MAPPING PREVIOUSLY UNMAPPED PLANETARY SURFACE: A SUPERVISED MULTISPECTRAL TERRESTRIAL/AQUATIC APPROACH IN NORTHEASTERN FINLAND

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Abstract. Although large numbers of imageries over planetary surfaces have been aquired by notable space missions over the past twenty years, the versatile technical remote sensing achievements, which have found their long-term and successful applications within the fields of different geosciences, have not been employed in planetology. High resolution imageries allow small-scale surface features to be observed, various filters allow different wavelength bands and surface units of different colour or spectral reflectance to be recorded. Also long-term missions transmit information about multitemporal changes, but such diversified multitemporal surface mapping, as possible by Landsat MSS data, to say nothing of the potential of the Landsat TM and SPOT equipment, are mostly unexecuted.

This paper contains an example of the aquatic environment research by computer-assited remote sensing using Landsat MSS data. The western parts of Lake Yli-Kitka, northeastern Finland were studied and mapped according to spectrally identified classes which were improved after field work by associated reclassification.

The Landsat classification of open water areas depends on the water quality and depth, or shore distance relations. The recognition of aquatic vegetation complexes is based on the main life-form (helophytic, nymphaeid, isoetid etc.) and the amount of recorded radiation reflected from the chlorophyll (or from other shallow bottom coverage) in respect to the open water surface radiation absorbance within near infrared wavelengths.

Aquatic areas are quite featureless in respect to their reflectance, especially in northeastern Finland area studied. The use of wide-channel multispectral satellite data has demonstrated to be valid under quite difficult circumstances. Similar or preferably more up-to-date planetary imagery data could be of high utility value in mapping various surface units of the terrestrial planets and large moons.

1. Introduction

Large quantities of Landsat multispectral scanner (MSS) data are continually being made available, and it is desirable that some interpretation could be carried out for aquatic areas, especially in Finland where the need for the effective control of water areas is essential for various purposes. This paper describes work done on Landsat MSS data interpretation, dealing in particular with the extraction of aquatic phenomena as well as complexes within the western part of the oligotrophic Lake Yli-Kitka (Figures 1 and 2).

Lake Yli-Kitka is situated in a region where the soil is mainly moraine shaped by glacial processes. The moraine coverse pre-quartenary rocks which consist of quartzite,

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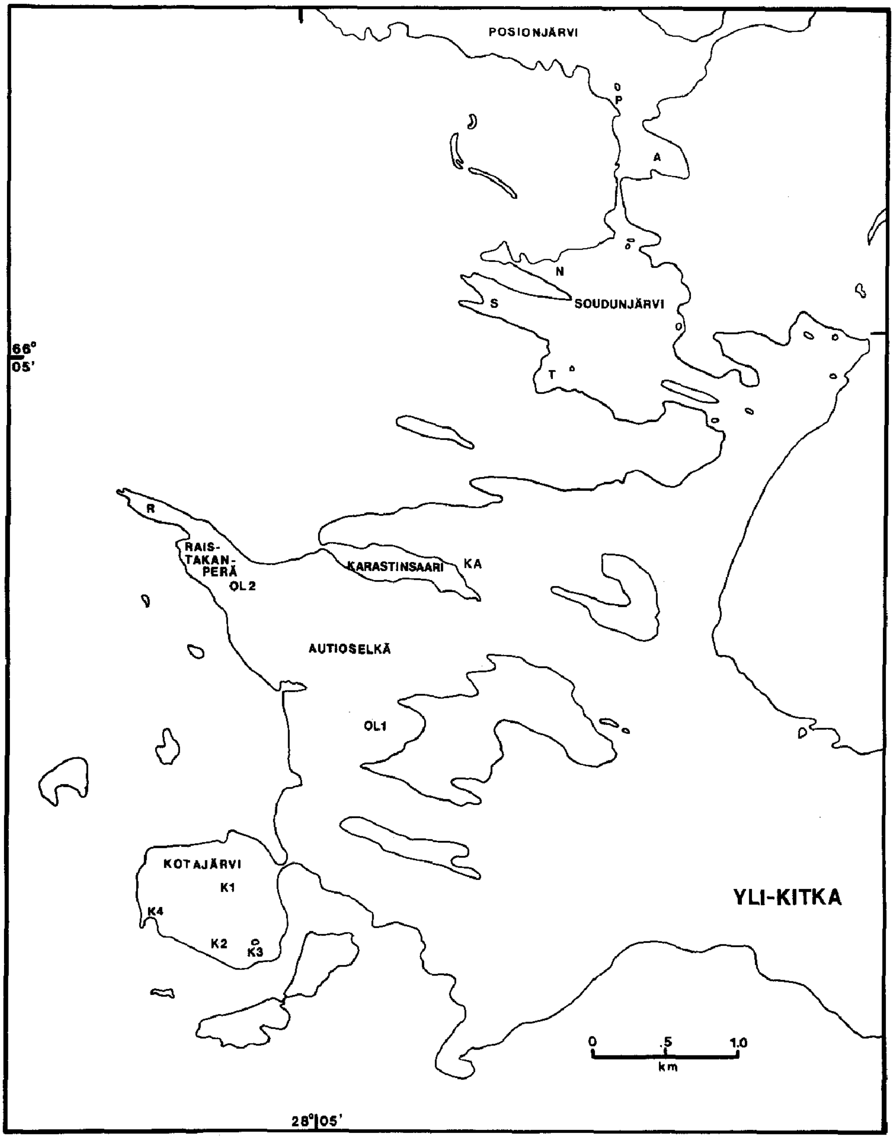

