LANDSAT and its application to evaluate the dynamics of the health condition of birch stands

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ABSTRACT: Methods were elaborated that would specify factors affecting the accuracy of the output of LANDSAT satellite images used to evaluate the dynamics of changes in the health condition of birch stands. In the period of investigations, in 1994–2000, the foliage of birch stands was very thin as a consequence of the large-scale absence of flushing in 1997. The output of this method is also specification of the degree of foliage of birch trees based on the altitude, stand age and forest site types in the air-polluted area of the Krušné hory Mts. (Northern Bohemia). These methods can be applied to other broadleaved stands.

Keywords: *Betula pendula* Roth; health condition; LANDSAT monitoring; methodology

In addition to conventional ground investigations, the application of aerial and satellite images monitoring the health condition of forests is continuously increasing. The first experiments using satellite images for these purposes in the Czech Republic were launched around 1985. In 1992 they were incorporated into forest practice and at the present time they are applied routinely to produce monitoring maps of the health condition of coniferous forest stands. The advantage of this method is that information on a vast area is obtained at one time, and that the interpretation and perception of the complex resulting image of the health condition of forests is uniform. The method also allows to carry out real annual monitoring on approximately 70–80% of the area of the Czech Republic with a resolution of 30 m in the respective region. However, there are certain conditions and limitations that should be respected when applying this method and in addition to this, its application in broadleaved stands has not been verified sufficiently yet.

Maps of the health condition of forests are produced by computerisation of digital video data of satellite images registered in the visible and infrared spectral area of radiation reflected from the earth's surface. At the present time the most satisfactory images are images from LANDSAT-TM and ETM+ scanners working on LANDSAT 5 and 7 satellites. The standard complete scene of these images captures a territory of approximately 180 × 180 km in 6 spectral channels in the visible and infrared band of radiation with a resolution of 30 m. In addition, the ETM+ scanner scans the panchromatic channel with a resolution of 15 m. The height of the satellite trajectory is 705 km, the time of encircling is 99 minutes and the period of recording is 8 days with two satellites. The satellites fly over the territory of the Czech Republic in the north-south direction at approximately 10.30 h summer time and one complete image is produced within tens of seconds.

The objective of the present paper was to test whether the interpretation of satellite images of birch stands in the Krušné hory Mts. would facilitate to obtain information about the overall health condition and its dynamics in the period of 1994–2000. The Krušné hory Mts. were affected by two extraordinary episodes that had a negative impact on the stability of forest stands in the area. In the winter 1995/1996, as a consequence of a long-lasting effect of icing, spruce stands were damaged both physiologically and mechanically (Lomský et al. 1996; Lomský, Šrámek 1999) and birch stands were damaged mechanically (Kula 1998; Kula, Kawulok 1998; Zach, Kula

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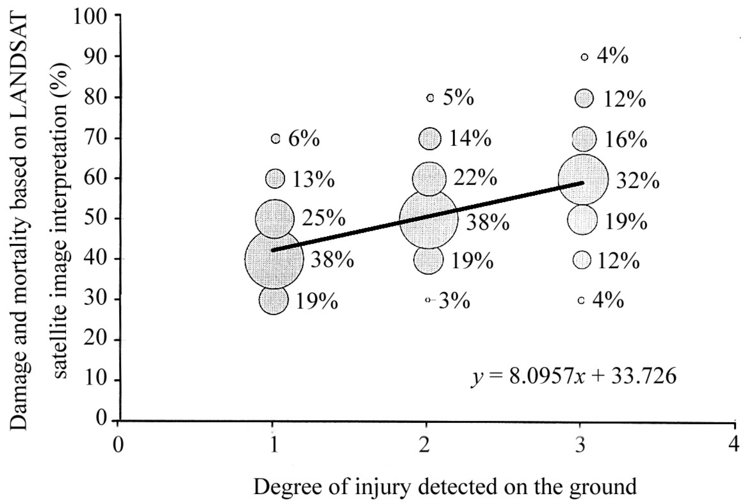

Fig. 1. Comparison of evaluations of damage to substitute birch stands in the Krušné hory Mts. in 1997

1999). In 1997, a hitherto unknown phenomenon appeared on an area of 14,210 ha, the absence of flushing of birch with a reduced area of 4,960 ha (KULA 1999). The extent of the declined birch stands that were affected by the absence of flushing increased in 1997–1999 (9–25–40%) and in 2000, in spite of its lower intensity (4–5%) the prognoses saying that as much as 50% of affected birch stands would decline were virtually fulfilled (i.e. 43.6–45%) (KULA et al. 1998, 1999, 2000; KULA 2000a,b).

METHODS AND MATERIAL

Preparation and interpretation of maps

Interconnection of the digital map of the forest detail with the data base of commercial books produces the basic identification data of the areas: compartment, plot and stand group, and the required map of birch stands with selected attributes from the commercial book serving as a mask when interpreting the satellite images and statistical evaluation of the results of the classification. The investigations included 30 areas of the Klášterec, Červený Hrádek and Litvínov forest districts. The results of ground investigations were used to correct the outputs of LANDSAT images (1997, 1998, 1999) that were added to the database of the map of birch stands through a key: compartment, plot and storey. The database of the commercial book enabled statistical interpretation of the dependence of birch damage on the altitude, groups of forest site types and stand age.

Interpretation of satellite images

We used satellite images from 1994 (14 July), 1995 (1 July), 1996 (1 June), 1997 (11 June), 1998 (10 August) and 2000 (19 June) for the evaluations.

