Hybrid characterisation – or how to use a local spatial model for extracting meaningful information from satellite data.

Anders Wästfelt[1] and Wolter Arnberg[2]

[1] Department of Human geography,
[2] Department of Physical Geography and Quaternary Geology,
Stockholm University
106 91 Stockholm

anders.wastfelt@humangeo.su.se, arnberg@natgeo.su.se

Abstract. The aim of the paper is to present an evaluation of hybrid characterisation – a method, which has been developed, for making possible local landscape analysis of remotely sensed data. The hybrid characterisation makes it possible to monitor, characterise and assess meaningful environmental dimensions at local scale. The method is designed to pick up landscape properties of importance for the analysis of land use effects on vegetation. Using the hybrid characterisation it is possible to compare different localities with regard to general descriptions and objectives yet being sensitive to the unique character of each locality.

1 Introduction

The purpose of this paper is to evaluate the method developed by us called "hybrid characterisation", which generally mean combining human knowledge with satellite data. A thematic goal is to investigate how landscape characteristics are linked to current land use. This has been approached through the use of "hybrid characterisation" in a case study in the lake Siljan area in northern Sweden. In hybrid characterisation, knowledge about the spatial arrangements (in the form of a spatial model) of landuse in villages is synthesised into the spatial processing of satellite data. The resulting image makes it possible to map and interpret unique properties in and between villages.

Landscape and village: concept and knowledge

We will first introduce both the used landscape concept and the village concept before going on to present the method. The method is then presented and used in the study area and finally evaluated.
The question of how landscape should be perceived has no easy answer, perhaps primarily because this depends on the perspective from which we investigate the world. For example, we may think of the landscape as something external and independent to us as human beings or as something that is primarily conceptualised and constructed by us [6]. The latter is seldom formalised in a GIS-study. From a social or political point of view, landscapes are so complex that it is not possible to handle all possible aspects or perspectives.

When conducting landscape analysis in social science there is always some kind of knowledge and former experience involved in the analytical process. There is always a relation between the physical landscape and the interpreters' experience (*cf.* [2]). This entails that an analysis is always based on both the human conceptualisations and the physical and ecological configuration, even if we are not conscious of these.
To interpret and understand land use and landscape characteristics it is also necessary to understand the basic model for how land use is organised today and how it was organised historically because the situation today always bear the mark of former times. These and other aspects of landscape are often accepted as common knowledge and are rarely defined or modelled either conceptually or spatially. Conceptualising this kind of "unformulated" knowledge in a spatial manner can, however, make it possible to conduct systematic interpretations of characters and values created by land use. Socially dependent information can then be extracted from satellite data.

The proposed analysis is build up by three elements. Firstly, a semantic conceptualisation of landscape, secondly a local spatial contextual analysis and thirdly in terms of interpretable relations between multiple local landscapes. We argue that this approach correspond to the essential feature of the landscape analysis, which include both a local perspective and always a greater whole [19].

To make it possible to implement this model of analysis in the context of GIS and Image analysis, the spatial model of the 'village' is used in the processing of the satellite image and representing semantically both a social concept and a social space. The village as a social space and as a constructed abstract geographical concept is not localisable to any one single point (pixel). Instead, it consists of a specific spatial configuration of a number of land use categories building up a unique characteristic local landscape. The village is thus understood as a product of human action on the ground as well as a result of landscape conceptualisation. A systematic interpretation of landscape can then be drawn from relations between different villages on a higher semantic level.

The village as a spatial concept

To make it possible to use satellite imagery for the interpretations of village and landscape characteristics, the configuration of villages needs to be transformed into a spatial analysis model (Figure 1&2). This can be based on knowledge pertaining to how the villages were historically organized. The presented spatial model for land-use includes the following basic categories: cultivated land, meadowland, and woodland. Today, former meadows have often transformed into various types of transition land, most of it consisting of shrub. Accordingly, transition-land is one of the categories used in the presented case study.