Fig. 1. Map of the area studied. Reference fields are indicated with abbreviations (see text).

phyllite, mica shist, and in the southern part of the lake, gabbro and ultrabasic rocks in particular (Saarelainen, 1980). The vegetation in the drainage area is mainly coniferous forests and peatland.

Most of the shores have a clear sloping littoral bed and are open to wind and wave action. The bottom substratum is mainly moraine on exposed shores and in sheltered places the mineral material is covered by a thin layer of organic sediment, mainly mud mixed with debris.

Fig. 2a.

Fig. 2b.

Fig. 2c.

Fig. 2d.

Fig. 2e.

Fig. 2. Aerial oblique photographs of some selected areas: (a) Southern Lake Kotajärvi, (b) head of Raistakanperä Bay, (c) western shore along Posionjärvi Lake outlet, (d) eastern bay beside the Ahvensalmi outlet, (e) view from the west over Soudunjärvi Lake.

The water is poor in nutrients and yellowish brown (electric conductivity 20–40 25 μS cm^{-1}, pH 7–7.5 and colour 30–40 Pt $mg\,l^{-1}$ in the Autioselkä area and 50–70 Pt $mg\,l^{-1}$ in the Soudunjärvi area during summer stagnation). The macrophytic vegetation also has an oligotrophent nature but is seldom densely developed except in the Soudunjärvi area which has more dense vegetation. Sparse, reedy helophyte (mainly Equisetum fluviatile) and isoetid (Isoetes lacustris) communities are dominant. Helophytes form a sparse, narrow belt around the lake except for the most exposed shores. Nymphaeids occur only in sheltered bays and only in the Soudunjärvi area do they make up a large portion of the vegetation. Nymphaeid vegetation consists mainly of different Sparganium species and Potamogeton natans. Maristo (1941) classified Lake Yli-Kitka as a Potamogeton filiformis-Chara-type lake which is typical of North-Eastern Finland.

2. The Landsat Data Interpretation Method

The Lake Yli-Kitka subscence of the Landsat MSS data 206-13 of the 15th July 1979, consisting of four spectral bands (Band 4 = 500–600 nm; Band 5 = 600–700 nm; Band 6 = 700–800 nm; Band 7 = 800–1100 nm) were processed by using the Univac 1100/22 computer system at the University of Oulu as well as XAP and ELLTAB calculation packages (Raitala and Hurskainen, 1984). Each picture element (pixel) of the subscene was displayed by the symbol of one of the spectrally defined classes or, if outside the adopted aquatic spectral range, left blank. Training or reference fields were chosen for each class so as to afford field work, after which a slight reclassification was done – especially for aquatic vegetation complexes by adopting some new classes. The course of this study is illustrated in Figures 3–6 and in the following sections.

3. Reference Fields

3.1. The Lake Kotajärvi Area

The base bottom constituent within the Lake Kotajärvi area (Figures 1 and 2a) is glacifluvial sand, outwashed from surrounding eskers (Aario *et al.*, 1974; Saarelainen, 1980) and covered by brownish mud. Within this small lake, which is almost a bay of Lake Yli-Kitka, the water depth ranges from less than 0.5 m near the shore to about 10 m in the middle of the open water area. A narrow, at most about 100 m wide, hydrolittoral vegetation zone borders the deep, open water areas of the lake.

