Silva Gabreta	vol. 3	p. 161–172	Vimperk, 1999

Bark beetle calamity assessment from remotely sensed data

Odhad rozsahu kůrovcové kalamity pomocí dálkového průzkumu

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Abstract
Spatial distribution of forest cover changes in the Šumava National Park and its Bavarian neighbourhood between 1987-1998 were assessed from satellite data, aerial photographs and field survey by combined image processing technique and visual interpretation. The study revealed less extensive changes in Norway spruce forests of the Czech side before 1992, their significant increase after 1992, and dramatic acceleration of them after 1995 in the whole area. Wind-damage episodes, clear-cut management, and air pollution mainly induced changes before 1992, while bark beetle, *Scolytidae*, seems to be the main factor responsible for changes after 1992 and especially those after 1995. Its outbreak has reached a serious calamity since that year. These reduced area of healthy and moderate damaged spruce class from 71% in 1987 to 52% in 1998, increased area of highly damaged and dead forest from 1% in 1987 to 16% in 1998, and caused total disintegration of some naturally valuable ecosystems.

Key words: Landsat 5 TM, neural classification, forest change

Introduction

The outbreak of bark beetle, *Scolytidae* on Norway spruce in Bohemian Forest in last few years opened lots of discussions about both the real „culprit“ of recent calamity and also about an appropriate forest management of cultural forests. Many of published articles on this topic go back to historic roots of bark beetle calamities and forest management (e.g., Nováková 1997, Vicena 1997, 1998). A very comprehensive review of forest development and problems related to the bark beetle in the Šumava National Park is documented by Zatloukal (1998). All these works point out, that late or incompletely exploited wind-damaged spruce stands worked as a trigger factor of all bark beetle explosions. Information in these and other related papers is based on data gained by field survey mapping and from statistical result about logging.

Aerial photographs for tree health evaluation mainly in infrared wave band region have been successfully used since the fifties (e.g. Murtha 1972; Flemming 1978) and new sensitive film materials and methodologies have been developed since that (Hildebrandt & al. 1991). But application of satellite remote sensing in forest inventory and health status assessment could became one of powerful techniques only after 1972, when earth observation sa-

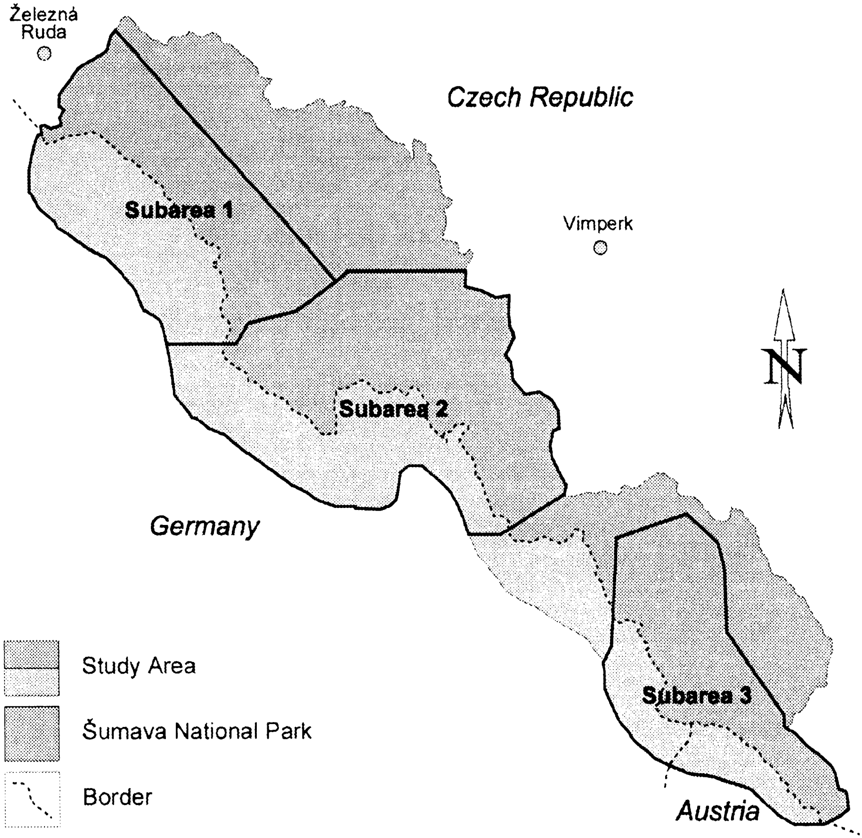

Fig. 1. – Total study area with its subareas 1–3.

