韓國林學會誌 78(2) : 168-176. 1989.
Jour. Korean For. Soc. 78(2) : 168-176. 1989.

Geographic Information Systems(GIS) Use in Forest Pest Management : A Simulated Study on Mountain Pine Beetle Infestation[1]

Kyu Sung Lee[2]

地理情報시스템(GIS) 利用과 山林 病蟲害 管理 : 소나무 좀벌레의 模型的 例[1]

李 奎 成[2]

ABSTRACT

Recent development of geographic information systems(GIS) provides a great deal of potential in handling a variety of spatial data required by forest resource managers. This study is designed to identify a possible GIS application in forest pest management. Several mountain pine beetle risk assessment parameters(stand characteristics, weather conditions, and topographic factor) were spatially analyzed through computer map overlaying operations in order to estimate the hazard level of the pest damage. In addition, the expected infestation route from an initially infected forest stand was located through further map analysis operations(distance measurement and connectivity analysis). Although current GIS technology may have a few limitations in operational situations, the computer based GIS has been proven as an invaluable tool to resource managers by providing flexible spatial data handing capabilities.

Key words : *GIS* ; *forest pest management* ; *mountain pine beetle* ; *remote sensing*

要 約

컴퓨터 기술을 바탕으로 최근 급속한 發達을 하고있는 地理情報시스템(GIS)은 여러 종류의 地圖를 다루어야하는 山林經營에 있어서 커다란 潛在力을 보이고있다. 이 硏究에서는 산림 病蟲害 管理의 모형적인 例를 통하여 GIS의 利用 가능성을 알아보려 한다. 林分의 특성, 氣候 狀況과 地形등 소나무 좀벌레의 發生을 좌우하는 因子들을 空間的으로 분석 종합하여 각 지역마다 발생 危險度를 指數로 표시하는 새로운 지도를 만들어 낼수 있었다. 또 다른 공간분석 방법을 통하여 이미 소나무 좀벌레에 感染된 하나의 林分으로부터 예상되는 擴散 경로를 찾아내었다. GIS의 實務的인 이용에는 여러가지 고려되어야할 점도 있지만, 공간적인 地圖分析을 통하여 산림 경영의 意思決定 과정에 필요한 여러가지 정보를 效果的으로 管理提供할 수 있다는 장점을 가지고 있다.

[1] 接受 1989年 3月 6日 Received on March 6, 1989.
[2] Dept. of Forest and Wood Sciences, Colorado State University, Fort Collins, Co 80523, USA.

INTRODUCTION

Damage caused by forest pests have been one of the most serious problems in forest management. Forest pest management deals with the detection and the estimation of pest damages on forests, the assessment of potential hazard for infection, and the control of pest populations through various techniques. These management practices require spatial data which are usually stored on maps. Typical types of spatial data needed for forest pest management are the location and size of areas of actual damage or potential pest risk, the topographic features, and other resource data (timber, water, recreation) related to the effects of forest pest damages.

Through proper maintenance and analysis of the spatial resource data, forest managers are able to assess the potential areas of pest hazard, to locate the expected infestation route, and to evaluate the impact of pest damage to other resources. Conventional maps used for storage of these spatial data are not effective for retrieving multiple combinations of data, or more importantly, spatial analysis purposes.

Recent development of geographic information systems (GIS) has a great deal of impact on forest resource management practices. Forest management involves multiple objectives for managing diverse resources such as timber, water, wildlife, and recreation. The spatial distribution and the condition of these resources is the primary information required for effective forest management. Whether successful management can be accomplished depends on proper use and maintenance of information on these resources.

In general, GIS can be defined as a computer based information processing technology to analyze, store, and display information on, primarily, spatial data as well as non-spatial data (Parker, 1988). With respect to the analytic functions of a GIS, the major application of GIS in forestry is to support decision making processes in a variety of management planning. On the other hand, if storage and display functions are emphasized, GIS can be considered as an effective database management system to inventory forest resource information on a spatial basis. However, the two main functions (analysis and inventory) should be associated properly in order to achieve the optimal use of GIS in forestry. Detailed technical concepts and background of GIS can be found from recent literature (Berry, 1986; Berry, 1987; Burrough, 1986; Ripple, 1987).