The first stage of interpretation of the images by geometrical transformation and correction to a cartographic S-JTSK representation for the eastern part of the Krušné hory Mts. was followed by radiometric correction and standardisation of the satellite images. The image of the frame was masked to leave only the birch stands that could be at least minimally classified from the satellite image: age of stand ≥ 7 years, species composition in the stand ≥ 50%, stand density ≥ 5 and stand area ≥ 0.5 ha. The entire common dynamics of the health condition was lin-

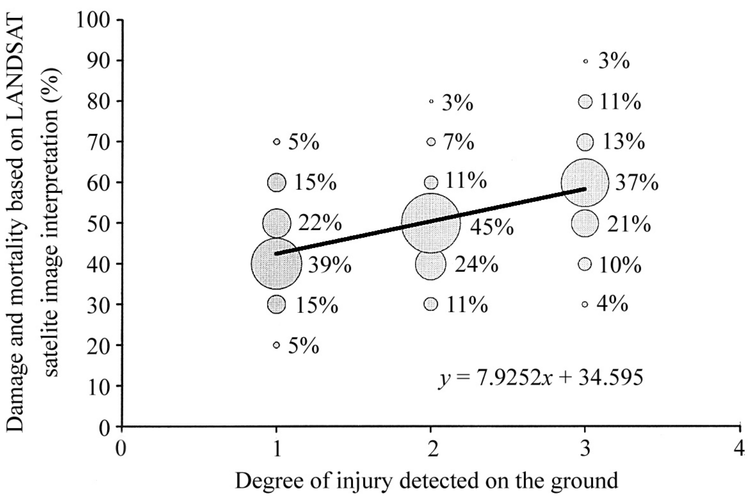

Fig. 2. Comparison of evaluations of damage to substitute birch stands in the Krušné hory Mts. in 1998

early divided into 10 degrees and generated by classifiers that evaluate the damage and mortality of birch stands on a scale by 10% (0–100%).

The ground investigations of birch injury (1997, 1998) were analysed and the evaluations of damage and mortality of birch stands from satellite images were compared. The evaluations of injury of the stand groups based on ground investigations and satellite images showed that the classifications were not separable but the connecting lines of the trend definitely point to a connection (Figs. 1 and 2).

RESULTS AND DISCUSSION

If the classification of the health condition of substitute birch stands interpreted from satellite images is to be correct, the crown canopy must exceed 70%, the representation of birch trees in the stand must be higher than 80% and the stand must be older than 25 years. The stand age can be corrected by setting the classifier. Many times the two other conditions cannot be satisfied in birch stands and that is why the classification is charged with a greater error than in adult spruce stands.

The results of evaluations of the health condition of birch stands from satellite images were compared with "historical" data from ground investigations that were conducted to work out an inventory of stand damage. Such comparisons require surface homogeneity in terms of the species composition of the stand and its canopy closure. Ground investigations used for interpretations of satellite monitoring are based on singled out images of the stand area that satisfy the above conditions; following field examinations the reference planes are situated. However, we did not keep to this procedure because when the ground investigations were conducted, we did not expect that they would be used for satellite monitoring. The species composition of most of the substitute birch stands and the canopy closure were irregular. Comparisons of the classification of the areas of stand groups would cause distortion because from the satellite image all the pixels from the area are included in the output while ground investigations take into account only birches that can occupy only a part of the area of the stand group. This problem cannot be removed by tightening up the parameters of filtration or by selection of areas of stand groups. This means that comparisons of classification from the image and from ground investigations are charged with random errors. All the same we can say that the achieved results of comparisons of ground and satellite interpretations are good and that the classification of satellite images is satisfactory to determine the dynamics of damage development in a time series.

Average damage of birch stands in dependence on altitude

Klášterec forest district (Fig. 3) – before 1994 the birch stands were not seriously damaged but since then the health condition has deteriorated, particularly on the high-lying plateaux 900–1,000 m above sea level, on average by 10% compared to the altitude of 300 to 800 m.This is a common phenomenon based mostly on climatic factors generally valid for the entire investigated territory. In 1995 the health condition improved by approximately 10%, especially at altitudes lower than 700 m; this trend was also observed in spruce stands for several years due to the gradual increase of coniferous trees. All the same, this positive trend was not observed at the higher altitudes to a corresponding extent. After the winter 1995/96, when icing occurred for a long time, the health condition deteriorated due to the breaking of crowns and tops (ZACH, KULA 1999). In 1997 and 1998 the health condition was impaired again and changed from the altitude of 700 m and progressively increased to as much as 85% at the altitude of 1,000 m; this phenomenon is associated with physiological disorders due to the absence of flushing in the birch stands in 1997 (KULA 1999). In 2000 the health condition at the altitude of 800 m became balanced and the health condition improved at the higher altitudes, but this can only reflect the fact that the dead stands were removed.

Janov forest district (Fig. 4) – the health condition of birch was worse at the lower altitudes than on the high plateaux (1994) and in 1995 the overall health condition improved up to the 700 m altitude and a moderate recession was recorded only at the altitude of 1,000 m. In 1997 this situation changed radically as a consequence of the absence of flushing in the birch stands. In 1998 a negative change was observed particularly at the medium altitudes of 500–600 m. Investigations in 2000 showed a positive change in the health condition; only the 800–900 altitudes deviated from the average.