tellites have been providing images with reasonable high ground resolution. And in spite of some critical perspectives (HOLMGREN & THURESSON 1998), it is widely used in numerous studies (e.g., JAAKKOLA & al. 1988, KEIL & al. 1990, ARDÖ & al. 1997) and proved its applicability in forestry research and practices on regional scale. It is quite often supported by ancillary data, e.g., terrain characteristics calculated from digital elevation model, generated in a geographical information system (EKSTRAND 1993).

Czech forests have been in the focus of satellite remote sensing research since the nineties, mainly in connection with forest decline in the North Bohemia (e.g. ROCK & ARDÖ 1993, ARDÖ & PILESJÖ 1995, ARDÖ 1998). The Czech Ministry of Agriculture utilises results of forest assessment from satellite TM data, carried out by the Forest Management Institute in Brandýs n. L. and STOKLASA Tech., Prague, in monitoring of forest health status (HENŽLÍK & STOKLASA 1995, STOKLASA 1997).

Table 1. – Extents of total study area, its three subareas and their forested size [km², %].

Part	Area	Forested area	
	[km²]	[km²]	[%]
Total study area	996	827	83
Subarea-1	220	205	93
Subarea-2	302	261	86
Subarea-3	168	146	87

Objectives

The objective of this study is a quantification of spatial extents of forest cover changes in the region from a time series of multispectral satellite data using digital image analyse and supported by visually interpreted aerial photographs and by field survey.

Study area

Central part of Bohemian Forest, including the Šumava National Park and adjacent 5 km wide stripe in Germany and Austria, became our study region (Fig. 1). Three more subareas were delineated within this region for more detailed interpretations of results both those expressed in relative size of each class to a reference area and those which are in map format outputs. Missing two different terms of satellite data in subarea 1 and 3 also determined such an approach. A priori knowledge of the territory we used to split the whole region. Table 1 shows the extents of total study area and the subareas 1–3 and their forest cover derived from administrative maps of forests.

Data and methods

Different algorithms have been tested in last twenty years for the detection of tree damages caused by a disease or a pest both from field and remotely sensed data (e.g. LECKIE & al. 1989). They investigated relationships between spectral characteristic of attacked trees or forest stands and their different degrees of damage. Also changes in crown foliage pattern or in patch spatial features of damaged stands have been in the focus of the researchers (MURTHA & WIART 1989, PREISLER 1993). We used neural net classification to distinguish four forest cover classes from Landsat 5 TM data within this study.

First class is represented by healthy and moderate damaged coniferous forest. Highly damaged and dead spruce forest is a second class. Clear cuts and all kinds of forest plantations younger than 10 years is a third one. The last class, mixed forest, includes typical mixed forest stands, broad-leaved forest, and plots with sparsely scattered trees. We qualify trees under a 30% of needle lost or yellowing as moderately damaged in the study.

Five terms (11-VII-87, 18-IX-89, 19-IX-92, 7-VIII-95, 10-VIII-98) of satellite Landsat 5 TM data, scenes 192/26 and 191/26, have been processed separately for each term on EASI/PACE system, PCI corp. Full set of five TM data terms was available only for the subarea 2, while the subarea 1 was missing term 7-VIII-95 and the subarea 3 term 18-IX-89. The whole territory was covered with 1987, 1992, and 1998 data.

All scenes of TM data were registered into map 1:25 000, Gauss-Krüger projection, using second order polynomial spatial transformation with near neighbour pixel value resampling and preserving 30m-pixel size.