The objective of this study is to identify the potential applications of GIS in forest pest management. Along with that, it is also intended to evaluate the possible problems which may occur when using a GIS in operational situations.

METHODS AND PROCEDURES

As a case study of GIS applications in forest pest management, the mountain pine beetle (*Dendrotonus ponderosae*) was selected. The mountain pine beetle is one of the most serious pests in the extensive pine forests of western North America from the Canadian Rocky Mountains to Northern Mexico. It has one generation per year in most parts of its range and spends all of its life cycle beneath the bark, except during midsummer when adults fly and attack new trees. The main host trees for this insect are lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), western white pine (*Pinus monticola*), and sugar pine (*Pinus lambertiana*) (Sartwell and Stevens, 1975).

Planning

The initial step of this study is concerned with the assessment of potential hazard of mountain pine beetle damage based on the habitat and the population dynamics of the insect. The hazard can be defined as the probability of an insect outbreak occurring in a particular stand or forest under a given set of conditions (Berryman, 1986).

Table 1. Variables associated with the hazard of mountain pine beetle.

Factor	Variables	High risk	References
Stand	proportion of host trees	high % pine	Schenk *et al.* (1980)
	density	high	
	diameter	large	Amman *et al.* (1977)
	age	old	Sartwell and Stevens(1975)
Topography	elevation	low	Amman *et al.* (1977)
Weather	temperature	hot summer	Safranyik *et al.*(1974)
	precipitation	low	Amman *et al.* (1977)

There are three major factors which can influence the hazard of mountain pine beetle damage: stand factors, topographic factors, and weather conditions. Table 1 shows the variables associated with the hazard of mountain pine beetle damage.

Once the level of hazard for mountain pine beetle infection on every location is obtained, the next approach is to predict the spread direction from an initially infected stand. The infestation route will be determined based on the hazard index of each stand, which is derived from the first analysis.

Study Area and Data Utilized

The San Juan Mountain area, located in southern Colorado, covers about 831 square kilometers. The data availability and detailed land cover information from a previous remote sensing study(Hoffer *et al.*, 1979) were the basis for the selection of this study area. The study area is characterized by a diverse and complex mixture of land forms and vegetation types. Elevation within the area ranges from approximately 1,800 meters to 4,300 meters. The climate in this area is typical of the Colorado Rockies, with very low relative humidity, abundant sunshine, cool summers and heavy winter snow. Temperature and precipitation varies with elevation.

In the GIS process, the first step is to encode spatial data into computer readable digital map format. For this study, two different approaches were used to create the digital base maps. Landsat Multispectral Scanner(MSS) data obtained on June 5, 1973, were used to derive the forest cover-type map, which would eventually provide the information on the proportion of host species(pines) for mountain pine beetle. Computer-aided classification, using a supervised maximum likelihood algorithm, of the Landsat MSS data resulted in a land cover map which included information on five different forest cover types. The other spatial data(stand age and density, weather, and elevation) were manually digitized and then registered together with the same coordinates of the map base. Figure 1 displays the simplified 3-dimensional view of digital elevation data over the study area. Each grid on the surface represents the area of about 10 ha. Data which were not available on conventional maps were converted into map format using existing tabular information and some hypothesis. Table 2 lists the digital base maps generated for the spatial map analysis of mountain pine beetle hazard and infestation models.