2 Hybrid characterisation

Landscape characteristics are here understood as a synthesis of the social and physical attributes of both a local and an entire landscape. To systematically interpret dimensions related to land use a local landscape model based on villages will be used. The characteristics are, seen as a combination of the appearance and size (scale) of spatial entities and the spatial relations existing between entities such as landuse categories inside the village. Satellite imagery includes too much information and yet not enough. An image includes a great deal of data which is not normally used and which can be associated with abstract features such as the manner in which villages appear in the image. This type of information cannot be found in a single pixel. Rather, and as Lillesand & Kiefer argue: ”…it may often be necessary to infer rather than directly observe, the characteristics of features based on their appearance on images” ([14], p.194). This means that not all-essential information can be directly recognised in the images but that it is possible to interpret what is behind a single pixel. Consequently, the reading process adds knowledge to the interpretation thus making it possible to understand what is seen. The central idea behind hybrid characterisation is to use a few landuse categories related to the village concept and then “distance” the interpretation from the pixels by creating a new image based on contextual information from large local surroundings. Information, which exists in the spatial configuration of the initial categories, is then used in combination with knowledge about the village to create a hybrid characteristic image, which in turn show the concept “village” in a new image, the village characters, and the whole landscape characteristics built up of villages. (In this study the following data have been used: A mosaic image of the following scenes: Landsat TM scene 194/18, 2000 07 28, Landsat TM scene 195/17, 2001 08 15 and Landsat TM scene 195/17.5 2001 07 05. Data on agricultural production to be used in the evaluation of results were provided by the Local administrative board Dalarna.)

Spatial context

Spatial context can be defined as the spatial relation between two pixels or classes. In contrast to texture, which is connected to a defined area and a contiguous group, the spatial context has no spatial delimitation. As Gurney & Townshed have argued: "Thus, contextual classification of any pixel can potentially involve, at least, the use of any other pixel (or group of pixels) from throughout the whole scene" ([8], p. 56). This condition in image data stems from the fact that: "first of all, remotely sensed data provide an alternative representation of geographical context to that given by maps … the context needs to be modelled as an endogenous variable", i.e. an endogenous variable inside the image ([15], p.1–5). The spatial context can be separated into two different kinds of context, internal class context and external class context.
The internal class context resembles a photo-interpretational reading of an image where parts and wholes (objects and areas) are recognised simultaneously (*cf.* [14]). This also shares common ground with the understanding of Kabanza *et al.* ([13], p. 329): "Yet, photo-interpretation is inherently based on many different types of knowledge, which are generally represented differently". The same can be said about landscape interpretation where no single type of knowledge is involved, but instead there are many different representations used and synthesised simultaneously. In the internal class context two different sized windows are used. This means that two different representations (spatial distribution at different scales) of each class are analysed in relation to each other, which describe the relative spatial size and distribution of the studied classes in the studied landscape. Accordingly, the relative spatial configuration extracted by using the different sized windows is the parameter used in describing the internal class context.

In hybrid characterisation the sizes of the windows are collected from interpretations of villages. Hence, scaling is not necessary (*cf.* [9], [10], [4]). Formally the basic principle of the internal class context analysis is to obtain a spatial contextual value from each pixel's surrounding by using two differently sized and simultaneously moving windows with radii r and R (Figure 3). This can be seen as a way of combining: "the microbe's and the mammoth's view of landscape" (*cf.* [12], p. 191), i.e. looking simultaneously with a small and a big field of view (fov) in the neighbourhood of each pixel. The value 1 means that there is complete similarity between the small and the large windows. The calculation is done for each location (pixel) in the image using a moving window technique, and for every separate landuse category corresponding to the village model. The formal description of the internal class context (ICCc) is as follows:

$$ICCc = (\text{number\_in\_fovr}/\pi r^2)/(\text{number\_in\_fovR}/\pi R^2)$$

Contextual relations can also be class dependent, we call these relationships external class context. It means that a unique contextual relation exists between two pixels belonging to different classes. The relation between different classes can be seen as a pair of relations. If three categories are studied, there are nine possible relations. The relationship with the class itself can be seen as the internal class context. The relation

between one pair has two outcomes, which means that there are two possible ways of looking at the relationship.
The external class context captures the contextual relationships between different classes in a specified range. The mixture of classes in the transition zone between landuse classes. The external context depends on the appearance and intense of classes in the local areas.
The value of this distance for each category, dc, is collected from field observations and related to the transition zones between landuse classes in the village model (Figure 2). A landuse index (LI) is calculated for each class, c, and scaled in the range 0 to 255 by applying a moving window with a radius dc on the ICCc-image, normalising with the maximal value of the area.

$$LI_c = \sum_{0}^{d} ICC_c / MAX(ICC_c) * 255$$

The landuse index (LI) now hold both the internal class context and the external influence distance dc for each class.