The field K1: The middle parts of this lake are deeper (down to 10 m) than the Secchi disc depth (about 3.9 m) causing the open-water-area type reflectance (Arkimaa and Raitala, 1983). There are, however, some small shallower areas resembling the near shore test fields (cf. K2, K3).

Test field K2: The spectrum of slightly shallower (mean depth exceeding 1.5 m down to 1.8 m) parts of the lake are also greatly affected by the poor infrared reflectance of the open water surface within infrared wavelengths. The brown, muddy bottom slightly affects the spectrum within the visible wavelengths. Sparsely distributed helophytic Equisetum fluviatile flora (> 10 plants m^{-2}, height about 0.6 m over the water surface) slightly raises the infrared reflectance from that of the open water surface by its high chlorophyll reflectance (Hoffer, 1978).

Test field K3: At the slightly shallower area of the southeastern part of Lake Kotajärvi the mean water depth is about 1 m, ranging from 0 to 1.5 m. Yellowish-brown water allows the brownish-gray, muddy bottom and its mainly nymphaeid, thin flora (Sparganium spp. about 80% of the vegetation covering about 5 to 10% of the area) with some isoetid (Isoetes lacustris about 20% of the vegetation) and small helophytic (Equisetum fluviatile) growing units to be visible. A small islet (ϕ about 40 m is also in this area (Figure 1).

Test field K4: The water depth here ranges from 0 to 1.4 m with a mean depth of about 0.4 m. The light brownish, sandy (depth from 0 to 1.0 m) and brownish, muddy (depth from 1.0 to 1.4 m) bottom with associated vegetation is visible through the yellowish-brown (60 Pt $mg\,l^{-1}$) water at the mouth of a small ditch (Figures 1 and 2a). The dense flora consists of helophytic (Equisetum fluviatile, 50% of vegetation, coverage 5 to 10%; and Carex rostrata, 40% of vegetation, coverage about 60%) and nymphaeid (Sparganium spp., about 3% of vegetation) and some isoetid vegetation at depths from 0 to 0.3 m, from 0.3 to 0.6 m, and down to about 1.0 m, respectively.

3.2. THE AUTIOSELKÄ AREA

Open lake test fields: The depth of open water areas within the Autioselkä area (OL 1, OL 2; Figure 1) is, at most, to about 11 m. The depth of the more open water area test field (OL 1) is greater (ranging from 1.8 to 6.5 m with an average of about 5 m) than that of the Raistakanperä Bay open water area test field (OL 2; ranging from 2.9 to 3.5 m with an average of about 3.3 m). The Secchi disc depth at both places is about 3.5 m, allowing the grey muddy and unvegetated bottom to insignificantly affect the reflected spectrum. The recorded intensities are the result of yellowish-brown (50 Pt mg l^{-1}) water and the reasons for the slight differences between the two open water areas are of locational origin.

Sparsely vegetated shoal test field: At the head of Karastinsaari Island (KA; Figure 1) there is a stony hydrolittoral area with a depth down to 1.2 m. The light brown and sparsely vegetated (Equisetum fluviatile, $> 1\ m^{-2}$, with some isoetids) sandy bottom near the shore changes further away from the shore to moraine with stones breaking the water surface. There is some incoherence in the occurrence of this area as the bottom is rough and close to the surface allowing the depth relations to strongly influence the reflected spectrum.

Densely vegetated test field: The head of Raistakanperä Bay (R; Figures 1 and 2b) is connected to Lake Yli-Kitka by a narrow bridged strait. This shallow and muddy bottomed bay head is nearly overrun by helophytic and nymphaeid vegetation (Figure 2b). As the bay is only about 150 m wide, some geolittoral areas may also be displayed in the pixels. The water is dark brown (150 Pt mg l^{-1}).

3.3. THE SOUDUNJÄRVI AREA

The short draining river of Lake Posionjärvi flows through a few small straits and through the shallow Lake Soudunjärvi to Lake Yli-Kitka (Figure 1). The shallow parts (< 1.5 m) of this channel are vegetated, the water is yellowish-brown and the bottom, where visible, is mainly of grayish mud.