Spatial Map Analysis

The first model(Hazard Index Model), which is to estimate the potential hazard of mountain pine beetle damage, requires simple map overlaying operations(Figure 2). The spatial distribution and the condition of the parameters which affect the habitat and population dynamics of mountain pine beetle is available on the nine base maps listed in

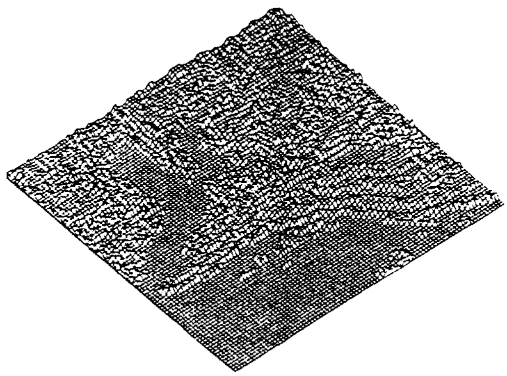

Figure 1. 3-D view of the study area.

Table 2. Digital base maps for spatial analysis.

Factor	Map Name	Data
Stand	FOR-TYPE	forest cover types
	AGE	forest stand age
	DENSITY	forest stand density
Topography	ELEVATION	1,800m-4,300m
	ASPECT	0-36℃ from north
Weather	AVGPRECP	average annual precipitation (1951-1980)
	73PRECP	1973 annual precipitation
	AVGTEMP	average summer temperature (1951-1980)
	73TEMP	1973 summer temperature (June-August)

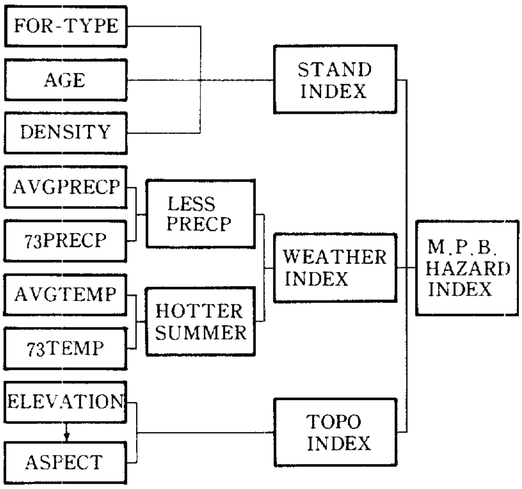

Figure 2. Hazard Index Model : map overlaying operations to assess potential mountain pine beetle hazard.

Table 1. Before overlaying operations, each of the nine base maps was reclassified so that area of high infection risk would be represented by higher index(Table 3). Assumptions used in the reclassifying operations were based on the previous studies on mountain pine beetle. However, the criteria for stratifying and indexing of the base maps may not be ecologically appropriate in some cases. Since the major objective of this study is to identify the capacity of GIS in handling numerous spatial data for a certain forest resource management purpose, it is desirable to consider more about the overall spatial analysis procedures.

Stand factors include three major parameters :

Table 3. Index for strata from each reclassified base map.

Map Name	Strata	Index
FOR-TYPE	Ponderosa Pine	9
	Pine/Fir	6
	Pine/Deciduous	5
	Fir/Spruce	2
	Oak/Aspen	1
AGE	81 years-	5
	61-80 years	4
	41-60 years	3
	21-40 years	2
	1-20 years	1
DENSITY	high	3
	medium	2
	low	1
ELEVATION	1,801-2,300 meters	5
	2,301-2,700 meters	4
	2,701-3,200 meters	3
	3,201-3,700 meters	2
	3,701-4,300 meters	1
ASPECT	south	4
	west	3
	east	2
	north	1
AVGPRECP & 73PRECP	200- 449 mm	6
	450- 599 mm	5
	600- 749 mm	4
	750- 899 mm	3
	900-1019 mm	2
	1020 mm-	1
AVGTEMP & 73TEMP	31℃-	8
	29-30℃	7
	27-28℃	6
	25-26℃	5
	23-24℃	4
	21-22℃	3
	18-20℃	2
	15-17℃	1

