DETECTING BURNT FOREST DAMAGE USING DIGITAL SPOT IMAGERY[1)]

Deteksi Kerusakan Hutan Terbakar Menggunakan Citra SPOT Dijital

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ABSTRAK

Mendeteksi kerusakan hutan melalui metode inventarisasi terestris dan/atau potret udara membutuhkan biaya yang mahal dan memakan waktu, khususnya untuk luasan yang besar. Dalam paper ini, penulis menguraikan kegunaan dari citra SPOT dijital untuk mendeteksi kondisi hutan paska kebakaran. Evaluasi dilakukan terhadap empat kelas kerusakan hutan yang terbakar.

*Studi ini memperlihatkan bahwa citra SPOT multispektral dapat digunakan untuk mengklasifikasi hutan terbakar menjadi kelas dengan tingkat kerusakan ringan, sedang, berat dan sangat berat. Analisis spasial yang juga dilakukan dalam studi ini memperlihatkan bahwa sebagian besar areal studi termasuk kategori kebakaran berat dan sangat berat. Meskipun hutan-hutan bekas tebangan baru cenderung mengalami intensitas kerusakan yang tinggi, kebakaran yang terjadi tahun 1998 tidak hanya membakar hutan bekas tebangan baru tetapi juga hutan bekas tebangan tua dan hutan primer***.**

INTRODUCTION

At present, most of forest management practices need timely and good quality of data/information for forestry applications. For forest fire management, it has been proven that satellite remote sensing offers very valuable information at various aspects of fire management problems, either at pre-fire planning, during fires or at the post fire, such as detection, suppression and mapping of burnt area. After fires, remote sensing system may provide information on forest damage quickly with high accuracy. After 1998 fires in East Kalimantan, only few organizations/companies that used digital satellite imagery to evaluate post-fire condition. Many of them used conventional ground survey to estimate the extent and stand condition which are usually time consuming and costly.

Availability of data in digital format coupled with better quality of computer technology, facilitate to map forest or land cover with per-pixel classification techniques

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because land/forest cover is directly related to pixel values on image. From previous experiences, it has also been proven that fine resolution of satellite data such as TM, SPOT and MESSR are useful for forest management. In this study, the author emphasized on the use of digital SPOT imagery for assessing post-fire vegetation condition.

At the present time, of several available satellite imageries, SPOT imagery offer several advantages over traditional photogrammetric. One SPOT scene covers approximately 360.000 ha, equivalent to almost hundreds of medium-scale aerial photos. The SPOT data are now available world wide on a constant cycle basis that may useful for forest monitoring. The availability of the data in digital formal also enable us to perform automated operations such as geometric correction, radiometric correction, edge/line detection, classification etc.

From February to April 1998, an extensive forest fires raged out of control through various parts of Southeast Asia including major part of East Kalimantan, Indonesia. During this period, the occurrence of fires was monitored using daily-acquired NOAA AVHRR and GMS imageries. Unfortunately, coarse spatial resolution of these two images makes them impossible to be used to detect the area of burnt forest. Finer spatial resolution of SPOT HRV data of only 20 m x 20 m, enable us to estimate post fire condition of burnt forest. In this study, SPOT data were used to zoom in the burnt area to accurately determine the nature of fires where possible.

The 1998 fires in East Kalimantan had caused serious impacts on forest and other vegetations as well as on socio-economic aspect of the community living surrounding the forest. The official estimate for the burned area in 1998 is about 507,239.5 ha causing financial losses amounting to Rp. 10.06 trillion. It was also reported that although in 1997 East Kalimantan Province was recognized as the most prepared in term of fire control, in early 1998, the fires had raged and intensified in March and April following a pattern similar to the 1982-1983 episode. It was reported that the 1998 fires were caused by large-scale land clearing. From 507,239.5 ha burnt, some of 315,132 ha (62.2%) were logging concessions. Only 1,857 ha of community agricultural lands and 10,758 ha of community plantation (estate crops) were burnt, while the rest were forested area.