Just in front of the river outlet, along the western shore of Lake Posionjärvi (P; Figure 1) there is a densely vegetated shoal with mainly nymphaeid (60% Sparganium spp., 30% Potamogeton natans) stands with some helophytic Equisetum fluviatile (areal coverages of about 30%, 20%, and 5%, respectively). The small islet (ϕ about 40 m) has been classified together with the water areas (Figure 2c).

In the small eastern bay beside Ahvensalmi strait (A; Figure 1) there are separate helophytic (Phragmites australis, $15\ m^{-2}$ and Equisetum fluviatile, $10\ m^{-2}$) and nymphaeid (40% Spaganium spp. and 40% Potomogeton natans) vegetation stands (Figures 1 and 2d).

In the Teljonlahti Bay (T; Figure 1) there are two separate growing units consisting of (a) nymphaeid (mainly Sparganium spp.) and elodeid (Potamogeton spp.), and (b) isoetid (Isoetes lacustris) vegetation respectively. Isoetids grow farther away from the corner of the bay and the shore and they are rimmed by a narrow elodeid zone on the deeper side.

The northernmost of the two western bays of Lake Soudunjärvi (N; Figures 1 and 2c) is characterized by dense nymphaeid (50% Sparganium spp. and 30% Potamogeton natans) vegetation with Isoetes lacustris (about 10%) and some Equisetum fluviatile (about 5%). Within the southern bay (S; Figure 1) there are nearly similar nymphaeidic and minor helophytic vegetation (including slightly more Potamogeton natans and Equisetum fluviatile and slightly less Sparganium spp.) than in the northern bay, and in place of Isoetes lacustris there are different Nuphar species, the leaves of which float on the water surface and give a more intensive spectral reflectance than the water-covered isoetids.

4. Classification

The print-form results of the attempts of the four-channel Landsat classification over aquatic areas in the western part of Lake Yli-Kitka are presented in Figures 3, 5, and 6.

The first stage of classification is to choose the test or reference fields used in the classification. In the case of aquatic areas it is most easily done for open lake and related areas which have a high absorbance within infrared wavelengths. Figure 3 represents the area studied in terms of five class symbols. When compared to the reference areas the print symbol '+' is designated as the deepest or at least the farthest away from the lake shore areas (reference fields K 1, and OL 1 in the middle of the Autioselkä area, Figures 1 and 3) having most extensive absorbance particularly within infrared wavelengths (Figure 4a). The reason for these more absorbing areas being farther away from the lake shores raises the question of water quality and wind transport phenomena.

In places class '/' forms zones along sublittoral areas between class '+' and the shoal classes (K 2, Figures 1 and 3). Of course this classification may arise from bottom-related effects transparent through the uppermost water layers, but it may also depend slightly on water quality or particles (humus, chlorophyll, turbidity) floating in the water (the Ahvenselkä and Soudunjärvi test areas).

Print symbol 'I' symbolizes sparsely vegetated shallow areas (K 3, Figures 1, 2e, 3) and some open water areas which are closely related to the '/' class (the Ahvensalmi and Soudunjärvi areas). In many places the class 'I' seems to occur in water which is on the shallower side in respect to the class '/', forming a slightly bottom and vegetation related sublittoral zone (cf. the print symbol 'I' and the Figure 2e).

Class symbol 'L' (Figure 3) represents the small amount of stony and barren shallow open water areas with fairly strong bottom and turbidity effects (cf. test field KA at the Ahvenselkä area).

As is seen the open water areas, especially those pairs indicated by '+' and '/', and by '/' and 'I', are best separated qualitatively, as the lack of appropriate in situ samplings allowed no direct quantitative comparisons to be made. The overall trend from class '+' via class '/' to class 'I' and 'L', however, clearly indicates an increase in reflectance (Figure 4a) and thus also an increase in turbidicity and productivity as well as a decrease in 'purity' and depth. There is, however, also a possibility to simplify the open water area

Fig. 3. Classification of open water areas. Each pixel represents an area of approximately 0.5 ha on the ground. For class symbols see text.