proportion of host species on a stand, stand age, and stand density. The FOR-TYPE map obtained from Landsat MSS classification includes five different forest cover types. It was assumed that each forest type has different proportions of pine trees. For example, 90% of the trees in ponderosa pine stand are pines, 60% of trees in the mixed pine and fir stand are pines, and so on. After non-forest classes were eliminated, each forest type class was renumbered according to the proportion of pine trees in its class. The AGE was reclassified into five forest stand age groups in which the older stand has higher index. Stand density data on the DENSITY map were divided into three density classes. These three reclassified maps were then overlaid in order to generate a map(STAND INDEX) which characterizes the stand factor for mountain pine beetle risk. Assuming that stand density is more critical variable to affect the mountain pine beetle infection, the reclassified DENSITY map was given higher weighting factor, 2, as compared to the other two maps. On the overlaying resulted in STAND INDEX map, the highest value $(9+5+2\times3=20)$ represents the stand condition of the highest risk for mountain pine beetle damage, which refers to the highest percentage of pine trees, the oldest stand age, and the most dense stand.

Since mountain pine beetle infection is most likely to occur with less precipitation and hot summer temperature, the weather factor was also considered. In order to locate the areas of less precipitation and higher summer temperature in 1973 as compared to the normal climate, average

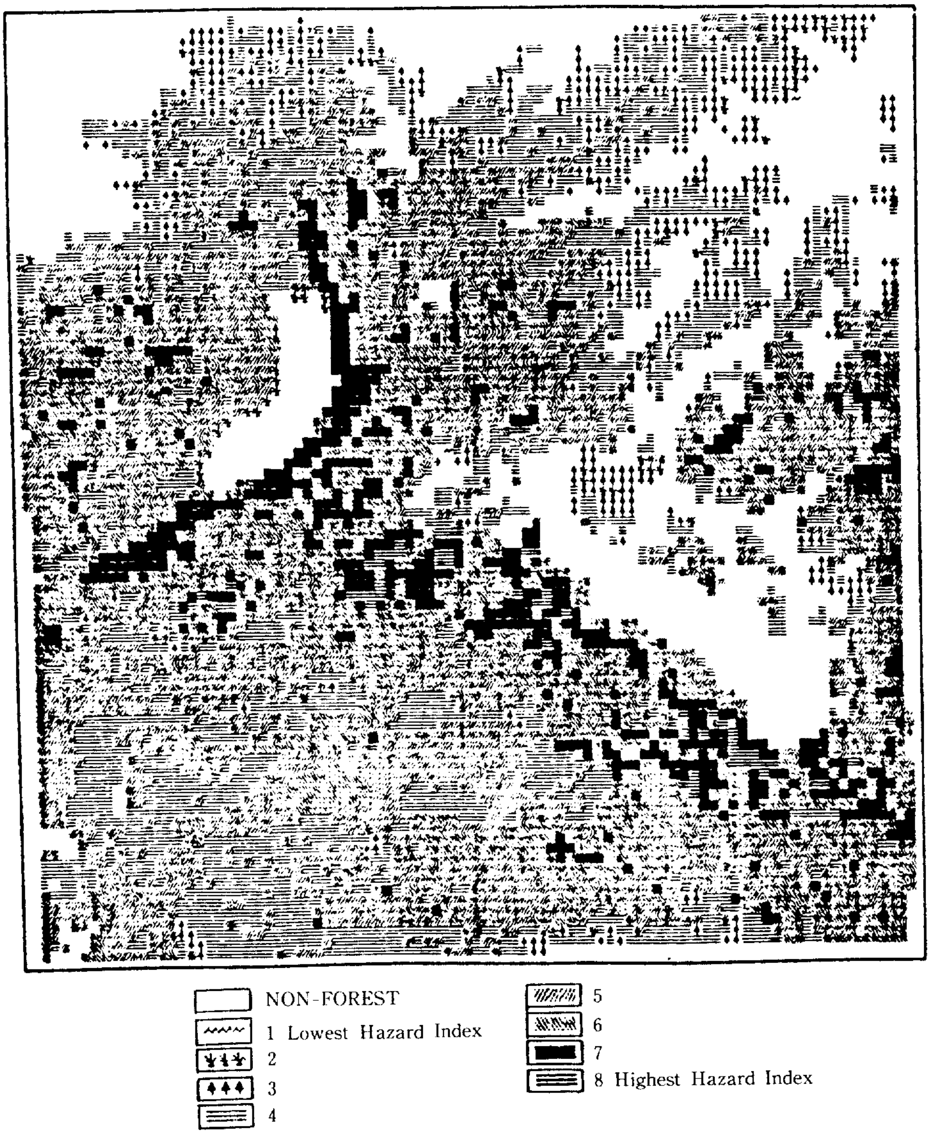

Figure 3. Mountain Pine Beetle HAZARD INDEX map.

annual precipitation and average summer temperature based on the thirty years of records from 1951 through 1980 were overlaid with the 1973 weather maps. The resulting map(WEATHER INDEX) indicates the relative weather conditions for the pest occurrence.

The study area has a wide range of elevation which has great impact on the pest habitat. The entire elevation range was divided into five classes. The lower elevation class has the higher index value which indicates the higher hazard of mountain pine beetle. Because aspect is also associated with the temperature variations, a different value was assigned to each aspect. Overlaying the elevation and the aspect data resulted in a map which indicate the topographic favor of mountain pine beetle(TOPO INDEX).

