common subject in forest inventory manuals (Lötsch and Haller 1973, Kramer and Akça 1987).

In Croatia, forest mapping based on aerial photographs was investigated by Tomašegović 1956, 1965, 1987b, Vukelić 1984 and Ćurić 1986.

Until now, many experts have dealt with the application of colour infrared (CIR) aerial photographs for damage inventories in forest trees and stands (Pelz and Riedel 1973, Masumy 1984, Hildebrandt et al. 1986, Hočevar and Hladnik 1988, Voss 1989, and others). Barszcz et al. (1993) used GIS and remote sensing to study the relationship between forest damage and environment status.

The application of CIR aerial photographs in forest damage inventories on larger surfaces in Croatia started in the 1980s (Kalafadžić and Kušan 1990). Thus, in 1988, CIR aerial photographs were used for a damage inventory and for the mapping of the beech – fir forests in Gorski kotar (Kalafadžić et al. 1992, 1994).

As part of the damage inventory in the lowland forests of Posavina (the forest basin Spačva and G.J. "Josip Kozarac", as well as EEFO "Opeke") in 1989, the relationship between the damage of the stands and some biotic (honey-dew) and abiotic influences (roads, channels, meliorated marshes) on the stands and the sites were studied (Kalafadžić et al. 1993b). The photointerpretation key for the common oak (*Quercus robur* L.) was also established and the damage assessment reliability on the CIR APs was investigated (Pernar 1994). Furthermore, the photointerpretaion key for the defoliation of the common ash (*Fraxinus angustifolia* Vahl) was established, and the defoliation evaluation methodology was tested (Fliszar 1990). Research on the possible automation of some procedures in the interpretation of aerial photographs for forest damage inventories is in course (Kušan and Pernar 1996).

Research on the stand parameter assessment on aerial photographs may be divided into two groups (Kušan 1996):

1) research of stand parameter assessment reliability
2) research of the relationship between stand parameters and parameters measurable on aerial photographs.

The stand parameter assessment reliability has been dealt with by many researchers: Lukić 1981, Pavičić 1983, Kostijal 1986, Kušan 1988, 1992, Benko 1993. As for research concerning the relationship between stand parameters and parameters measurable on aerial photographs, they can be divided into several groups.

Kostijal (1986) investigated the relationship between the number of tree crowns observable on aerial photographs and the mean volume tree diameter.

Kušan and Krejči (1993) investigated, using multiple correlation, the relationship between the mean stand height, the number of trees per ha, the mean stand crown width and the stand volume per ha.

Pilaš (1994) investigated the relationship between the mean stand height, the number of trees per ha, the mean stand crown width, the mean crown surface and the mean stand age.

Benko (1995) investigated the relationship between the common oak volume (*Quercus robur* L.) and various tree parameters (tree height, tree crown diameter, crown surface, length of illuminated tree crown, etc.).

The volume of forest stands is assessed more and more economically by means of aerial photographs. By using a multiple regression analysis, regression equations have been obtained in which the relationship between photogrammetrically assessed values and terrestrially surveyed volumes of the stand is expressed with a satisfactory average error of +/-9-10%, relatively independently of the site, photograph type and interpretor (Akça and Zindel 1987).

Jakšić (1996) investigated the possible use of regression equations in volume assessment by photointerpretation.

Forest management is a very complex activity and includes several different components (biological, economic, sociological) which are interconnected into a complicated system. In this system, there are many resources (forest land, trees, people, time, money) which are in mutually restrictive relations (Buongiorno and Gilles 1986). An organized use of forests, including the achievement of economic effects and the preservation of forest stability, assumes correct decision making with regard to time, place, quantity and manner of forest resource exploitation (Čavlović 1994).

The introduction of modern technologies in natural resource management and environment quality recovery became one of the prerequisites for the improvement of status and change monitoring. For the development of this process, reliable information on current status and on realistic possibilities of change control must be made available (Kalensky 1991).

Simultaneously with the development of computer technology, research has also developed with the aim of finding a global information system for the receipt, storage, processing and analysis of a large quantity of spatially defined data, and this is the geographic information system – GIS.

The analysis of data obtained by remote sensing methods provides information on the objects and phenomena on the Earth's surface which is spatially defined (inventory taking and monitoring of interesting objects and phenomena, surveys and mapping, etc.). This information can then be directly included into a GIS to make possible the linking, processing, storage and analysis of various types of spatially defined data which, as stated above, can be presented in the form of thematic maps or mathematical models (Kalensky 1991).

Talking about forest status means such data provided by the forest inventory (Kalafadžić and Kušan 1991) which describe the type, quantity, quality, growth, physiological condition, tree and stand productivity, as well as all other details necessary for forest management and for planning in forestry.

The maintenance of forest stability with constant yields and all the important sociological aspects may be ensured under the ever-increasing demands put on the forest, by continuous and high-quality planning based on reliable forest inventories. A forest inventory supplies information on the existing plant communities, growing stock, superficies, volume increment and health. After processing, the collected data are used in many forestry disciplines, from mathematical (biometrics, dendrometry, etc.), through technical (geodesy, photogrammetry, cartography) to biological ones (silviculture, phytocenology, conservation, ecology) providing the basis for any serious planning in forestry. Moreover, knowledge obtained through a forest inventory serve in planning other segments of the national economy (tourism, infrastructure, nature preservation, etc.). For this reason, the inventory must give reliable information at as low a cost as possible and by applying all the achievements provided by the science in this field (Kalafadžić and Kušan 1991).

It is on this basis that remote sensing was introduced into forest inventory operations. Techniques of the interpretation of aerial photographs have been developed and, with time, the surveying techniques for all essential stand parameters, too. In sum, aerial photographs have become an important tool for proper inventories.

Taking a forest inventory is the sphere where a forestry specialist surveys, collects and interprets basic forestry data which then serve for primary planning in forestry (Lötsch 1968), namely for a wider planning of the national economy (Zöhrer 1974). By means of automatized and computerized graphics (digital cartography) and modern data collection methods (remote sensing), as well as with the use of computers for data processing, the speed of data preparation for planning and for performing forest management work has increased considerably. According to Lukić (1993), the application of a GIS and the ever-increasing development of computer technology present a milestone in new forest inventories within the multipurpose forest exploitation, because those who have good and timely information have the future of development, too.

Since the forest is a dynamic ecosystem with continuous changes in time and space, for any planning within this system it is necessary to survey its current state and to determine all changes taking place in it. On the basis of determined development trends, the future is anticipated. "The future is the child of the past and the present" (Neidhardt 1971). The uncertanly of the forecast regarding the future state becomes greater with the prolongation of the planning period, and the correctness of the forecast is checked by periodical inventories.

The continuity of forest development monitoring as a long-term process of the increase of biomass in space and time assumes continuous and long-term planning, the permanent conduct and constant control of all procedures regarding the forest, unified into a professionally established entity – management (Meštrović et al. 1992).

Planning is virtually to act of looking into the future prior to making any decision (Pranjić 1987). On the basis of past events, future actions can be foreseen and planned to achieve the desired aim. The fact that past events and all changes in the forest status can be properly monitored by means of photographs has helped foresters in many countries to improve forest management and to carry out planning in forestry (Mroczynski 1976, Itten et al. 1985, Buer 1987, Coleman et al. 1990, Hussin and Shaker 1995). The results of interpretation are most often linked with other data in a GIS which is used for analyses, simulations and planning.

The results of a forest inventory consist of two parts: one descriptive (text, tables, graphs) and one cartographic (topographic, forest-economic and thematic maps). In the computer era, the first part presents attributes and relationship databases and the second part provides digital cartography that allows for a rational and economic use of maps and enables them to be completed and adjusted to the real state in the field, i.e. their daily updating (Kalafadžić and Kušan 1991).

The development in the field of computer techniques and software makes it possible to link up cartographic and graphic databases with relationship bases into one unique information system for the land, thus providing an inflow of correct and fresh information on forests as an essential prerequisite for successful management. Such a system must be designed in a way that a fast flow, documentation and exchange of information is possible between all levels (Tomanić 1990) and that the data can be exchanged with other databases (Kušan et al. 1992a). The system must meet some basic criteria (Lund 1988) such as plasticity, polyfunctionality, integrity and multitemporality.

Because of the large amount and variety of data obtained by inventories for high-quality planning and decision making on the operation of forest management and forestry policy, the establishment of a unique information system for forestry is necessary (Kušan and Kalafadžić 1994). Having in view its great possibilities and fast development, a GIS can be the carrier of such a unique information system for the forestry of Croatia (Brukner et al. 1992, Kušan et al. 1993).

Lately, in much research work, the main role in planning has been given to the spatial information system with special reference to the advantages offered by the use of a GIS (Patrono 1995).

According to Nijkamp and Scholten (1993), such a spatial information system is becoming an indispensable tool in efficient planning.

GIS technology has found permanent application in many disciplines dealing with the study, exploitation and management of natural resources:

- geology (Schetselaar et al. 1990, Bocco et al. 1990, Akinyede 1990)
- geography (Lee 1991)
- hydrology (Smart and Rowland 1986, Mallants and Bodji 1992, Rasamee and Suwanwerakamtorn 1994)
- pedology (Skidmore et al. 1991)
- environmental protection (Fleet 1986, Dulaney 1987, Stendback et al. 1987, Besio and Roccatagliata 1991)
- forestry (Consoletti 1986, Sieg et al. 1987, Keefer 1989, Susilawati and Weir 1990, Lesyen and Goossens 1991, Hentschel 1996).

So far, GIS technology has been applied in the forestry of Croatia in several ways, namely:

- GIS model for EEFO "Opeke" (Kušan et al. 1992a)
- GIS model application in forest management (Kušan and Kalafadžić 1992)
- GIS model application in forest exploitation (Kušan et al. 1992b)
- GIS technology application in forest classification in Croatia for seed production purposes (Benko et al. 1993)
- GIS application in hydropedological researche (Mayer 1993).

APPLICATION OF THE DIGITAL TERRAIN MODEL IN FORESTRY
PRIMJENA DIGITALNOG MODELA RELJEFA U ŠUMARSTVU

The modern planning and management of space require the construction of an efficient GIS. A significant qualitative improvement of the GIS is achieved by the introduction of a DTM into the database, by means of which the data are geometrically and exactly located in the space with respect to both their position and their height. To construct a DTM with adequate characteristics, it is necessary to collect data containing positional and elevational information about the ground (Gajski et al. 1994).

The DTM can be one of the GIS elements. The accuracy of produced DTMs has been the preoccupation of research scientists since the very beginning of their preparation and application in 1958 (Kušan 1996). Accuracy depends on the amount and selection of points on the basis of which the DTM is constructed, on the selected interpolation points and the adjustment method (Jergović 1994).

The use of DTMs has become the usual practice in forestry (Gossard 1978), regardless of whether technical or biological disciplines are involved (Kušan 1995). As far as technical disciplines are concerned, the DTM can be used for:

- mapping from aerial photographs (Schneider and Bartl 1994)
- orthophotograph, orthophotoplan and/or orthophotomap preparation (Ecker 1992, Miller et al. 1994)
- road project engineering (Dvorscák and Hrib 1992, Becker and Jäger 1992)
- forest opening planning (Dietz et al. 1984, Shiba and Löffler 1990, Sessions 1992, Nearhood 1992, Knežević and Sever 1992, Dürrstein 1992, Pičman i Tomaz 1995, Hentschel 1996).

In biological disciplines, DTM can be used to calculate individual habitat features (terrain slope, exposure, insolation, etc.) which, as ecological variables, can then be used for:

- vegetation study (Antonić et al. 1994)
- study of ecological fauna niches (Štefanović and Wiersema 1985)
- simulations in climate and air pollution studies (Tesche and Bergstrom 1976)
- interception and transpiration evaluation (Kändler 1980)
- soil type maps (Skidmore et al. 1991)
- landscape architecture (Posavec 1993)
- park and arboretum landscaping (Repić 1995).

In the case of photographs of mountainous terrain or spatially very heterogeneous areas, in addition to the results of interpretation, it is also necessary to include additional information in the form of grid – thematic maps (pedological, vegetation, etc.) as well as maps describing terrain characteristics (slope, exposure, DTM). In this way, significant improvements in the interpretation results can be obtained (Skidmore 1988b, Lillesand and Kieffer 1994).

The advantage of DTM is the possibility to make a three dimensional projection of an interesting terrain configuration, and by simple visualisation to plan and to determine the direction of forest openings more easily, thus facilitating considerably the maintenance of the sensitive natural balance which nowadays is particularly endangered.

AIM OF THE WORK
CILJ RADA

The main aim of this work was to find a way of linking all existing data, as well as data acquired by the interpretation of aerial photographs, into a unique information source, and to generate new information as a basis for planning in forestry, by using the methods of a geographical information system (GIS).

To accomplish this aim, it was necessary:

- to process the results of interpretation of colour infrared (CIR) aerial photographs
- to make maps with various thematic contents
- to digitalize existing maps (pedologic, geologic, phytocenologic, economic)
- to organize databases
- to assign to each acquired layer an attribute data table (numerical and descriptive) by means of which it was possible to connect digitalized maps with tabular data
- to produce a digital terrain model (DTM) and to establish new layers (slope, exposure, etc.) based on it
- to incorporate new acquired elements into the established GIS model and to connect them with the existing elements
- to analyze all acquired data (numerical and cartographical) at the same time per individual layer or per multilayer overlap
- to process statistically-obtained dependences (exposure, slope, plant community, taxation elements, damage stage, etc.).

Such an approach to the problem, using GIS technology, relieves the expert of routine jobs (hand mapping, establishing new layers from existing ones, etc.) and leaves him more time for decision making in space management, i.e. planning, and opens new possibilities of research.

Research carried out will indicate the possibilities of the use of remote sensing (in this case, CIR APs) and GISs for planning in forestry and for environmental study.

The established GIS model can be used in all future research, and in addition will serve as the basis for the establishment of GISs for other protected areas in Croatia.