Amalgamating all the studied classes into a new false spectral image holding local contextual information can then create the local contextual information. The local contextual characters then describe the spatial variability in the surrounding of each pixel and also where the concept "village" appears in the whole studied landscape. The local context is then used to create hybrid characteristic classes in-between the initially studied classes based on their spatial appearance, the relative spatial distribution and their local mix. The local context can also be used to investigate the variability of landscape characters between villages.

Traditionally, satellite images are converted into objects or classes that are semantically defined as different landcovers [14]. Heterogeneity in reflectance is normally a problem in statistically based classification of remotely sensed images such as supervised or unsupervised classification. These problems stem from the fact that pixels are seen as thematically and spatially independent of each other. For example, Arbia [1] states: "In the classic (statistically) procedure, image pixels are viewed as (spatial) independent even if, from a methodological point of view, dependence is now recognised as an inherent characteristic of remotely sensed data".
Increased image resolution means that the single pixel has become less important and that essential information exists in the combination of neighbouring pixels. The spatial surroundings of a single pixel are important for gaining an understanding of what the pixel represents. This specific problem can be reduced if textural or contextual information is added. As a number of studies have attested to, the use of spatial context has made it possible to increase the thematic accuracy (see [3], [8], [1], [17], [18], [5]). In the presented research the spatial context is used to create a semantically shift from pixels values/classes to villages.

Processing for hybrid characterisation

The process starts with the selection of categories in relation to the village model. The selection is made from an unsupervised classified image. This classification is done in order to produce a manageable number of classes for the choice of landuse categories. Land use categories such as cultivated land, former meadows (transition land) and woodland are extracted and stored as binary masks. The spatial contextual processing then extracts and handles the local spatial contextual information of the study area.
After all steps in the hybrid characterisation have been completed, local characteristics are finally visualised through statistical separation, which generates the hybrid characteristic image. This results in a characterisation through which the individual configurations of villages appear and can be interpreted at the regional level.
The whole process is schematically illustrated in figure 4 the process from raw satellite image via landuse classes to hybrid characteristics is illustrated.
The procedure comprises the following steps:
Unsupervised classification of the satellite image is performed and the result is stored as binary masks for each class. Different landuse categories are then extracted. These include cultivated land, meadows (currently most shrub and in this study called transition land), and pure forest.
The internal class context (see figure 3) for each single proxy landuse category is analysed through two different sized windows simultaneously. The extent of the windows is retrieved from fieldwork (cultivated land, for example, ranges in scale size from 150 m to 1500 m).
Based upon the field interpretations of "villages" in the studied area, the local influence distance dc between landuse categories is defined. This is based on interpretations and knowledge about current and former landuse. The identified distance is used to integrate the internal class context from the former step in the process of external class context over an area with the radius dc to produce a new image in which the values are related to local context.
The three individually processed images, which now hold local spatial contextual information about both internal and external class context, are merged into a false multispectral rgb-image, which carries information about the local characteristics.
Through statistical clustering of the colour image the local characteristics are separated into classes. This process generates hybrid characteristics through which it is then possible to interpret local landscape characters in and between villages in the studied area.

The aggregation process in which local context (internal and external class context) is incorporated with field interpretations of villages reveals the villages in the resulting image. The image also visualises hybrid characteristics of villages. The hybrid characteristics can thus be used for a general interpretation of the landscape in the study area and also for the comparison of villages.

3 Discussion and evaluation of the hybrid characterisation

The hybrid characterisation image consists of categories in which every single pixel represents the local characteristics of the pixel neighbourhood. The extent of each hybrid character depends upon the amount of similar local characteristics in the whole study area.
The resulting image can not be read as a traditional map, nor is it a map of landcover or landuse categories. Firstly, it has a connection to vegetation represented as radiance values in the remotely sensed imagery. Secondly, it carries information about the local spatial context, and thirdly it carries the external context between land use classes. Finally the spatial concept of villages in general is represented by the selection of classes and field interpretations.

The image is open to interpretation at four different levels.

1. At the level of the single pixel. Each pixel holds information concerning in what part of a village the pixel is located. It can be directly interpreted from the new hybrid classes.
2. The value of each pixel describes local "landuse" character in the neighbourhood of each pixel (this corresponds to the local contextual analysis and the empirically measurements implemented).
3. How "villages" appear and how the pattern matches the village model. This makes it possible to compare and interpret villages by reading the hybrid characteristic image.
4. The proportion of different villages and hybrid characteristics in the whole area, which indicate different kinds of characters.