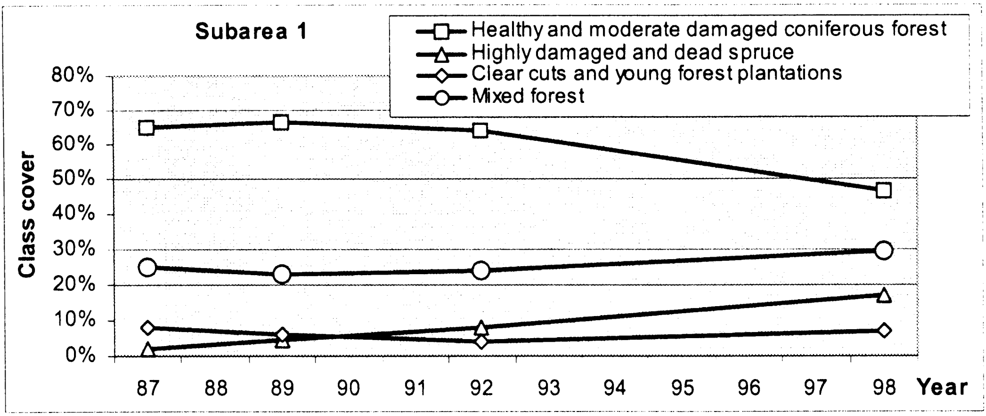

Fig 2. – Development of forest cover classes in subarea 1 expressed in [%] of forest ground.

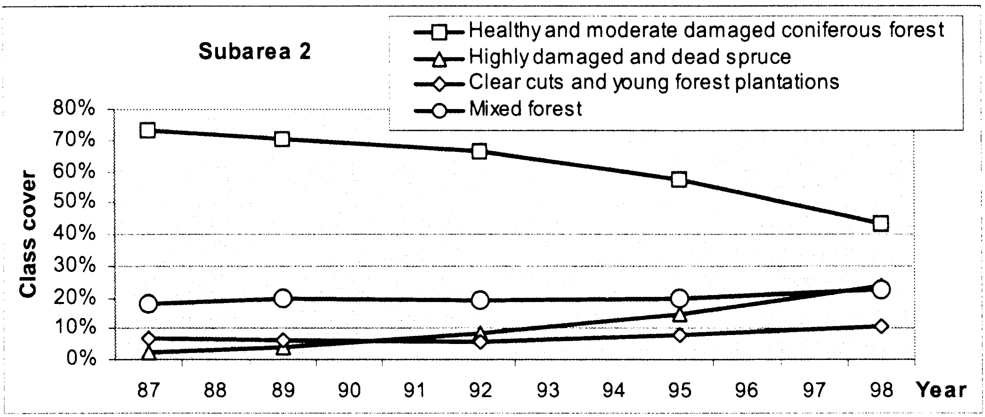

Fig. 3. – Development of forest cover classes in subarea 2 expressed in [%] of forest ground.

We trained neural net classifier for each data term and carried out classification from five TM bands (2, 3, 4, 5, and 7) inside forest mask (forest area). Training and result verification for 1998 term classification were based on field survey and aerial multispectral and spectrozonal photos. Training plots for other terms (1987, 1989, 1992, 1995) of satellite data issued from colour, spectrozonal, and multispectral photos temporally coinciding with appropriate TM data. We eliminated by image filtering all plots less than 3-pixel size in the sense of 4-direction connectivity in resulting thematic map.

We calculated differences between individual terms of classification results using map algebra and cross tabulation operations. Accuracy assessment of 1998 term classification was carried out by randomly sampled pixels in the image, compared with true class in the field. The overall accuracy is based on calculation of confusion matrix.

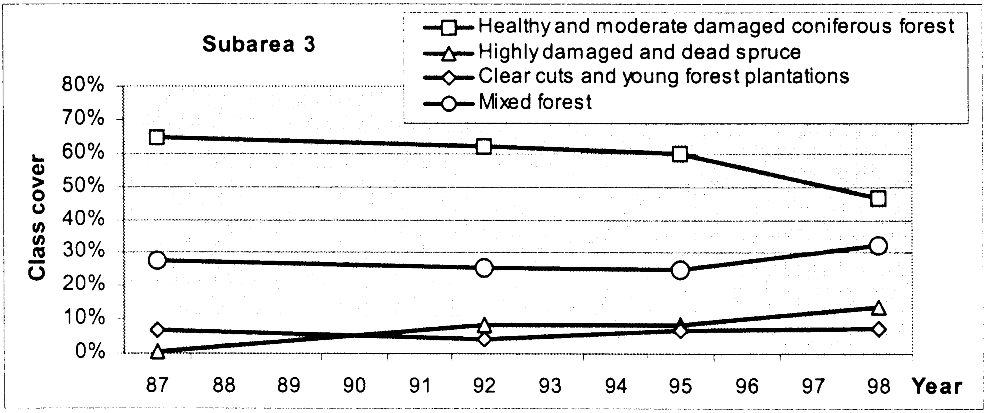

Fig 4. – Development of forest cover classes in subarea 3 expressed in [%] of forest ground.