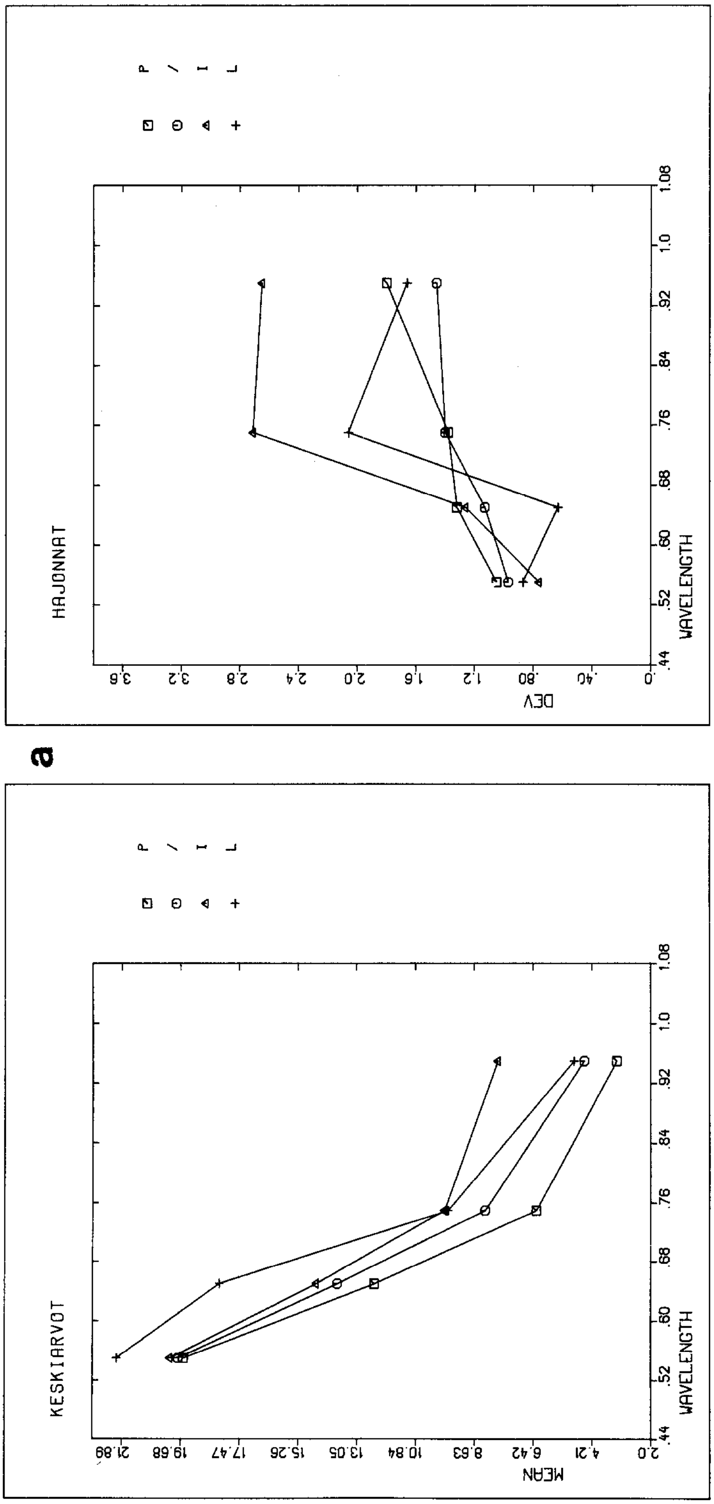
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Fig. 4a.