Combining the three maps of major factors (stand, weather, topography) was done by using the same map overlaying operations described above. Since the stand factor is considered the most important for mountain pine beetle infection, it was assigned a larger weighting factor compared to the other two. To simplify the results of overlaying the three maps, the outcome values were normalized into values zero to eight, where the value eight indicates the highest hazard index for mountain pine beetle infection(MPB HAZARD INDEX, Figure 3).

The second model(Infestation Model) is associated with the pest spread direction and distances from an initially infected forest stand(Figure 4). The spread will be determined by different hazard index values derived from the previous analysis. Distance measurement operations were used to create a map which indicates relative proximity to the initially infected stand. The hazard index values on the MPB HAZARD INDEX map were renumbered as friction values which could modify the proximity. In order to observe the expected spread route, another hypothesis was added. Suppose that there is a seed-tree stand which has genetically superior inheritance and therefore, must be protected from the pest infestation for further genetics research. The contagion route

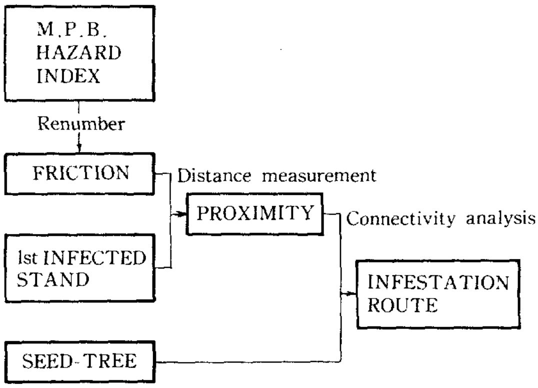

Figure 4. Infestation Model : map analysis to locate expected infestation route.

from the initially infected stand to the seed-tree stand could be identified through a connectivity operation(INFESTATION ROUTE, Figure 5).

RESULTS AND DISCUSSION

The MPB HAZARD INDEX map, resulting from the first model, actually involves seven different data sets of risk assessment parameters : proportions of host trees, stand age, stand density, drought, summer temperature, elevation, and aspect. Every location on this map has a hazard index value which summarizes the seven risk assessment parameters. Without spatial analysis of map overlaying using GIS, this operation may be impossible, or even if it is possible, it would be a very cumbersome and time-consuming task. For example, higher hazard index values were found on the area of high risk parameters such as high pine percentage stands, old and dense stands, low elevation, south-faced slopes, low precipitation and high temperature. It seems very obvious to have higher hazard index values over the areas of high risk parameters. However, retrieving and generalizing of these high risk parameters from several sources can not be effectively done without computer-assisted GIS processing.

