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Landsat-Aided Forest Site Type Mapping

By using numerical interpretation of Landsat imagery combined with color infrared photography and map data, it was possible to map forest site types faster and with lower costs than when using traditional methods.

INTRODUCTION

IN FOREST MANAGEMENT forest land must be classified into site type classes. One possibility is to classify it according to the flora. Such a system is used in Finnish forestry planning and forest taxation. The classification is based on the forest type theory developed by A. K. Cajander (1913, 1949).

ABSTRACT: *Forest site types were interpreted with a maximum likelihood classification of Landsat imagery. On the basis of such interpretation, an operational system for site type classification was developed. A spectral site type model was also created. The study area was situated in northern Finland near the Arctic Circle. The numerical interpretation was tested by random sampling. Some classes were accurate enough for an operational system without field checking. About two-thirds of the area needed more information. The new forest site type classification method, entitled KAUKO, is a multi-phase system. The first phase is the interpretation of Landsat MSS imagery, followed by utilization of base map data, visual interpretation of color infrared photographs, and field checking. With KAUKO it was possible to make the forest site type classification three times as fast as with the traditional method. More than one quarter of the expenses of this classification were saved by using the KAUKO method in test classification.*

According to the theory, biologically equal sites have similar vegetation cover and they belong to the same forest type. Taxation class is more accurate than forest type in describing site quality. The taxation class involves both the forest type and special site characteristics, including stoniness, marshiness, and thickness of raw humus.

The potential for classifying forest sites in northern Finland by numerical interpretation of Landsat imagery was studied. A further aim was to develop an operational method of classification using imagery. The most important need for this method was forest taxation.

Spectral signatures of plant species and canopies (e.g., Gates *et al.*, 1965) provide a theoretical basis for site type interpretation. Growth potential of a site has an impact on the reflected electromagnetic radiation; Kharin (1973) observed the reflectance of red light to be higher in barren sites than in luxuriant ones, and Tom and Miller (1980) have successfully classified forest sites by using satellite imagery and other data. However, their site classification differs from the Finnish classification of forest types, which is primarily based on lesser vegetation.

Tucker *et al.* (1975) and Tucker (1979) have noted a high negative correlation between the biomass, water content of leaves, amount of chlorophyl, and the spectral reflection of red light. A corresponding positive correlation was found for the near-infrared radiation. The negative correlation between the reflectance of red light and growth potential of the site may mainly be caused by the other absorption maximum of chlorophyls which lies in the red light area (*cf.* Hildebrant, 1976).

When classifying sites using satellite imagery, one must also consider factors other than the occurrence

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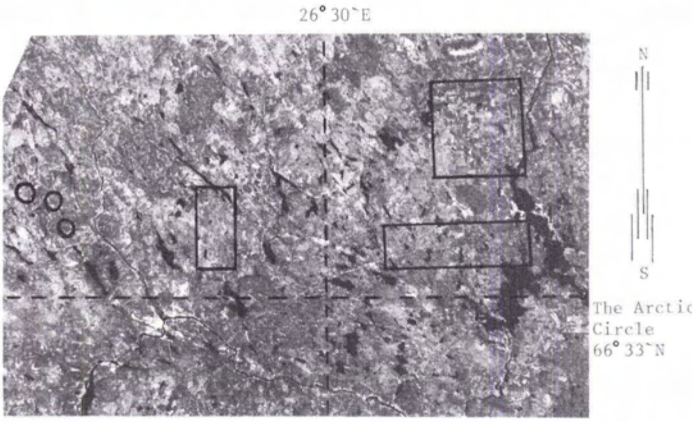

FIG. 1. Study areas. Rectangles—areas for numerical interpretation; circles—test areas of site classification methods. Landsat MSS-5. Scale about 1:1 500 000.

of plant species related to a given forest type. Complementary factors include canopy structure, density, shades, zenith angle, and azimuth angle as well as viewing angle (Knipling, 1970; Colwell, 1974). Different phenotypes of the same forest site type (e.g., clear cut area and closed stand) require spectral classes of their own.