LIST OF SYMBOLS AND ABBREVIATIONS
POPIS SIMBOLA I SKRAĆENICA

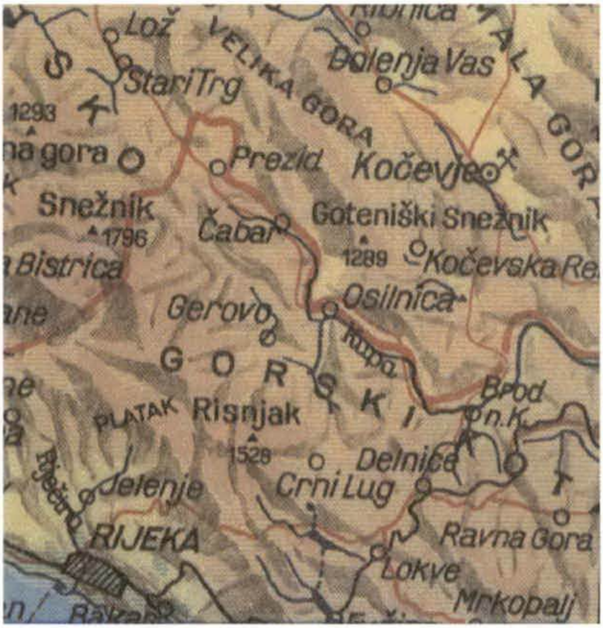
Abi – Fag –	*Abieti – Fagetum dinaricum* Treg. 1950
Arem – Pic –	*Aremonio – Picetum* Ht. 1938
B –	regression coefficient
BETA –	standardized regression coefficijent
Blech – Abi –	*Blechno – Abietetum* Ht. 1950
BUKVAIO –	beech – damage index
BUKVASO –	beech– mean damage
BUKVAUS –	beech – relative share
Cal – Abi –	*Calamagrosti – Abietetum* Ht. 1956
D1.30 –	breast diameter (photogrametric data)
DMR –	digital terrain model (DTM)

DTER –	breast diameter (field data)
EEFO–	educational experimental forest object
ftg. –	photogrammetric data
G –	base surface (photogrammetric data)
G. J. –	management unit
GEOL –	geological categories
GIS –	geographical information system
GTER –	base surface (field data)
Hom – Fag –	*Homogyno alpinae – Fagetum sylvaticae* Ht. 1938/Borh. 1963
ICK –	colour infrared (CIR) aerial photographs (Aps)
IO –	damage index
JELAIO –	fir – damage index
JELASO –	fir – mean damage
JELAUS –	fir – relative share
JSO –	unique damage stage (UDS)
List – Pic –	*Listero – Piceetum abietis* Ht. 1938/Fuk. 1969.
N-H–	number of trees (photogrametrical data)
NP –	National park
NTER –	number of trees (field data)
R –	digital terrain model (DTM)
RASP –	exposure
RFITFIN –	phytocenose, plant communities
RISPED –	pedocartographic units
RSLP –	ground slope
SMREKAIO –	spruce – damage index
SMREKASO –	spruce – mean damage
SMREKAUS –	spruce – mixture share
SO –	mean damage
Std. dev. –	standard deviation
ter. –	field data
TIN –	Triangular Irregular Network
UKUPIO –	total damage index
UKUPSO –	total mean damage
V –	volume (photogrammetrical data)
VTER –	volume (field data)

RESEARCH AREA
PODRUČJE ISTRAŽIVANJA

The National Park "Risnjak" in the western part of Croatia extends some fifteen kilometers from the sea in a straight line (Figure 1).

Figure 1.Geographical position and map of research area
Slika 1. Zemljopisni položaj područja istraživanja



The surface area of the NP "Risnjak" is 3227.90 ha with the peak Veliki Risnjak as its highest point (1528 m) and its lowest point in the Leska depression (676 m). The Park includes the central part of the Risnjak massif which extends from the Kupa river source to Gornje Jelenje and from Crni Lug to Snježnik.

When the boundary of the NP "Risnjak" was determined, care was taken to encompass into one entity over the smallest area possible the most typical natural and scientific phenomena on one hand, and all the most important esthetic elements on the other hand.

The geographical position of the Risnjak massif, as well as that of the entire Gorski kotar, makes this area very interesting because it presents a very strong climatic and vegetational barrier between continental Croatia and the Croatian littoral.

In the investigated area to which the Park gravitates, the oldest deposits, composed mostly of clastic elements, are of the Upper Carboniferous Age. A large space is occupied by the Lower and Middle Permian deposits where, in addition to clastic sediments, limestone occurs, too. In the Triassic deposits, predominant are limestone-dolomite and limestone surfaces with sporadically expressed stratification, but also with a vertical, i.e. lateral dolomite and limestone exchange. The Credaceous sediments contain deposits of limestone, limestone breccia and limestone with dolomites. The youngest – Quartenary sediments are settled in plains on mountain platforms and in river valleys.

Within the boundaries of the Park, in its southern part, the oldest geological elements are Triassic deposits composed of clay – marl – sandstone and dolomite-sandstone strata. The Triassic deposits are overlaid by the Middle Mesosoic, Jurrasic sediments of limestone and dolomites of a medium-grained to a very compact structure. The Jurrasic deposits occupy the largest part of the Park surface.

Owing to such complexity and the variability of pedogenetic factors and their influence on pedogenetic and pedoevolutionary processes, a relatively large number of soils is in this area found on all systematization levels: type, subtype, variety, form (Martinović et al. 1994).

In the NP "Risnjak", the soils found on pure limestone and dolomite are: black earth-soils (melanosol), brown soils (cambisols over limestone), loess soils (luvisols) and on softer, clastic limestone and dolomites, clay and crystalline – rendzinas as the primary stages of pedogenetic development.

On silicate supstrates (sandstone, sand clays and conglomerates), the acid brown (dystric cambisols) and brown podsolic soils (brunipodsols) were determined. On both groups of substrates, sporadically colluvial soils were determined, and on limestone and dolomites rocky tracts too.

Risnjak is located in the aera where maritime and continental influences are encountered, also with the influence of the Alps from the northwest and of the Dinaric Alps in the southeast, which causes moderately warm summers, rainy autumns, and long and severe winters (Kamenarović 1970).

In the investigated area, the moderately cold climate reigns with a large amount of precipitation, high air humidity, frequent frosts, a shorter vegetation period and high and long-lasting snow cover.

A particularly precious trait of the Risnjak massif is its vertical zoning of forest vegetation, characteristic of the western Dinaric Alps (Rauš et al. 1992). The most important and the largest by surface area is the Dinaric beech-fir forest (*Abieti-Fagetum dinaricum* Treg. 1950). It is followed by the sub-Alpine beech forest (*Homogyno alpinae-Fagetum sylvaticae* /Ht. 1938/ Borh. 1963).

On Risnjak, the vegetation of mungo pine with the honeysuckle family (*Lonicero-Pinetum mughi* /Ht. 1938/ Borh. 1963) is particularly conserved, among which rare and endangered plant species grow.

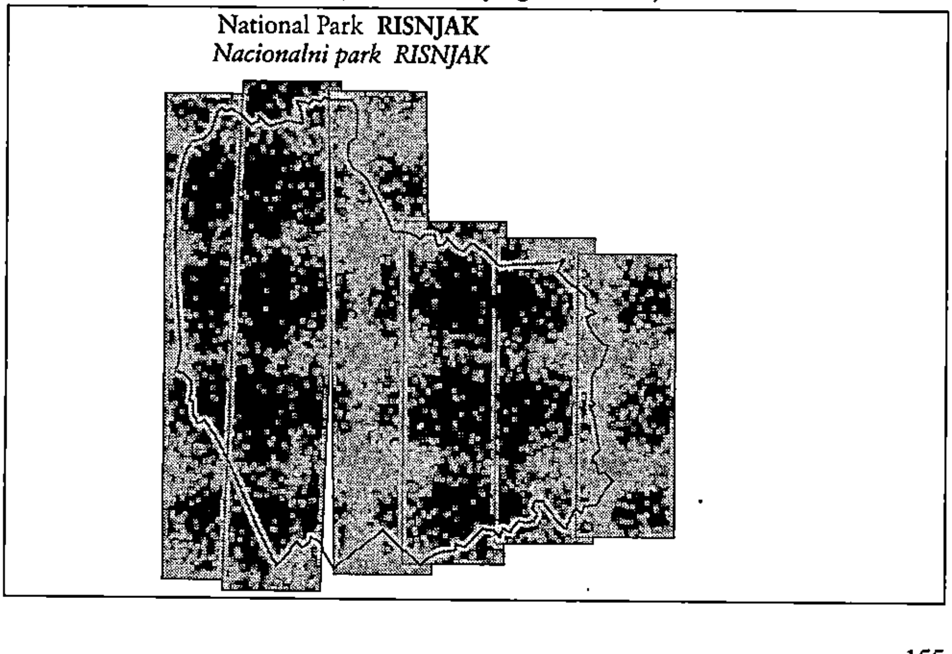
METHODS OF WORK
METODE RADA

PHOTOINTERPRETATION
FOTOINTERPRETACIJA

Delineation
Delineacija

The delineation was made on the CIR aerial photographs taken in the period from August 1 to 10, 1988, using a Zeiss Jena LMK 305/23 photogrammetric normal angle camera with Kodak Aerochrome Infrared 2443 film.

Figure 2. Photographed area map with drawn flight lines
Slika 2. Karta snimljenog područja s ucrtanim prugama snimanja



The NP "Risnjak" surface was covered with 6 strips, namely by 90 air photos in a mean scale of 1:5754 (4680 to 6820), (Figure 2).

The longitudinal overlap of adjacent photographs (in a strip) was between 55 and 70%, and the lateral (between strips) had to be between 10 and 30%. This, however, was not achieved in a short section between central strips, so a small surface in the southern part of the Park remained unphotographed.

On the CIR aerial photographs, stands were extracted by means of visible differences between individual image elements of forest stands such as: tree species, mixture proportion, stand canopy, crown size, damage stage, parent substrate appearance etc. Interpretation was made using a mirror stereoscope with a magnification of 8x.

In each extracted stand, between 20 and 60 trees were examined with respect to tree species and damage status. The number of examined trees depended on the extracted stand (stratum) surface. In total, 364 strata were extracted and 9457 trees were examined.

Damage Assessment
Određivanje oštećenosti

Trees for interpretation purposes were selected according to a randomly positioned systematic sample (grid) inside the carefully extracted, homogeneous strata. Using the grid method, a uniform distribution of interpreted tree crowns per extracted strata washas been obtained. The variability of all photogrammetrically estimated variables inside the strata is unsignificative.

On the transparent foil, a grid of lines at a distance of 5 mm was drawn. By means of linear intersections, a grid of sample points was defined. The number of interpreted trees varied according to the size of individual delineated strata. The foil was randomly placed on the delineated aerial photograph. As a sample, the tree nearest to the sample point, namely, to the grid line intersection in the top right square from the sample point, was taken. Tree examination was made in the stereomodel under a magnification of 8x.

As the basis for damage status assessment, the provisions from the "Guidelines" (1987) for inquiries on forest decline in Croatia were used. According to these "Guidelines" (Prpić et al. 1988), the stage of tree damage was assessed according to a determined percentage of assimilation organ absence (needles, leaves), the percentage of yellow needles/leaves and the percentage of branch decline.

For photointerpretation purposes, the said features had to be considered together, because they will thus be projected on the aerial photograph. According to Kalafadžić and Kušan (1990, 1993) every tree on the ground and on the aerial photograph should be estimated with a unique damage stage (UDS), as a global estimation of all said features.

During the forest damage inventory using the CIR aerial photographs (Kalafadžić and Kušan 1989), it was noted that the damage stage range (26-60%), according to the damage stage scale used in the European Community (Hildebrandt et al. 1986), was too wide. Therefore, on the basis of the investigated increment in differently damaged trees, the range was divided into two substages (2.1 and 2.2).

Such a division was also confirmed by the proposals in AFL (1988) where the same damage degree scale was suggested for spruce, and which coincided with the experiences of Hočevar, too (1988).

Trees were classified into groups/classes according to damage stages during photointerpretation of CIR APs by using a carefully established photointerpretaion key, in which the method of individual tree species and the projection of the tree damage stages on aerial photographs was shown in an illustrative and descriptive manner.

The photo interpretation key was constructed for the main tree species: fir (*Abies alba* Mill.), spruce (*Picea abies* Karst.) and beech (*Fagus sylvatica* L.) on the basis of experiences in Central Europe (Löffler et al. 1984) and field observations carried out during aerial photographing. In addition to the said species, the interpretation was also made for: mugho pine (*Pinus mugo* Turra.), mountain maple (*Acer pseudoplatanus* L.) and mountain ash (*Fraxinus excelsio*r L.), but not being predominant, these species were indicated as "other broadleaved species" (OBS).

For each stratum, damage indicators were computed. Classification of the single tree damage status (tree crowns) was made according to a completed damage stage scale of the European Community, namely the terrestrial enquiries on forest decline in Croatia (Kalafadžić and Kušan 1989, 1990b). Forest stands were classified into damage stages according to scale (Kalafadžić and Kušan 1990b), on the basis of mean damage (SO) by the formula (1). A good indicator is the damage index (IO) expressed by the formula (2):

$$SO(\%)=\frac{\sum f_i x_i}{\sum f_i}\ (1)\quad IO(\%)=\frac{\sum f_{(2-4)}}{\sum f_{(0-4)}}100\ (2)$$

where fi= the number of trees in i– damage stage.

xi= i– stage interval centre in the damage stage scale for single trees (x_0=5%; x_1=17,5%; $x_{2.1}$=32,5%; $x_{2.2}$=50%; x_3=80%; x_4=100%).

Strata were grouped into damage stages 20% wide. Thus obtained areas with various damage stages were mapped on a basic state map and the damage map was made.

Stand Parameter Measurements

Izmjera sastojinskih veličina

On the CIR aerial photographs, together with damage assessment, some stand parameters were also measured. These measurements were made on 36 aerial photographs, namely on 878 sample plots. A grid of points with drawn sample plots was placed on each stereopair, inside the previously delineated strata. On such a systematic sample and on each linear intersection inside the plot, tree species were determined, the tree crown diameter was measured, and all trees inside the plot were counted.

The optimal sample plot size was the plot with 20 to 30 observable tree crowns (Spurr 1960). For each photograph scale, the sample plot surface area (circle) was calculated. The surface area of a single sample plot ranged between 608 and 1,241 sqm.

The stand volume was read from the increment-yield tables. By means of the number of trees, the most suitable valuation rate was chosen, i.e. the one with a similar number of trees per ha. Wherever necessary, the interpolation was made. The normal volume data were reduced by means of canopy to obtain real data per ha for each stand (stratum).

For fir, the Swiss tables were used (EAfV 1966), for beech the Špiranec's tables (1975) and for spruce Wiedemann's tables 1936/42 (Meštrović and Fabijanić, 1995).

On the basis of the tree crown diameter (natural crown size) and the tree crown projection surface as measured on the aerial photographs, the fir, spruce and beech base surface and breast diameter were assessed.

The linear equations obtained by multiple regression (Kušan and Pernar 1996a) were used to assess the breast diameter and base surface of fir, spruce and beech. By correlation analysis, it was found that the relationship between these parameters was very strong for all three tree species.
For the breast diameter, the linear equation $d_{1.30}=f(D)$; $d_{1.30}=b_1D$, was used and for the base surface $g=f(Pk)$; $g=b_1Pk$.

Fir (N = 2146)
$d_{1.30} = 5.73366D$ $r=0.9534$
$g = 0.003637Pk$ $r=0.8770$

Spruce (N=2048)
$d_{1.30} = 6.798789D$ $r=0.9802$
$g = 0.004798Pk$ $r=0.9364$

Beech (N=1920)
$d_{1.30} = 5.051564D$ $r=0.9777$
$g = 0.0027=46$ $r=0.9417$

MAP DIGITALIZATION
DIGITALIZACIJA KARATA

To develop the graphical part of the GIS model, existing maps were digitalized:
1. contours and topographic maps 1:5000
2. topographic map of a wider area of the NP "Risnjak" 1:18000

Although the map was made as an excursion map, it contains all the important elements. To allow its use in a GIS (ARC/INFO), the vectorization was made with simultaneous attributisation in layers.

