REMOTE SENSING AND LANDSCAPE METRICS TO IDENTIFY AND TO ASSESS SITE-SPECIFIC DAMAGE IN CULTIVATION SYSTEMS OF CENTRAL EUROPE

With 4 figures and 1 table

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Zusammenfassung: Fernerkundung und Landschaftsstrukturmaße zur Beschreibung und Erfassung von teilschlagspezifischen Pflanzenschäden in landwirtschaftlichen Anbausystemen Mitteleuropas

Die Umsetzung einer teilflächenspezifischen Landwirtschaft erfordert eine genaue Kenntnis über die räumliche Verteilung von teilschlagspezifischen Pflanzenschäden. Fernerkundungsdaten erlangen bei der Informationsgewinnung für den Prozess des "*Precision Farming*" zunehmend an Bedeutung. Es stellt sich die Frage, welchen Einfluss hat die räumliche Auflösung der Fernerkundungsdaten auf die Erkennbarkeit von teilschlagspezifischen Pflanzenschäden und welche räumliche Auflösung ist für die Erkennbarkeit von teilschlagspezifischen Schäden notwendig. Die Bewertung des Einflusses der räumlichen Auflösung auf die Erkennbarkeit von teilschlagspezifischen Pflanzenschäden erfolgt auf der Grundlage von Landschaftsstrukturmaßen. Die Ergebnisse zeigen, dass mit der angewendeten Methode der Einfluss der räumlichen Auflösung auf die Erkennbarkeit von verschiedenen Stressfaktoren in landwirtschaftlichen Flächen beschrieben werden und ein Schwellenwert der räumlichen Auflösung ermittelt werden kann, ab dem teilflächenspezifische Pflanzenschäden nicht mehr korrekt erfasst werden können.

Summary: For the implementation of a site-specific management an exact knowledge of the heterogeneity within the fields is necessary. Remote sensing data offers the possibility to identify the heterogeneity within fields with comparatively small expenditure. However, the question arises which influence scaling has on the recognition of site-specific plant damage and which spatial resolution is necessary for the identification of site-specific damage?

The study introduced a methodology using landscape metrics to estimate the influence of spatial scale on the structure and identification of pathogen infestations and nitrogen stress in crops. The results indicate a useful description of the influence of scale on the identification of stress factors in winter wheat. Also it is possible to denominate a threshold value of the spatial resolution, from which site-specific plant damage cannot any longer correctly be apprehend.

1 *Introduction*

In order to realize the objectives of a sustainable agriculture, the management of agricultural production is changing from a uniform management to a site-specific management (GRENZDÖRFFER 1998; EBEL a. GRAFF 1994). For the implementation of a site-specific management an exact knowledge of the heterogeneity within the fields is necessary. The definition of Precision Farming therefore contains the integration of information technology within the agricultural production. *"Precision agriculture is a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production"* (DIXON a. MCCANN 1997, 17). Remote sensing offers the possibility to identify the heterogeneity within fields with comparatively small expenditure. KÜHBAUCH defines the contribution of remote sensing within Precision Farming as a tactical field supervisor (KÜHBAUCH 2002, 83), as the interpretation of remote sensing data allows the localization of patches with abnormal features. For the acquisition of site-specific plant damage a variety of operational remote sensing sensors with different spatial and temporal resolutions is available today.

The hypothesis is that, due to the decrease of the spatial resolution of remote sensing image, the information content of the images will be reduced. In the context of a stronger application of remote sensing data in Precision Farming, the question arises whether the resolution of the image has any influence on the recognition of site-specific plant damage. Also, which spatial resolution is necessary for identifying site-specific damage? The objective of this study is the formulation of a threshold value of spatial resolution, from which site-specific plant damage cannot any longer be assessed correctly. In this study a new technique is proposed to quantify spatial pattern changes of an agricultural test site in dependence on a changing resolution. The assessment of the influence of spatial resolution is based on a QuickBird-2 satellite image. To identify the minimum resolution that is necessary to estimate site-specific plant damage, QuickBird images were re-sampled to produce a data set with different spatial resolutions ranging from one to thirty metres. After the implementation of a maximum likelihood classification for these data sets, different landscape metrics were calculated. The results indicate a useful description of the influence of scale on the identification of site-specific plant damages. Also, it is possible to identify a threshold value of spatial resolution, beyond which site-specific plant damage cannot be identified correctly.