The hybrid characterisation procedure operates at the local level and a regional interpretation of the resulting image is possible.
The hybrid characteristic image is a representation of what constitutes and make a village unique. With this in mind, the resulting image is possible to read in a mode where the knowledge about villages guides the interpretation (*cf.* [16]). Different configurations of villages can then be compared with each other. This hybrid characterisation reveals villages/local spaces, which can be interpreted as different responses to landuse, historical processes, and delineation structures of properties.
The displayed villages show different configurations. Looking at the hybrid characteristic image (figure 5) it is possible to find the centre of each village (interpretation level 1) which appears in a clear red colour in figure 5. In this case all pixels in this class are close to the respective centre of each village and each location has a relatively large and concentrated area of cultivated land. Other villages appear in a light red colour which, according to the analysis, implies that the relative amount of arable land is less than for the red areas or that they are heterogeneously distributed. The characteristics, which include former meadows (currently shrub), reveal how concentrated or mixed the shrub growing in areas between the forest and arable land is.

A single village (interpretation level 3) can be studied by viewing the image from the centre towards the margin. The sequence of classes is studied. Interpreting the villages in this way indicates that the landscape consists of nodes of cultivated land surrounded by mixed categories lying in-between distinct areas of cultivated land and former meadows, which corresponds to the implemented village model.
Some villages appear in a polarised configuration where the most concentrated hybrid characters appear extensively, which can be seen in figure 5. Other villages appear mostly by characters indicating complex configuration and mixed landuse classes in the neighbourhood of each pixel. In the following section the resulting image will be evaluated by comparison to direction of production.

Evaluating the hybrid characteristic image against landuse data.

What types of landuse occur in the transitional zones of the village model? Is there a connection between a particular local hybrid character and a particular type of production?
In order to answer these questions the types of production in four villages have been cross-matched with the hybrid characteristics (figure 6). The result of this matching shows that there is a dominant type of production in the polarised villages whereas in the non-polarised villages there is a more diversified production.
As far as the relation between individual hybrid classes and types of production is concerned, it can be seen that in the non-polarised villages all of the existing types of production are evident, both centrally in the village and on their peripheries.
In the polarised villages, on the other hand, only silage and grain production is located centrally in the village while meadows and fodder production are found on the periphery of the village; i.e. far from the centre in the village model.
Our interpretation of this study is that the relation between type of production and character indicates that the polarised villages have undergone a process of change from what was a previously high level of variation to a more homogenous expression. This interpretation is reinforced by the fact that the qualities of the villages coincide with the reorganisation resulting from changes in (land) ownership. In the case presented here, Boda has yet to be reorganised and exhibits the most heterogeneous and diversified landscape. Våmhus was however recently reorganised but the effects of this change have not yet become evident in the physical landscape. Stumsnäs and Siljansnäs were reformed, which corresponds to the reorganisation of properties in the 1970s. This may also be seen as a historical aspect of varying depth in the environments presented here.
The polarised villages are farmed traditionally by one or a few farmers and an increasing homogenisation of the landscape is apparent, a situation which conforms to the narrow base of production. In the less polarised villages land use is to a greater extent based on small-scale production and individualised land subdivisions. This is reflected in the range of types of production and the spatial distribution of production in the diagram.
The relations between types of production and hybrid characteristics show that production is focused on a few land-use categories in places where the landscape's

character is polarised. For Stumsnäs and Siljansnäs mainly grain, fodder-arable, silage production classes correspond to hybrid categories 8 and 10. The maximum value for a particular production category also corresponds to hybrid 10, which means that production at these places is mostly located at the centre of the village.

In contrast to Siljansnäs and Stumsnäs, Boda presents a different picture. Here the range of production types is more varied and relatively more widely distributed among the hybrid categories. The largest part of production here is in hybrid category 8, which means that most of the land use is located in areas in these villages that are characterised by small-scale production and variations in the landscape. It also means that a greater part of the production takes place farther out in the village model. The concentration is higher in Våmhus than in Boda but not as concentrated in a single location as in Stumsnäs and Siljansnäs.

In the polarised environments, the percentage of the "fodder-meadow" (production class 10) and "other meadow" (production class 12) types of land is low and where it does occur it is found mostly on the periphery of each village. In the varied environments, however, the "fodder-meadow" and "other meadow" categories occur in all the hybrid classes, which means that they are equally spatially distributed in the villages. This also means that the variety of types of production corresponds to the hybrid images both inside the village and to the expression of the villages as a whole. It can also be seen that within the polarised areas, the "fodder-meadow" and "other meadow" types of cultivation have been forced out of the central parts of each village in favour of silage and fodder production. The values discussed above in relation to the concept of "village" can in principle be both quantified and followed up at a later date via the hybrid characters. In short, this means that the interdependence between characters and types of production shows that the method creates meaningful information.