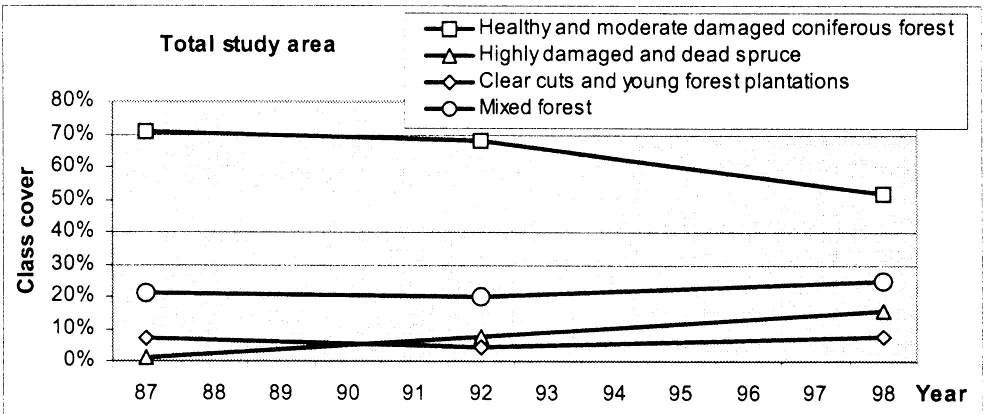

Fig. 5. – Development of forest cover classes in total expressed in [%] of forest ground.

Results and discussion

Two types of outputs demonstrate the development of forest cover changes in last decade. The first one shows the trajectory of changes of four investigated classes in individual subareas 1–3 (Figs. 2–4) and in total study area (Fig. 5). Classes of clear cuts and young forest plantations are in common category here to avoid misinterpretation due to their very close trajectories.

Figure 6 documents proportions between these two classes. It informs about extents of cover classes in percentage in each forest territory. There is similar course of changes in the subarea 1 and subarea 3 (Fig. 2, 4). The healthy spruce class decreased by 18% between 1987–98 and highly damaged and dead class increased from 2% to 17% in subarea 1 and from 1% to 14% in subarea 3. Most of the changes took place in these subareas after 1992.

The trajectory of changes in subarea 2 displays much steeper and regularly rising course than in subareas 1 and 3 (Fig. 3.). Significant changes occurred there already before 1992 (an

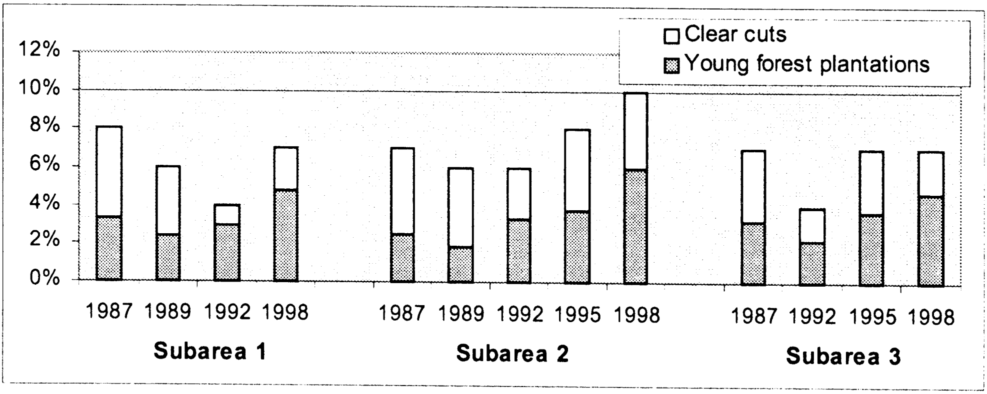

Fig. 6. – Proportions between clear cut and young forest plantation classes expressed in [%] of forest ground.

increase of highly damage class by 7%) and accelerated between 1995-98. While in 1987 the first class occupied 73% of subarea 2, it was only 43% in 1998. On the contrary, area of highly damaged forest reached 22% in 1998, from 2% in 1987.