The digitalized map contains eight layers which can be used on a computer either jointly or separately. By means of a special program, transformation to other meaures (scales) or projections is possible.

The purpose of a digitalized map is to allow all other themes to be entered in a geocoded form in the same way, so that the contents can overlap for all themes in a uniform manner. Another purpose is to facilitate the introduction of modifications and additions, if any, because the map is the basis for data entry into the GIS database from all other thematic fields:

3. thematic map of forest communities – phytocenological map 1:25000
4. forest soil map – pedological map 1:50000
5. thematic hydrogeological map 1:25000
6. stand damage map 1:10000
7. management map 1:25000.

Digitalization was done using PC computers (386/40 Mhz, 8 MB RAM) to which the digitaliser (DRAWING BOARD II – CalComp) and the ver. 12 AutoCAD program were conected.. With this program, it was possible to assign to every point on the map the values of its terrestrial coordinates, which ensures easier subsequent transformation to other scales. In the ARC/INFO program, errors which occurred by digitalization were corrected using the PC ARC EDIT, CLEAN and BUILD modules. After all errors had been corrected, the heights of each contour, such as read from the analogue topographic map, were assigned graphically as attributes.

DIGITAL TERRAIN MODEL (DTM) DEVELOPMENT
IZRADA DIGITALNOG MODELA RELJEFA (DMR)

The digital terrain model (DTM) for the area of the NP "Risnjak" was developed using the program ARC/INFO – TIN modules (Triangular Irregular Network), on the basis of digital data for the contours from the topographic map.

The final DTM version was obtained in three forms:

– grid form, with shaded height for certain factors and with 3D impression
– coloured 3D form with colours per elevation class
– 2D form onto which coloured elevation classes were entered.

The purpose of the developed DTM was not only to provide a view of space, but also to provide ground slopes, exposures and visibility from single points, as well as to plot other themes under research (stand damage, taxation elements, pedological characteristics, plant communities, etc.).

RESULTS OF RESEARCH
REZULTATI ISTRAŽIVANJA

GIS-MODEL FOR THE NP "RISNJAK"
GIS-OV MODEL ZA NP "RISNJAK"

The GIS-model was established using the program package MODEL (old name GRID), developed for data use and preparation in ecological modelling (Antonić et al. 1994). This is the grid GIS program for personal computers with some elements of the vector GIS (grid overlapping with linear objects, operation with contours etc.). The program has the possibility to make DTMs on the basis of vector or point data. MODEL supports various forms of data (grid, lines and points). Grid and line data are stored as binary databanks, and point data as – dbf – databanks.

For the realisation of the GIS – model in this work, the procedures which can be presented shematically as a flow chart were used (Figure 3).

By means of the functions incorporated in the MODEL for solving more complex requirements (trigonometric functions, azimuth and Sun elevation, etc.) and usual grid functions ("neighbourhood", statistical functions, reclassification, making colour composites, colour separation, as well as surface functions – slope, hillshade, visibility), the desired modelling was developed.

Inside the GIS-model, all accessible information sources were geocoded and stored as separate layers, thus enabling easy manipulation between thematic and topographic data (Figure 4).

The established grid GIS-model for the NP "Risnjak" consists of 30 layers[1]:

1. pedocartographic unit;
2. geological categories (according to rock composition and permeability);
3. plant communities;
4. spatial distribution of mean breast diameters per ha (field data – ter.);
5. spatial distribution of mean breast diameters per ha (photogrammetric data – ftg);
6. spatial distribution of base surfaces per ha (ter.);
7. spatial distribution of base surfaces per ha (ftg.);
8. spatial distribution of volumes per ha (ter.);
9. spatial distribution of volumes per ha (ftg.);
10. spatial distribution of number of trees per ha (ter.);
11. spatial distribution of number of trees per ha (ftg.);
12. relative share of fir (ftg.) – Figure 5;
13. relative share of beech (ftg.) – Figure 6;
14. relative share of spruce (ftg.) – Figure 7;

[1] In the paper several examoles of layers are shown (Figures 5 to 12). Other established layers are given given in the author's dissertation (Pernar, 1996)

Figure 3: Procedures used in establishing a GIS-model for the NP "Risnjak"

Slika 3. Slijed postupaka za uspostavu GIS - modela NP "Risnjak"

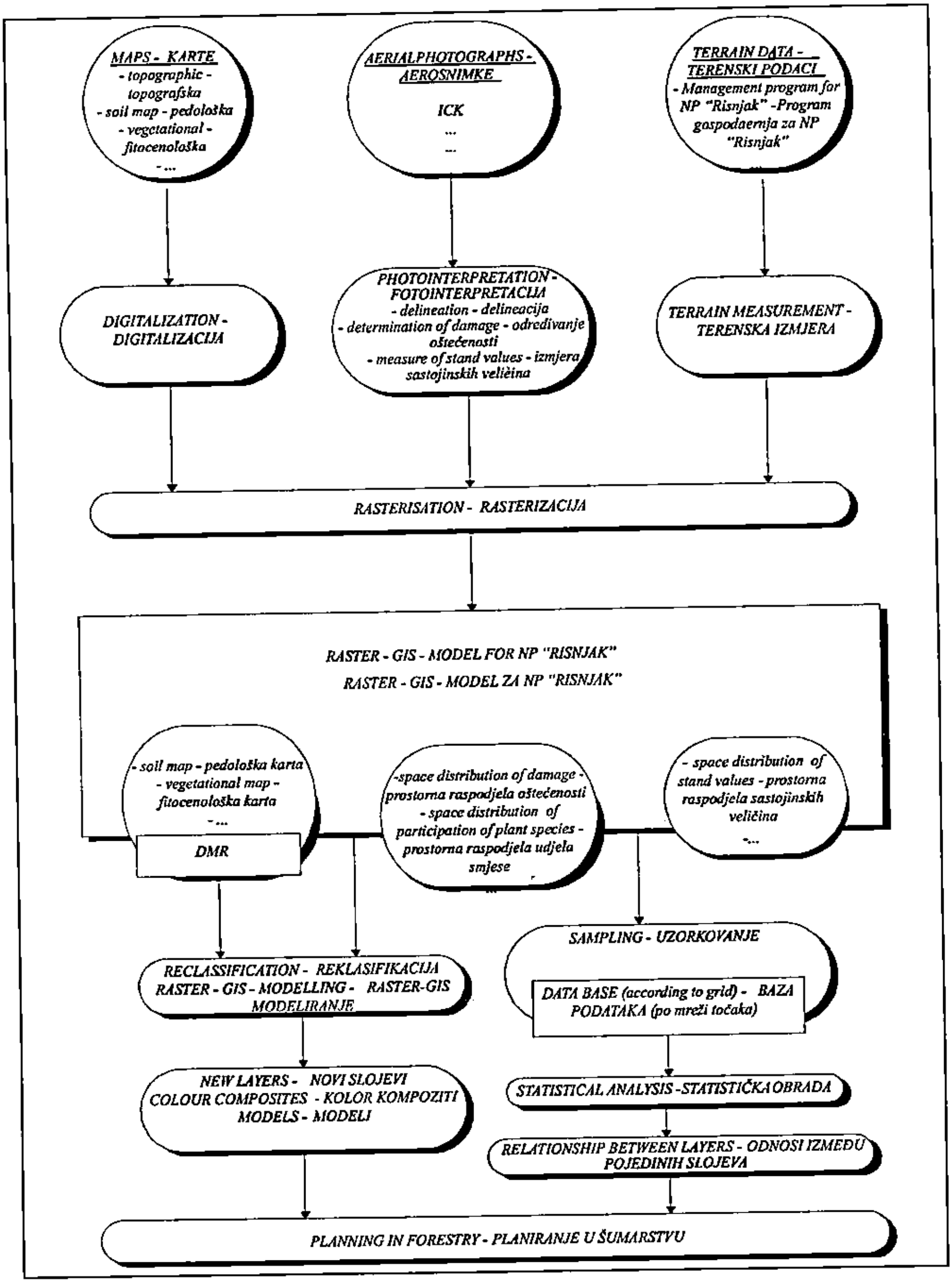


Figure 4. Schematic review of layers and thematic (attribute) data in a GIS-model
Slika 4. Shematski prikaz slojeva i tematskih (atributnih) podataka u GIS - modelu

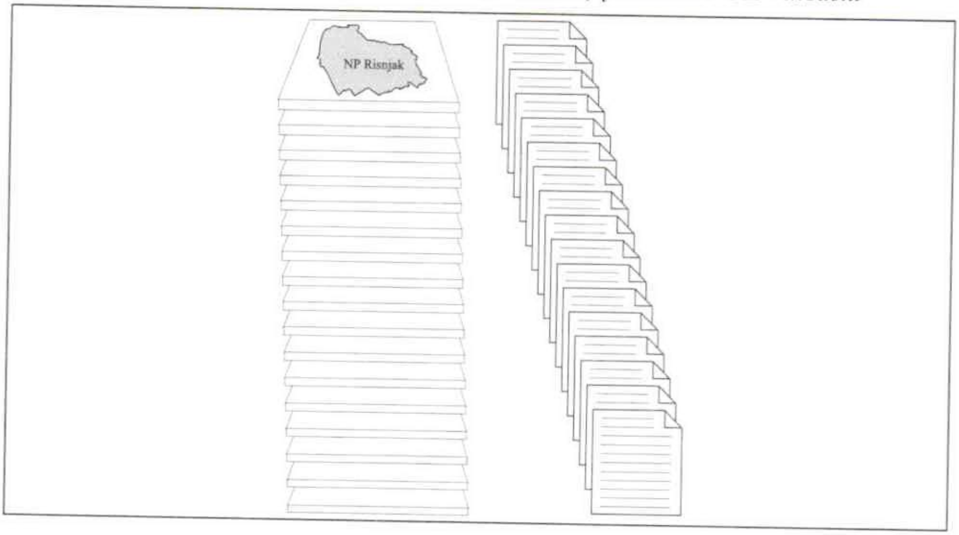


Figure 5. Relative share of fir in cover (ftg.)
Slika 5. Relativni udjel jele (ftg.)

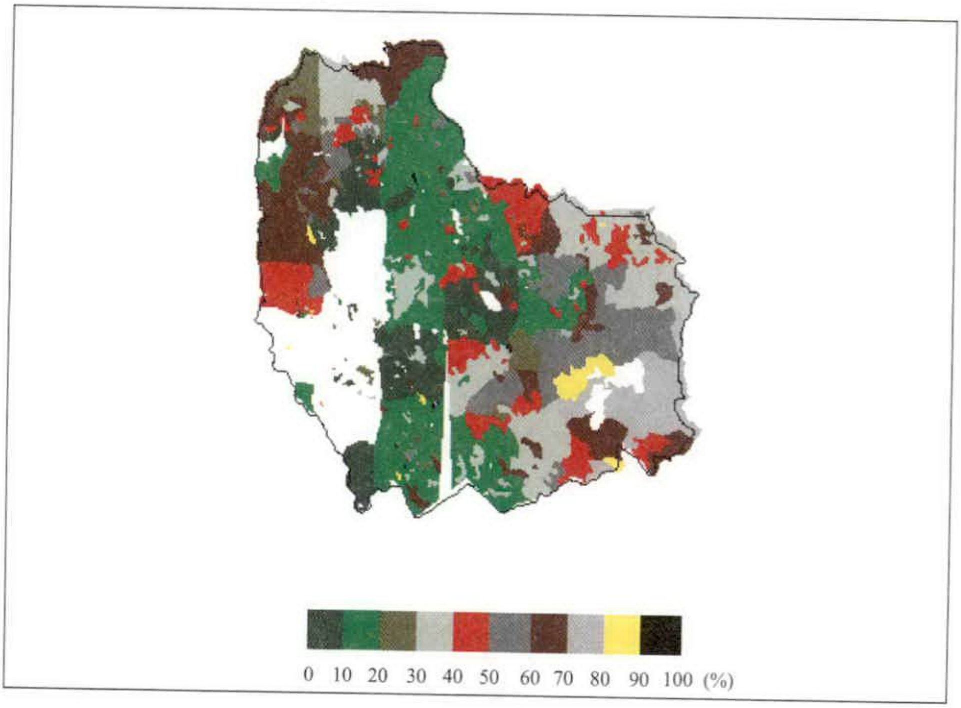


Figure 6. Relative share of beech in cover (ftg.)
Slika 6. Relativni udjel bukve (ftg.)

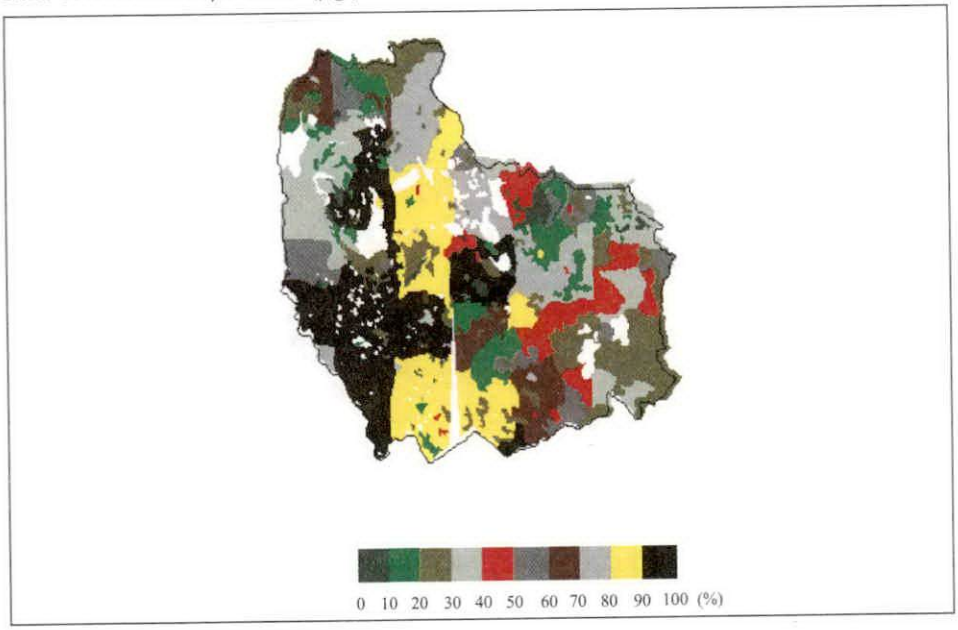


Figure 7. Relative share of spruce in cover (ftg.)
Slika 7. Relativni udjel smreke (ftg.)