In East Kalimantan, ITCI Ltd. concession area located in Southern part of East Kalimantan Province also suffered from fires. Within ITCI Ltd. concession area, the fire occurred from February to April destroying major part of the area. As we all may aware that fires remove vegetation cover, reduce ecosystem quality and species diversity as well as cause serious economic losses. Now, several logging companies face post-fire problems including implementation of rehabilitation techniques on burnt area, as well as techniques for salvage logging. Prior to develop rehabilitation and salvage logging plans, the evaluation of post-fire vegetation should be made. In order to provide timely and accurate information, the post-fire condition was evaluated using digital SPOT imagery.

The study was performed:

- to detect burnt forest damage quantitatively from digital SPOT HRV imagery;
- to evaluate whether the SPOT HRV could discriminate all damage classes;
- to evaluate the relationship between the age of logged over forest (annual cutting year) and the damage classes.

MATERIAL AND METHODS

Test Site and Supporting Data

The test site was ITCI Ltd. concession area, East Kalimantan, which is located between South-latitude 0°15’00” and 1°00’00”; and East-longitude 116°15’00” and 117°00’00”. Inside the test site, ground survey for data and information collection related to forest damage was conducted. All data and information obtained were then analyzed to support image processing, at the Laboratory of Forest Inventory, Faculty of Forestry, Bogor Agricultural University.

Two scenes of SPOT HRV (multispectral) imagery covering the major part of the study site were used. The scene centers are S000°30’12” and E116°42’25” (K302/J351); and S001°00’14” and 116°35’43” (K302/J502), acquired on June 5th 1998, approximately two months after fire.

Ground survey was performed two months after fire in order to achieve the study objective. To perform geometric correction and spatial analysis, the following maps were used as reference:

- topographic maps with scale of 1:50,000 and 1:100,000; and
- cutting year and forest potential maps of 1:100,000 scale

Software and Hardware

ER Mapper 5.5 image processing software was used to perform an image analysis of the SPOT data. The classified image was then overlaid with annual-cutting block map and spatially analyzed using GIS software ArcView Ver. 3.1 and ArcInfo, installed on PC IBM Compatible, and its essential accessories.

Methods

The procedure included the following steps:

- Geometric correction (Image-to-map rectification);
- Digitizing the annual cutting block boundary from the existing map and road from monitor screen;
- Establishment of forest damage categories;
- Assessment of accuracy;
- Image classification; and
- Spatial analysis.

Geometric Correction

Prior to performing other analysis, the images were accurately geo-corrected. Spatial interpolation using affine transformation equation, followed by intensity interpolation using nearest neighbour algorithm were conducted to get root mean square error (RMSE) less than 0.5. The first images (K302/J351) were rectified using 10 GCPs, which provided RMSE of 0.1 pixels, while the second images were geo-corrected using 13 GCPs with RMSE of 0.16 pixels. In order to perform image classification the two images were then mosaicked.

Establishment of Forest Damage Category and Land Cover Classes

The results of the study are expected to be used as reference in the implementation of rehabilitation techniques. The following four classes of forest damage classes performed by ITCI-Faculty of Forestry IPB (1998) were used:

- <u>Unburnt tropical forest</u>
  This class consisted of unburnt natural and logged-over tropical forests mostly located in the southern part of the study area. Mangrove forest, which dispersed in Balikpapan Bay are also included in this class. The predominant tree species are *Shorea* spp (meranti), *Dipterocarpus* spp (keruing) and *Dryobalanops* spp (kapur). On specific and limited site, *Agathis borneensis* was also occured.
- <u>Unburnt plantation forest</u>
  This class consisted of unburnt plantation forest (timber estate) within the ITCI Hutani Manunggal Ltd. (IHM) territory and rubber plantation of other estate crop companies including community agricultural lands, homogenously distributed in the area.
- <u>Bare land</u>
  This class is a land without vegetation or very sparse vegetation cover, includes roads; base camps, log yards, gravelpit, paved surface in Eastern part of ITCI Ltd. and other forms of bare lands.
- <u>Slightly burnt forest</u>
  This class is a forest area that has predominant healthy life-trees of more than 75%
- <u>Moderately burnt forest</u>
  This is a forest area, which has healthy life-trees ranging from 50% to 75%
- <u>Severely burnt forest</u>
  This is a forest area, which has healthy life-trees ranging from 25% to 50%
- <u>Extremely burnt forest</u>
  This is a forest area, which consisted of healthy life trees less than 25%.