Litvínov forest district (Fig. 5) – the dynamics of the health condition was most progressive because the relatively balanced incidence of damage and the health condition of birch stands continued with only a slight decline at the 700 m altitude and the quality of the stands was slightly impaired only at the highest altitudes. A progressive change took place at the 700–900 m altitude in 1997 and the health condition did not impair at the lower altitudes below 600 m until 1998; this can also be associated with physiological disorders (drought) that caused drying up of trees in the monitored stands and early shedding of leaves. In 2000 about a 10% regeneration was observed. We cannot exclude the elimination of the stands whose health condition was the worst and the fact that they were not incorporated in the new forest management plan.

Average injury of birch stands in dependence on their age

The health condition changed in dependence on the age particularly in the youngest trees (of less than 20 years of age).

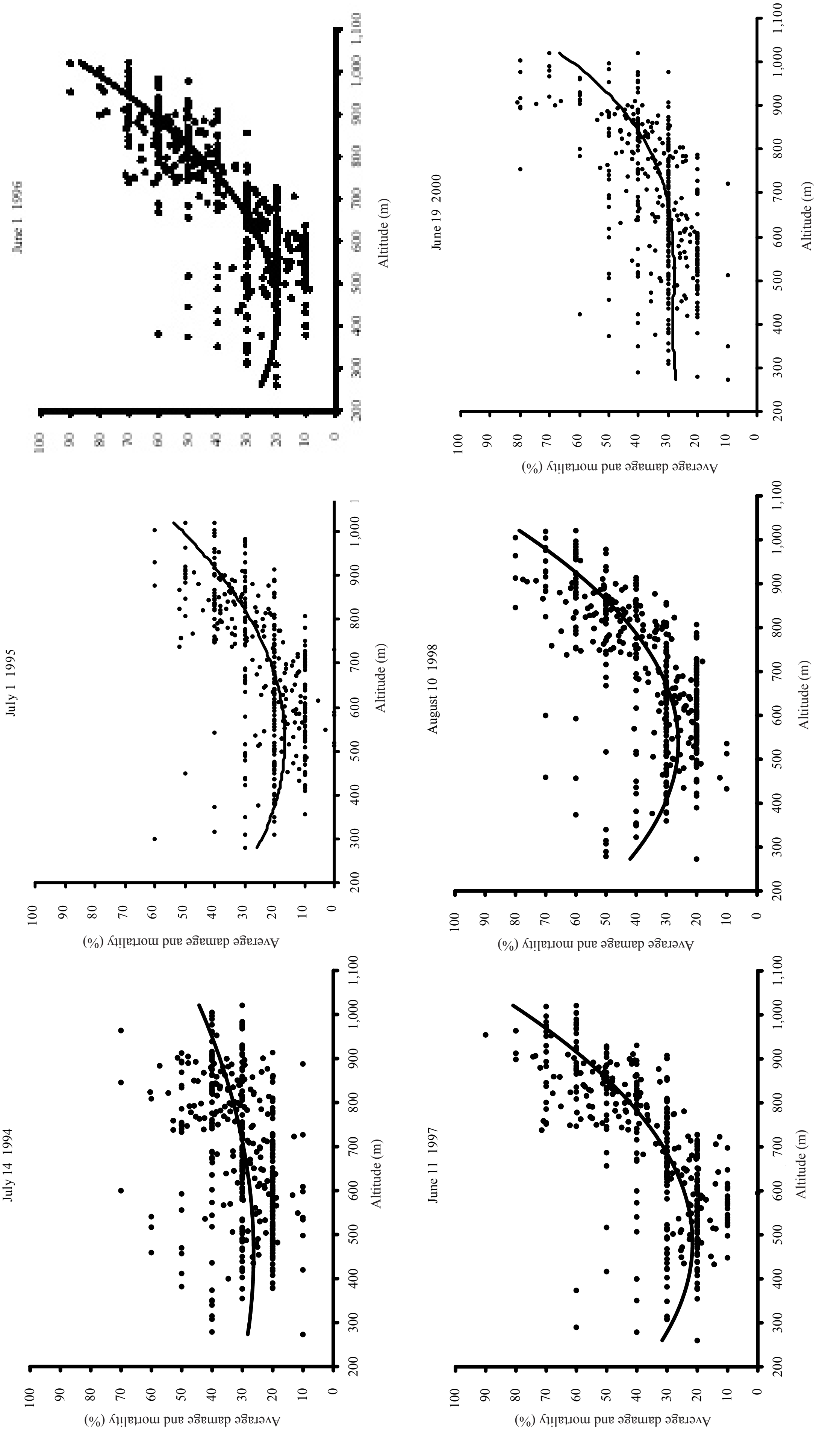

Fig. 3. Average damage and mortality (%) of birch stands in dependence on the altitude (m) of Klášterec nad Ohří forest district. Interpreted from the LANDSAT satellite images