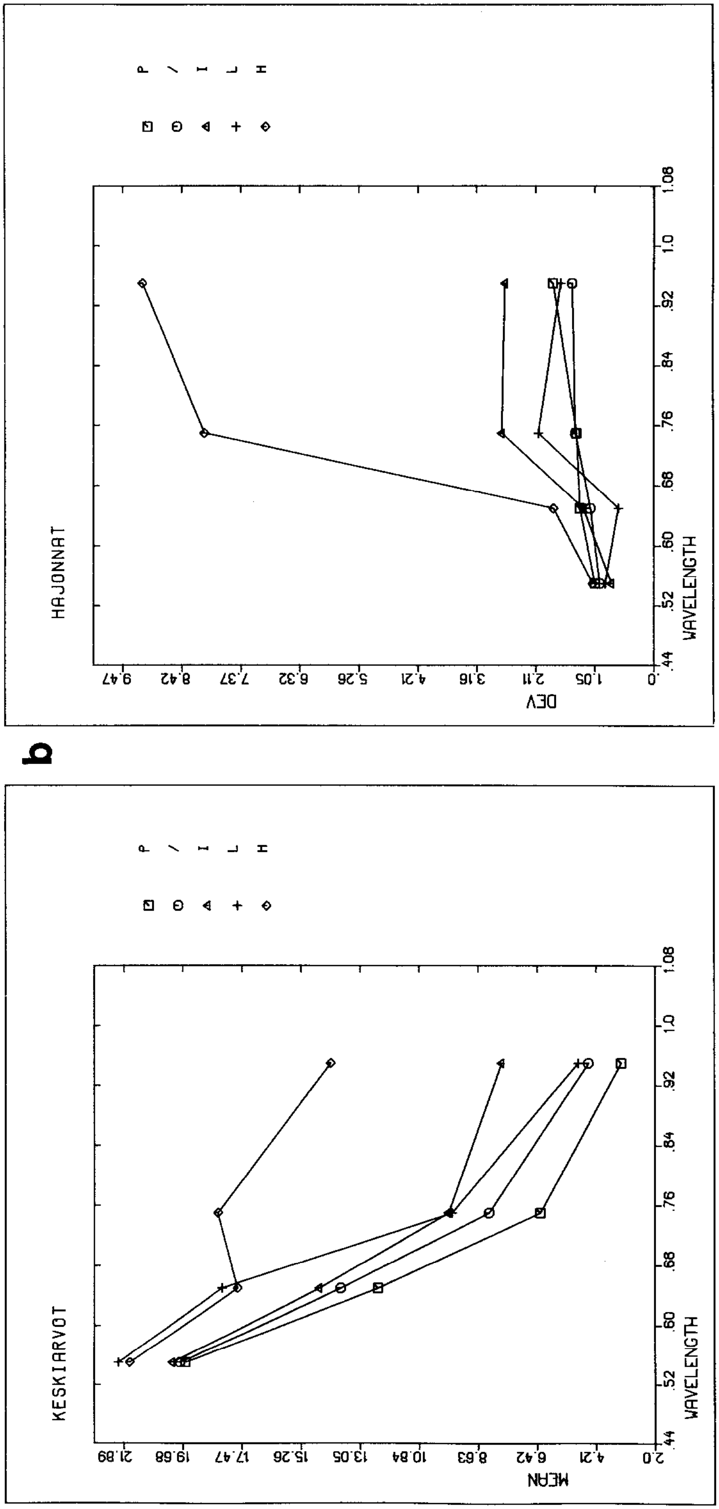

Fig. 4b.