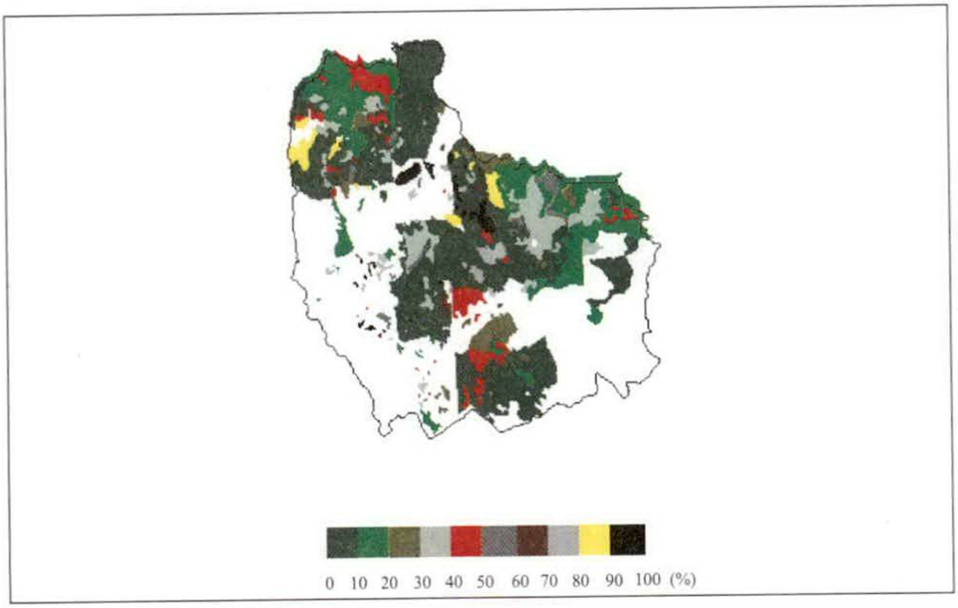


Figure 8. Spatial distribution of fir mean damage (ftg)
Slika 8. Prostorna raspodjela srednje oštećenosti jele (ftg.)

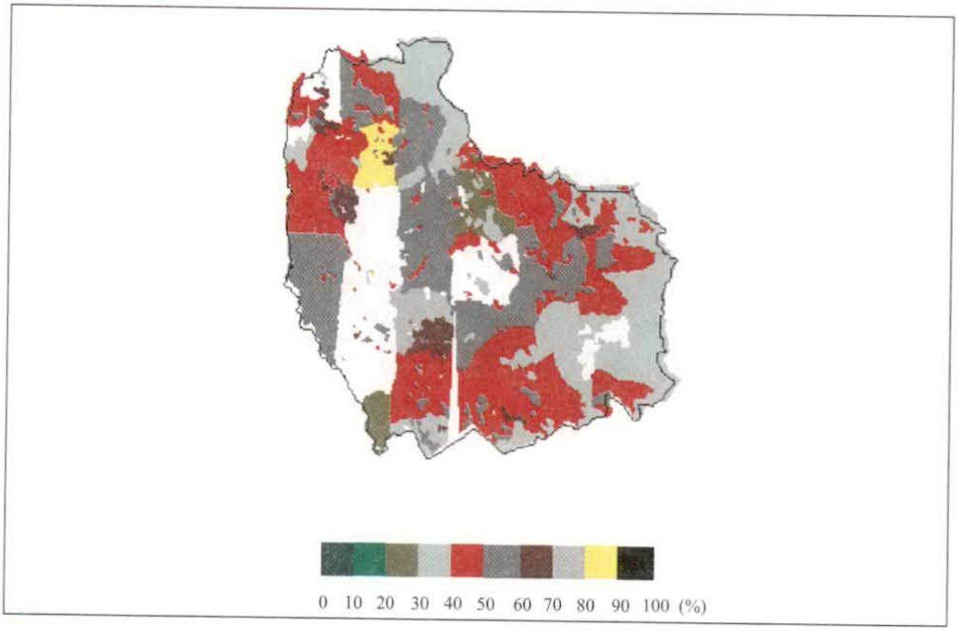
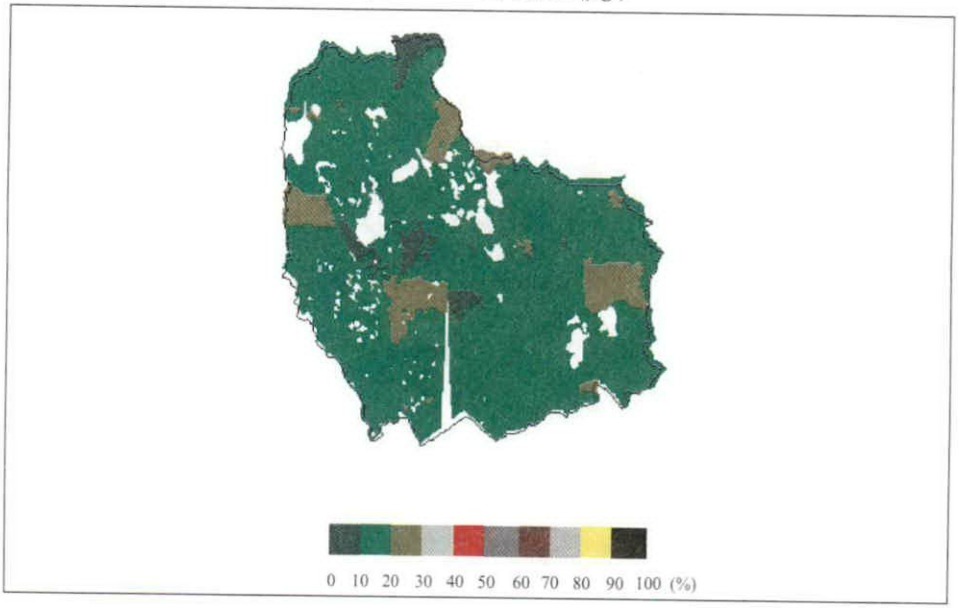


Figure 9. Spatial distribution of beech mean damage (ftg)
Slika 9. Prostorna raspodjela srednje oštećenosti bukve (ftg.)



15. spatial distribution of fir mean damage (ftg) – Figure 8;
16. spatial distribution of beech mean damage (ftg.)– Figure 9;
17. spatial distribution of spruce mean damage (ftg) – Figure 10;
18. spatial distribution of fir damage index (ftg.);
19. spatial distribution of beech damage index (ftg.);
20. spatial distribution of spruce damage index (ftg);
21. spatial distribution of conifers mean damage (ftg.);
22. spatial distribution of deciduous trees mean damage(ftg.);
23. spatial distribution of conifers damage index (ftg.);
24. spatial distribution of deciduous trees damage index(ftg.);
25. spatial distribution of total mean damage (ftg.) – Figure 11;
26. spatial distribution of total damage index (ftg.);
27. digital terrain model (DTM);
28. ground slope;
29. ground slope per class according to Löffler (1991) – Figure 12;
30. angle of deviation from the south (exposure);

The Park area is presented by the point grid with a 50 m pitch on X and a 50 m pitch on Y. The point grid was generated on the computer. Linked up to each layer are attribute data with corresponding coordinates.

Figure 10. Spatial distribution of spruce mean damage (ftg)
Slika 10. Prostorna raspodjela srednje oštećenosti smreke (ftg.)

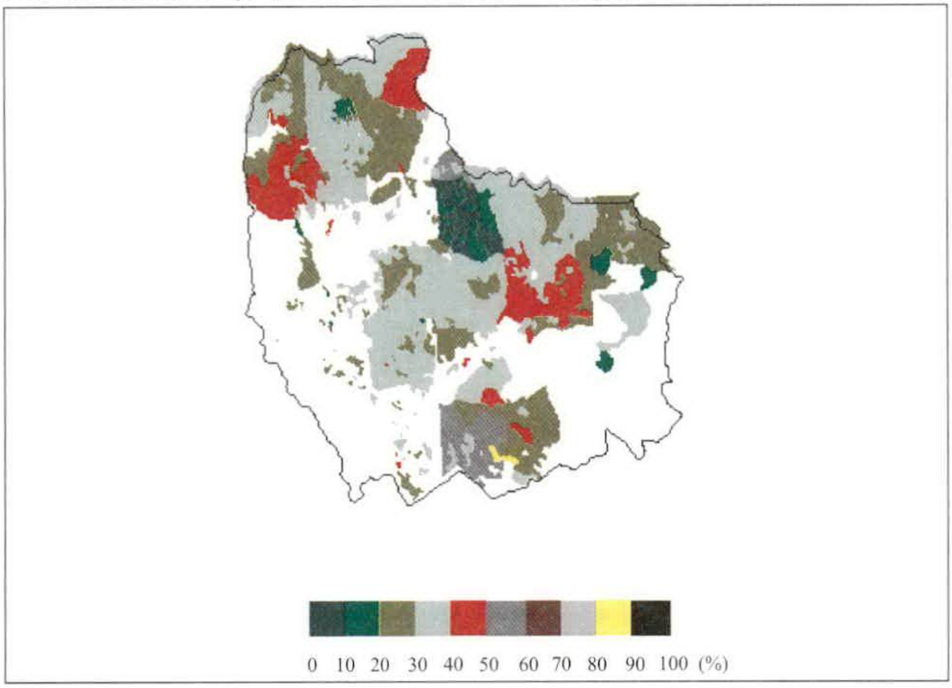


Figure 11. Spatial distribution of total mean damage (ftg.)
Slika 11. Prostorna raspodjela ukupne srednje oštećenosti (ftg.)

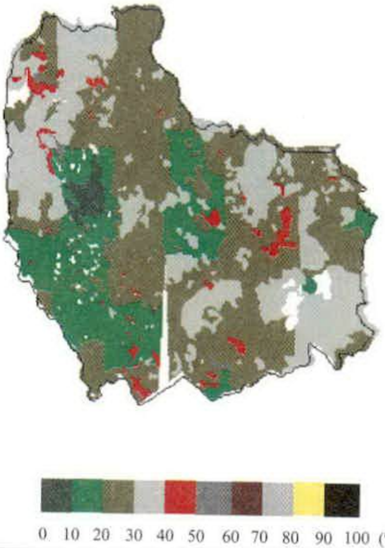
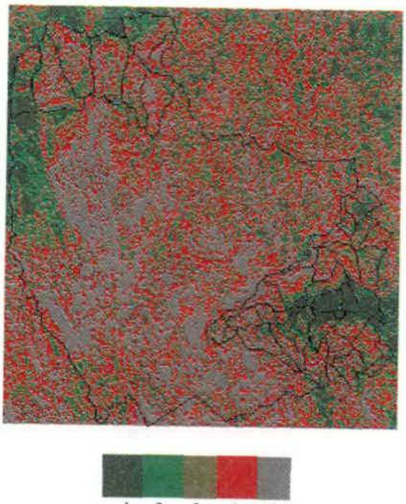


Figure 12. Ground slope per class according to Löffler (1991)
Slika 12. Nagib terena po klasama prema Löffler-u (1991)



The data used for establishing the GIS-model were obtained by the interpretation of CIR APs, map digitalization and field surveys (the data from the Management Program).

All vector themes were grid converted at a pixel size of 10 x 10, which corresponds to the square size of 2 x 2 mm on the map.

NEW LAYERS
NOVI SLOJEVI

Inside the established raster GIS – model for the NP "Risnjak", the preparation of new contents (layers) was started by using some of the procedures shown in the flow chart in Figure 3 above. In this way, on the basis of the results of the interpretation of CIR APs, the attribute data and layers for the relative share of individual tree species within the investigated stand was obtained (Figures: 5, 6, 7). Then, from the layers and damage data for individual tree species, new layers were generated and the data were obtained for the mean damage and the damage index separately for broadleaved and coniferous trees, as well as the data on total damage per strata (Figure 11).

New layers obtained in this way can be a starting point for many further analayses and are useful to researchers dealing with forest damage in planning their future research.

The layers with stand parameters measured on CIR aerial photographs which are outside the compartments where management isconducted, can indicate the condition of stands in a closer area of the Park, as well as providing an inventory of management parameters.

From the digital terrain model using raster – GIS modelling, the slope and exposure layers were obtained. Ground slope was computed for each pixel from the 3x3 neighbourhood in DTM as the highest slope of the regression plane obtained by the smallest square method through 9 points.

The exposure layerwas also obtained from the 3 x 3 neighbourhood as an angular deviation of the highest slope direction from the north. This being a cyclic variable, the lowest (0°) and highest (360°) values obtained were equal, so standardization in relation to the absolute angular distance from the given orientation was made. In this way, the values from 0° to 180° were obtained.

Since the DTM, namely the ground slope, is very important for research work in various fields, especially in the field of forest exploitation, the next step was the establishment of a new layer (Figure 12). As a karst region is involved, slope variability is very high and it did not suffice to take into account the average slope on some of the surface area.

There are several functions by means of which slope variability can be defined (variation coefficient, arithmetical volume of the given neighbourhood value, standard deviation, etc.).

The new slope layer was calculated from standard deviations of 9x9 neighbouring pixels, so on the basis of the surfaces of 0.81 ha (resolution 10x10m), the spatial slope variability was expressed (low stand.dev.-uniform slope, high stand.dev.-variable slope). The new layer obtained can serve for planning forest openings, namely for optimal forest road network project engineering.

DATA ANALYSIS
ANALIZA PODATAKA

The statistical data processing was made using the CSS – Statistical program package. The data used for statistical processing were been obtained by systematic sampling on a computer-generated 50 x 50 m point grid from all layers in the geographical database.

Damage difference tests between plant communities
Testiranje razlika oštećenosti između biljnih zajednica

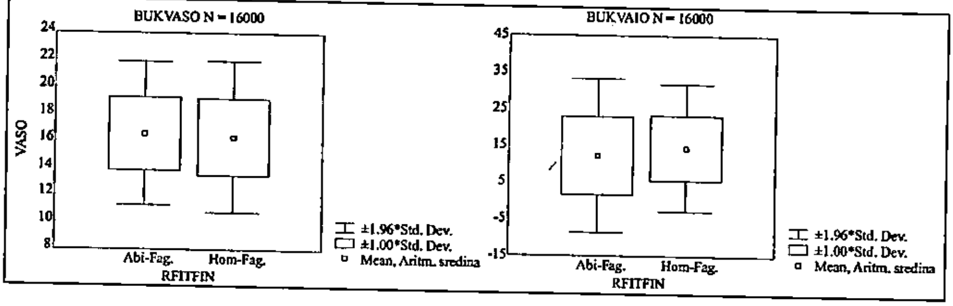
Tests concerning differences in mean damage and the damage index between plant communities were carried out using t-tests for dominant tree species in plant communities.

Tests concerning differences in mean damage and the damage index for beech between the plant associations *Abieti-Fagetum* and *Homgyno-Fagetum* did not show the existence of any significant differences (Table 1, Figure 13).

Table 1. Difference test for beech mean damage and damage index between the plant associations Abi-Fag. and Hom-Fag.
Tablica 1. Testiranje razlika srednje oštećenosti i indeksa oštećenosti bukve između fitocenoza Abi-Fag. i Hom-Fag.