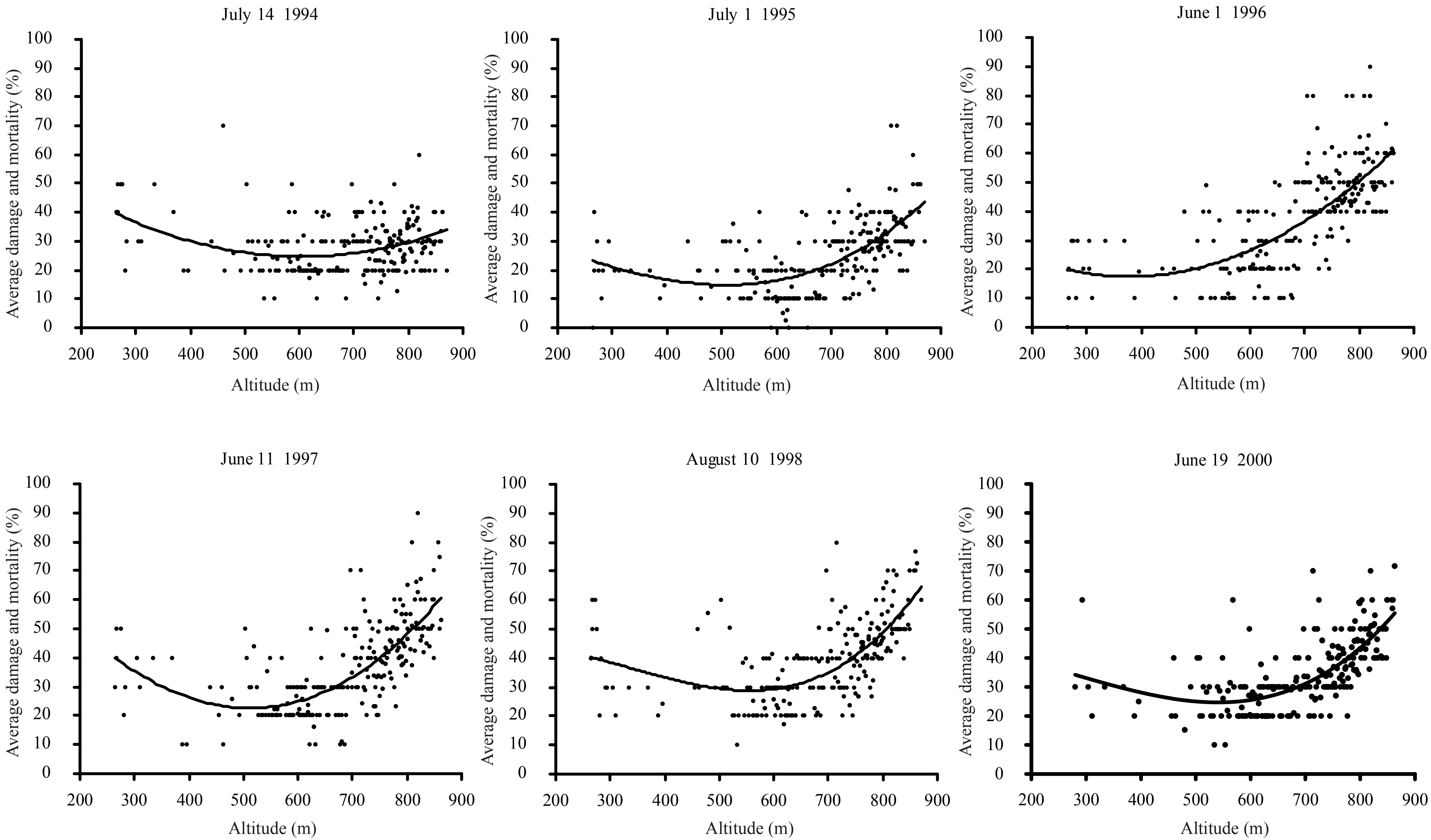

Fig. 4. Average damage and mortality (%) of birch stands in dependence on the altitude (m) of Červený Hrádek forest district. Interpreted from the LANDSAT satellite images