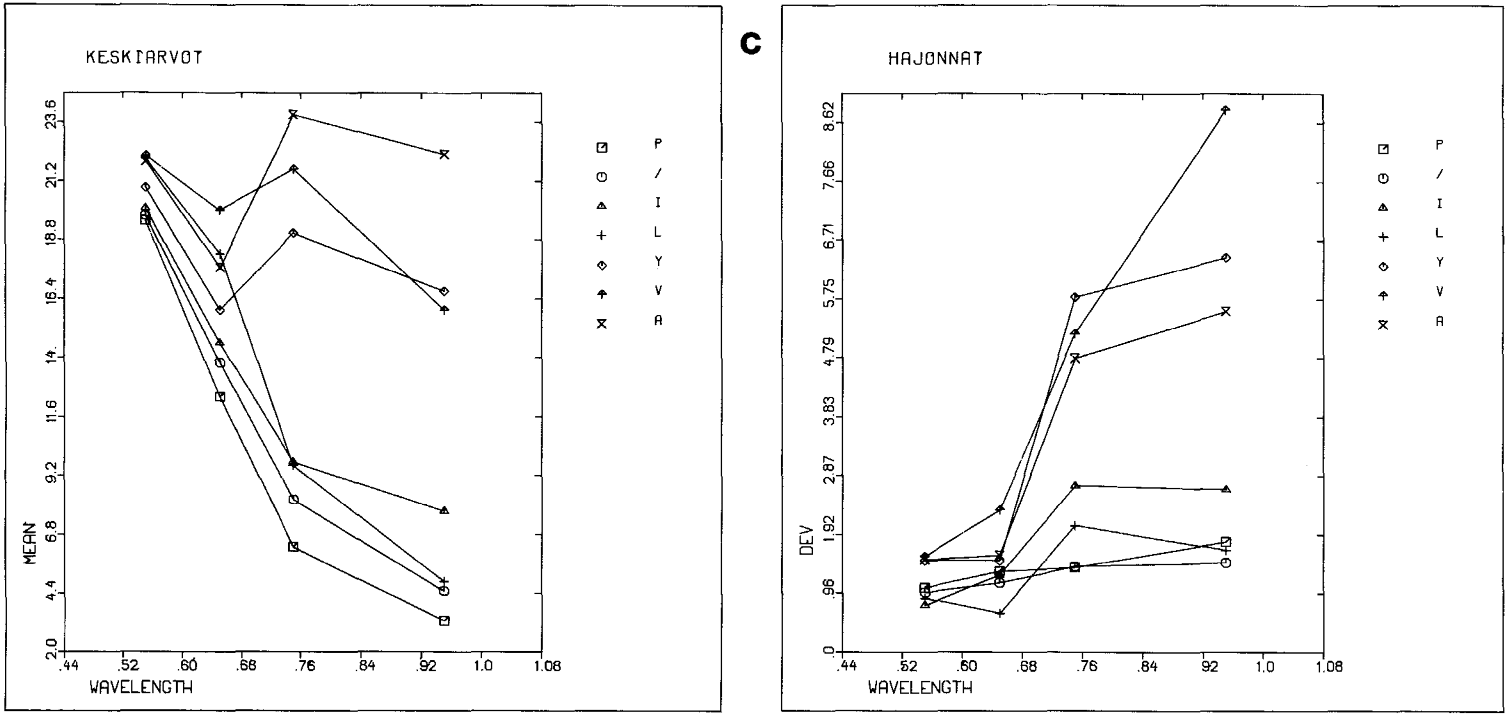

Fig. 4c.

Fig. 4. The formal spectra 'Keskiarvot' and standard deviation 'Hajonnat' of different classes in the classification (a) of open water areas (Figure 3), (b) including a wide littoral class (Figure 5), and (c) with three littoral subclasses (Figure 6). For class symbols see text and Figures 3, 5, 6. The purest open lake class is, however, indicated here by the symbol 'P'.

Fig. 5. Classification including a wide littoral class. For scale see Figures 1 and 3, and for class symbols see text.

Fig. 6. Aquatic area classification with three littoral subclasses. For scale see Figures 1 and 3, and for class symbols see text.

classification by reading two or more adjoining classes together to form a wide open lake class if one should be needed.

The second stage of the classification procedure is to renew the classification by adopting new reference fields in order to find a remedy for the lack of near shore aquatic areas in Figure 3. Two near-shore growing units from the western bays of Lake Soudunjärvi were chosen to form new reference fields. These reference fields are slightly different (Figure 2e) and incoherent in themselves resulting in a wide variety of different aquatic flora areas being classified with this class symbol (H; Figure 5). In respect to the previous open lake classes the relatively high infrared reflectance is most indicative for this new class (Figure 4b) allowing the previoulsy unclassified reference areas (Figures 1 and 3) to be found in Figure 5. The reference fields with dense vegetation (K 4, the head of Raistakanperä Bay, all the bays of Soudunjärvi Lake, and the areas in the vicinity of Posionjärvi's outlet mouth; Figure 2) are classified separately from other aquatic areas because helophytic and nymphaeid flora covers large proportions of these areas thus raising the infrared reflectance (Figure 4b). In addition to large areas which are clearly found to be aquatic vegetation complexes, this class symbol also often borders open water areas (cf. the Kotajärvi area, Figures 1, 2a, 5) thus indicating different narrow littoral zone phenomenae. Because of the incoherence of this class, some terrestrial areas are misclassified and represented by the same class symbol in Figure 5 (cf. with Figure 1).

The third stage in correcting the classification deficiencies (misclassifications of some terrestrial areas with an aquatic class symbol as well as the too unspecific nature of this class in indicating dense aquatic vegetation; Figure 5) is to seek more reference fields within this class or within a given area – the classification of which should be more accurate. In the last print (Figure 6) the wide littoral class of Figure 5, indicating all aquatic vegetation areas with only one print symbol, is substituted by three new classes (Figure 4c) allowing some differences to be found within vegetation zones (Jantunen *et al.*, 1984). Due to the small size of individual vegetation units and the large pixel surface area the adopted new classes are best described only qualitatively (Figure 2).