Changes in the total study area resemble those in the subareas 1 and 3 (Fig. 5 and Table 2). That indicates less dramatic changes outside the subareas 1-3, the complement to the whole study area, perhaps because of better climatic conditions in lower altitude forest stands and less extended spruce monocultures there. Area of healthy and moderate damaged spruce class has reduced there from 71% in 1987 to 52% in 1998 and area of highly damaged and dead forest class has increased from 1% in 1987 to 16% in 1998.

The main reason of the reduction of clear cuts and young plantation class in 1992 in comparison with that in 1987 both in total area and subareas is a shift of some healthy young forest plantations to the class of healthy and moderate damaged spruce. The proportion of clear cuts to young forest plantations shows Fig. 6. While the size of clear cuts, which represent plots usually no longer than two or three years after logging (bare ground), seems quite stable, the category of young forest plantations has been increasing since 1989. It is because of shifts from bare soil category to heterogeneous category of young forest plantations. This category including plots covered with different succession stages of vegetation mixed with deciduous or coniferous saplings. Neither spectral nor spatial resolution of TM data enable to separate e.g. mixed forest reforestation from spruce once because of a very similar spectral characteristics caused by other plant species present there.

The increased size of fourth class in 1998 is resulting from application of some mixed forest reforestation practises in last years and from some misclassified forest stands. The fourth class was the most confusing class of the classification.

Earlier studies of forest cover changes in Bohemian Forest used different classification keys

Table 2. – Development of forest classes cover in total study area expressed in [%] of forest ground.

Date	Healthy and moderate damaged coniferous forest	Highly damaged and dead spruce	Clear cuts and young forest plantations	Mixed forest
11-VII-87	71%	1%	7%	21%
19-IX-92	68%	8%	4%	20%
10-VIII-98	52%	16%	7%	25%

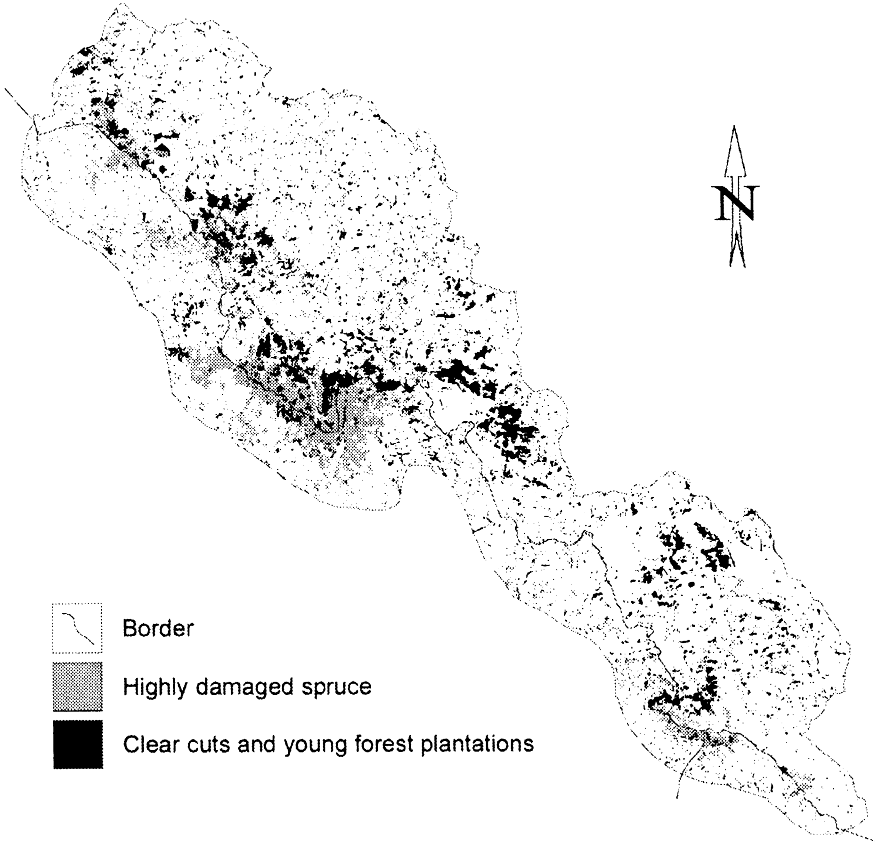

Fig. 7. – Two classes of forest cover in total study area in 1998.