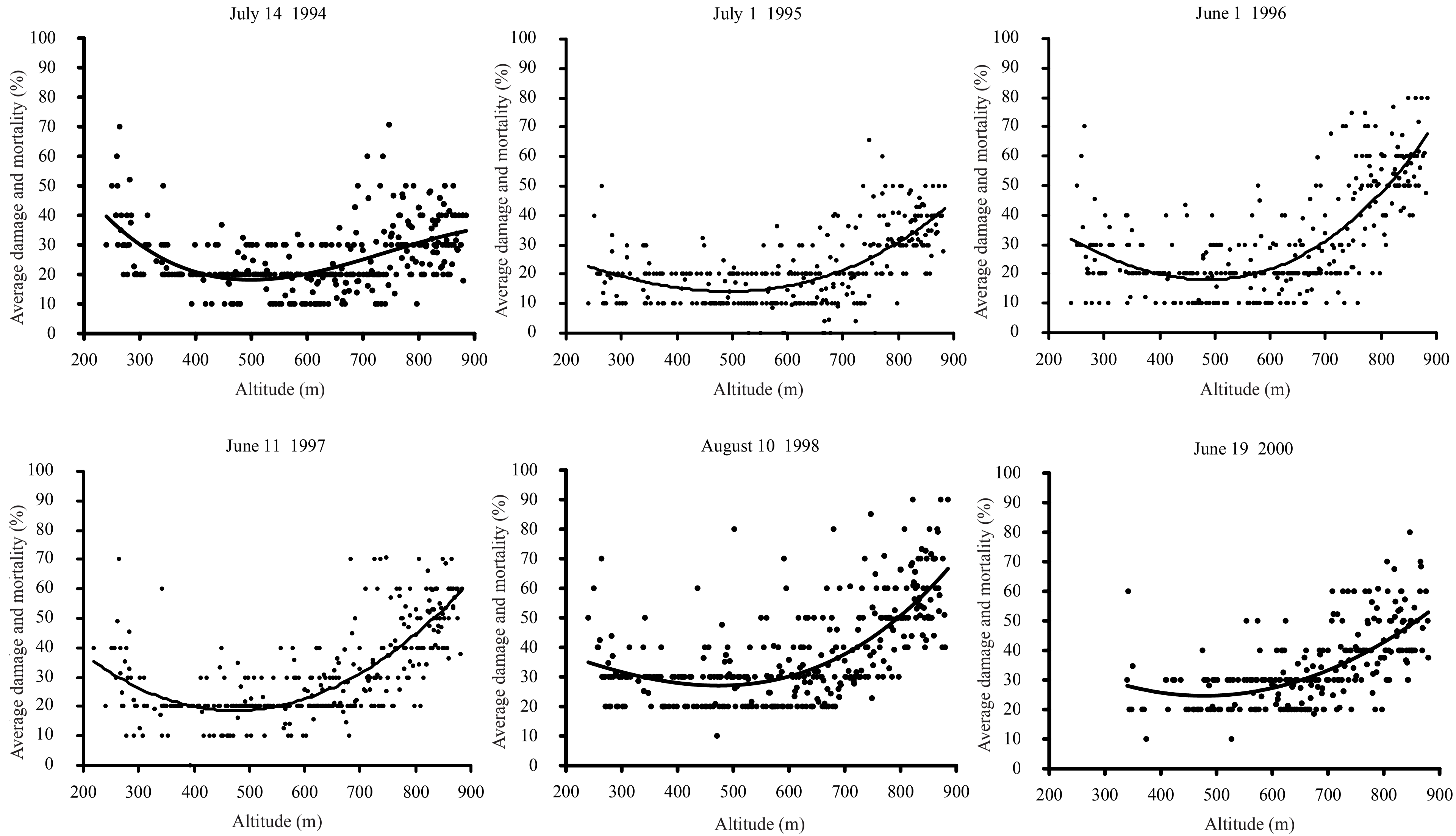

Fig. 5. Average damage and mortality (%) of birch stands in dependence on the altitude (m) of Litvínov forest district. Interpreted from the LANDSAT satellite images

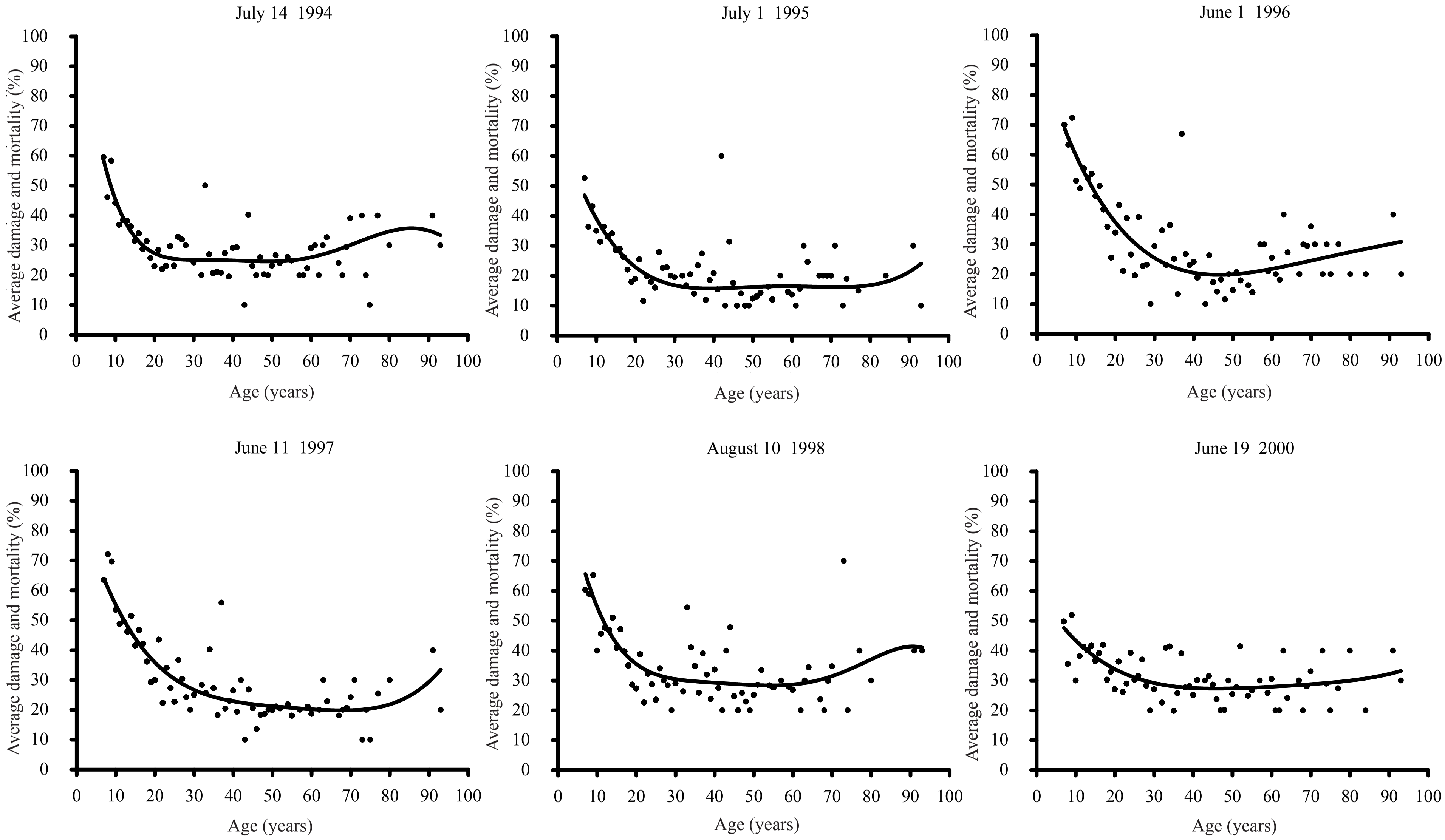

Fig. 6. Average damage and mortality (%) of birch stands in dependence on their age (years) in Klášterec nad Ohří forest district. Interpreted from the LANDSAT satellite images