The band 7 intensity relations indicate that the vegetation coverage on the water surface is quite similar and thin in the case of classes 'Y' and 'V' but clearly increases in the case of class 'A', which possibly indicates some clearly helophytic areas (as well as pixels also extending partly over some geolittoral areas). The overall trend from class 'Y' via class 'V' to class 'A' depicts an increase in reflectance within the infrared Landsat MSS band 6 (Figure 4c) which, in turn, indicates the respective increase in the vegetation over, on and just below the water surface (helophytes, nymphaeides and some isoetids). The high 'V' class intensities within band 5 (red) may, in places, arise from aquatic vegetation and turbidity, but also in places from increasing soil proportion within the pixel area (misclassified terrestrial 'V' symbols, for example). Within band 4 wavelengths which almost penetrate through the whole water column to the bottom, classes 'V' and 'A' are greener or more vegetated than class 'Y' – or at least their vegetation is either more helophytic or nympheidic than that of class 'Y'.

An example of class 'Y' is at Ahvensalmi Bay (Figure 2d) where nymphaeidic flora (indicated by 'Y' in Figure 6) in the middle of the bay is surrounded by helophytes near the shore ('A' and 'V') and by sparsely vegetated open water area ('I') near the mid-channel. The head of Raistakanperä Bay is classified mainly by symbols 'Y' and 'A' where the symbol 'Y' exhibits a slightly more sparsely vegetated southern part and symbol 'A' symbolizes a more densely vegetated northern part. The class 'V' reference field is on the southern end of Kotajärvi Lake (K 4, Figure 1) where a densely vegetated and mainly helophytic area is situated in the mouth of a small ditch (Figure 2a). The classification along the narrow littoral zone around the Kotajärvi Lake and in other places near the shore may depend on the proportion of the terra within the pixel area. There the symbol 'A' displays those pixels covering slightly terrestrial or geolittoral areas, while the symbol 'V' stands for more aquatic pixels.

5. Conclusion

It has been shown that it is possible to map the aquatic area of Lake Yli-Kitka by using the Landsat MSS data. 'Pure' water effectively absorbs the near infrared part of the spectrum while different phenomena, evidently related to turbidity, chlorophyll, depth relations and shore vicinity, change and spectrum, especially within near infrared wavelengths, allowing some spectrally different open lake classes to be identified. It is also possible to identify several sublittoral aquatic flora complexes on the ground of lifeform and vegetation density as aquatic areas with helophytes reflect more infrared radiation than those with nymphaeides. These in turn reflect better than such areas where the vegetation is entirely, to some extent, submersed (cf. Long, 1979).

Of course this aquatic area classification and mapping method has many defects and need for improvement, which mostly arises from the large (0.5 ha) pixel area on the surface, and the wide spectral bands of the MSS sensor. The recorded pixel intensity values are possibily caused by several different surface units within the 0.5 ha area thus allowing only areally large surface complexes to be qualitatively identified. For this reason, this study of the Lake Yli-Kitka area with its abrupt shores and clear waters allows only the lower limits of method useability to come forth.

Improvements will be gained by further Landsat data studies – supported by field work – which allow also quantitative evaluations, and by using the new Landsat-D satellite data with a ground resolution of about 30 x 30 m (Marelli, 1982).

6. Discussion

Although the aquatic environment is typically only a terrestrial surface unit, its different parts are so similar to each other, in respect to the reflectance, that this remote sensing procedure well illustrates the possibilities of applying multispectral data in the mapping of for example compositional, structural, erosional and depositional aspects of surfaces of other terrestrial planets.

Each planetary mission should include multispectral imaging equipment to allow for more versatile and exact use of the data acquired by the preparation and launching of an expensive space probe. Data handling and telecommunications may be quite involved due to the large amount of information secured by the multispectral imaging system. However, the multitemporal planetary events could be assumed to take place so slowly (except atmospheric and polar phenomena on Mars, volcanism and related phenomena on Io, and the clouds of Venus, Jupiter, and Saturn) that there is no need to attempt to continuously image the planetary surface but multispectral imaging could be restricted to situations when high-rate telecommunication does not disturb other measurements and when the surface illumination is the best possible with respect to the multispectral channels used.

Earth is, of course, a special imaging object because it is possible to make a supervised classification aided by field work. The situation, when considering other planetary bodies, is more difficult and the first approach is naturally an unsupervised imaging data treatment. Additional information will, however, be acquired by using different data bases recorded by other adjoining instrumentation of the space probe, especially in the case where they are measuring some surface-related phenomena.

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