As briefly mentioned earlier, the stratification and indexing of the mountain pine beetle hazard factors might not have solid backgrounds in some

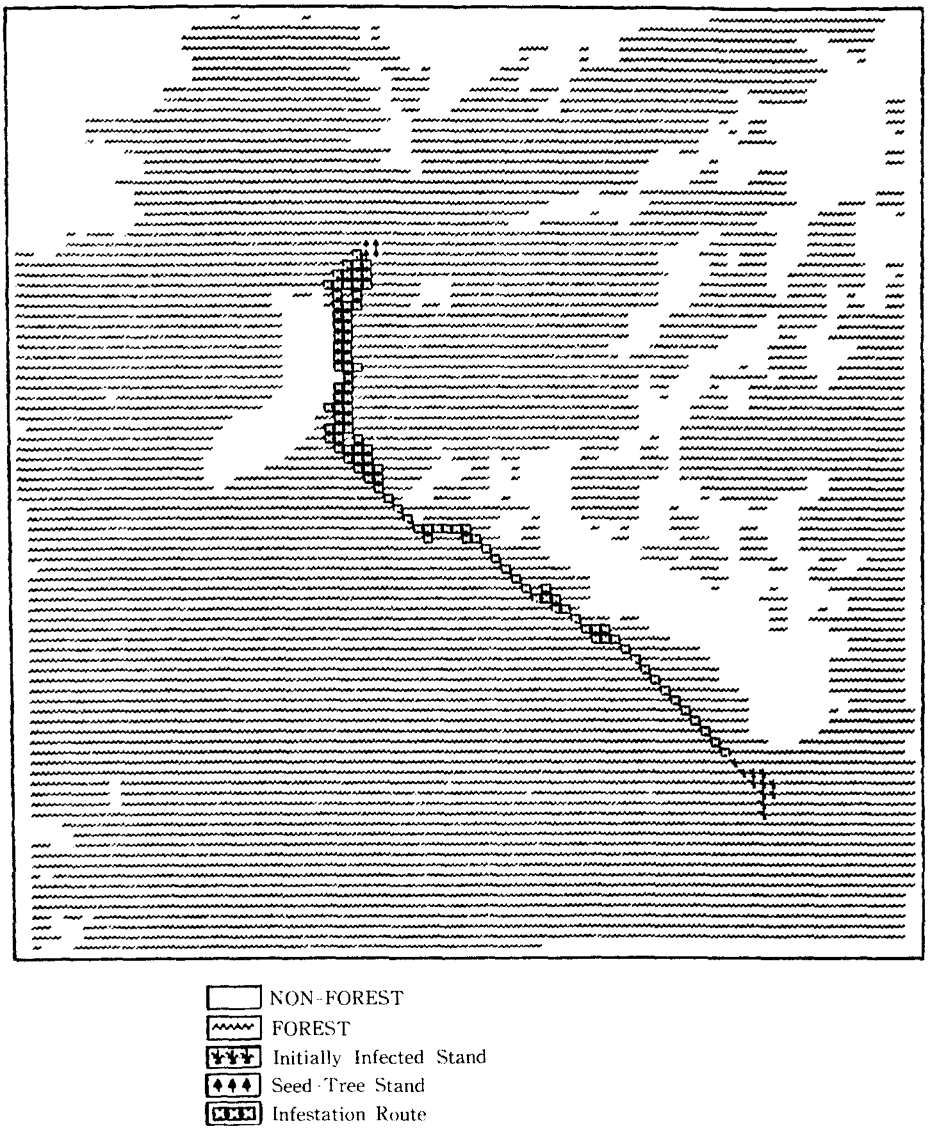

Figure 5. Expected INFESTATION ROUTE map.

cases. In fact, the criteria for such stratification and indexing of each hazard variable would heavily depend on the regional environments and the pest manager's experiences. The flexibility of reassigning index values and weighting factors at any stages of overlaying process is another key advantage of GIS in decision making procedure.