Variable *Varijabla*	Unit *Jedinica*	Arith. mean *Aritmetička sredina* Abi-Fag.	Hom-Fag.	t	N	p	N - Abi-Fag.	N - Hom-Fag.	Std. dev. Abi-Fag.	Std. dev. Hom-Fag.	F	p
1	2	3	4	5	6	7	8	9	10	11	12	13
BUKVASO	(%)	16.40	16.33	.9181	10450	.3585	8456	1996	2.848	2.859	1.007	.8293
BUKVAIO	(%)	11.89	14.48	-0.32	10450	.0000	8456	1996	10.38	8.831	1.383	.0000

Figure 13. Differences test in mean damage and damage index for beech between the plant associations Abi-Fag. and Hom-Fag
Slika 13. Grafički prikaz razlika srednje oštećenosti i indeksa oštećenosti bukve između fitocenoza Abi-Fag. i Hom-Fag



In tests concerning differences in mean damage and the damage index for fir between the plant associations *Abieti-Fagetum* and *Calamagrosti-Abietum* (Table 2, Figure 14), and *Abieti-Fagetum* and *Blechno-Abietum* (Table 3, Figure 15), as well as the associations *Calamagrosti-Abietum* and *Blechno-Abietum* (Table 4, Figure 16), significant differences were noticed in all cases.

Table 2. Difference test for fir mean damage and damage index between the plant associations Abi-Fag. and Cal-Abi.
Tablica 2. Testiranje razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Abi-Fag. i Cal-Abi.

Variable *Varijabla*	Unit *Jedinica*	Arith. mean *Aritmetička sredina* Abi-Fag.	Cal-Abi.	t	N	p	N - Abi-Fag.	N - Cal-Abi.	Std. dev. Abi-Fag.	Std. dev. Cal-Abi.	F	p
1	2	3	4	5	6	7	8	9	10	11	12	13
JELASO	(%)	44.42	50.53	-9.27	9013	0.000	8086	929	9.058	9.960	1.209	.0001
JELAIO	(%)	91.40	93.59	-5.52	9013	.0000	8086	929	11.670	8.915	1.713	.0000

Figure 14. Differences test in mean damage and damage index for fir between the plant associations Abi-Fag. and Cal-Abi.
Slika 14. Grafički prikaz razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Abi-Fag. i Cal-Abi.

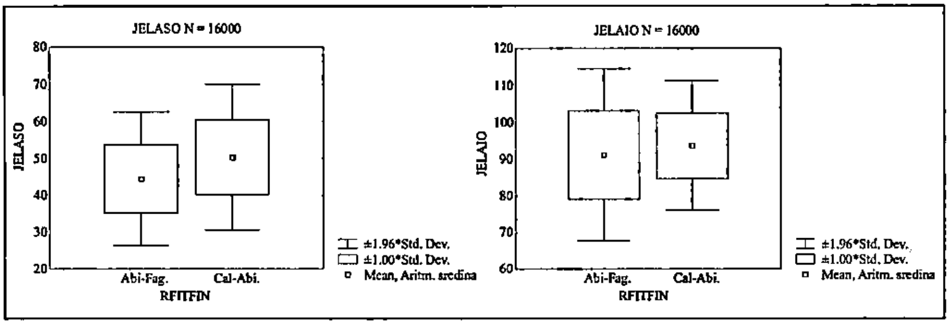


Table 3. Difference test for fir mean damage and damage index between the plant associations Abi-Fag. and Blech-Abi.
Tablica 3. Testiranje razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Abi-Fag. i Blech-Abi.

Variable *Varijabla*	Unit *Jedinica*	Arithm. mean *Aritmetička sredina* Abi-Fag.	Blech-Abi.	t	N	p	N - Abi-Fag.	N - Blech-Abi.	Std. dev. Abi-Fag.	Std. dev. Blech-Abi.	F	p
1	2	3	4	5	6	7	8	9	10	11	12	13
JELASO	(%)	44.42	37.50	10.22	8264	.0000	8086	180	9.057	3.110	8.478	.0000
JELAIO	(%)	91.40	81.82	10.96	8264	.0000	8086	180	11.669	6.761	2.978	.0000

Figure 15. Differences test in mean damage and damage index for fir between the plant associations Abi-Fag. and Blech-Abi.

Slika 15. Grafički prikaz razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Abi-Fag. i Blech-Abi.

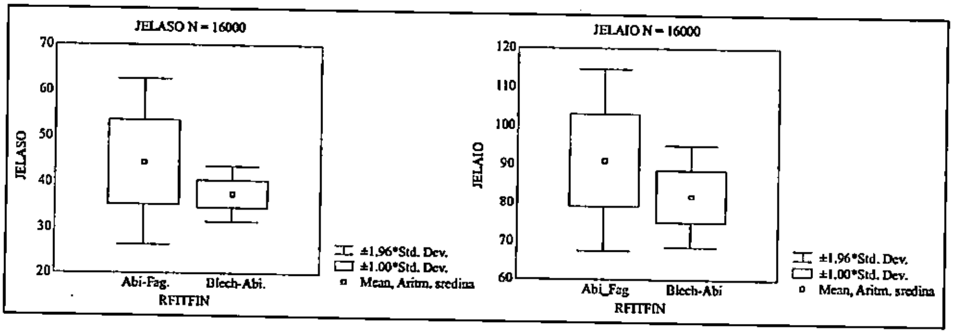


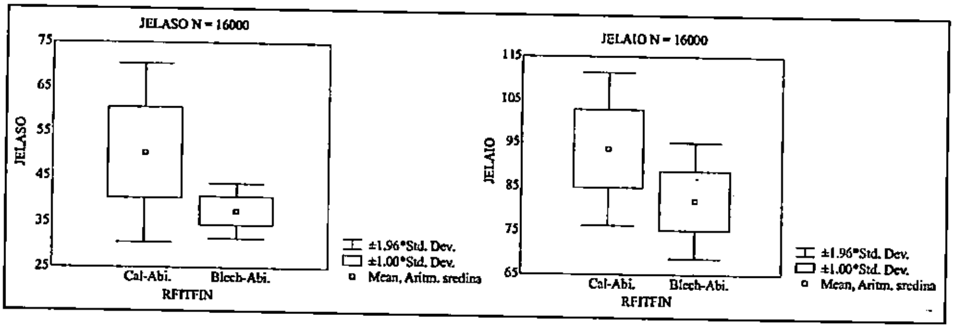
Table 4. Difference test for fir mean damage and damage index between the plant associations Cal-Abi. and Blech-Abi.

Tablica 4. Testiranje razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Cal-Abi. i Blech-Abi.

Variable *Varijabla*	Unit *Jedinica*	Aarithm, mean *Aritmetička sredina* Cal-Abi.	Blech-Abi.	t	N	p	nN-Cal-Abi.	nN-Blech-Abi.	Std. dev. Cal-Abi.	Std. dev. Blech-Abi.	F	p
1	2	3	4	5	6	7	8	9	10	11	12	13
JELASO	(%)	50.53	37.50	17.37	1107	0.000	929	180	9.960	3.110	10.25	.0000
JELAIO	(%)	93.58	81.82	16.78	1107	0.000	929	180	8.915	6.761	1.738	.0000

Figure 16. Differences test in mean damage and damage index for fir between the plant associations Cal-Abi. and Blech-Abi.

Slika 16. Grafički prikaz razlika srednje oštećenosti i indeksa oštećenosti jele između fitocenoza Cal-Abi. i Blech-Abi.



Tests concerning differences in mean damage and the damage index for spruce between plant associations *Aremonio – Piceetum* and *Listero – Picetum* also showed considerable differences (Table 5, Figure 17).

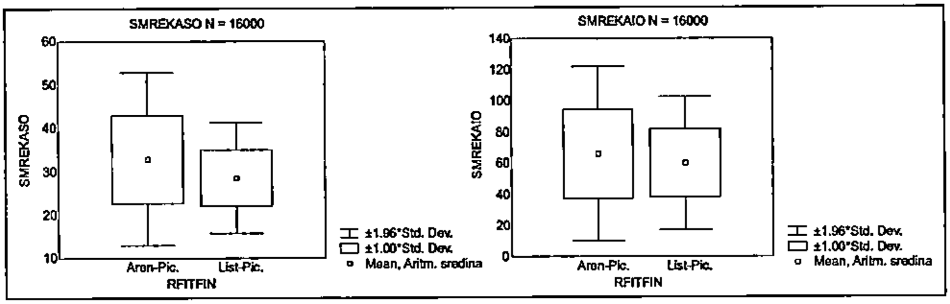
Table 5. Difference test for spruce mean damage and damage index between the plant associations Aren-Pic. and List-Pic.

Tablica 5. Testiranje razlika srednje oštećenosti i indeksa oštećenosti smreke između fitocenoza Aren-Pic. i List-Pic.

Variable *Varijabla*	Unit Jedinica	Arithm. mean *Aritmetička sredina* Aren-Pic.	List-Pic.	t	N	p	N - Aren-Pic.	N - List-Pic.	Std. dev. Aren-Pic.	Std. dev. List-Pic.	F	p
1	2	3	4	5	6	7	8	9	10	11	12	13
SMREKASO	(%)	33.07	29.13	4.19	324	.0000	70	256	9.869	5.945	2.755	.0000
SMREKAIO	(%)	68.18	61.80	2.15	324	.0315	70	256	28.632	19.675	2.117	.0000

Figure 17. Differences test in mean damage and damage index for spruce between the plant associations Aren-Pic. and List-Pic.

Slika 17. Grafički prikaz razlika srednje oštećenosti i indeksa oštećenosti smreke između fitocenoza Aren-Pic. i List-Pic.



However, due to significant differences in the variabilities of the analyzed parameters (SO, IO) between all subgroups (plant associations), the interpretability of the t-tests is questionable.

Partial linear correlations
Parcijalne linearne korelacije

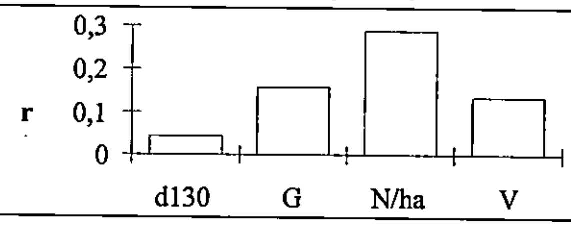
1.) By using partial linear correlations, the connection between dendrometric parameters measured on site and those obtained by measurement on CIR aerial photographs was checked.

There is a high correlation between photogrammetrical and terrestrial data ($p=0.05$) for all observed dendrometric parameters (Table 6, Figure 18).

Table 6. Correlation between photogrammetrical and terrestrial data
Tablica 6. Korelacija terenskih i fotogrametrijskih dendrometrijskih parametara

p < 0.05; N=2710	D130	G	N H	V
1	2	3	4	5
DTER	.04	-.31	-.36	-.26
GTER	.11	.16	-.03	.18
NTER	.05	.37	.29	.35
VTER	.34	.07	-.38	.14

Figure 18. Correlation between photogrammetrical and terrestrial data
Slika 18. Grafički prikaz korelacije terenskih i fotogrametrijskih dendrometrijskih parametara



Owing to the sample size (2710 trees), correlations are significant regardless of the relatively low values of correlation coefficients.

Terrestrial data are reduced to a constant inside compartments and photogrammetrical ones inside strata, which decreases the spatial variability of observed parameters inside the GIS-model.

The highest correlation was obtained between the number of trees, because this variable is least affected by measurement errors (it is observed directly), the others being loaded with the stochastic variability of regression models.

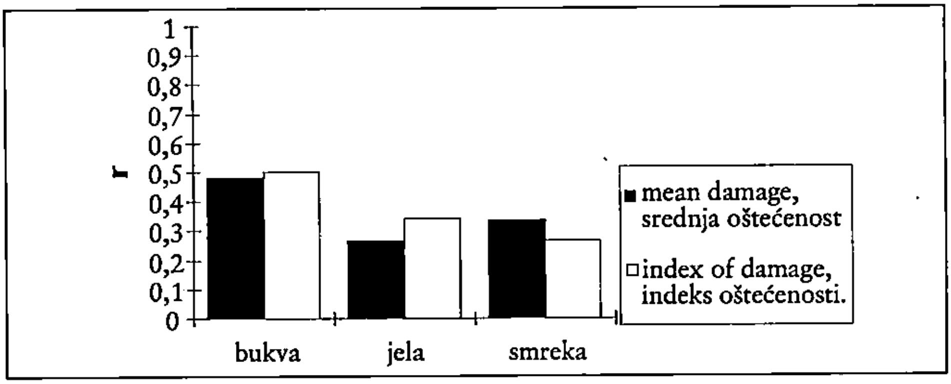
More precise conclusions about correlations between terrestrial and photogrammetrical parameters may be obtained by research on a systematic sample.

2.) The partial linear correlations were also used to study the relationship between the frequency (mixture share) and mean damage, namely the damage index for dominant tree species (Table 7, Figure 19).

Table 7. Correlations of frequency (mixture share) and mean damage for dominant tree species
Tablica 7. Korelacija zastupljenosti (udio smjese) i oštećenosti prema dominantnim vrstama

	BUKVASO	JELASO	SMREKASO	BUKVAIO	JELAIO	SMREKAIO
1	2	3	4	5	6	7
BUKVAUS	.4832	-.1185	-.1918	.5014	-.1483	-.1477
	p=0.00	p=0.00	p=0.00	p=0.00	p=0.00	p=0.00
JELAUS	.0240	.2693	.0737	-.2815	.3429	.0639
	p=.007	p=0.00	p=.000	p=0.00	p=0.00	p=.000
SMRE-KAUS	-.6022	.0576	.3346	-.3446	.0804	.2677
	p=0.00	p=.000	p=0.00	p=0.00	p=.000	p=0.00

Figure 19. Partial linear correlations, the frequency (mixture share) and mean damage, namely damage index for dominant tree species
Slika 19. Grafički prikaz korelacija zastupljenosti (udio smjese) i oštećenosti prema dominantnim vrstama



The results of the correlation analysis show that the larger the share of a certain species in the mixture, the higher the site suitability, and that the damage correlates positively with its share.

If the share of individual tree species in the mixture is interpreted as the site suitability for respective species, and if the increase of damage is interpreted as loss of physiological resistance, then from the said results it can be assumed that the physiological resistance decreases as the site suitability for the respective species increases.

3.) The total mean damage and the damage index correlated with the tree base surface and the volume. The correlation analysis was made on a sample of 6,997 trees. The obtained correlation coefficients (Table 8) lead to the suggestion that the bigger the tree base surface, i.e. the volume, the higher the total damage.

Table 8. Correlation of total damage with tree base surface and volume
Tablica 8. Korelacija ukupne oštećenosti s temeljnicom i volumenom

$p < 0.05$; N=6997	UKUPSO	UKUPIO
1	2	3
G	.74	.78
V	.76	.80

4.) The correlation analysis between the dendrometric parameters (the tree base surface and the volume) and the terrain elements (DTM, slope) shows an inverse correlation, namely that the base surface and the volume decrease when the height above sea level increases (DTM), but also that they decrease when the slope increases (Table 9).