4 Conclusion

In this paper the hybrid characterisation of cultivated landscapes has been presented and evaluated. The analytical model combines a spatial model of "village" with the processing of satellite data. In turn, it creates the opportunity to analyse villages/local spaces. The approach extracts landscape characteristics in the form of hybrid classes from satellite data.

The question concerning the extent to which there is a relation between current landuse and landscape characteristics was formulated for evaluation. It is possible to draw the conclusion that there is a local correlation between hybrid characters and landuse, which mean that where is at interdependency between landscape configuration and landuse.

The spatial dimension constitutes this relationship and need future research. Which landscape values exist in between landscape characters and land use would be a desirable focus of study. However, the conclusion can be drawn that meaningful landscape dimensions could be productively extracted from remote sensed data.

Many attempts have been made to bridge the gap between researchers working with remote sensing and those in the social sciences. For the most part these attempts have resulted in "vertical" absolute spatial descriptions of the spatial distribution of different socially related problems (*cf.* [7]). Often, the concrete studies fail to go beyond the direct vertical correspondence between satellite imagery and society. This study shows that by both including a local spatial dimension and the human conceptualisations of the village in the form of a model it becomes possible to add a horizontal dimension and transform the view of landscape from one point in space to many points in the studied landscape. This in turn also raises the opportunity to extract an interpretable hybrid image of how the social landscapes behind the image make use of land. The hybrid characterisation then makes it possible to interpret dimensions of the landscape that are not otherwise visible or accessible through the analysis of remotely sensed images or by fieldwork in the landscape. The analysis is founded upon sensitivity to the spatial dependencies which build up the villages and dimensions which make sense for the land users.

The approach implies that the analysis is conducted in the zone between the knowledge held by the interpreters and the reflectance of the physical and ecological aspects of the landscape. The resulting image can then be regarded as an interpretable picture of the individuals' as well as the society's handling of landscape. And it can be interpreted and understood as relational between many different local spaces.
The conclusion is that the limitations in the use of remote sensing in GIS are not so much to do with the technology, but rather more to do with how to make sense of satellite data and known concepts in combination. The approach presented here makes it possible to move freely over the semantic boarder between physical and ecological representations and the human conceptualisation of landscape.
The resulting image can be understood in terms of "Visualised Intangible Social Landuse Effects" (VISLE).

We argue that the social concepts can never be analysed as physical and/or ecological objects. On the other hand the physical and ecological defined objects cannot be used to explain concepts and features which are a product of human interaction with land in society.

To summarise, by "hybrid characterisation" it is possible to:

- Freely move between an anthropocentric interpretation of landscape and the representation of landscape in satellites.
- Productively make use of satellite imagery as a tool in social science.
- Handle integrated landscape values using satellite images as a tool.

The results imply that it is fruitful to use concepts which consist of a complex of spatial relations. This offers the possibility to handle questions about how differences in individual and collective landuse are connected to differences in transition, in history, in land owner's intentions and in landscape values.