Distance measurement and connectivity operations in the second model produce one of the most important maps in controlling forest pest spread. Accurate and reliable prediction of potential infestation route should be the first approach to prevent the devastation by pest attacks. In this study, the contagion route was located only under the given target point, the seed-tree stand. However, the most likely contagion route can be located for every possible direction even without a target point for more flexible operations.

Even though the resulting maps produced from these map analysis operations may not be employed as absolute indicators of mountain pine beetle hazard, this approach would provide invaluable information to forest pest managers for proper pest management planning and practice. However, there are a few limitations and problems in applying these techniques to operational situations. First, the data needed for this kind of analysis is not always available. For example, the spatial information of forest stand and weather have a great deal of temporal variabilities and updating this information can be a serious obstacle. Various space remote sensing data may be a proper solution for the problem of data updating. The second limitation is related to the lack of integration with other resource information on the same area. Forest pests can cause serious impacts on several resources, such as timber, water, wildlife, and recreation. GIS in forest pest management should be able to integrate the other resources to analyze the impacts of forest pest damage. Finally, forest damages are usually caused by more than one insect or disease. Complications resulting from multiple forest insects/diseases requires more complex data and analysis operations in addition to currently available GIS functions.

CONCLUSIONS

Forest pest management has been dealing with significant amounts of spatial data. This study was designed to demonstrate the potential applications of GIS technology in forest pest management. Potential hazard of mountain pine beetle damage and expected spread patterns could be assessed effectively by using simple map overlaying and distance measurement operations. Considering the time and the effectiveness of analyzing all spatial data required by forest pest managers, GIS has a great potential to improve data management and analysis for forest pest management. However, a fully operational use of GIS should be made with consideration of data encoding, integration with other resource information, and functional capacity for a specific site conditions.

ACKNOWLEDGEMENT

The author would like to thank Dr. Roger M. Hoffer, Director of Remote Sensing and GIS Program at Colorado State University, for providing the Landsat MSS and digital topographic data sets and for his advice throughout this study.

LITERATURE CITED

1. Amman, G.D., M.D. McGregor, D.B. Cahill, and W.H. Klein. 1977. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. US FOR. Serv. General Technical Rep. INT-36, 19pp.
2. Berry, J.K. 1986. Geographic information systems(Part III) : learning computer assisted map analysis. Jour. of Forestry, 84 : 39-43.
3. Berry, J.K. 1987. Fundamental operations in computer-assisted map analysis. Int. Jour. Geographic Information Systems, 1(2) : 119-136.
4. Berryman, A.A. 1986. Forest Insects : Principles and Practice of Population Management. Plenum Press, New York, NY. 279pp.
5. Burrough, P.A. 1986. Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press, Oxford. 194pp.
6. Hoffer, R.M., M.D. Fleming, L.A. Bartolucci, S.M. Davis, and R.F. Nelson. 1979. Digital processing of Landsat MSS and topographic data to improve capabilities for computerized mapping of forest cover types. LARS Tech. Rep. 011597, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, IN. 159pp.
7. Parker, H.D. 1988. The unique qualities of a geographic information system : a commentary. Photo. Engr. and Remote Sensing, 54(11) : 1547-1549.
8. Ripple, W.J. 1987. Geographic Information

Systems For Resource Management : A Compendium. American Society for Photogrammetry and Remote Sensing, Falls Church, VA. 288pp.

9. Sartwell, C. and R.E. Stevens. 1975. Mountain pine beetle in ponderosa pine. Jour. of Forestry, 73 : 136-140.

10. Schenk, J.A., R.L. Mahoney, J.A. Moore and D.L. Adams. 1980. A model for hazard rating lodgepole pine stands for mortality by mountain pine beetle. Forest Ecology and Management, 3 : 57-68.

11. Safranyik, L., D.M. Shrimpton, and H.S. Whitney. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Can. Forest Service. Forest Tech. Rep. 1, 26pp.