(Henžlík & Stoklasa 1995, Stoklasa 1997) for degrees of damage in Norway spruce stands and they developed them to more detail evaluation with a support of information from forestry maps and other stand characteristics. Forest monitoring organised by the Czech Ministry of Agriculture is also based on this principle. Detail methodology (classification algorithm) to this monitoring has not been published yet. Also Keil & al. 1992, used ancillary data (digital elevation model, soil map) and carried out „stratified" classification, i.e. separately classified disjunctive areas delineated from supportive data.

Unfortunately, it is impossible to compare our results with those cited above. There are two reasons for this:

1. classification keys are not identical
2. field surveys for stand assignment to a class are subjective and based on different personal experience of a surveyor

The second type of outputs are thematic maps. They inform about forest cover in total study area in 1998 (Fig. 7) and about temporal and spatial distribution of forest classes in the subarea 2 within 1987–1998 (Fig. 8–12). Only two the most monitored classes (highly damaged spruce, clear cuts and young forest plantations) are presented in the set of maps in the latter case because of an easier recognition for the reader.

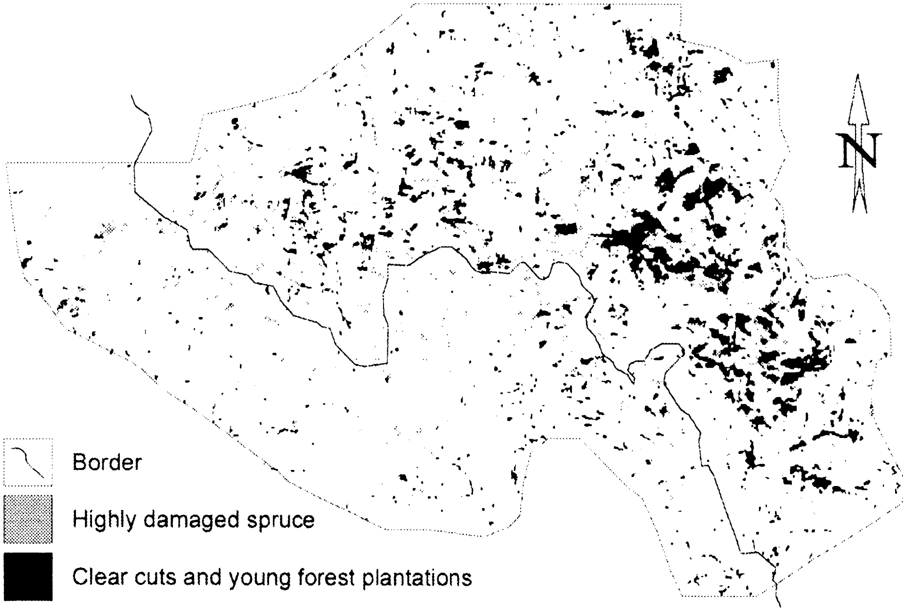

Fig. 8. – Two classes of forest cover in subarea 2 in 1987.

Even if searching for main reason of bark beetle explosion, its direction and velocity of spreading, were not objectives of this study, we can point out from the time series on, at least, two potential reasons of recent calamity in Czech side of Bohemian Forest.

One reason has originated in the Bavarian National Park (Fig. 9, 10), where forest core zone development has been left totally on natural regeneration processes and bark beetle from these forests highly influenced especially subarea 2.

Small patches of open forest plots after wind damages on Norway spruce and clear cuts in the Czech side seems to be the second place of the bark beetle explosion in the Bohemian Forest, mainly in subarea 1. But this hypothesis is necessary to verify by analysing higher resolution spatial data (e.g. aerial photos), because forest edges are always a mixture of different adjacent classes (bare ground, shadows, bushes, grass, etc.) in Landsat TM 5 data. That is why a transfer of one or two pixels (30, 60 m) from one class to another is difficult to identify with high accuracy.

The overall accuracy of neural net classification of Landsat 5 TM data, 1998, was an 86%. We did not carry out accuracy assessment for other classified data terms.