MATERIALS AND METHODS

STUDY AREA

The study area encompasses three sub-areas of 20,000 to 40,000 hectares, the total area being 90,000 hectares (Figure 1). The sub-areas were located immediately north of the Arctic Circle (66°33′N) and between longitudes 25°05′E and 27°30′E.

The sub-areas represented a typical sample of the forests in northern Finland. Mineral soils covered slightly less than half the total land area, the rest being peatland. About half of the mineral soil area was dominated by Norway spruce (*Picea abies* Karst.) mature forests. Some proportion of them had been regenerated over the past few decades by means of clear cutting, soil cultivation, and planting of Scots pine (*Pinus sylvestris* L.). The spruce stands were centered in arctic hill areas where the soil was rather fine and impermeable. The other half of the mineral soil contained natural pine stands which grew on coarser-grained soil types.

About half of the peatland was treeless open bog. The rest of the peatland was either pine and birch swamps (*Betula pubescens* Ehrh.) or spruce and birch swamps. The tree stand both on mineral soil and peatland mostly resulted in only partial crown closure. Consequently, lesser vegetation had an influence on the radiation reflected from the stands.

Terrain elevation in the study area varied from 120-m to 405-m above sea level. The variation of the total temperature sum during the growth period was from 750 to 875 d.d. (degree day) units calculated with a threshold value +5°C.

DEVELOPMENT OF INTERPRETATION MODEL

The study areas were analyzed from Landsat-2 imagery (path 206, row 13), acquired on 15 July 1979, using a maximum likelihood classification of all four wavelength channels. The study area was also classified by means of unsupervised clustering based on absolute distance.

Figure 2 illustrates the various phases of interpretation. Old site maps, made for taxation classification, and panchromatic aerial photographs (scale 1:60 000) were used for searching 311 forest stands in the study area to form a group of potential ground truth areas. These stands represented nearly all site/tree stand combinations found in the area. Their area varied between 4 and 30 ha. All stands were observed using low altitude aircraft. About half of the stands were also checked in the field. The site type, proportion of tree species, development class, grade of crown closure, and characteristic of lesser vegetation were checked of ground truth areas.

The site type classes used in Finnish forest taxation and forest management are named IA, IB, II, III, IV, and waste land. Those classes represent the growth potential of the forest soil. The taxation classes are independent of tree stocking; they are signified for open land, too. Class IA is the richest and IV the poorest. The rest of forestry land is waste land, being outside active forestry.

In principle, fresh soil forests belong to taxation class IB (richer site type is rare in northern Finland), middle barren mineral soil forests belong to class II, and barren mineral soil forests to class III. The special site characteristics such as marshiness, thick raw humus, and stoniness often lower the principal taxation class. Special characteristics particularly influence fresh mineral soil forests. The typical species of lesser vegetation for fresh mineral