2 The test-site

To estimate the influence of resolution on the recognition of site-specific plant damage, a sufficient database is needed. In particular a test surface is needed, on which one can determine all plant damages. This gives the opportunity to compare the real damage situation on the test site with the reflection images obtained by the satellite images. For this study, the chosen test site was an agricultural field on which winter wheat was cultivated. The test site was created in the vegetation period 2001/2002 on the experimental homestead "Dikopshof" of the University of Bonn. The test site contains a surface of 5.22 ha, which was divided into twelve allotments with a size of 44.85 x 45 m. For the determination of healthy and damaged patches a two-factorial attempt was created. The first factor refers to the nitrogen maintenance: six plots were provided with normal nitrogen abundance, while the nitrogen application was reduced in the other six allotments. The second factor contains a different treatment with fungicides. Six allotments received a regular fungicide treatment, while the application of fungicides was reduced in the other six allotments. All in all four different treatments resulted: (Fig. 1)

1. Nitrogen treatment regular (Nb) / fungicide treatment regular (Fb)
2. Nitrogen treatment regular (Nb) / fungicide treatment reduced (Fr)
3. Nitrogen treatment reduced (Nr) / fungicide treatment regular (Fb)
4. Nitrogen treatment reduced (Nr) / fungicide treatment reduced (Fr)

In total, there are nine allotments in which plant damages arise, consisting of either a lack of nitrogen, an infestation with fungal decay, or the combination of nitrogen lack and fungal decay. During the vegetation period, field inquiries took place in the test site every 7th day. The attention was focused on the detection of plant damage, in order to receive an adequate knowledge base for the analysis of the QuickBird-2 data.

3 Methods

In order to evaluate the influence of spatial resolution on the identification of site-specific plant damage, three methodical steps are necessary:

1. Modification of the spatial resolution to produce a suitable data set with different spatial resolution.
2. Classification of the data to identify the plant damage in the different data sets.
3. Computation of landscape metrics for evaluating the influence of spatial resolution on the identification of site-specific plant damage.

3.1 The modification of the spatial resolution

As the QuickBird-2 satellite records both a multi-spectral image with a spatial resolution of 2.8 m and a panchromatic image with a spatial resolution of 0.7 m, it is possible to generate a multi-spectral image with a resolution of 0.7 m. For this purpose the two images were combined. The advantage of this methodology is that the spectral information of the multi-spectral bands remains unchanged, while the spatial information increases. The result of the fusion is an image that shows the structure of the test site in detail. Thereby the choice of the training pixels within the classification process is substantially simplified and as result the classification accuracy will be enhanced. For the creation of data sets with smaller spatial resolution than the original, the multi-spectral QuickBird image was re-sampled. For the re-sampling, the Cubic Convolution method was tested. This re-sampling method is an interpolation of third order, i.e. the pixel values of the interpolated picture are averaged over the 16 surrounding neighbouring pixels of a 4 x 4 window. The advantage of this method is the change of the pixel values, so that the mixed pixel creation can be simulated.

3.2 The digital identification of site-specific plant damages

To identify the degree of plant damage, all data-sets (the original and the synthetic data sets) were classified with a supervised algorithm, the maximum likelihood algorithm. The following six land cover classes were derived:
1. Wheat (healthy) with sufficient nitrogen supply (Fb – Nb)
2. Wheat (diseased) with sufficient nitrogen supply (Fr – Nb)
3. Wheat (healthy) with nitrogen absence (Fb – Nr)
4. Wheat (diseased) with nitrogen absence (Fr – Nr)
5. Soil (B)
6. Power pole (M).

In figure 2, the classification results are presented for the data sets with a spatial resolution of 0.7 m, 2.8 m, 4 m, 15 m, 20 m and 30 m.

The quality of the classification results was estimated through random coincidence points. For all classification results 100 points were set, and their real land cover was compared with the ground truth information of the test site. The classification of the data with a spatial resolution of 0.7 m shows a total accuracy of 93%. With the decrease of spatial resolution to 30 m, the accuracy of the classification is reduced to 55%.