References

1. Arbia, G., R. Benedetti & G. Espa (1999): "Contextual Classification in Image Analysis: an Assessment of Accuracy of icm", in *Computational Statistics & Data Analysis*, vol. 30, pp. 443–455.
2. Arler, F (2000): "Aspects of Landscape or Nature Quality", in *Landscape Ecology*, vol. 15, pp. 291–302. Kluwer Academic Publishers.
3. Barnsley, M. J. & S. L. Barr (1996): "Inferring Urban Land Use from Satellite Sensor Images Using Kernel-Based Spatial Reclassification", in *Photogrammetric Engineering & Remote Sensing*, vol. 62, no. 8, pp. 949–958.
4. Chen, D & D. Stow (2003): "Strategies for integrating information from multiple spatial resolutions into land use/land-cover classification routines". in *Photogrammetric Engineering & Remote Sensing* Vol.69, No. 11, November 2003, pp. 1279–1287.
5. Ehlers, M & M. Gähler & R. Janowsky (2003): "Automated Analysis of Ultra High Resolution Remote Sensing Data for Biotope Type Mapping: New Possibilities and Challenges", in isprs *Journal of Photogrammetry & Remote sensing*, vol. 57, pp. 325–326.
6. Frank, A. (2001): "Tiers of Ontology and Consistency Constraints in Geographical Information Systems", in *International Journal of Geographical Information Science*, vol. 15, no. 7, 667–678.
7. Fox, J., R. Rindfuss, S. Walsh, & V Mishra (eds.) (2003): *People and the Environment, Approaches for Linking Household and Community Surveys to Remote Sensing and* gis. Kluwer Academic Publishers: Boston, Dordrecht, London.
8. Gurney, M. C. & J. R. G. Townshed (1983): "The Use of Contextual Information in the Classification of Remote Sensed Data", in *Photogrammetric Engineering and Remote Sensing*, vol. 49, no. 1, pp. 55–64.
9. Hall, O & W. Arnberg. (2002): "A method for landscape regionalization based on fuzzy membership signatures", in *Landscape and Urban Planning*, vol. 59, pp. 227–240.
10. Hall, O. & G. J. Hay (2003): "A Multiscale Object-Specific Approach to Digital Change Detection", in *International Journal of Applied Earth Observation and Geoinformation*, vol. 4, no. 4, pp. 311–327.
11. Holt-Jensen, A. (1999): *Geography: History & Concepts.* sage Publications: London.
12. Hägerstrand, T. (1991): "Globalt och lokalt", in *Om tidens vidd och tingens ordning*. Byggforksningsrådet: Stockholm.
13. Kabanza, F. D. Bourdua, G. Bénié (2001): "Intelligent Image Analysis for Environment Monitoring", in *Advances in Environmental Research*, vol. 5, pp. 327–335.
14. Lillesand, T. M. & R. W. Kiefer (1999): *Remote Sensing and Image Interpretation*. Wiley & Sons: New York.
15. Liverman, D et. al. (1998): *People and Pixels. Linking Remote Sensing and Social Science*. National Research Council: Washington, D.C.

16. MacEachren, A. (1995): *How Maps Work: Representation, Visualisation, and Design*. Guilford Press: New York, London.
17. Walstra, J. & J. Van Der Kwast (2001): *Contextual Vegetation Classification. Using the Spatial Reclassification Kernel to Classify Heterogeneous Vegetation from* dais *Images*. Department of Physical Geography, Faculty of Geographical Science, Utrecht University.
18. Wicks, T. E., G. M. Smith & P. J. Curran (2002): "Polygon-Based Aggregation of Remotely Sensed Data for Regional Ecological Analyses", in *International Journal of Applied Earth Observation and Geoinformation*, vol. 4, pp. 161–173.
19. Wästfelt, A. (2004): *Continuous landscapes in finite space: making sense of satellite images in social science*. Hugo förlag. Uppsala.

Fig. 1. Torrberg village. Photo by Arkair.

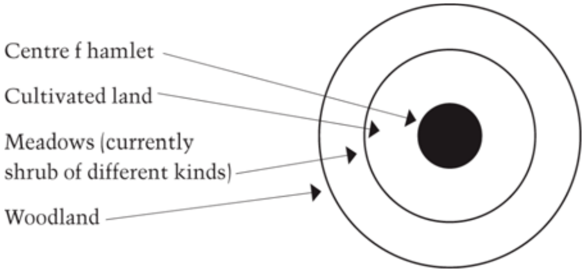

Fig 2. Historical village model – the local spatial aspect.

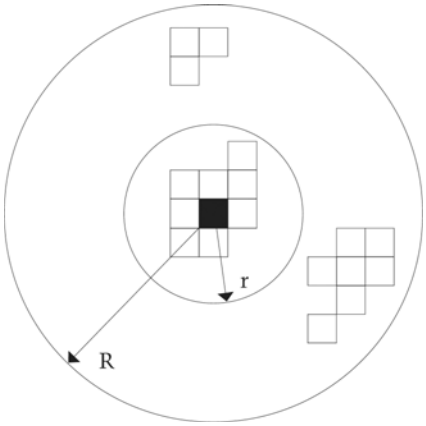

Fig 3. The internal class context is the relation between the number of observations in the large (R) and the small (r) field of view.