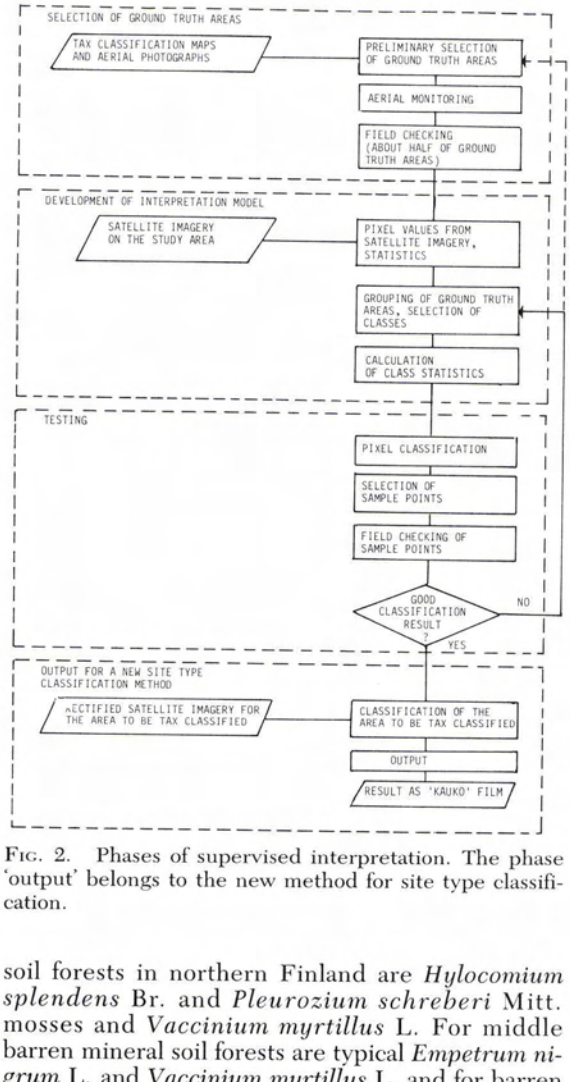

FIG. 2. Phases of supervised interpretation. The phase 'output' belongs to the new method for site type classification.

soil forests in northern Finland are *Hylocomium splendens* Br. and *Pleurozium schreberi* Mitt. mosses and *Vaccinium myrtillus* L. For middle barren mineral soil forests are typical *Empetrum nigrum* L. and *Vaccinium myrtillus* L. and for barren soil forests *Vaccinium myrtillus* L. and *Calluna vulgaris* Hull. twigs and *Cladonia* sp. lichens.

After field checking, spectral values of pixels within ground truth areas were selected interactively on the Landsat imagery using a Nova-Comtal minicomputer color display system. Stand statistics (means by channels and covariances between channels) were used for calculating the Bhattacharyya-distances or B-distances showing spectral divergence of ground truth areas (Fukunaga, 1972). B-distance can be expressed as a formula:

$$B = \frac{1}{8}(\mathbf{M}_b - \mathbf{M}_a)^{\mathrm{T}} \left[\frac{\Sigma_a + \Sigma_b}{2}\right]^{-1} (\mathbf{M}_b - \mathbf{M}_a) + \ln \frac{|(\Sigma_a + \Sigma_b)/2|}{|\Sigma_a|^{1/2}|\Sigma_b|^{1/2}}$$

where B is the B-distance between ground truth areas a and b,
$\mathbf{M}_a$ the mean vector of ground truth area a,
$\mathbf{M}_b$ the mean vector of ground truth area b,
Σ_a the covariance matrix of ground truth area a, and
Σ_b the covariance matrix of ground truth area b.

These distances were then grouped and plotted as a graphic dendogram. In the dendogram the stands combine according to their mutual distance measured with the B-distance.

By means of grouping, one could find the ground truth areas that were similar in their spectral values. If the site type of ground truth areas within a spectral group was also similar, the spectral values were combined and a new statistic was calculated. Thus, each class had a statistically sufficient amount of pixels. The new statistic was used in maximum likelihood classification. If the site types were very heterogeneous within a spectral class, e.g., open bog and mineral soil, the class was left out of classification. Only 49 stands, from more than 300 analyzed, were qualified as ground truth areas. The maximum likelihood classification employed 23 classes, the statistics of which were calculated from the spectral values of pixels in these 49 stands.

The Landsat image was rectified to the base map coordinate system prior to classification, and resampled to a 50- by 50-m pixel size. The final classification of the study area was done with CDC Cyber 170 computer with ELLTAB classification program.