The conditions of forest cover classes are shown in Figure 1.

During ground survey, tree conditions are grouped into (a) healthy life-tree (*pohon sehat*), (b) partially burnt life-tree (*pohon merana*), (c) marketable dead tree (*pohon mati baik*) and totally burnt tree (*pohon mati hangus*). The condition of each affected tree is shown in Figure 2.

(a) **(b)**

(c) **(d)**

Figure 1. Ground condition of several forest damage classes (The photos were taken on April 30, 1999 by author) (a) Unburnt tropical forest, (b) Slightly burnt tropical forest, (c) Moderately burnt tropical forest (upper-left part of the image), severely burnt tropical forest (upper-right part of the image). Unburnt tropical forest (lower part of the image), (d) Extremely burnt tropical forest

(e) **(f)**

(g)

Figure 1. Continued (e) Burnt Land Clearing; (f) Burnt plantation forest (Acacia mangium) and (g) Unburnt plantation forest (middle part of the image)

(a) **(b)**

(c) **(d)**

Figure 2. Photos of tree condition (a) Healthy life tree; (b) Partially burnt life-tree; (c) Marketable dead-tree and (d) Totally burnt tree

To reduce misclassification during computer-assisted processing, the coverage of cloud and cloud shadow were separated as individual cover classes.

Digitizing the Annual Cutting Block

The polygon of logged over forest were digitized from the map of annual cutting block. To get more realistic information from the map, personal interview to the staff of Planning Division of ITCI Co. Ltd. pertaining the realization of logging activity was done.

While roads were digitized on monitor screen, by tracing a mouse cursor along the center of each road. The digitized pixels were then saved as a vector format (Arc/info format)

Image Analysis

In this study, a hybrid of supervised and unsupervised classification was applied. The unsupervised classification using isoclass algorithm was performed by generating a number of unlabelled classes. This is particularly useful to facilitate training area selection.

Based upon data and information available from maps coupled with ground truth data, a set of training areas representing each class performed above was then generated. The training areas were selected interactively by comparing ground truth data and their appearance on screen. To reduce error during placement of the training site, the ITCI Ltd. concession area boundaries map as well as road and river maps were overlaid. In general, the training area was plotted at the middle part of homogenous area.

To determine whether the SPOT data provide accurate classification, accuracy assessment and interclass separability analysis were conducted. The accuracy was estimated using overall and Kappa accuracy measures, while the separability analysis was evaluated using Transformed Divergence measure. The classified image was exported to ArcInfo format for spatial analysis using ArcView. In general, the flow of data analysis is depicted in Figure 3.