3.3 Evaluating the influence of scale

To quantify the influence of spatial resolution on the assessment of site-specific plant damage, landscape metrics were calculated on the basis of the classified images. The landscape metrics offer the possibility to compare the changes of landscape structure with the change of the spatial resolution. They are defined as quantitative indices to describe structures and patterns of a landscape (O'Neill et al. 1988). The development of the landscape metrics is based on information theory (Shannon a. Weaver 1964) and the theory of fractal geometry (Goodchild a. Mark 1987; Xia a. Clarke 1997). Altogether, landscape metrics can be computed for three levels: "patch", "class" and "landscape". The evaluation of the influence of spatial resolution refers to the changing landscape metric values reflecting the change of spatial resolution.

In this study the calculation of the landscape metrics was accomplished with the public domain FRAGSTATS program (Version 2.0) (McGarigal a. Marks 1994). For all classification results, seven landscape metrics at the class and landscape level were calculated. The criteria for selecting the landscape metrics was based on the information content of the metrics with regard to the spatial structure and their sensitivity in relation to resolution-dependent changes. Table 1 gives an overview of the calculated landscape metrics.

The first metric *PLAND* equals the different surface portions of the patches of different land cover classes. The specification of this index is counted in percent. The index *Number of patches (NP)* represents the extent of subdivision of the patch type and informs about the patch number of a specific land cover class or at the entire landscape.

Also, the number of the existing edges influences the structure of the landscape. The metric *Total edge (TE)* computes the total edge length both for all patches of each land cover class and for all patches of the entire

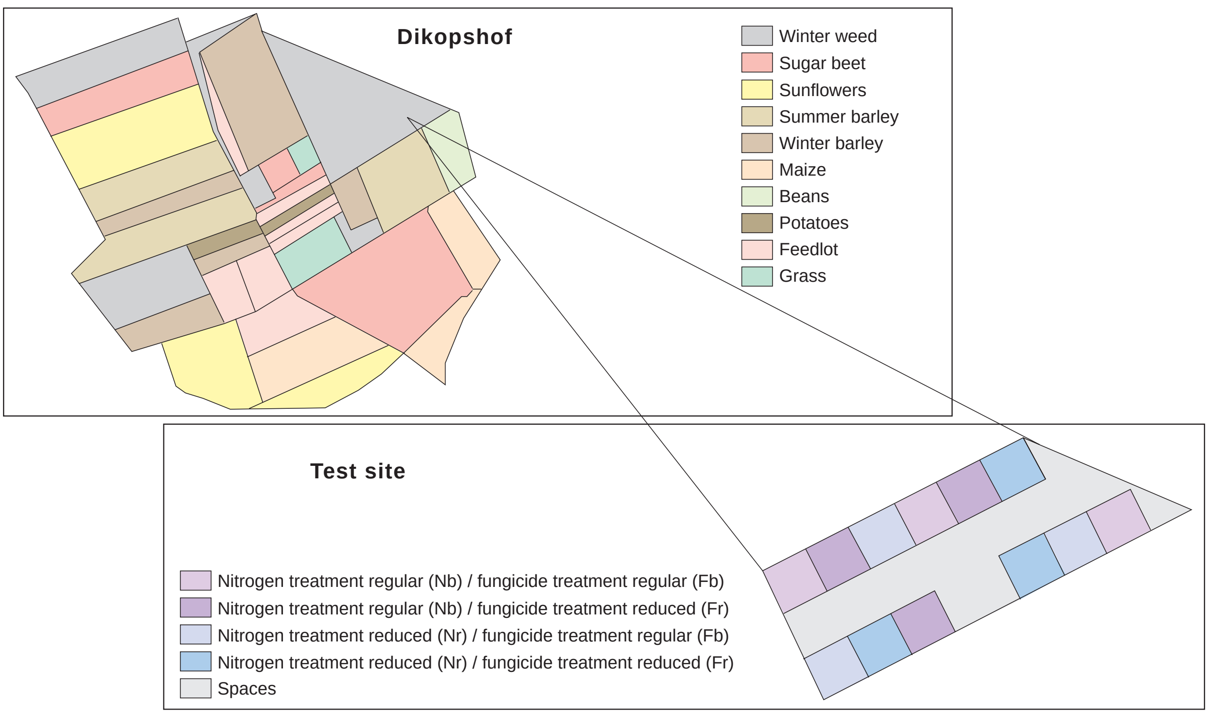

Fig. 1: The Dikopshof test-site (vegetation period 2001/2002)
Die Versuchsfläche – Dikopshof
http://uf.ilb.uni-bonn.de/versuchsgueter/diko/Default.htm