TESTING OF INTERPRETATION RESULTS BY RANDOM SAMPLING

Classes having similar information and spectral values were combined before sample point selection. After combining, there were 13 classes from the 23 original. Sample points were selected by random sampling with interactive programs from the classification results. A sample zone was delineated with the first program on the color display with a cursor. The zone covered one kilometre on both sides of roads. The second program made the sample within this zone. It checked class by class (*cf.* Fitzpatrick-Lins, 1981) pixels which were surrounded by pixels of the same class. They were potential sample points. Then it selected the final sample points of the population of potential points. Thus, the sample points lay inside a uniform stand of at least 3 by 3 pixel or 2.25 ha (Todd *et al.*, 1980). This restriction was placed because of the inaccuracy of geometric correction and to avoid errors caused by mixed pixels. The sample program gave the map coordinates of sample points. Three forestry professionals checked the points in the field. A total of 479 sample points were field checked, 459

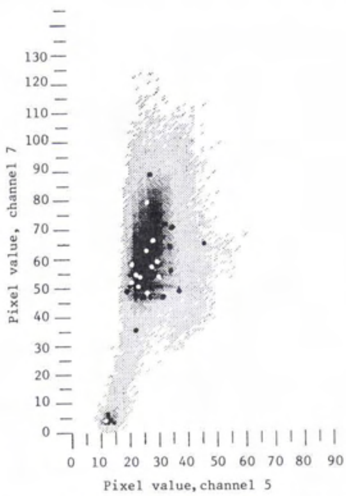

FIG. 3. Frequency table of MSS-5 and MSS-7 images of the study area. When the greytone becomes darker, frequencies get higher. The table also includes the means of classes from supervised interpretation (black-and-white points).

of which were on forest land, and the rest on agricultural land. Of the points on forest land 386 were on mineral soils and 71 on peatland.

RESULTS

SPECTRAL CLASSES

Figure 3 is a frequency table between Landsat MSS channel 5 and channel 7. The means of the red and the near-infrared channel of the classes used in the maximum likelihood interpretation are also shown on the figure. Part of the area of the highest frequencies does not have the mean of any class. The potential ground truth areas checked in the field, having spectral means of pixels located in this area, varied on site type. They included many kinds of conifer-dominated mineral soil forests and peatland. Because the variation of ground truth areas was so high, this spectral class was excluded. Better interpretation results were expected by letting these pixels fall into neighboring classes.

SAMPLE POINT ACCURACY

Table 1 shows the results of field checking compared to Landsat interpretation. The accuracy of most classes of Landsat interpretation is quite low but the error is usually only one-sided, either overestimation or underestimation.

The main reasons for incorrect interpretation results were marshiness and the variable influence of raw humus layer for fresh mineral soil stands, stoniness and cutting waste for middle barren and barren mineral soil stands, and the ambiguity of the whole site type system in northern Finland. Marshiness and thickness of raw humus layer does not seem to influence the reflected radiation, so that classes could be delineated on that basis from the Landsat imagery. For example, the mature fresh mineral soil spruce forests (classes 1 and 3) were a clear spectral class but the interpretation of actual wood production capacity, the taxation class, failed. The cause for misclassifications was the same in unploughed fresh mineral soil regeneration areas (classes 4 and 7).

Cutting waste on richer site type affects spectral reflection similar to *Cladonia* species on poorer sites. Sometimes cutting waste in an unploughed regeneration area can cause reflection similar to soil of a ploughed regeneration area (overestimation error by class 6). Cutting waste was the main reason for underestimation errors of class 11.

Stoniness seems to influence spectral values to some extent (higher visible and lower near-infrared reflection), but a clear spectral class could not be distinguished for stony sites. Two thirds of test points of class 8 were stony while one third had no stones, which occasioned an underestimation error. Stoniness caused the overestimation errors of class 11, too.

The test method applied in this study, where the person checking the sample points did not know the interpretation result of Landsat imagery, may have been even "too" objective. This can have resulted in the impression that the interpretation was less appropriate than in reality. The interpretation result of the Landsat imagery must be regarded as good when taking into consideration on the one hand the fine structure of site classification and on the other hand the room left for interpretation.