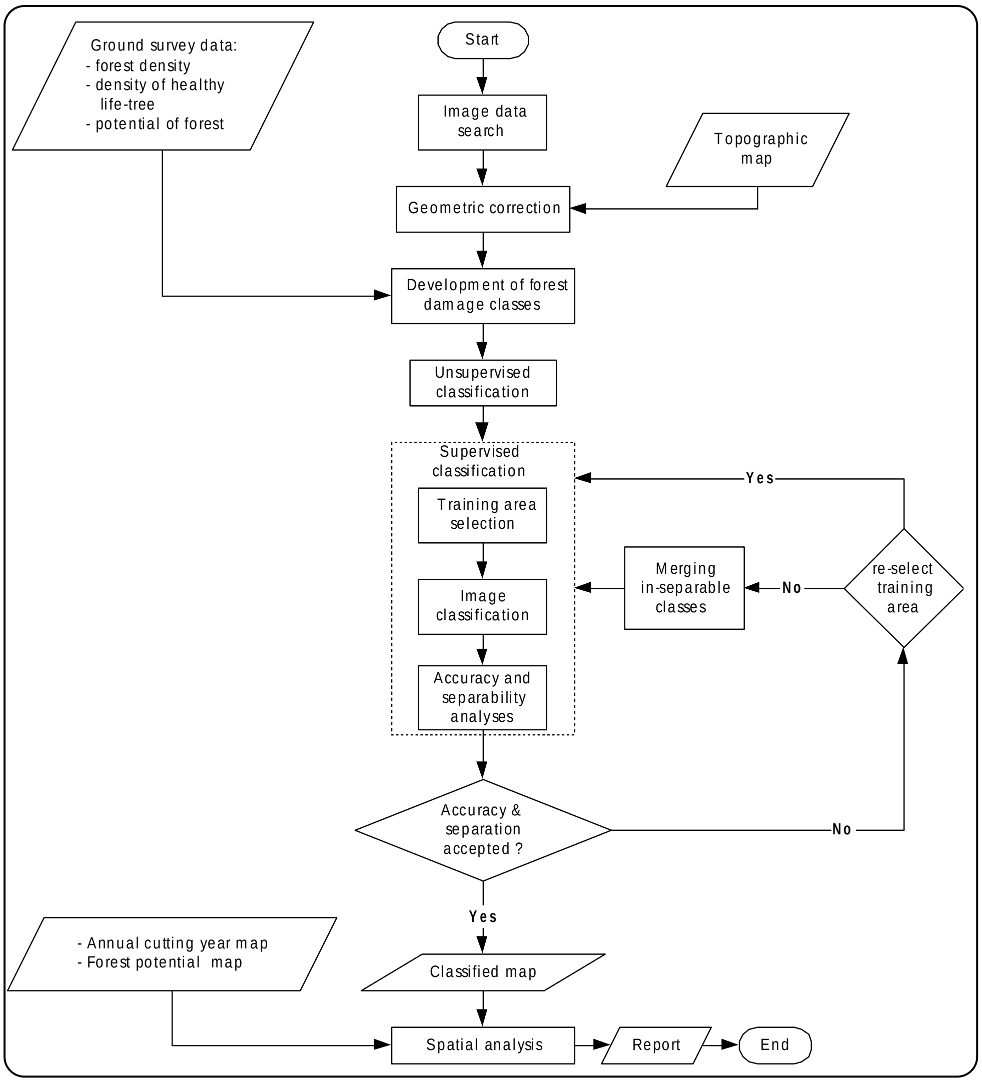

Figure 3. Flow diagram of the study

DISCUSSIONS

Feature Selection

To perform quantitative analysis, standard false color composite image of band XS3 as red, XS2 as green and XS1 as blue was created. This provides an immediate feature of post-fire condition. Through visual interpretation either on hardpaper or on computer screen, burnt and unburnt areas could be obviously discriminated. Light red colors correspond to unburnt vegetation either natural or plantation forests, while black with slightly red color shows burnt areas, mainly severely and extremely burnt forest. Since the emphasize was to discriminate the degree of forest damage digitally based on percentage of healthy life-tree, visual interpretation was performed to assist quantitative analysis especially during the selection of training area. In this study, since SPOT multispectral data have only three bands, feature evaluation was done using single band, two-band and three-band combinations. Of all possible combination evaluated, the study found that the best accuracy and inter-class separability were provided but using three-band combinations, i.e., band "XS1" (0.5 to 0.59 μm green), band "XS2" (0.61 to 0.68 μm, red) and band "XS3" (0.7 to 0.89, near infra red). As proved by Jaya and Kobayashi (1995), band combination using visible and infrared bands was recognized to be useful for detecting biomes or vegetation changes. Green band was expected to provide valuable information on green reflectance of healthy vegetation. Red band that corresponds to chlorophyll absorption of healthy green vegetation biomass present in a scene. This is particularly useful for land and water discrimination (Jensen, 1986).

Statistical analysis performed to evaluate classification accuracy and inter-class separability provides a promising result. The Kappa accuracy using all shows that, the damage degrees of burnt class were classified well, providing accuracy of 95%. The inter-class separability of damage classes using full set band also showed an excellent separation, better than using two or single band combination. The study found that good classification of burnt forest could be obtained using full set band of SPOT HRV.