Table 9. Correlation of tree base surface and volume with terrain elements
Tablica 9. Korelacija temeljnice i volumena s elementima reljefa

$p < 0.05$; N=6997	G	V
1	2	3
R	-.36	-.40
RASP	.10	.12
RSLP	-.23	-.22

5.) The existence of an inverse correlation between the total damage (SO, IO) and terrain elements was shown by the partial correlation analysis on a sample of 12,784 trees (Table 10). From the results obtained, it can be seen that the damage decreases with an increase in the height above sea level (DTM) and an increase of the slope (RSLP). Exposure and total damage do not correlate, which leads to the suggestion that the exposure (RASP), due to the fact that it is strictly locally conditioned, is an insufficiently precise indicator.

Table 10. Correlation of damage with terrain elements
Tablica 10. Korelacija oštećenosti s elementima reljefa

$p < 0.05$; N=12784	UKUPSO	UKUPIO
1	2	3
R	-.43	7-.51
RASP	.00	.01
RSLP	-.19	-.24

Multivariant regression
Multivarijatna regresija

1.) The multiple regression analysis was used to investigate relationships of the base surface (Table 11) and the volume (Table 12) with terrain elements (DTM, slope, exposure). The results obtained coincide with those of the partial linear correlation (the linear coefficient symbols are equal to the symbols of the regression coefficients).

Table 11. Multivariant regression of tree base surface with terrain elements
Tablica 11. Multivarijatna regresija temeljnice s elementima reljefa

R= .39980751 R^2= .15984605						
F(3.6993)=443.49 $p < 0.0000$ Std. Error of estimate, *Std. greška procjene*: 2.7994						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			18.68806	.221970	84.1919	.000000
R	-.331992	.011437	-.00612	.000211	-29.0290	.000000
RASP	.108730	.011030	.00698	.000708	9.8576	.000000
RSLP	-.126065	.011463	-.03878	.003526	-10.9975	.000000

Table 12. Multivariant regression of volume with terrain elements
Tablica 12. Multivarijatna regresija volumena s elementima reljefa

R= .43359868 R^2= .18800782						
F(3.6993)=539.72 p < 0.0000 Std. Error of estimate, *Std. greška procjene*: 46.318						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			279.3128	3.672615	76.0528	.000000
R	-.374500	.011243	-.1161	.003487	-33.3089	.000000
RASP	.125915	.010844	.1360	.011708	11.6119	.000000
RSLP	-.108433	.011269	-.5614	.058347	-9.6220	.000000

2.) The results obtained by the regression analysis of mean damage (Table 13) and damage indices (Table 14) with terrain elements also coincide with those of the linear correlation. The linear coefficients have the same symbols as the regression coefficients.

Table 13. Multivariant regression of mean damage status with terrain elements
Tablica 13. Multivarijatna regresija srednje oštećenosti s elementima reljefa

R= .43574187 R^2= .18987098						
F(3.12780)=998.42 p.0000 Std. Error of estimate, *Std. greška procjene*: 7.1472						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			47.70860	.413120	115.4836	.000000
R	-.411090	.008351	-.01889	.000384	-49.2278	.000000
RASP	.016842	.008051	.00280	.001337	2.0920	.036454
RSLP	-.069264	.008390	-.05386	.006524	-8.2557	.000000

Table 14. Multivariant regression of damage index with terrain elements
Tablica 14. Multivarijatna regresija indeksa oštećenosti s elementima reljefa

R= .48223411 R^2= .23254973						
F(3.12543)=1266.9 p < 0.0000 Std. Error of estimate, *Std. greška procjene*: 17.752						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			104.2314	1.059149	98.4105	.000000
R	-.450265	.008138	-.0544	.000982	-55.3315	.000000
RASP	.032694	.007908	.0139	.003350	4.1344	.000036
RSLP	-.091375	.008177	-.1836	.016429	-11.1750	.000000

3.) The multiple regression analysis was also used to investigate relationships between the mean damage of dominant tree species and terrain elements (DTM, slope, exposure).

The regression coefficients obtained for beech (Table 15) and spruce (Table 16) are negligible, while the results obtained for fir (Table 17) show that an increase in height above sea level (DTM) is followed by an increase in damage, similar to the case of slope (RSLP), where anthe increase in slope is followed by an increase in fir damage.

Table 15. Multivariant regression of beech damage status with terrain elements
Tablica 15. Multivarijatna regresija oštećenosti bukve s elementima reljefa

R= .08315875 R^2= .00691538						
F(3.12201)=28.321 p < 00000 Std. Error of estimate, *Std.greška procjene*: 3.0730						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			16.82780	.181212	92.86227	.000000
R	-.029111	.009448	-.00052	.000169	-3.08102	.002068
RASP	.033378	.009119	.00215	.000587	3.66026	.000253
RSLP	-.060259	.009490	-.01826	.002876	-6.34952	.000000

Table 16. Multivariant regresion of spruce damage status with terrain elements
Tablica 16. Multivarijatna regresija oštećenosti smreke s elementima reljefa

R= .04648488 R^2= .00216084						
F(3.7485)=5.4030 p < 00104 Std. Error of estimate, *Std. greška procjene*: 10.239						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			30.86084	1.093272	28.22795	0.000000
R	.005823	.011832	.00050	.001018	.49209	.622672
RASP	.045667	.011642	.00992	.002529	3.92261	.000088
RSLP	.002426	.011820	.00248	.012105	.20522	.837405

Table 17. Multivariant regression of fir damage status with terrain elements
Tablica 17. Multivarijatna regresija oštećenosti jele s elementima reljefa

R= .54784497 R^2= .30013411						
F(3.10944)=1564.4 p < 0.0000 Std. Error of estimate, *Std. greška procjene*: 8.9207						
	BETA	Std. Err. of BETA *Std. pogreška od BETA*	B	Std. Err. of B *Std. pogreška od B*	t(12201)	p
1	2	3	4	5	6	7
Intercpt			8.475030	.577413	14.67758	.000000
R	.513960	.008258	.034014	.000547	62.23712	.000000
RASP	-.003692	.008105	-.000819	.001798	-.45549	.648766
RSLP	.108239	.008273	.114805	.008775	13.08295	.000000

INTERPRETATION OF RESULTS
INTERPRETACIJA DOBIVENIH REZULTATA

According to the set aim and by the research carried out, certain results and knowledge have been obtained about both GIS-technology, as a tool for the realisation of the given aim, and about numerous possibilities for its use in multidisciplinary research.

Great advantages of GIS-technology in relation to the traditional (classical) method of data collection and analysis have been noticed. These advantages are manifested in an efficient and simple use of data collected in various manners (field survey, remote sensing, etc.), in an abundance of collected data and their easy accessibility and modification, in the possibilities of cartographic presentation of data in layers and a large number of combinations as required for purposes of analysis and many other advantages.

The data used to establish the grid GIS-model for the NP "Risnjak" were obtained by the interpretation of CIR aerial photographs, field surveys (Management Program for the NP "Risnjak" 1991-2000) and the digitalization of existing maps. Strata obtained by aerial photograph delineation were also digitalized, which allowed spatial distributions from the data to be interpreted on the CIR aerial photographs (damage and stand parameters). By the digitalization of compartments, the spatial distribution of taxation parameters measured on site was obtained. All vector themes were grid converted at 10 x 10 m pixel size. Grid-converted data are suitable for the presentation of thematic subjects and for their subsequent analysis.

All information sources inside GIS-models were geocoded and stored as separate layers, which allows unlimited handling with either thematic or topographic data.

The raster GIS-model is composed of 30 layers. Data with corresponding coordinates are assigned to each layer attribute.

From such thematic contents obtained by the interpretation of aerial photographs, new layers were established using some of the procedures shown in Figure 3.

By means of raster – GIS modelling, the slope and exposure layers were obtained from DTM. Their further processing enables to present and calculate daily insolation and insolation in various seasons, stormwater flows, etc.

Having in view the importance of DTM, i.e. of the ground slope for research work in many fields, especially in the field of forest exploitation, a new layer based on ground slope classes was made (Figure 12). In this way, it is possible to plan forest openings, namely to design an optimal network of forest roads.

On the basis of earlier research, statistical analyses (correlation and multivariant ones) were carried out for some layers. The results of these analyses allow us to investigate the impact of individual environment characteristics on forest damage, stand parameters, etc. and indicate a direction for future multidisciplinary research aimed at complex analyses of all environment characteristics.

All prepared thematic contents (layers) with attribute data form the database for the NP "Risnjak", which presents a large potential for further research and planning, always open and adaptable to new data.

CONCLUSIONS
ZAKLJUČCI

The research concerning the use of the results of the interpretation of APs and the geographical information system for planning purposes in forestry was carried out using the example of the NP "Risnjak". The aim of the research was to find a way of linking all existing data on the site in one unique information source and to generate new information as a basis for planning by using geographic information system methods.

From the research carried out and the results obtained, the following conclusions can be made:

1) By using the interpretation of CIR aerial photographs, a large amount of data (tree damage, stand parameters, etc.), applicable in many fields of science and economy was collected. The results of the interpretation of aerial photographs are suitable for studying and monitoring environment status and changes and thus present a very good basis for planning.

2) By monitoring the results over a certain period of time a forecast of future conditions is possible.

3) The results of the interpretation of aerial photographs can be presented cartographically or in the form of tables and diagrams. Cartographic data are translated into digital form by digitalization. The grid conversion of these data provides a basis for the spatial presentation of tabular data. In this way, various thematic layers are obtainable which can be later used for analysis purposes.

4) The geographic information system is a suitable tool for putting together data from various sources, but all these data should be georeferenced so that their uniform overlapping is possible.

5) The established GIS-model for the NP "Risnjak" consists of 30 thematic layers based on the data from various sources: the interpretaton of CIR aerial photographs, field surveying (the data from the Management Program) and map digitalization.

6) Assigned to each layer is its respective attribute database, generated on a 50 x 50 m point grid through all layers, which is always open and adaptable to newly-received data. This database is at the same time permanently archived material which can be easily reproduced at any moment.

7) All entered data present a good basis for future research and planning with the help of GIS-technology which allows better analyses of existing data and forecasts of future conditions, which is a prerequisite for good planning.

8) These data can be used in various fields of forestry, such as forest management, ecological research, forest exploitation, etc.

9) By means of various mathematical and statistical methods, the data from the GIS-model can be analyzed and on the basis of such analyses the relationship and dependence between various parameters essential for planning in forestry can be studied.

10) The given examples of analyses show the complexity of the study of forest conditions and the impact of individual environment characteristics on these conditions. At the same time, they indicate the necessity of such analyses as well as of remote sensing and GIS technology for good planning in forestry.

11) The established GIS-model and the analyses carried out justify such an approach in the study and the performance of tasks put before specialists from various fields with regard to the planning of management and control in both protected areas and exploitation forests.

12) The establishment of such a GIS-model is not the end of this task, but the beginning of the construction of just one part of a general planning system, one of timely and correct decision making, the so-called *decision support system*.

REFERENCES
LITERATURA

Arbeitsgruppe Forstlicher Luftbildinterpreten, 1988: Auswertung von Color – Infrarot – Luftbildern. pp. 32, Freiburg. In: Hildebrandt, G. (ed.), Forstliche Bundesversuchsanstalt, Wien.

Akça, A., and Zindel, U., 1987: Zur Vorratsschätzung mit Hilfe von digitalen Luftbilddaten und Regressionsmodelle bei der Baumart Fichte. Allg. Forst- u. J. Ztg. 158(7-8): 109-115.

Akinyede, J. O., 1990: A geotechnical GIS concept for highway route planing. ITC Journal 3: 262-269.

Antonić, O., Belušić, R., Ananić M., and Kušan, V., 1994: GRID 1.0: Development of landscape ecology GIS-functions. In: Čerić, V., and Hljuz Dobrić, V. (eds.), 16th International Conference on Information Technology Interfaces, University Computing Centre, Zagreb, pp. 467-470.

Barszcz, J., Kozak, J., and Widocki, W., 1993: Use of GIS and Remote Sensing to Study the Relationships between Forest Decline and Environmental Conditions in the Silesi and Beskid Mts. (Karpaty Mts.). In: Žihlavnik, Š., and Scheer, L. (eds.), Zbornik referátov, Medzinárodné sympózium, Technical University in Zvolen, Faculty of Forestry, pp. 129-131.

Becker, G., and Jäger, D., 1992: Integrated design, planning and evaluation of forest roads and logging activities using GIS-based interactive CAD-system. In: Sessions, J. (ed.), Proceedings, Workshop on Computer supported planning of roads and harvesting, Feldafing , pp. 159-164.

Benko, M., 1993: Procjena taksacijskih elemenata sastojina na infracrvenim kolornim aerosnimcima. Glas. šum. pokuse 29: 199-274.

Benko, M., Kušan, V., and Lindić, V., 1993: Primjena GIS tehnologije pri razvrstavanju šuma Hrvatske za potrebe sjemenarstva. CAD FORUM '93, Zbornik radova, CAD sekcija Saveza društava arhitekata Hrvatske, Zagreb, pp. 77-85.

Benko, M., 1995: Procjena drvne zalihe sastojine multivarijatnom analizom čimbenika mjerljivih na aerosnimkama (disertacija). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 237 pp.

Besio, M., and Roccatagliata, E., 1991: Object oriented GIS improving environmental compatability in Italian rural landscape planning. In: Ondaatje, D. A., (ed.), EGIS '91, EGIS Foundation in Utrecht, Faculty of Geografical Sciences, Brussels, Vol. 1, pp. 95-105.

Bocco, G., Palacio, J., and Valenzuela, C.R., 1990: Gully erosion modelling using GIS and geomorphologic knowledge. ITC Journal 3: 253-261.

Brukner, M., 1994: GIZIS – osnove, INA – INFO, Zagreb, 204 pp.

Buer, K. Y., 1987: Utilisation of extracted satellite information for forest managament. In: Proceedings of Willi Nordberg Symposium, Towards Operational Cartographic Application, Graz, pp. 243-247.

Buongoiorno, J., and Gilless, K. J., 1986: Forest management and economics. Macmillan, New York, 285 pp.

Colby, M. E., 1991: Environmental management in development, the evolution of paradigms. Ecological Economics 3(3): 193-213.

Coleman, T. L., Gudapati, L., and Derrington, J., 1990: Monitoring forest plantations using Landsat Thematic mapper data. Remote Sensing of Environment 33(3): 211-221.

Consoletti, W. L., 1986: GIS in Industrial Forest Management. J. For. 84(9): 37-38.

Čavlović, J., 1994: Linearno programiranje u planiranju i gospodarenju jednodobnim šumama. Glas. šum. pokuse 31: 435-442.

Ćurić, T., 1986: Fotointerpretacijsko izlučivanje sastojina (diplomski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 22 pp.

Dietz, P., Knigge W., and Löffler H. D., 1984: Walderschliessung eine Lehrbuch für Studium und Praxis unter besonderer Berücksichtigung des Waldwegwbaugs. Paul Parey, Hamburg and Berlin, 196 pp.