The number of test points varied a lot by classes. Some classes, such as 9 and 10, were spectrally so narrow that the sampling program could not find many nine-pixel clusters of the same class. Spectrally and informatively narrow classes should be combined before test point sampling more than was done.

Peatland could not be distinguished from mineral soils in general. When interpreting Landsat imagery, they either remained unclassified or were classified into classes of mineral soil. The appropriate class of mineral soil where peatland is classified implies the productive capacity of the peatland as well as whether it has been drained. Yet, very reliable results cannot be obtained.

The results from unsupervised classification resembled those from maximum likelihood classification. However, field checking revealed that the geographical boundaries of site types in maximum likelihood classification corresponded to the reality better than in unsupervised classification. In unsupervised classification less area remained unclassified than in maximum likelihood classification. Added classified area was mostly peatland and it did not increase the area of reliable interpretation.

KAUKO—AN INTEGRATED METHOD FOR CLASSIFYING FOREST SITE TYPES

A portion of the classes of Landsat image analysis represented reasonably well only one forest site type or taxation class. Such classes were 2, 5, 6, 8, and 11 (in Table 1). The rest of the classes only gave implications of the site types. For practical site classification, the Landsat image analysis was sufficiently reliable in about one third of the mineral soil area in the whole study area. Accordingly, it was not possible to classify all forest sites merely on the basis of the Landsat image. The interpretation result was introduced as one element in a new forest site type classification method, which was entitled the KAUKO method. The data sources of KAUKO are the following:

- Interpretation result of Landsat imagery
- base map
- color infrared aerial photograph
- field work.

KAUKO was developed to provide a method where the objectivity, automation, and low-cost of computer analysis combine with the logic and versatility of visual interpretation. The interpretation result of the Landsat image is plotted by graphical plotter on a transparent overlay to a forest stand map at 1:10 000 scale (Figure 4). The number inside the stands refers directly to taxation class (actual wood production capacity) but those compartments also need additional information, especially information on rocky and stony land from the base map. The letter identifies the forest type (e.g., fresh mineral soil or *Hylocomium-Myrtillus* type forest). Further data are added to the satellite image as presented in Figure 5.

The interpretation result drawn on a transparency, i.e., interpretation film, is superimposed on a transparency copy made of the base map. Using a waterproof pen the peatland, rock, and stony land are marked on the KAUKO film. Roads and waters are marked to facilitate subsequent layout. The additive information is combined to the Landsat information manually. Hoffer and Swain (1980) combined map data to Landsat imagery in a numerical interpretation phase with good results. Digital combination was considered in the KAUKO system too complicated and maybe also too expensive for an operational method. The 50-m pixel size would also have been too large. In the future, digital combination will be more useful.

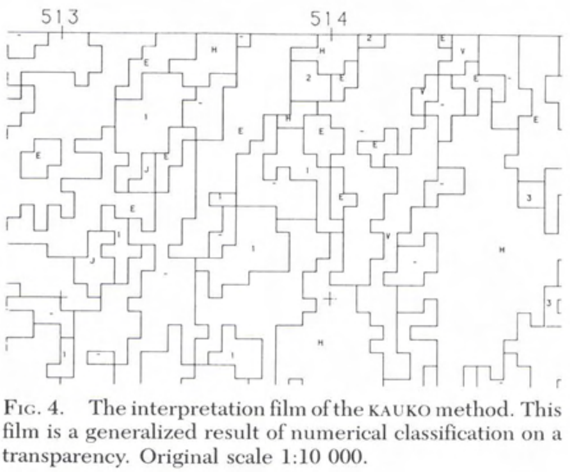

FIG. 4. The interpretation film of the KAUKO method. This film is a generalized result of numerical classification on a transparency. Original scale 1:10 000.

The completed interpretation film is superimposed on a color infrared photograph of 1:10 000 scale. The compartments are amended along with reviewing the stand boundaries. By means of the interpretation film and color infrared photograph, one can increase the number of the forest stand compartments which are given a taxation class and forest type estimate prior to field checking.