Forest Damage Classification

As mentioned earlier, in order to select training area, unsupervised classification using isoclass algorithm was performed. In this clustering process, 15 unidentified classes were generated. By interactive interpretation on both false color composite and clustered images, coupled with ground survey data, 10 classes from the 15 classes mentioned earlier were developed. An ancillary data and information were also used to give identity of the 10 clusters generated. Forest concession boundary map, roads map and visual interpretation data were applied to discriminate categories with high spectral overlap. Plate 1 is the classified image using supervised classification of SPOT imagery performed in this study. It is shown, that unburnt natural tropical and plantation forests were obviously discriminated from burnt forest. However, it was noted that little confusion occurred between these two classes. Some pixels of unburnt tropical forest were classified into unburnt plantation forest. Among four forest-damage classes no significant confusion occurred between slightly, moderately, severely and extremely burnt forests classes,. Considerable confusion was only found between the severely burnt class and thr no-data class. In fact, pixel value of no-data class is null which is similar to very dark area or very deep-water body. Ground truth data collected in June 1998 (two months after fire) showed that there are many totally burnt trees within this moderately burnt area. The totally burnt tree seem to have a very low reflectance which similar to no-data and deep water. As reported by Guyot (1990), optical properties of forest canopies depend mainly on the optical properties of leaves and underlying soil. In some cases, however, they are also affected by optical properties of other parts of plants, such as bark on the branches, flowers, fruits, etc. In this study site, particularly within the severely and extremely burnt forests, of which the tree crown density is relatively low, the effect of burnt forest floor and burnt trees were dominant and mask out the effect of green biomass (chlorophyll) of healthy life trees. In the standard false color composite, these classes show black and very dark black (pixel value near to zero). Although confusion was found between extremely burnt area and water body (especially deep water), this confusion could be avoided for the pixels present within the study area. By using spatial context during visual interpretation, the deep-water body class shown as dark blue was then reidentified as totally burnt forest. In general, the results have shown that classification of the degrees of forest damage using SPOT data were accurate, with kappa accuracy value more than 90%. Inter-class separability analysis also provides a promising result, where damage classes could be separated successfully.

Using computer-assisted classification, the presence of clouds and their shadow had caused considerable confusion. Much confusion occurred between cloud and barren land. Some pixels of cloud were classified into barren land, and inversely, some barren land pixels were labeled as cloud. This confusion is likely to occur because biomass burning provided organic hygroscopic particles, which increase the available cloud condensation nuclei, then generated brighter clouds. The brighter clouds could reflect much more solar radiation in to the space that similar to the characteristic of barren land (Robock, 1988 in Chuvieco & Martin, 1994).

Relationship between the age of logged over area on forest damage

Fuel is one of the three main factors, which influence fire behavior. Certain properties and characteristics of fuel which play an important role in affecting forest behavior are fuel size, fuel arrangement, fuel volume, fuel type, fuel pattern and fuel condition (Heikkila *et al*., 1993). The basic idea of the study is that logged-over forest could have high accumulation of logging waste (fuel) due to bucking, felling, yarding and road construction. Newly logged forests tend to have large amount of logging waste (dead fuel) accumulation compare to either old logged over forest or virgin forest. In this study, a relationship between fire intensity and age of logged forest has been recognized. In fact, logged over forests will have much more dead fuel than virgin forest. Furthermore, the volume of fuel could determine the total heat that can be produced during a given fire, and then the total heat plays an important role in the spread of the fire. A large amount of dead fuel, particularly within newly logged forest has caused high intensity fires. This is due to the fact that the amount of fuel burnt per hectare will affect the intensity with which an area will burn. The greater the fuel quantity per hectare the higher fire intensity will be produced, therefore the greater will be the total heat produced by the fires. Therefore, there is a large amount of heat transferred through radiation and convection to surrounding area. This radiation causes the pre-heating of the surrounding fuels and enables a surface fire to spread and may contribute to a fire jumping a fuel break. In some areas, sufficient amount of dead stems and branches may be present to allow for a fast spreading crown fire. During ground verification, the author found much more dead fuels within logged over forest than in virgin forest. The older the logged forest, the lesser amount of dead fuels (logging waste) available. During course of time, some of them may have decomposed and mineralized. Although logs, stumps, and large branches are categorized as heavy fuels, when they dry, they will develop very hot fire, and then may create spot fires, when the fuels moisture is low.