Table 1: Overview of the calculated landscape metrics (LSM) to analyze raster image files (using FRAGSTATS)
Überblick über die verwendeten Landschaftsstrukturmaße (LSM) zur Analyse von Rasterbildern (Verwendet nach FRAGSTATS)

Name	*Range of values*	*Level*
Percentage of Landscape (PLAND)	0 < PLAND ≤ 100	Class
Number of Patches (NP)	NP ≥ 1	Class & landscape
Total Edge (TE)	TE ≥ 0	Class & landscape
Area-Weighted Mean-Shape-Index (AWMSI)	1<=AWMSI<=2	Class & landscape
Patch Richness (PR)	PR ≥ 1	Landscape
Mean Nearest-Neighbour Distance (MNN)	MNN > 0	Class & landscape
Contagion (CONTAG)	0 < CONTAG ≤ 100	Landscape

landscape. The indication of the edge length is counted in metres.

The *Area Weighted Mean Shape Index (AWMSI)* describes the shape complexity of the patches. The shape complexity of smaller pixels is affected by pixel size rather than by the real characteristics. Therefore, this index considers larger patches more than smaller patches.

Patch richness (PR) is a simple measure of landscape composition and diversity. The basis of the calculation is the number of land cover classes in the entire landscape.

On the basis of the distance metric *Mean Nearest Neighbour Distance (MNN)*, specifications about the configuration of landscape features can also be derived. This index calculates the middle distance of neighbouring patches belonging to the same land cover class.

The *Contagion index (CONTAG)* measures the degree of clumping of all landscape patches and is based on two probabilities: (1) The probability that a randomly chosen cell belongs to patch type i and (2) the probability that – given a specific cell is of patch type i – one of its neighbouring cells belongs to patch type j. The product