The aerial photograph with superimposed transparency of the base map and interpretation film is then taken to the field where forest type and taxation class of indistinct forest stand compartments are checked while completing stand boundaries. After field work, the compartments of taxation classes are drawn on the base map transparency. Eventually, a cartographer will draw the final map of tax classification on the base map.

THE COMPARISON OF THE KAUKO METHOD WITH CONVENTIONAL TECHNIQUES

A comparison was made of KAUKO with two site classification methods requiring more field work.

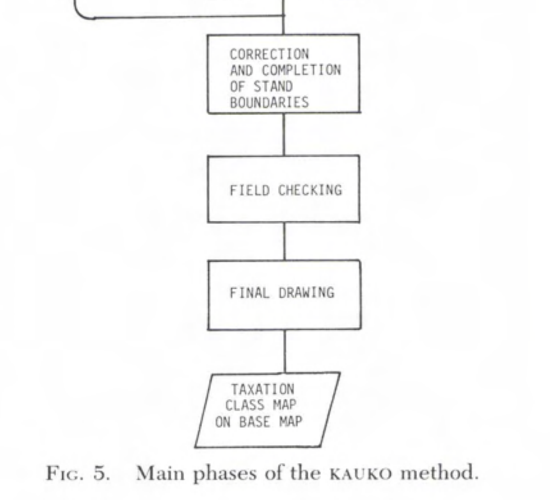

FIG. 5. Main phases of the KAUKO method.

TABLE 1. SAMPLE POINT ACCURACY. TEST POINTS ON MINERAL SOIL

Class of interpretation*	Number of correctly classified points (same taxation class in interpretation and in field), percentage	Number of points underestimated for site richness in Landsat interpretation, percentage	Number of points overestimated for site richness in Landsat interpretation, percentage	Total percentage	Number of field checked points
1. Spruce-dominated mature forest. Fresh mineral soil, taxation class II.	46	5	48	100	65
2. Spruce or pine dominated advanced-aged thinning stand, fresh mineral soil, taxation class II.	69	10	21	100	29
3. Spruce dominated mature forest, fresh mineral soil, taxation class III.	50	50	0	100	6
4. Open or half open fresh mineral soil, taxation class II.	51	0	49	100	53
5. Ploughed fresh mineral soil regeneration stand, taxation class II.	90	3	7	100	31
6. Ploughed fresh mineral soil open stand, taxation class II.	58	0	42	100	12
7. Open fresh mineral soil, taxation class II.	100	0	0	100	4
8. Pine dominated advanced-aged thinning stand, middle barren mineral soil, taxation class III.	66	35	0	100	55
9. Half open pine stand, middle barren mineral soil, taxation class II.	50	0	50	100	2
10. Open middle barren mineral soil, taxation class II.	0	0	100	100	3
11. Pine dominated barren mineral soil stands, taxation class III.	69	17	14	100	126
Total					386
Class 12. was a peatland class and class 13. was water.					

* Taxation classes for interpretation classes were obtained according to ground truth areas.

The methods compared were (1) the conventional method where geographical boundaries of site classes are drawn on base maps or aerial photographs in the field (referred to as the basic method); (2) the color infrared method (referred to as IR-field method), where homogeneous forest stands are delineated indoors by stereoscopic interpretation of color infrared aerial photographs and their site types are checked in the field; and (3) the KAUKO method. Three analysts classified each of three areas, using a different method for each area. This was done so that each area was classified using each method. In other words, the test was arranged as the three-factor Latin square. The total area of the three test areas encompassed 1631 ha. The areas contained a total of 31 private estates.