Considering the spatial relationship between the age of logged over forest and the digitally classified map obtained using full set SPOT HRV bands, the study found that severely damaged forest occurred within the areas of recently logged (84/85 ~ 90/91). As summarized in Table 1 and shown graphically in Figure 4, of four burnt forest classes evaluated, major proportion of the areas were recognized as severely burnt (83%). The highest proportion of severely burnt forest was found within 1989/1990 block area (6,217 ha). In general, large proportions of severely burnt forests were occurred between logged over forest of 1984/1985 (14 years after logged) and 1990/1991 cutting years (8 years after logged), ranging from 2,027 ha to 6,217 ha. Major part of annual cutting years of 1977/1978, 1978/1979 and 1975/1976 which logged 20, 21, and 23 years ago respectively also suffered from severe fire. From the results of spatial analysis performed by overlaying forest damage classes and wood potential distribution map, it was known that 51% of burnt forest area have burnt trees volume of approximately 35 m^3 per ha. Estimated total volume of burnt trees was about 2.47 million cubic meter.

A little anomaly was found within cutting year blocks of 1978/79, 1977/78 (21 years) and 1975/76 (23 years). Within these cutting blocks, the burnt forests were as severely damaged. If there is no "re-logging activity" conducted in these blocks, the extreme drought condition occurred between February and April 1998 had caused forest fires in such condition, in which the fire burnt out not only dead fuels (logging waste), but also standing life trees and other green vegetations. Although in some parts of the area, volume, size, type, pattern, condition and continuity of fuels from logging waste influenced the forest damage intensity, in this 98 fire the extreme drought condition had escalated the fire intensity into all forest conditions. According to the information obtained during field visit done in April 1989, there is no logging activity conducted since the 1997/1998 cutting year. Thus, it is defined that the annual cutting years of 1997/1998 to 2004/2005 is considered as virgin forests.

Remote sensing data applied in this study was recognized as an ideal tool for estimating post fire condition of forest. This is particularly useful for post-fire fuel management by combining degree of forest damage estimated from SPOT imagery and auxiliary data such as annual cutting-year, forest potential or topography map, is expected to be useful for local fuel management as well as to support global fuel management. The experiences gained from this study are also quite promising for post fire rehabilitation and salvage logging.

CONCLUSIONS

The useful findings from this study include, the following conclusions:

1. SPOT HRV imagery could be used to detect burnt forest damage intensity successfully. Four damage classes, i.e., slightly, moderately, severely and extremely burnt forest could be recognized accurately with accuracy of more than 90%. The inter-class separability of these classes are excellent.
2. The presence of cloud shadows had caused considerable confusion in digital classification especially on extremely burnt forest class. Since automated correction of this misclassification could not be performed, visual interpretation by applying spatial context is required.
3. The study shows that most of the burnt area was severely damaged (83%). During the 98 fires, fire not only burnt out newly logged forest area, but also old logged area as well as virgin forest.
4. Analysis of spatial distribution of burnt forest, showed that geographical origin of the fires might be come from northern and eastern part of the area. Extremely and severely burnt forests were found predominantly in the northern and eastern part of the area. While unburnt forests are found in the southern and southwestern part of the study area.
5. Although no quantitative measurement conducted during the study, in general, recently logged forests have large amount of easily combustible fuel, and logging waste. Therefore, it can be concluded that the severely burnt forest tend to occur within the recently logged forest.