Dulaney, R. A., 1987: A GIS for large area environmental analysis. GIS '87, Proceedings, American Society for Photogrammetry and Remote Sensing, San Francisco, Vol. 1, pp. 206-215.

Dvorscák, P., and Hrib, M., 1992: Development and present state of utilizing computing techniques in projecting forest roads in Slovakia. In: Proceedings, Workshop on Computer supported planning of roads and harvesting, Feldafing, pp. 85-93.

EAfV – Eidgenössische Austalt für das forstliche Versuchwessen, 1966: Ertragstafeln, Tanne, Birmensdorf ZH, 70 pp.

Ecker, R., 1992: Digital ortophoto generation based on high-quality DTM, ITC Journal 1: 59-64.

Estes, J. E., 1992: Remote sensing and GIS integration research needs, status and trend. ITC Journal 1: 2-10.

Fleet, H., 1986: Scanning to Digitalize Mapped Data. J. For. 84(9): 38-41.

Fliszar, I., 1990: Inventarizacija oštećenosti stabala i sastojina poljskog jasena (*F. angustifolia* Vahl) s obzirom na intenzitet napada jasenove pipe (*Stereonychus fraxini* Deger.) interpretacijom ICK aerosnimki (diplomski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 68 pp.

Gossard, T. W., 1978: Applications of DTM in the forest service. Photogrammetric Engineering and Remote Sensing 44(12): 1577-1586.

Hentschel, S., 1996: GIS-gestützte Herleitung der flächenhaften Erschliessungswirkung von Wegenetzen am Beispiel von ARC/INFO. Forsttechnische Informationen 1-2: 8-13.

Hildebrandt, G., Grundmann, H., Schmidtke, H., and Tepassé, P., 1986: Entwicklung und Durchführung einer Pilotinventur für eine permanente europaeische Waldschadeninventur. KfK – PEF 11, Karlsruhe, 84 pp.

Hočevar, M., 1988: Ugotovljanje in spremljanje propadanja gozdov v aerosnemanji. Gozdarski vestnik 2: 53-66.

Hočevar, M., and Hladnik, D., 1988: Integralna fototerestrična inventura kot osnova za smotrno odločanje u gospodarenju z gozdom. Zbornik gozdarstva in lesarstva 31: 93-120.

Hočevar, M., Hladnik, D., and Kovač, M., 1995: Ecological Monitoring of Preserved Forested Landscapes in Slovenia by Means of Remote Sensing and GIS. In: Salonen, T., and Oja, S. (eds.), Abstracts of Invited Papers IUFRO X Xth World Congress, Tampere, pp. 331-332.

Hussin, Y. A., and Shaker, S. R., 1995: Monitoring tropical forest land use changes using remote sensing and GIS. In: Salonen, T., and Oja, S. (eds.), Abstracts of Invited Papers IUFRO X Xth World Congress, Tampere, pp. 305-306.

Itten, K. I., Nanayakkara, S. D. F. C., Humbel, R., Bichsel M., and Sommer, M., 1985: Inventory and monitoring of Sri Lankan forests using remote sensing techniques. In: Schmidt-Haas, P. (ed.), Proceedings IUFRO Congress: Inventoring and monitoring endangered forests, Zürich, pp. 93-98.

Jacksman, J., Gordon R., and Eggenberger, M., 1991: Natur– und Landschaftsschutz in der forstlichen Planung. Schweiz. Z. Forstwes. 142(3): 221-226.

Jakšić, A., 1996: Određivanje volumena sastojina hrasta lužnjaka pomoću ICK aerosnimki (diplomski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 32 pp.

Jano, A. P., 1986: A Critical survey of the operational use of spacenorm remote sensing in Canadian forestry. Proceedings Division 6, 18th IUFRO World Congress, Ljubljana, pp: 154-165.

Jergović, S., 1994: Određivanje načina interpolacije i optimalne veličine mreže pri izradi digitalnog modela terena. Meh. šumar. 19(3): 199-204.

Jordan, G. A., and Erdle, T, A., 1989: Forest management and GIS. What have we learned in New Brunswick? The Canadian Institute of Surveying and Mapping Journal 43(3): 287-295.

Jukić, T., 1994: Analiza prostora i GIS u procesu planiranja urbanih područja. In: CAD FORUM, Proceedings, CAD Sekcija udruženja hrvatskih arhitekata, Zagreb, 4 pp.

Kalafadžić, Z., 1984: Primjena daljinskih istraživanja u šumarstvu. Bilten za daljinska istraživanja i fotointerpretaciju 8(1): 20-23.

Kalafadžić, Z., 1987: Primjena ICK aerosnimaka u šumarstvu. Šum. list 111(1-2): 61-66.

Kalafadžić, Z., and Kušan, V., 1989: Opadanje prirasta jele (*Abies alba* Mill.) kao posljedica novonastalih oštećenja šuma u Gorskom kotaru. Šum. list 113(9-10): 415-422.

Kalafadžić, Z., and Kušan, V., 1990: Ustanovljavanje stanja šuma na velikim površinama primjenom infracrvenih kolornih (ICK) aerosnimaka. Glas. šum. pokuse 26: 447-459.

Kalafadžić, Z., and Kušan, V., 1990a: Definiranje stupnja oštećenosti šumskog drveća i sastojina. Šum. list 114 (11-12): 517-526.

Kalafadžić, Z., and Kušan, V., 1991: Visoka tehnologija u inventuri šuma. Šum. list 115 (11-12): 509-520.

Kalafadžić, Z., Kušan, V., Horvatić, Z., and Pernar, R., 1992: Der Gesundheitszustand der Tanne (*Abies alba* Mill.) in Südwestern Croatien auf Grund der Farb -Infrarot – Luftbild interpretation. In: Prpić, B., and Seletković, Z. (eds.), Tagungsband der VI IUFRO Tannensymposium, Forstliche Fakultaet, Zagreb, pp. 219-231.

Kalafadžić, Z., and Kušan, V., 1993: Mogućnost pridobivanja informacija iz umjetnih Zemljinih satelita. Šuma. list 117(6-8): 293-307.

Kalafadžić, Z., Kušan, V., Horvatić, Z., and Pernar, R., 1993a: Inventarizacije oštećenosti šuma u Republici Hrvatskoj primjenom infracrvenih kolornih (ICK) aerosnimki. Glas. šum. pokuse, pos. izd., 4: 163-172.

Kalafadžić, Z., Kušan, V., Horvatić, Z., and Pernar, R., 1993b: Oštećenost šuma i neki čimbenici okoliša u šumskom bazenu "Spačva". Šum. list 117(6-8): 281-292.

Kalafadžić, Z., Kušan, V., Horvatić, Z., and Pernar, R., 1994: Experience in use of colour infrared (CIR) aerial imagery in forest decline assessment in the Republic of Croatia. In: Tagungsband, Symposium Photogrammetrie und Forst, Freiburg, pp. 189-197.

Kalensky, Z. D., 1991: Overview of FAO remote sensing activities in the Central/Eastern European countries. In: Buchroithner, M. F. (ed.), Proceedings of the 11th EARSeL Symposium, Graz, pp. 157-165.

Kamenarović, M., 1970: Nacionalni park Risnjak. Vodič, Zagreb.

Kändler, G., 1986: Die Ermittlung von Bestandesparametern als Eingangsgrössen für Interpretationsmodelle mit Hilfe aerophotogrammetrischer Verfaren (Disertation). Freiburg, 156 pp.

Keefer, J. B., Fanelli, E. S., and Hanson, R., 1989: Using PC ARC/INFO for Industrial Forest Resource Management (Manuscript). ITT Rayoner, 10 pp.

Knežević, I., and Sever, S., 1992: Računalom podržano određivanje optimalne gustoće traktorskih vlaka pri stalnoj gustoći kamionskih cesta. Meh. šumar. 17(3-4): 41-51.

Kostijal, V., 1986: Korelacijski odnos uočljivog broja krošnji u stereomodelima jednodobnih šuma bukve s prsnim promjerom centralnog plošnog stabla (magistarski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 56 pp.

Kramer, H., and Akca, A., 1987: Leitfaden für Dendrometrie und Bestandesinventur. Frankfurt am Mein, 365 pp.

Kušan, V., 1988: Točnost određivanja površine projekcije krošnje obične jele (*Abies alba* L.). Šum. list (11-12): 489-496.

Kušan, V., 1992: Procjena volumena sastojina četinjača fotointerpretacijom aerosnimaka uz pomoć prirasno-prihodnih tablica. Meh. šumar. 17(3-4): 53-66.

Kušan, V., and Kalafadžić, Z., 1992: Application of GIS technology to integrated forest management system. 1. superscr. Alps-Adria Workshop on Satellite Data Evaluation and GIS Technologies, Keszthely.

Kušan, V., Kalafadžić, Z., Belušić, R., and Ananić, M., 1992a: Primjena GIS-tehnologije u šumarstvu. In: Baletić, B. (ed.), Proceedings of CAD FORUM '92, CAD Sekcija Saveza društava arhitekata Hrvatske, Zagreb, pp. 125-132.

Kušan, V., Vondra, V., Martinić, I., Ananić, M., and Belušić, R., 1992b: Linking GIS and Harwest regression models. In: Sessions, J. (ed.), Proceedings of the Workshop on Computer supported planning of Roads and Harwesting, Feldafing, pp. 165-174.

Kušan, V., and Krejči, V., 1993: Regresijski model za procjenu volumena sastojina hrasta lužnjaka (*Q. robur* L.) aerosnimkama. Radovi 28(1-2): 69-77.

Kušan, V., and Kalafadžić, Z., 1993: Digitalizirane aerosnimke kao jedan od slojeva GIS-a u uređivanju šuma. In: CAD FORUM '93, Zbornik radova, CAD Sekcija Saveza društava arhitekata Hrvatske, Zagreb, 73-76.

Kušan, V., and Kalafadžić, Z., 1994: Daljjinska istraživanja i GIS kao dio jedinstvenog informacijskog sustava šumarstva. Bilt. dalj. istr. fotoint. 13: 83-91.

Kušan, V., 1996: Pristup daljinskim istraživanjima i GIS-u u hrvatskome šumarstvu. Šum. list (3-4): 171-178.

Kušan, V., 1996a: Točnost digitalnog modela reljefa nizinskog, brdskog i gorskog područja. In: Sever, S. (ed.), Zaštita šuma i pridobivanje drva, Šumarski fakultet Sveučilišta u Zagrebu and Šumarski institut, Jastrebarsko, Zagreb, pp. 411-422.

Kušan, V., and Pernar, R., 1996: Procjena oštećenosti stabala hrasta lužnjaka digitalnom obradom ICK aerosnimki. In: Sever, S. (ed.), Zaštita šuma i pridobivanje drva, Šumarski fakultet Sveučilišta u Zagrebu and Šumarski institut, Jastrebarsko, Zagreb, pp. 149-158.

Kušan, V., and Pernar, R., 1996a: Procjena prsnog promjera i temeljnice najznačajnijih vrsta drveća Gorskoga područja na temelju veličina mjerljivih na aerosnimkama. In: Sever, S. (ed.), Zaštita šuma i pridobivanje drva, Šumarski fakultet Sveučilišta u Zagrebu and Šumarski institut, Jastrebarsko, Zagreb, pp. 157-168.

Lee, J., 1991: Analyses of Visibility Sites on Topographic Surface. IJGIS 5(4): 413-429.

Lesyen, M. M., and Goossens, R. E., 1991: Forest map updating in a GIS using high spatial resolution satellite data. In: Ondaatje, D. A., (ed.), EGIS '91, EGIS Foundation in Utrecht, Faculty of Geografical Sciences, Brussels, Vol. 1, pp. 653-661.

Lillesand, T. M., and Kiefer, R. W., 1994: Remote sensing and image interpretation (3rd ed.). John Wiley and Sons, Inc., New York, 750 pp.

Lo, C. P., 1986: Geographic Information Systems (chapter 9). In: Applied Remote Sensing, Longman Inc., New York, pp. 369-387.

Löffler, H., Hennak, C., Jaechisch, W., and Scharnagl, G., 1984: Beispille für Interpretationsschlüssel zur Auswertung von Infrarot – Farbluftbildern für die Waldschadensinventur. Allgemeine Forstzeitschrift 27: 1089-1092.

Loetsch, F., 1968: Zur zukünftigen Entwicklung der Forsteinrichtung unter besonderer Berücksichtigung der Waldinventur. Forstarchiv Jg. 39(11-12): 237-244.

Loetsch, F. and Haller, K. E., 1973: Forest inventory (2nd ed.). BLV München, Vol. 1, 436 pp.

Lukić, N., 1981: Ispitivanje pouzdanosti fotointerpretacijske inventure drvnih masa šuma jele u odnosu na listu podataka dobivenu mjernom fotointerpretacijom. Šum. list 105(3-4): 133-145.

Lukić, N., 1993: Inventarizacija šuma u sklopu višenamjenskog iskorištavanja. Glas. šum. pokuse, pos. izd., 4: 133-138.

Lund, G. H., 1988: A Primer on Integrating Resource Inventories US Dep. of Agricult. Gen. Tech. Report WO-49, 64 pp.

Mallants, D., and Badji, M., 1991: Integration of GIS and deterministic hydrologic models: a powerful tool for environmental impact assessment. In: Ondaatje, D. A., (ed.), EGIS '91, EGIS Foundation in Utrecht, Faculty of Geografical Sciences, Brussels, Vol. 1, pp. 671-680.

Martinić, I., 1993: Planiranje u šumarstvu čini moto sa suvremenim tehnologijama. Meh. šumar. 18(1): 17-21.

Martinović, J., Vranković, A., and Pernar, N., 1994: Tla Nacionalnog parka "Risnjak". Zbornik radova, 40 godina NP "Risnjak", Crni Lug, 131-136.

Masumy, A. S., 1984: Interpretationschlüssel zur Auswertung von Infrarotfarbluftbildern für die Waldschadens Inventur. Allgemeine Forstzeitscrift 27: 687-689.

Mayer, B., 1993: Proces osnivanja šumarskog hidropedološkog informacijskog sustava (ŠHPIS) na osnovi monitoringa podzemnnih i površinskih voda u Kupčini, Varoškom lugu, Česmi i Turopoljskom lugu. Radovi 28(1-2): 171-184.

Meštrović, Š., 1984: Nature Conservation in Yugoslavia. Radovi 229 -240.

Meštrović, Š., 1987: Uređivanje šuma s posebnom namjenom. Glas. šum. pokuse, pos. izd., 3: 137-150.

Meštrović, Š., Pranjić, A., Kalafadžić, Z., Križanec, R., Bezak, K., and Kovačić, Đ., 1992: Uređivanje šuma. In: Rauš, Đ. (ed.), Šume u Hrvatskoj, Šumarski fakultet Sveučilišta u Zagrebu and "Hrvatske šume" p.o. Zagreb, Zagreb, pp. 131-153.

Meštrović, Š., and Fabijanić, G., 1995: Priručnik za uređivanje šuma. Ministarstvo poljoprivrede i šumarstva, Zagreb, 416 pp.