Conclusions

1. The study confirmed dramatic Norway spruce decline in Bohemian Forest in the last years and demonstrated spatial development of this decline.
2. It proved suitability of neural net classifier on multispectral satellite Landsat 5 TM data for assessment of forest cover change on a regional scale. It helps to understand temporal-spatial dimension of these changes through a retrospective analysis especially in the case, where more detail data (e.g. aerial photos) are available.
3. More ancillary data (environmental conditions – terrain configuration, species and age

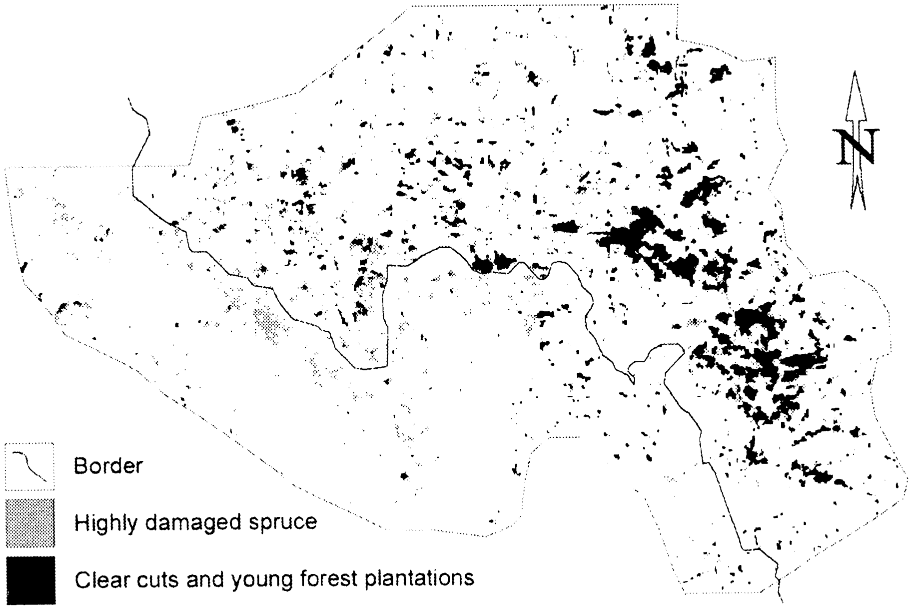

Fig. 9. – Two classes of forest cover in subarea 2 in 1989.

structure, etc.) would be necessary to employ in the analyses if we want also to search for sources, vectors and intensity of the calamity.

4. This method does not enable to detect small patches (less than 3 pixels area) of freshly attacked trees both on the forest edge and also within the closed canopy cover.

Acknowledgement
This work was supported by EC project „Integrated risk assessment and new pest management technology in ecosystems affected by forest decline and bark beetle outbreaks". We thank to Dr. Josef Hejzlar from the Hydrobiological Institute of CAS and to the Czech Agency for Nature and Landscape Conservation, namely Dr. Jindřich Rejl, for enabling us to share Landsat 5 TM 1995, 1998 data, respectively.

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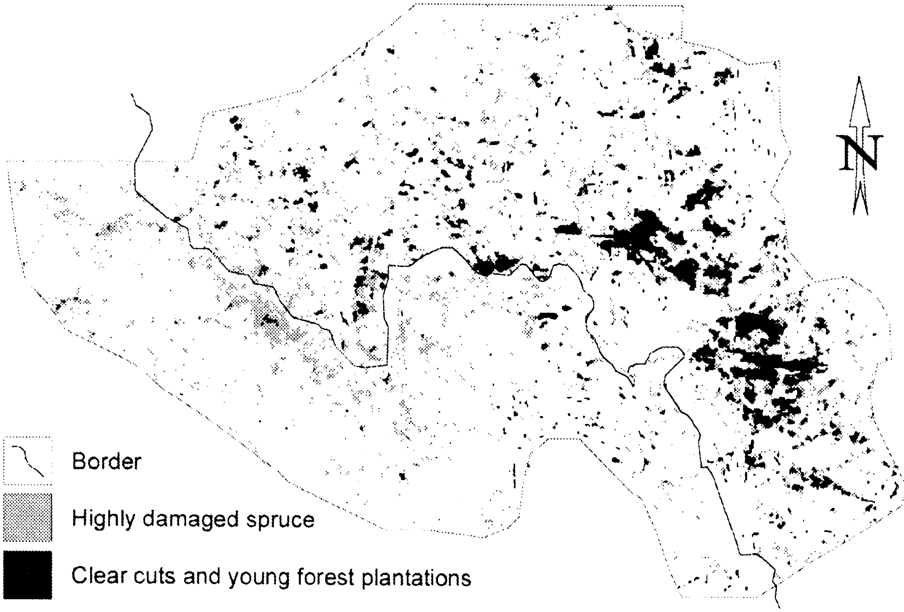

Fig. 10. – Two classes of forest cover in subarea 2 in 1992.