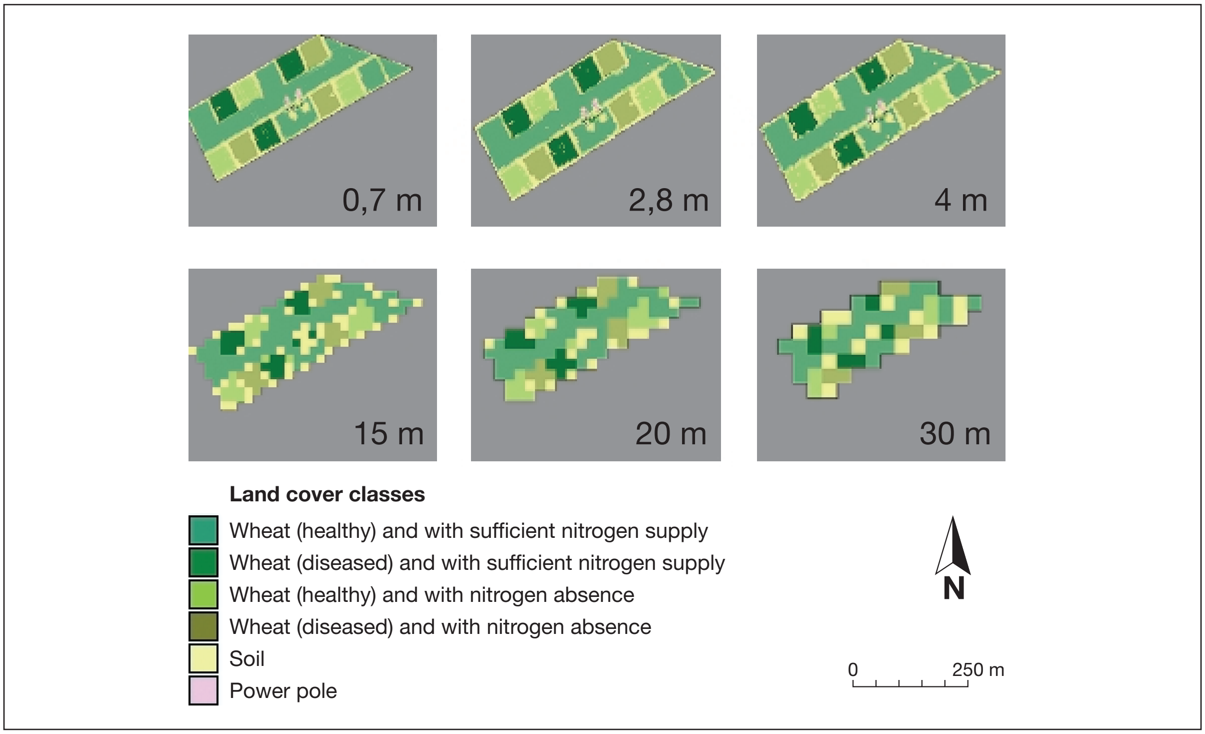

Fig. 2: Results of the maximum likelihood classification using data-sets with different spatial resolution
Ergebnisse der Maximum-Likelihood-Klassifikation auf der Grundlage unterschiedlich aufgelöster Daten

of these probabilities equals the probability that two randomly chosen adjacent cells belong to patch type i and j (McGarigal a. Marks 1994). The *Contagion index* measures both patch type spreading as well as patch type dispersion. The values are indicated in percentages, approaching zero when the patch types are maximally disaggregated and interspersed, and approaching one hundred when all patch types are maximally aggregated, i.e., when the landscape consists of a single patch type only.

4 *Results and Discussion*

Since landscape metrics offer the possibility to describe the spatial pattern of a landscape, the changes of these metrics in relation to changing pixel size were analysed. The analysis results of the landscape level are displayed in figure 3 for the spatial resolutions 0.7 m, 2.8 m, 4 m, 15 m, 20 m and 30 m. The *PR* values show no changes between the resolutions of 0.7 m and 4 m, as all six land-cover classes are identified up to a spatial resolution of 4 m. A further decrease of the spatial resolution leads to the fact that the land-cover class "power pole" can no longer be distinguished, decreasing the *PR* value from six to five. Similar to the *PR* value, the other five calculated metrics decrease with the spatial resolution reduction as well. Between a resolution of 0.7 m and 2.8 m the *NP* values decrease from 750 to 15. That means that the number of identified patches of the test site is reduced from 750 patches to 15 patches. These results indicate a loss of information about structural characteristics of the test site, as the aggregation of the pixels led to an incorrect representation of the pixels with plant damage.

The *AWMSI* values also decrease with resolution changes from 0.7 m to 15 m. This decrease of information about the shape complexity occurs especially between a spatial resolution of 2.8 m and 15 m. In this range, the shape complexity of the individual patches is more and more characterized by the pixel size than by the real characteristics. The decrease of the Indices *CONTAG* and *MNN* is smaller than the decrease of *AWMSI*. This indicates that the spatial distribution of several land cover classes is seized over a larger range of different spatial resolution then the shape complexity. The change of the values permits a conclusion about the change of the information content of the images