The similarity of classification results achieved with the methods was compared not only by means of taxation class distributions but also by converting the taxation classes into index numbers indicating the growth of tree stand, i.e., tax cubic metres. The tax cubic metres are not dependent on tree stocking, as neither are taxation classes, but indicate the capacity of soil for wood production in certain climatic conditions. The tax cubic metres can be given as growth per hectare m^3/ha (per year) or as a total figure by multiplying the growth per ha by the total area. The tax cubic metre figure of a forest area, e.g., of a private estate is computed by multiplying the tax cubic metres per ha counted by means of taxation class distribution by the area of the property. The growth figures (tax cubic metres) corresponding to a taxation class are produced by national forest inventories.

With the basic method the average wood production capacity of the whole test area of 1631 ha was 1.04 m^3/ha (per year), with the IR-field method 1.02 m^3/ha and with the KAUKO method 0.98 m^3/ha, respectively. Thus, the difference between the KAUKO method and the basic method was 6 percent. With the KAUKO method, which eliminates much of the field work, the field crew often classified borderline cases to a lower class. Figure 6 also shows a certain cautiousness when compared with the basic method. In the results with the KAUKO method there is less of taxation class IB, indicative of good wood production, but more of taxation class III and tax-exempt waste land than in the results with the other two methods.

With the KAUKO method 45 percent of the estates deviated not more than ±10 percent in wood production capacity from the result with the basic method, 71 percent being within the range of ±15 percent. The biggest deviations occurred for the estates where either marshy mineral soil or peatland covered most of the area. The deviations between the IR-field method and the basic method were smaller than those between the KAUKO method and the basic method.

EFFICIENCY OF CLASSIFICATION

The IR-field method did not make the site classification much faster, because the work indoors took a lot of time. The total speed of the KAUKO method as compared with the basic method was 2.7 times as fast whereas the field work became 4.3 times as fast (Figure 7). It was calculated that the basic work of the KAUKO, i.e., building and testing of the interpretation model, will cost approximately $18,000 US for the whole satellite image. Making the KAUKO film with all the appropriate phases costs 3.7 cent/ha. With the KAUKO method, a 26 percent cost savings was achieved in site classification, when taking into consideration all working phases and costs.

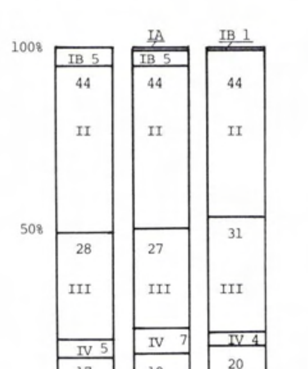

FIG. 6. Taxation class distributions with three classification methods. IA through IV are taxation classes, J is waste land.

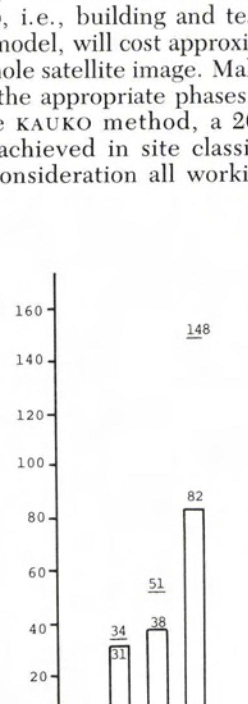

FIG. 7. Average classification speed (hectares/hour) with three methods. Columns: total speed (work indoors + field work). Lines above columns: field work.