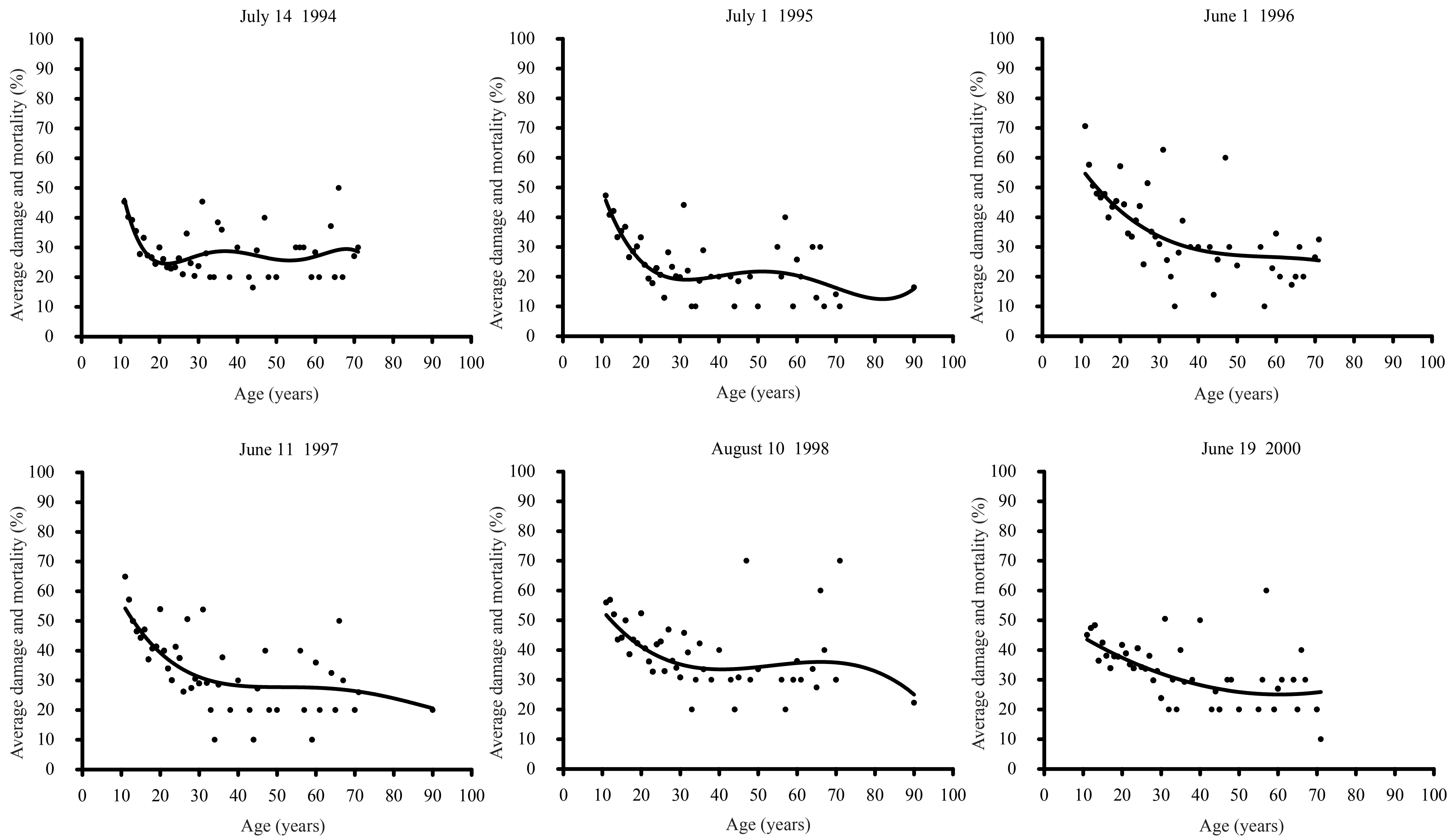

Fig. 7. Average damage and mortality (%) of birch stands in dependence on their age (years) in Červený Hrádek forest district. Interpreted from the LANDSAT satellite images