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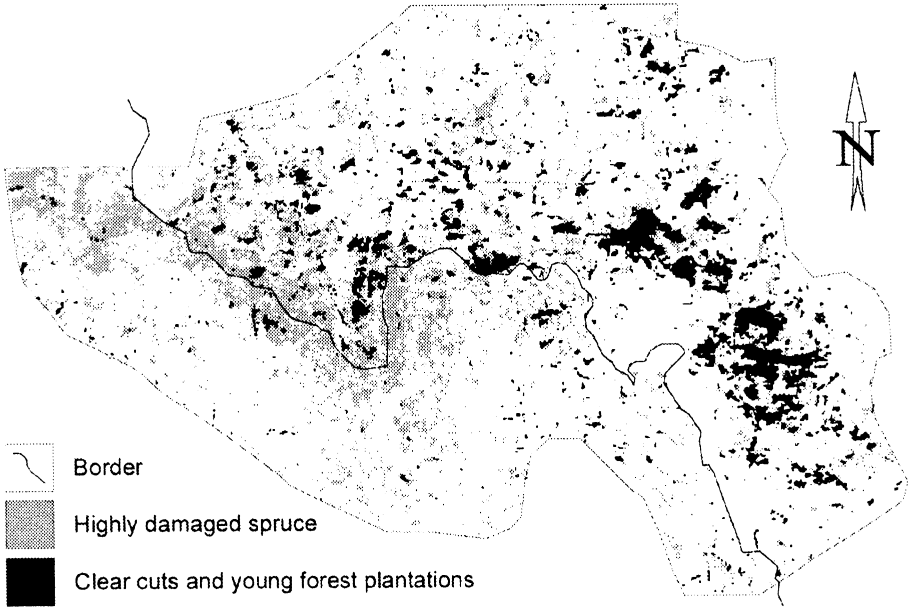

Fig. 11. – Two classes of forest cover in subarea 2 in 1995.

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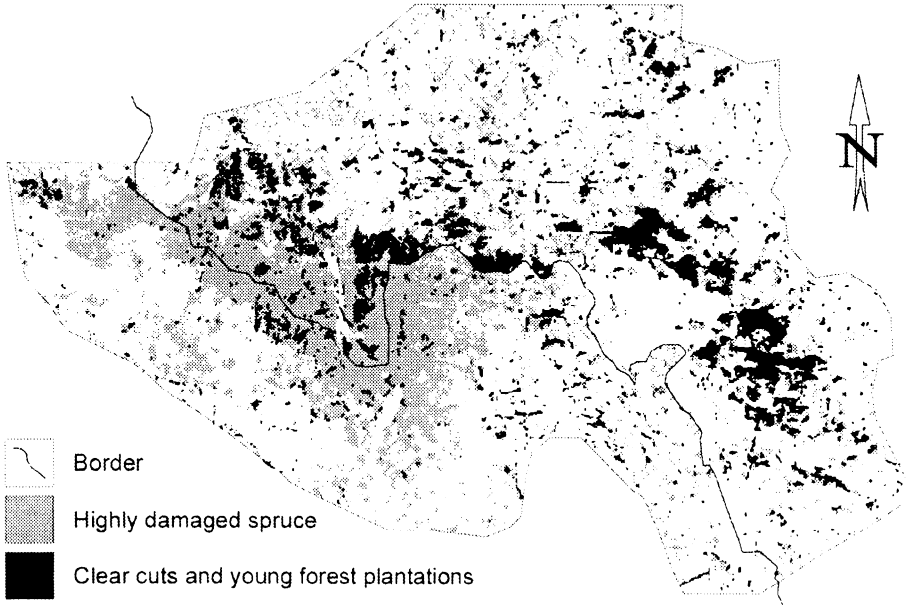

Fig. 12. – Two classes of forest cover in subarea 2 in 1998