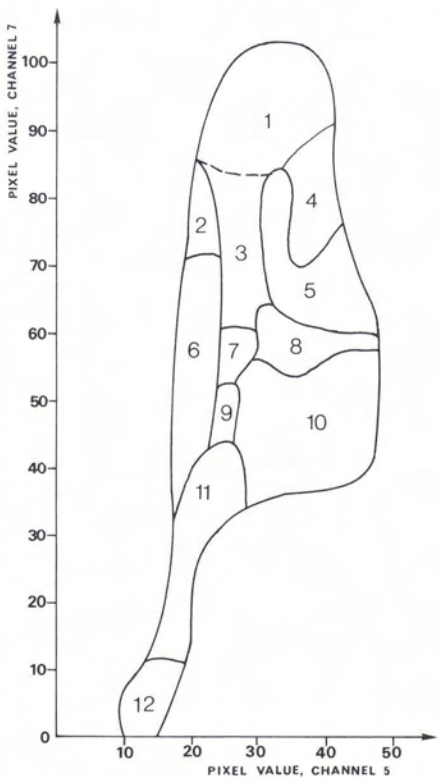

FIG. 8. Spectral site type model. (1) Open bogs, fields, regeneration areas of fresh mineral soil. (2) Deciduous-dominated fresh mineral soil. (3) Regeneration areas of fresh mineral soil, peatland. (4) Open bogs. (5) Regeneration areas (ploughed) of fresh mineral soil. (6) Conifer-dominated fresh mineral soil. (7) Pine swamps, open or half open fresh forest land. (8) Open or half open middle barren mineral soil. (9) Middle barren mineral soil with trees. (10) Barren mineral soil. (11) Spruce swamps (higher infrared), wet open bogs (lower infrared). (12) Water.

DISCUSSION

SPECTRAL SITE MODEL

Numerical interpretation of the satellite image produced the spectral site model presented in Figure 8. The model shows schematically the location of various canopy types in the coordinates. The axes in the coordinate system are the red light and near-infrared radiation. Accordingly, the borders of spectral signature of various canopy types are drawn in two wavelength areas. The basis for drawing the borders was provided by the definition areas of maximum likelihood classes which were plotted.

From the area specifications one can conclude that the information content in some classes is more unambiguous than in others. For example, the spectral area which covers most pine swamps is vague as for its contents. In other satellite images and other geographical areas the shape of the model and scope of classes vary, but the mutual position of the classes seems to remain constant.

SOURCES FOR INTERPRETATION ERRORS

Error sources in interpretation of the satellite imagery are

- The site has characteristics of two different site types. Such intermediate types were very frequent in the study area. This error source is related both to problems in the site classification system and to interpretation of the satellite image.
- The sites are different, but their reflected radiation is similar. In the study, peatland was confused with mineral soil. One reason for this is water, which lowers the reflectance of the red light, thus giving the same pixel values for peatland and forested areas (*cf.* Myers, 1970)
- Treatment of forest. Often the cutting waste and soil cultivation cause the area to be classified as a site type which is more barren than in reality.
- The pixels on the borders of stands or mixed pixels. Located on the border between two site types, the pixel gets its value partly from both types and is often classified into a third site type.
- The ground truth area does not represent the expected information class.

Satellite image analysis can primarily be applied in delineating various canopy types. How successful the interpretation of taxation class or actual wood production capacity of a site is, depends mainly on the correlation between canopy type and wood production capacity.

POSSIBILITIES WITH THE KAUKO METHOD

In testing with the KAUKO method, it was possible to achieve such significant time and cost savings that KAUKO was taken into use in site classification for forest taxation in northern Finland. For one third of the mineral soil area, a sufficiently reliable estimate of site type was obtained through interpretation of the satellite image. Those classes for which one cannot give an unambiguous estimate of wood production capacity are also useful. When interpreting aerial photographs, it is much easier to correct the rough borders of site type than to start interpretation without preliminary data.

Landsat image analysis provides the KAUKO method with an objective basis which makes the working of various estimators consistent, also balancing seasonal impacts. The principal problems with the KAUKO classification were concerned with marshy land and peatland. Field work must be focused on peatland and small properties in order to avoid random errors.

New satellites, such as the Landsat-5 Thematic Mapper, will increase the possibilities for using KAUKO. Spatial resolution of the Landsat MSS images is often sufficient in extensive regions as in northern Finland. However, the data processing costs will decrease in the next few years so that it may be worth introducing Thematic Mapper images also in extensive areas. Thus, the harmful classification errors due to pixel location on the border between two forest stands can be diminished. Application of the KAUKO method is not confined to site classification only, but it seems applicable even to a larger extent in forest planning.

Acknowledgments

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