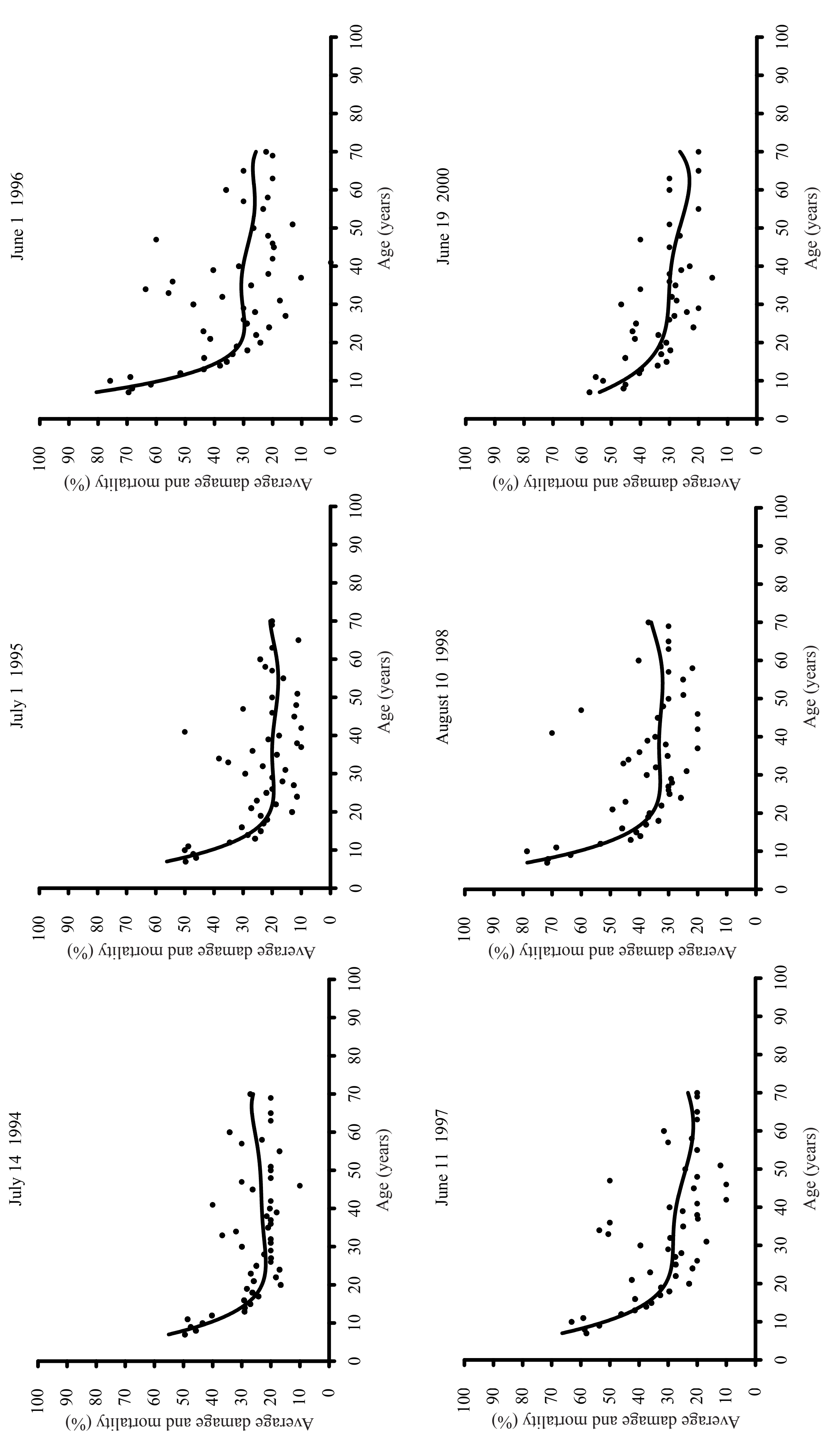

Fig. 8. Average damage and mortality (%) of birch stands in dependence on their age (years) in Litvinov forest district. Interpreted from the LANDSAT satellite images

In Klášterec forest district (Fig. 6) the condition of stands younger than 20 years deteriorated, while no crucial changes appeared in the other stands (1994). In 1995 this positive trend was observed not only in stands older than 20 years but also in the first two age categories. In 1996, icing affected the second age class stands (breaking) (KULA, KAWULOK 1998) much more heavily than the first age classes where, however, long-lasting bending of trees caused by icing could result in frost ruptures and consequently in physiological disorders. The situation was similar in 1997–1998 and it was not until 2000 that it returned to the level of 1994.

In birch stands of Janov forest district (Fig. 7) we discovered partial deviations seen as s-shaped sagging of curves indicating the mildest injury in the oldest stands, well-balanced health condition in the middle-aged stands and the most serious health impairment in the youngest stands. In 1994 a part of the stands of the 1st degree differentiated and this situation continued in 1995, but the older stands regenerated. In 1997 an overall impairment of the health condition of stands up to the age of 50 years was seen. In 1998 the situation of 1997 was confirmed and the improvement of the overall health condition did not begin until 2000.

In the investigated period the birch stands of the 1st age class of Litvínov forest district (Fig. 8) underwent crucial changes; stands older than 20 years were on the same level of injury, i.e. in 1994–1995 it was 20–25%; in 1997 the situation in the oldest stands improved. The impaired health condition of 1998 did not improve until 2000 and only in the older stands. Stands of the 1st and 2nd age classes of 1994–1995 were considerably impaired and this situation lasted until 1998. A partial improvement was observed in 2000.

The groups of forest site types as a complex site factor indicate that there are partial differences between the respective forest districts and the years of investigations; however, in principle they reflect the regularities described in connection with the altitude. Especially at lower altitudes the structure of harmful factors is different from that at the middle and high altitudes (KULA, ZABECKA 2001).