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Plate 1. The post-fire & land cover classes using supervised algorithm (overlaid with annual cutting year)

Table 1. Areas of burnt forest classes for each cutting year

Logging Year Block	Age of LOA (year)	Slightly burnt	Moderately burnt	Severely burnt	Extremely burn	Remark
NCY	0	729	7	3520	242	Virgin forest
2004/2005	0	21	7	660	44	Virgin forest
2003/2004	0	2	9	436	5	Virgin forest
2002/2003	0	29	39	754	64	Virgin forest
2001/2002	0	49	67	251	2	Virgin forest
2000/2001	0	29	33	550	6	Virgin forest
1999/2000	0	209	41	1385	27	Virgin forest
1998/1999	0	187	142	770	85	Virgin forest
1997/1998	1	47	40	1481	70	LOA
1996/1997	2	2	0	740	12	LOA
1995/1996	3	30	29	598	82	LOA
1994/1995	4	11	46	161	36	LOA
1993/1994	5	5	19	119	4	LOA
1992/1993	6	38	44	1113	22	LOA
1991/1992	7	12	25	1010	65	LOA
1990/1991	8	512	615	5650	335	LOA
1989/1990	9	74	134	6217	378	LOA
1988/1989	10	367	553	4537	151	LOA
1987/1988	11	171	374	4554	388	LOA
1986/1987	12	205	269	2027	170	LOA
1985/1986	13	418	573	4105	395	LOA
1984/1985	14	179	399	4935	369	LOA
1983/1984	15	48	21	2018	145	LOA
1982/1983	16	73	1	793	53	LOA
1981/1982	17	65	5	370	75	LOA
1980/1981	18	187	1	508	39	LOA
1979/1980	19	141	27	1012	45	LOA
1978/1979	20	246	255	3844	242	LOA
1977/1978	21	397	543	2572	210	LOA
1976/1977	22	140	14	1461	57	LOA
1975/1976	23	64	28	4775	143	LOA
1974/1975	24	1	1	353	6	LOA
1973/1974	25	4	15	418	30	LOA
1972/1973	25	84	0	1844	4	LOA
1971/1972	26	11	0	703	0	LOA
Total (ha)*)		4787	4376	66244	4001	
Proportion (%)		6	6	83	5	

Remarks: LOA=logged over area
*) only the classes of forest cover

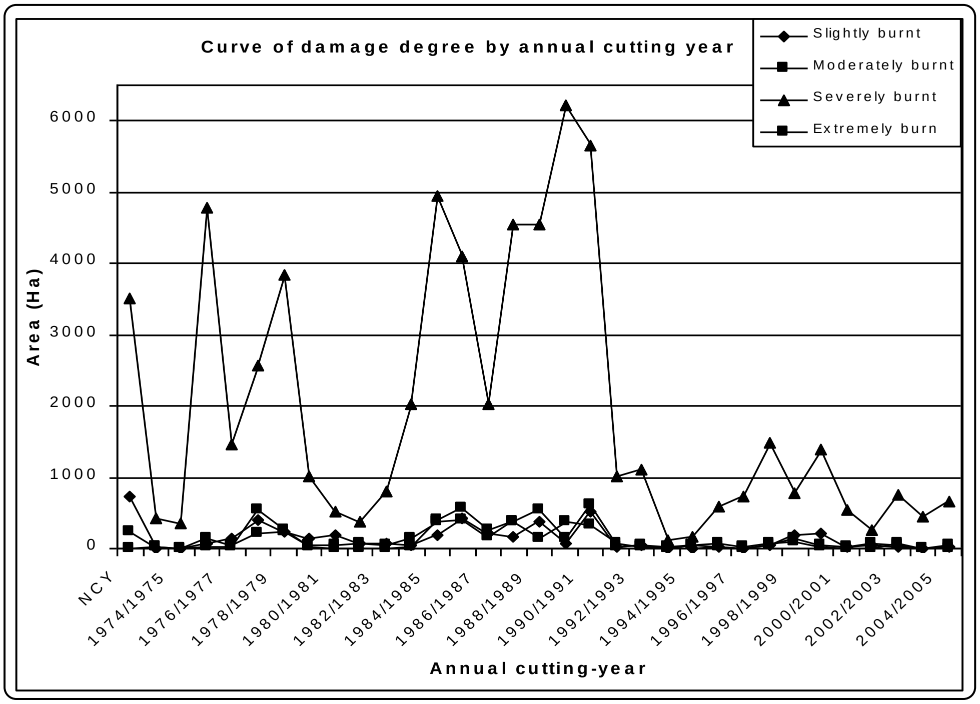

Figure 4. Pie chart of each forest damage degree by potential classes

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