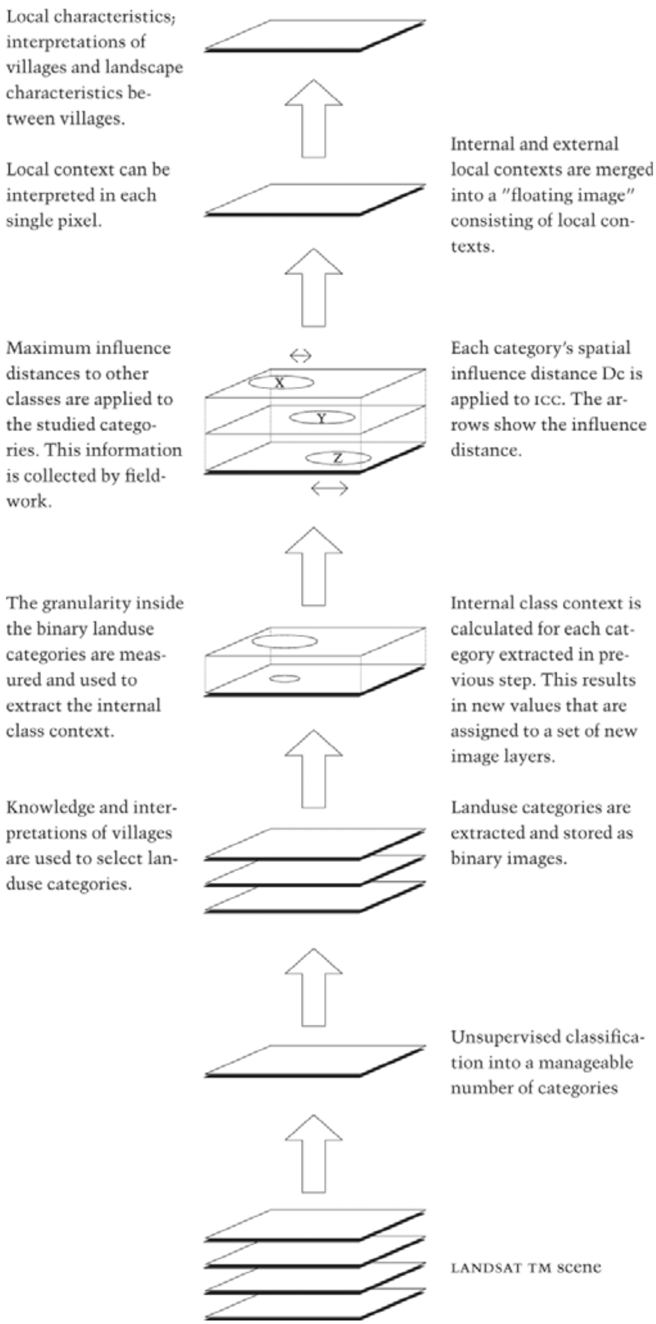

Fig 4 Processing scheme of hybrid characterization (read from bottom to top)