CONCLUSIONS

It is concluded from the evaluations of the health condition of birch stands using satellite images that in 1995 the health condition of stands of all age classes up to an altitude of approximately 700 m slightly improved. The situation of stands lying above 700 m remained approximately the same. In 1997 the damage of all the stands younger than 30 years lying above 700 m was tremendous, below the altitude of 700 m and in older stands the situation remained virtually the same. In 1998 the damage of birch stands above 700 m continued and was heavier, particularly in Litvínov forest district. At the same time, the health condition of stands older than 30 years lying lower than 700 m degraded too, i.e. by ca. 10%. In 2000 the health condition of birch stands of all age classes above the altitude of 700 m slightly improved. This also applies to the dynamics of damage and mortality development based on the groups of forest site types.

The method of evaluation of the health condition of birch stands based on satellite LANDSAT images from the TM and ETM+ scanners can provide results of acceptable accuracy in case that minimal conditions for classification capacity are respected.

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LANDSAT a jeho aplikace v hodnocení dynamiky zdravotního stavu porostů břízy

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ABSTRAKT: K hodnocení dynamiky změn ve zdravotním stavu porostů břízy s využitím snímků družice LANDSAT byla zpracována metodika s vymezením limitujících faktorů ovlivňujících přesnost výstupu. Hodnocené období 1994–2000 se vyznačuje velmi nízkým olistěním porostů břízy po jejich velkoplošném nevyrašení v r. 1997. Výstupem je i vymezení stupně olistění břízy v závislosti na nadmořské výšce, věku porostu a souborech lesních typů v zasažené krušnohorské oblasti (severní Čechy). Metodický postup lze aplikovat i na další listnaté porosty.

Klíčová slova: bříza *Betula pendula* Roth; zdravotní stav; LANDSAT monitoring; metodologie

Cílem příspěvku bylo ověřit možnost vyhodnocením družicových snímků v porostech břízy, získat informace o jejich celkovém zdravotním stavu a jeho dynamice v období 1994–2000 v Krušných horách, které se vyznačuje dvěma mimořádnými epizodami s negativním dopadem na stabilitu lesních porostů této oblasti.

Propojením digitální mapy lesnického detailu a databáze hospodářských knih vzniká soubor základních identifikačních údajů ploch sloužící jako maska při zpracování družicových snímků a statistickém vyhodnocení výsledků klasifikace.

Po zpracování snímků geometrickou transformací a korekcí do kartografického zobrazení S-JTSK pro oblast východního Krušnohoří navazovala radiometrická korekce a standardizace dat družicových snímků. Obraz snímku byl maskován tak, aby na snímcích zůstaly pouze porosty břízy, které splňovaly minimální podmínky klasifikovatelnosti z družicového snímku: stáří porostu ≥ 7 let, zastoupení v porostu ≥ 50 %, zakmenění ≥ 5 a výměra porostu ≥ 0,5 ha. Celá společná dynamika projevu zdravotního stavu byla lineárně rozdělena na 10 stupňů a vygenerována klasifikátory, které hodnotí poškození a mortalitu porostů břízy ve stupnici po deseti procentech (0–100 %).

Z hodnocení poškození porostních skupin terestricky a podle družicového snímku vyplývá, že klasifikace sice nejsou separabilní, ale spojnice trendu ukazují na jednoznačnou souvislost (obr. 1 a 2).

Z hodnocení zdravotního stavu porostů břízy z družicových snímků vyplynulo, že v roce 1995 došlo k mírnému zlepšení zdravotního stavu porostů do nadmořské výšky 700 m, a to pro porosty všech věkových tříd. Nad hladinou 700 m n. m. zůstal stav přibližně stejný. V roce 1997 nastal dramatický nárůst poškození nad hladinou 700 m n. m. a u všech porostů mladších 30 let pod hladinou 700 m n. m. i u starších porostů zůstal stav přibližně stejný. V roce 1998 přetrvává a zhoršuje se poškození porostů břízy nad hladinou 700 m n. m., a to zejména na LS Litvínov. Současně se asi o 10 % zhoršuje zdravotní stav i pod hladinou 700 m n. m. a u porostů starších 30 let. V roce 2000 se mírně zlepšuje zdravotní stav břízy nad hladinou 700 m n. m., a to pro porosty všech věkových tříd (obr. 3 až 5).

V závislosti na věkové struktuře se měnil zdravotní stav především v nejnižších věkových stupních (do 20 let) (obr. 6 až 8). Námraza (1995/1996) výrazněji postihla porosty druhé věkové třídy (zlomy) (Kula, Kawulok 1998) než prvního věkového stupně, kde však dlouhodobé ohnutí námrazou mohlo způsobit mrazové kýly a následně fyziologické poruchy. Nejnižší poškození bylo stanoveno v nejstarších porostech, vyrovnaný zdravotní stav byl v porostech středního věku a nejhorší situace byla v nejmladších porostech.

Soubory lesních typů jako komplexní stanovištní faktor naznačují dílčí rozdíly ve zdravotním stavu porostů břízy mezi jednotlivými lesními správami a sledovanými roky. Obecně však potvrzují zákonitosti popsané v souvislosti s nadmořskou výškou. Zvláště v nižších polohách se odráží odlišná struktura škodlivých činitelů od poloh středních a vysokých (Kula, Zabecka 2001).

Metoda hodnocení zdravotního stavu porostů břízy z družicových snímků LANDSAT ze skenerů TM a ETM+ je schopna poskytovat s přijatelnou přesností výsledky, pokud jsou splněny minimální podmínky klasifikovatelnosti.

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