Miller, D. R., Finch, P., and Fon, T. C., 1994: A model of DTM and orthophotograph quality using aerial photography. Tagungsband, Symposium Photogrammetrie und Forst, Freiburg, pp. 227-237.

Mroczynski, R. P., 1976: Application of satellite collected and computer analyzed data to the management of the Central hardwood forest. In: Hildebrandt, G. (ed.), Proceedings Remote Sensing in Forestry, XVI IUFRO World Congress, Oslo, pp. 171-181.

Nearhood, D., 1992: Planning ground based harvesting using digital elevation models. In: Sessions, J. (ed.), Proceedings, Workshop on Computer supported planning of roads and harvesting, Feldafing, pp. 94-99.

Neidhardt, N., 1971: Prognoziranje. Šum. list 95(9-10): 312-316.

Nijkamp, P., and Scholten, H. J., 1993: Spatial information systems: design, modelling and use in planning. IJGIS 7(1): 85-96.

Patrono, A., 1995: GIS, geomorphology and environmental impact assessment. ITC Journal 4: 345-346.

Pavičić, D., 1983: Pouzdanost fotointerpretacijskog određivanja horizontalnog sklopa u sastojinama (diplomski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 54 pp.

Pelz, E., and Riedel, G., 1973: Erste praktische Grossanwendung von Falschfarben-Luftbildern bei der Zustander Forsteinrichtung in einem Gebiet mit akuten und chronischen Rauchschäden an Kiefer. Beitrage für die Forstwirtschaft 4: 158-161.

Pernar, R., 1994: Način i pouzdanost određivanja oštećenosti hrasta lužnjaka (*Q. robur* L.) na infracrvenim kolornim (ICK) aerosnimkama. Glas. šum. pokuse 31: 1-34.

Pičman, D., 1994: Utjecaj konfiguracije terena i hidrografijskih prilika na ekonomsku opravdanost izgradnje optimalne mreže šumskih prometnica. Glas. šum. pokuse 31: 231-316.

Pičman, D. and Tomar, I., 1995: Određivanje težišta odjela primjenom osobnih računala u svrhu izračunavanja srednje udaljenosti privlačenja. Šum. list 3: 91-103.

Pilaš, I., 1994: Regresijski modeli za procjenu starosti sastojina na aerosnimkama. Meh. šumar. 19(3): 181-186.

Posarić, D., 1993: Primjena daljinskih istraživanja u inventuri šuma. Meh. šumar. 18(2): 65-71.

Posavec, S., 1993: Digitalni model terena kao podloga za projektiranje hortikulturnih elemenata (diplomski rad). Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 55 pp.

Pranjić, A., 1987: Pouzdanost rezultata izmjere šuma. Glas. šum. pokuse, pos. izd., 3: 161-176.

Probst, J. R. and Crow, T. R., 1991: Integrating biological diversity and resource management. Journal of Forestry 89(2): 12-17.

Program gospodarenja šumama GJ Nacionalnog parka "Risnjak" (1991-2000). Odjel za uređivanje šuma, Delnice.

Prpić, B., Komlenović, N., and Seletković, Z., 1988: Propadanje šuma u Hrvatskoj. Šum. list 112(5-6): 195-215.

Rauš, Đ., Meštrović, Š., Trinajstić, I., Vukelić, J., and Španjol, Ž., 1992: Zaštićeni prirodni objekti u Hrvatskim šumama. In: Rauš, Đ. (ed.), Šume u Hrvatskoj, Šumarski fakultet Sveučilišta u Zagrebu and "Hrvatske šume" p.o. Zagreb, Zagreb, pp. 197-222.

Repić, R., 1995: Digitalni model reljefa Arboretuma Lisičine. Meh. šumar. 20(2): 107-111.

Reutebuch, S. E., 1987: PC-based analytical stereoplotter for use in Forest Service field office. Proceedings, ASPRS – ACSM fall conv. Am. Soc. Photogramm. and Remote Sensing, Falls Church, VA. 223-232.

Schetselaar, E. M., van Dijk, P. M., and Al Fasatwi, A., 1990: Digital image processing of geophisical data using a raster – based GIS. ITC Journal 3: 248-252.

Schneider, W. and Bartl, R., 1994: Forstliche Kartierung und GIS – Daten – Erfassung aus Luftbildern nach dem Monoplotting – Verfahren. Tagungsband Symposium Photogrammetrie und Forst, Freiburg, pp. 317-328.

Sessions, J., 1992: Using network analysis for road and harvesting planning. In: Sessions, J. (ed.), Proceedings, Workshop on Computer supported planning of roads and harvesting, Feldafing, pp. 26-35.

Shiba, M. and Löffler, H. D., 1990: Computer Application for Environmental Impact Evaluation in the Opening – up Planning process. Proceedings XIX IUFRO World Congress, Montreal, pp. 214-225.

Sieg, G. E., Scrivani, J. A., and Smith, J. L., 1987: Incorporating GIS topographic information in Forest inventory estimates. In: GIS ž87, San Francisco, Proceedings, Vol. 2, pp. 423-430.

Skidmore, A. K., 1989b: An expert system classifies eucalypt forest types using TM data and digital terrain model. Photogrammetric Engineering and Remote Sensing 55(10): 1449-1464.

Skidmore, A. K., Ryan, P. J., Dawes, W., Short, D., and O'Longhlin, E., 1991: Use of Expert System of Map Forest Soils from a GIS. IJGIS 5(4): 431-454.

Smart, C. W., and Rowland, B., 1986: GIS in Tennessee Valley Authority. J. For. 84(9): 36-37.

Smyrnew, J. M., 1990: Trends in Geographic Information System Technology. Journal of Surveying Engineering 116(2): 105 pp.

Spurr, S. H., 1960: Photogrammetry and photointerpretation (2nd ed.). Ronald press company, New York, 472 pp.

Štefanovič, P. and Wiersema, G., 1985: Insolation from digital elevation models for mountain habitat evaluation. ITC Journal 3: 177-186.

Stellingwerf, D. A., 1986: Remote Sensing in European forestry, Proceedings Division 6, 18th IUFRO World Cŏngress, Ljubljana, 166 – 177.

Stenback, J. M., Travlos, C. B., Barrett, R. H., and Conglation, R. G., 1987: Application of remotely sensed digital data and a GIS in evaluating deer habitat suitability on the Thama deer winter range. In: GIS '87, San Francisco Proceedings, Vol. 2, pp. 440-445.

Susilawati, S. and Weir, M. J. C., 1990: GIS applications in forest land management in Indonesia. ITC Journal 3: 236-244.

Suwanwerakamtorn, R., 1994: GIS and hydrologic modelling for the management of small watersheds. ITC Journal 4: 343-348.

Tesche, T. W., and Bergstrom, R. W., 1976: Use of digital terrain data in meteorological and air quality modelling. Photogrammetric Engineering and Remote Sensing 44(12): 1549-1559.

Tomanić, S., 1990: Standardization rules of information systems and their application in integrated forest operation planning and control. XIX IUFRO World Congress in Montreal, Proceedings of 8-3:04 Subject area: 260 – 271.

Tomašegović, Z., 1956: Razmatranja o fotoplanu Turopoljskog luga. Šum. list 80(5-6): 154-166.

Tomašegović, Z., 1965: O pouzdanosti fotogrametrijskih slojnica šumskih područja. Geodetski list: 19(10-12): 259-304.

Tomašegović, Z., 1987a: Primjena fotogramatrije i fotointerpretacije u planiranju. Glas. šum. pokuse, pos. izd., 3: 85-94.

Tomašegović, Z., 1987b: Značenje stereoortoplanova za šumske regije umjerenih zona (matematičko – tehnički i ekonomski aspekti). Geodetski list 41(4-6): 121-134.

Uputstva za provođenje ankete "Umiranje šuma". Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 40 pp.

Voss, H., 1989: Untersuchung und Kartierung von Waldschäden mit Methoden der Fernerkundung. Abschlussdokumentation, DLR, Teil A, Oberpfaffenhofen, 244 pp.

Vukelić, J., 1984: Doprinos fotointerpretacijske analize vegetacijskom istraživanju šumskih zajednica Nacionalnog parka "Risnjak". Glas. šum. pokuse 23: 95-140.

Zöhrer, F., 1974: Waldinventur als Ingenieurwiessenschaft. Mitt. Bundestforsch. aust. Forst u. Holzwirtsch 99: 1-14.

PRIMJENA REZULTATA INTERPRETACIJE AEROSNIMAKA I GEOGRAFSKOG INFORMACIJSKOG SUSTAVA ZA PLANIRANJE U ŠUMARSTVU

SAŽETAK

Istraživanje primjene rezultata interpretacije aerosnimaka i geografskog informacijskog sustava za planiranje u šumarstvu provedeno je na primjeru NP Risnjak. Cilj je istraživanja bio pronalaženje načina za povezivanje svih postojećih podataka o terenu i podataka dobivenih interpretacijom aerosnimaka u jedinstveni izvor informacija, te generiranje novih informacija kao podloga za planiranje primjenom metoda geografskog informacijskog sustava (GIS).

Podaci upotrijebljeni za uspostavu rasterskoga GIS modela za NP Risnjak dobiveni su interpretacijom infracrvenih kolornih (ICK) aerosnimaka, izmjerom na terenu (Program gospodarenja za NP Risnjak 1991 – 2000. god.) i digitalizacijom postojećih karata.

Na ICK aerosnimkama izlučene su sastojine (delineacija) prema vidljivim razlikama u slikovnim pojedinostima šumskih sastojina, kao što su: vrsta drveća, omjer smjese, sklopljenost sastojine, veličina krošnje, stupanj oštećenosti, pojava matičnoga supstrata itd.

Delineacijom aerosnimaka dobiveni su stratumi također digitalizirani, čime je omogućeno dobivanje prostornih raspodjela iz podataka interpretiranih na ICK aerosnimkama (oštećenost, dendrometrijski parametri). Sve vektorske teme rasterizirane su uz veličinu piksla 10 m x 10 m.

Unutar GIS modela svi su izvori informacija geokodirani i pohranjeni kao zasebni slojevi, čime je omogućeno nesmetano međusobno rukovanje, bilo tematskim, bilo topografskim podacima.

Uspostavljeni rasterski GIS model za NP Risnjak sastoji se od 30 tematskih slojeva:

1. pedokartografske jedinice
2. geološke kategorije (prema sastavu stijena i vodopropusnosti)
3. biljne zajednice
4. prostorna raspodjela srednjih prsnih promjera po ha (terenski podaci – ter.)
5. prostorna raspodjela srednjih prsnih promjera po ha (fotogrametrijski podaci – ftg.)
6. prostorna raspodjela temeljnica po ha (ter.)
7. prostorna raspodjela temeljnica po ha (ftg.)
8. prostorna raspodjela volumena po ha (ter.)
9. prostorna raspodjela volumena po ha (ftg.)
10. prostorna raspodjela broja stabala po ha (ter.)
11. prostorna raspodjela broja stabala po ha (ftg.)
12. relativni udjel jele (ftg.)

13. relativni udjel bukve (ftg.)
14. relativni udjel smreke (ftg.)
15. prostorna raspodjela srednje oštećenosti jele (ftg.)
16. prostorna raspodjela srednje oštećenosti bukve (ftg.)
17. prostorna raspodjela srednje oštećenosti smreke (ftg.)
18. prostorna raspodjela indeksa oštećenosti jele (ftg.)
19. prostorna raspodjela indeksa oštećenosti bukve (ftg.)
20. prostorna raspodjela indeksa oštećenosti smreke (ftg.)
21. prostorna raspodjela srednje oštećenosti četinjača (ftg.)
22. prostorna raspodjela srednje oštećenosti listača (ftg.)
23. prostorna raspodjela indeksa oštećenosti četinjača (ftg.)
24. prostorna raspodjela indeksa oštećenosti listača (ftg.)
25. prostorna raspodjela ukupne srednje oštećenosti (ftg.)
26. prostorna raspodjela ukupnog indeksa oštećenosti (ftg.)
27. digitalni model reljefa (DMR)
28. nagib terena
29. nagib terena po klasama
30. kutni otklon od juga (izloženost).

Uza svaki je sloj vezana atributna baza podataka, generirana na mreži točaka 50 m x 50 m kroz sve slojeve, a koja je uvijek otvorena i prilagodljiva za dopunu novim podacima. Baza je podataka ujedno trajno pohranjen materijal koji se u svako doba može vrlo lako umnožiti.

Iz tematskih sadržaja dobivenih na osnovi interpretacije aerosnimaka modeliranjem su izrađeni novi slojevi (relativni udjeli dominantnih vrsta drveća).

Rasterskim GIS modeliranjem iz digitalnoga modela reljefa (DMR) dobiveni su slojevi nagiba i izloženosti. Njihovom daljnjom obradom moguće je izračunati i prikazati osunčanost padina tijekom dana i u različita godišnja doba, tok oborinskih voda itd.

Budući da nagib terena ima značajnu ulogu za obavljanje radova u mnogim područjima istraživanja, posebno u području iskorištavanja šuma, izrađen je novi sloj po klasama nagiba terena. Time je omogućeno planiranje otvorenosti šuma, odnosno projektiranje optimalne mreže šumskih prometnica.

Na osnovi ranijih istraživanja za neke su slojeve provedene statističke analize (korelacijska i multivarijatna). Testirane su razlike u oštećenostima između biljnih zajednica. Parcijalnim linearnim korelacijama ispitana je veza između dendrometrijskih elemenata mjerenih na terenu i onih dobivenih mjerenjem na ICK aerosnimkama, a također i veza između zastupljenosti (udjela smjese) i oštećenosti dominantnih vrsta drveća. Multivarijatnom regresijskom analizom istraživan je odnos strukturnih elemenata i oštećenosti dominantnih vrsta drveća s elementima reljefa (nadmorska visina, izloženost, nagib).

Rezultati provedenih analiza omogućavaju proučavanje utjecaja pojedinih značajki okoliša na oštećenost šuma, sastojinske veličine, te upućuju na smjer budućih multidisciplinarnih istraživanja s ciljem kompleksnih analiza svih značajki okoliša.

Navedene analize upućuju na svu složenost proučavanja stanja šuma i utjecaja pojedinih značajki okoliša na to stanje.

Uneseni su podaci osnova za buduća istraživanja i planiranja uz pomoć GIS tehnologije, koja omogućuje bolje analize postojećih podataka i predviđanja budućih stanja, što je preduvjet za ispravno planiranje.

Svi izrađeni tematski sadržaji (slojevi) s atributnim podacima čine bazu podataka za NP Risnjak koja pruža velike mogućnosti za daljnja istraživanja i planiranja i koja je uvijek otvorena i prilagodljiva za izmjene ili dopunu novim podacima.

Ključne riječi: infracrveni kolorni aerosnimci (ICK), fotointerpretacija, geografski informacijski sustav (GIS), rasterski GIS model, NP "Risnjak", digitalni model reljefa (DMR), planiranje u šumarstvu