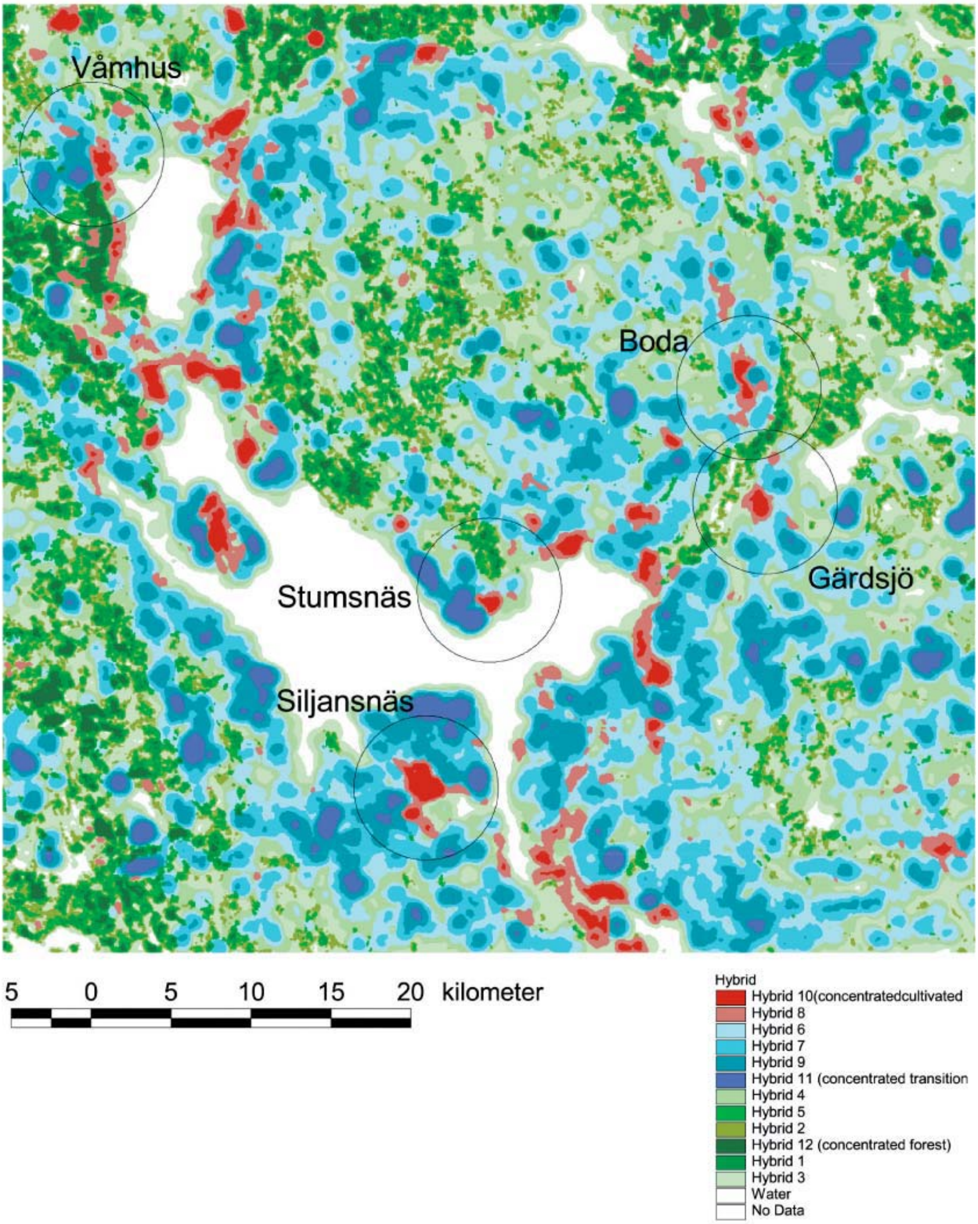

Fig 5. . Hybrid characters of the Lake Siljan district. The villages included in the evaluation are marked with circles.

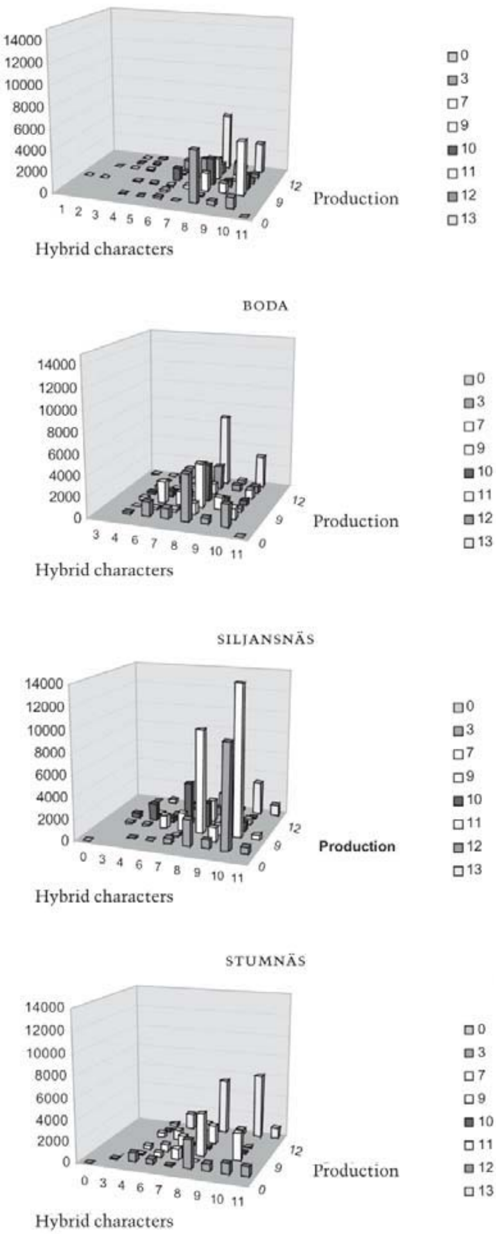

Fig 6 Diagrams showing cross matching between hybrid categories and agricultural production. Production classes, 3 grain, 7 fallow, 9 fodder arable, 10 fodder meadow, 11 other, 12 other meadow, 13 silage.