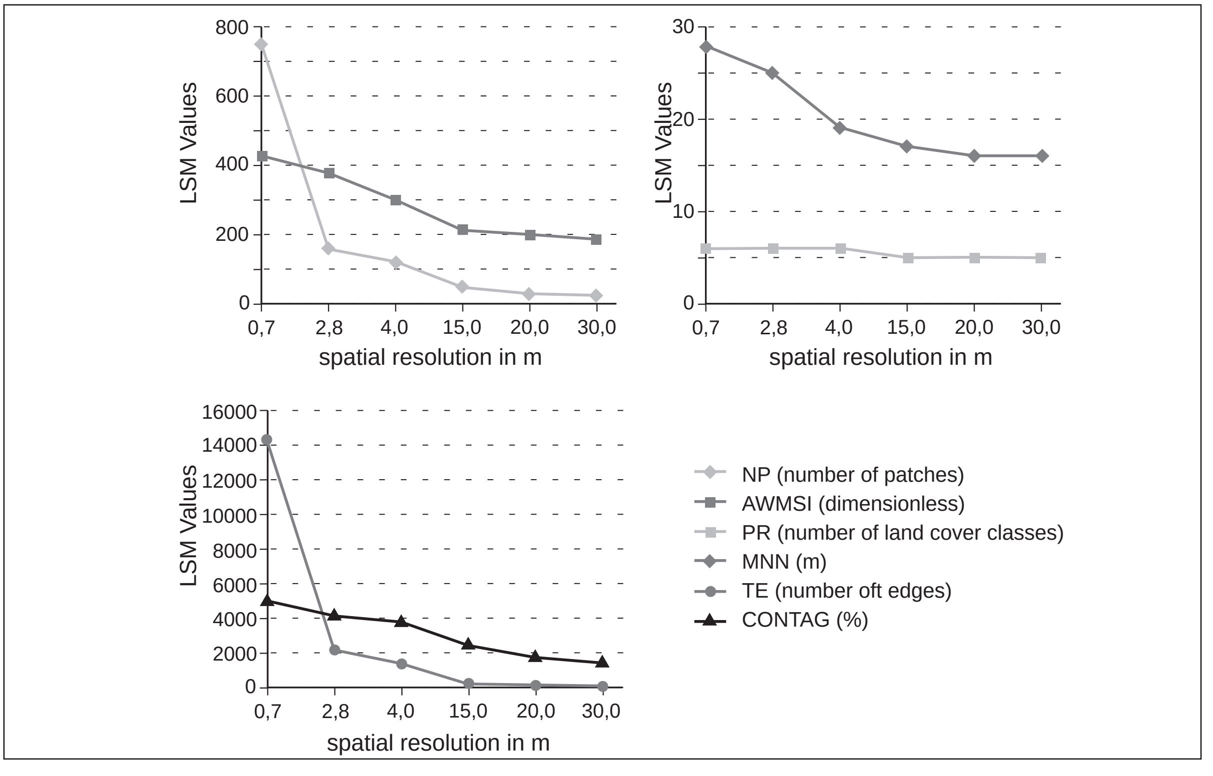

Fig. 3: Variation of the landscape metrics (LSM) by changing spatial resolution (landscape level)
Veränderung der Landschaftsstrukturmaße (LSM) mit der räumlichen Auflösung (Landschaftsebene)

in comparison to the spatial structure of the test site. A significant loss of information about the structure of the test site is identified, indicated by the decrease of values for the spatial resolution classes of 0.7 m to 15 m.

The analysis of the landscape metrics of the class level between one and fifteen meters allows a specification of this statement (Fig. 4). The *PLAND* values show that the surface portions of the analysed land cover classes are relatively constant up to a spatial resolution of 5 m. At a spatial resolution of 6 m, all three analysed land cover classes exhibit variations of the surface portions. This indicates that the surface portions of the three land-cover-classes are not identified correctly with resolutions beyond 5 m. The analysis of the metrics *NP* and *TE* show a reduction of values between a spatial resolution of 1 m and 5 m. Due to the aggregation of the pixels, it is not possible to differentiate all patches, and particularly small patches are no longer recognized. This explains the decrease of the *TE* values as well, because the edge length correlates with the number of patches.

The separation of different land cover classes on the basis of their shape complexity is possible up to a spatial resolution of 5 m. A further decrease of the spatial resolution leads in similar *AWMSI* values for all three land-cover-classes.

Both the correctness and detailedness of the information content on the structure of the agricultural test site decline with decreasing spatial resolution. The results indicate that in general terms, the structure of the test site can no longer be identified correctly at resolution levels of 5–6 m and beyond (Fig. 4).

5 Conclusion

The study shows that the identification of site-specific plant damage with remote sensing techniques requires extremely high spatial resolutions. The analysis of the landscape metrics suggests a threshold value of 6 m spatial resolution. Thus, the requirement of a spatial resolution of 10 m – claimed by WILTSHIRE et al. (2002) – is assessed as not sufficient for the identification of site-specific plant damage.

At present, these extremely high spatial resolutions are provided only by very few satellite systems (e.g. Ikonos or QuickBird-2). The disadvantages of these systems are the very small Instantaneous Field of View (IFOV) and the relatively high acquisition costs. The satellite RapidEye, planned for 2006/2007, does not exhibit these disadvantages, because the IFOV contains an extent of 80 km x 1,500 km by a temporal resolution

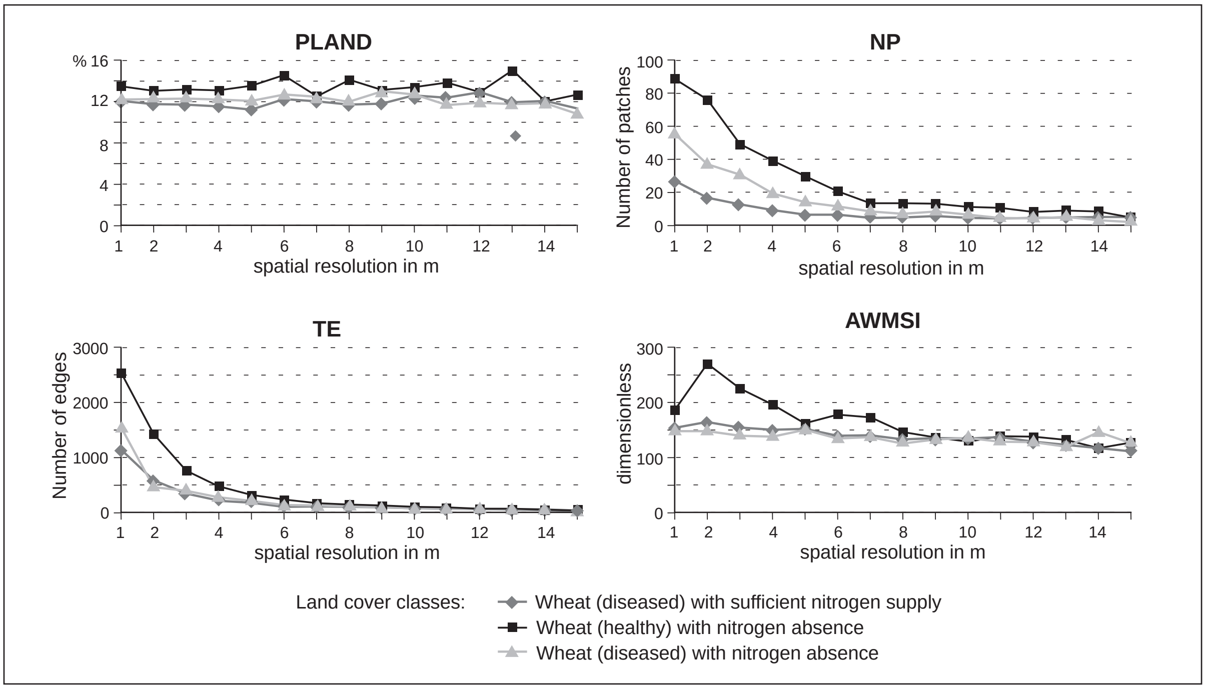

Fig. 4: Variation of the landscape metrics (LSM) by changing spatial resolution (class level)
Veränderung der Landschaftsstrukturmaße (LSM) mit Veränderung der räumlichen Auflösung (Klassenebene)

of one day. In addition, the data will be offered at low cost. For the identification of site-specific plant damage, this satellite will therefore play an important role.

The introduced method represents a simple practice for identifying the required spatial resolution, and can be transferred to other remote sensing applications. Due to global change, remote sensing data is increasingly used for the registration of land cover changes, such as changes of vegetation or changes in urban areas. Particularly urban areas are characterised by very heterogeneous structures. It is therefore of the utmost importance to answer the question which spatial resolution is necessary correctly to identify this heterogeneity.

A lot of studies point out the scale dependence of spatial structures and spatial heterogeneity (e.g. Turner et al. 1989; O'Neill et al. 1996; Moody a. Woodcock 1995; Qi a. Wu 1996; Wu et al. 2000), but a general understanding of the scale influence is still lacking (Wu a. Hobbs 2002; Wu et al. 2002). This study analysed the changes of different landscape metrics in relation to changing pixel size, allowing a better appreciation and understanding better the influence of scale. Therefore, the study contributes to the general understanding of the resolution influence of spatial patterns.

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