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Application of airborne imaging spectrometry system data to intertidal seaweed classification and mapping

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Abstract

The aim of this paper is to test the ability of imaging radiometers to describe the principal seaweed and seagrass beds along the coast of Brittany (France). In this work we used CASI, an instrument with programmable narrow bands. On the ground, regions of homogeneous vegetation cover were mapped using differential GPS positioning. Ground spectra were recorded with a field spectroradiometer (Spectron SE 590), for substratum and different species. Their analysis shows variations in relation to pigment characteristics, vegetation structure and environmental conditions.

An algorithm sequence based on field work and according to the technical sensor characteristics, was developed to discriminate the dominant species. The classified CASI image was compared with ground data. The main results are the following :
(a) the visible wavelengths allow good discrimination between green, red and brown algae.
(b) the infrared wavelengths allow separation of two main types of brown species, seagrasses and the identification of floating seaweed.

Introduction

Seaweeds form a major component of the intertidal environment on earth. Mapping of seaweeds for natural resource assessment and ecosystem characteristics is essential. Traditional mapping of intertidal areas was principally based upon field work where *in situ* observations are projected on maps (Joubin, 1909; Davy De Virville, 1962; Jacobs, 1979). Aerial photography has also been used (Floch, 1967; Perez & Audouin, 1973). However, these classical methods are tedious, costly and the quality of information is limited (Austin & Adams, 1978; Belsher *et al.*, 1983).

Remotely sensed images provide a source of optical tools for characterizing types of littoral zones. Using a SPOT simulation radiometer, it has been shown that it is possible to distinguish the main groups of marine seaweeds, including green, red and brown algae (Viollier *et al.*, 1985) and to identify typical sedimentary units of the littoral zone (Zbinden, 1985). But the coarse spatial and spectral resolutions (respectively 20 m, 3 bands), limit applications to large, homogeneous species cover.

Fine resolution imaging spectrometry has been used to characterize spectral features associated with aquatic macrophytes and seagrasses *in situ* (Guillaumont, 1991; Borstad, 1992; Zacharias *et al.*, 1992; Malthus 1993; Armstrong, 1993).

The purpose of this work is to test the contribution of the fine spectral and spatial resolutions of an imaging spectrometer to describe the principal seaweed and marine seagrass beds along the coast of Brittany (France).

This study is based on :
- field work such as ground spectra acquisition and determination of homogenous areas limits with GPS.
- processing the imagery of the CASI airborne instruments.

Description of site studied

The Roscoff to Siec Island stretch is located along the English Channel on the coast of North Brittany (Figure 1). The major features of the physical environment have been described by Sournia *et al.* (1987). Mean wind velocity always exceeds 2 m s^{-1} and is commonly around 7 m s^{-1}. Sea surface temperature ranges from 8 °C in winter to 16 °C in summer. Tides are semidiurnal with ranges of 3.6 m during neap tides and 7.7 m during spring tides with a maximum of 10 m.

The most important point in relation to seaweed distribution is the presence of rocky shores remarkable for their large standing crops of intertidal and subtidal seaweeds with the following zonation towards the sea: *Fucus vesiculosus* (L.), *Fucus serratus* L., *Himanthalia elongata* (L.) S.F. Gray, *Laminaria digitata* (L.) Lamour and *Laminaria hyperborea* (Gunn.) Fosl.

Fucus vesiculosus and *Fucus serratus* are the dominant intertidal algae. *Ascophyllum nodosum* (L.) Le Jolis is abundant on rocks and sheltered side of small islands. *Zostera marina* L. grows in sheltered water. *Laminaria* is confined to the more exposed shore where the water depth can be as much as 15 m.

Material and methods

Fieldwork

Spectral information on vegetation is required in order to precisely characterize their radiometric properties and thus create an airborne sensor bandset that is suitable for this coastal application.

Measurements were made using a Spectron SE 590 (Rollin & Milton, 1991). It measures radiance in 252 spectral channels over 358–1137 nm with a resolution of approximately 11 nm. However, due to the instrument sensitivity, measures over 900 nm are less reliable. *In situ* spectroradiometric measurements were made in August and September 1993 during the low spring tides. Measurements were obtained during two hours around local true noon. These observations have been collected in the same environmental conditions as imagery acquisition. Two sensor heads were used for subsurface downwelling radiance and above surface reflectance. Scans were obtained at approximately 1.5 meters over targets using a field of view (FOV) of 15 °. Spectra were acquired for targets varying from sediment to dense algal cover under different moisture conditions.

Differential GPS (Global Positioning System) was used to record position within 2 m accuracy and to map regions of homogeneous vegetation cover (Figure 2).

Airborne sensors

Airborne instruments offer an enhanced spectral resolution not yet available on spaceborne platforms. CASI or Compact Airborne Spectrographic Imager is a pushbroom imaging spectrometer. Details of this instrument are given by Gower *et al.* (1992). The along track resolution is a function of aircraft speed, number of spectral bands and integration time, while the across track ground resolution is a function of the aircraft altitude only. Its instantaneous field of view (IFOV) is 1.2 mrad and its field of view 35°.

CASI can operate in two modes:

1. In spectral mode, spectra at 1.8 nm intervals with a resolution of 3 nm are acquired over 40 lines (looks). Up to 288 spectral bands may be positioned anywhere between 410 and 980 nm, although calibration is only guaranteed between 430 and 870 nm.
2. In spatial mode, it works like a multispectral detector. Depending on aircraft speed, altitude and integration time, up to 15 spectral bands of any width may be defined and implemented immediately at the finest spatial resolution of 512 pixels across track.

Acquisition of imagery

Imagery was acquired over the study site from Roscoff to Siec Island on September 18th 1993, during spring low tide coefficient of 114.

ARAT (Avion de Recherche pour l'Atmosphere et la Télédétection) carried the CASI sensor. ARAT is a Fokker 27 owned and operated by a consortium including CNES (Centre National d'Etudes Spatiales), Météo France, IGN (Institut Géographique National) and INSU (Institut National des Sciences de l'Univers). It was obtained for this mission through the PNTS (Programme National de Télédétection Spatiale). ARAT has a very high flying stability with a minimum speed of 130 knots and is equipped with GPS navigation system. The altitude was 3000 m yielding along-track resolution of 5.5 m and across track of 3.8 m over a swath of 1850 m. For this configuration, 13 bands are

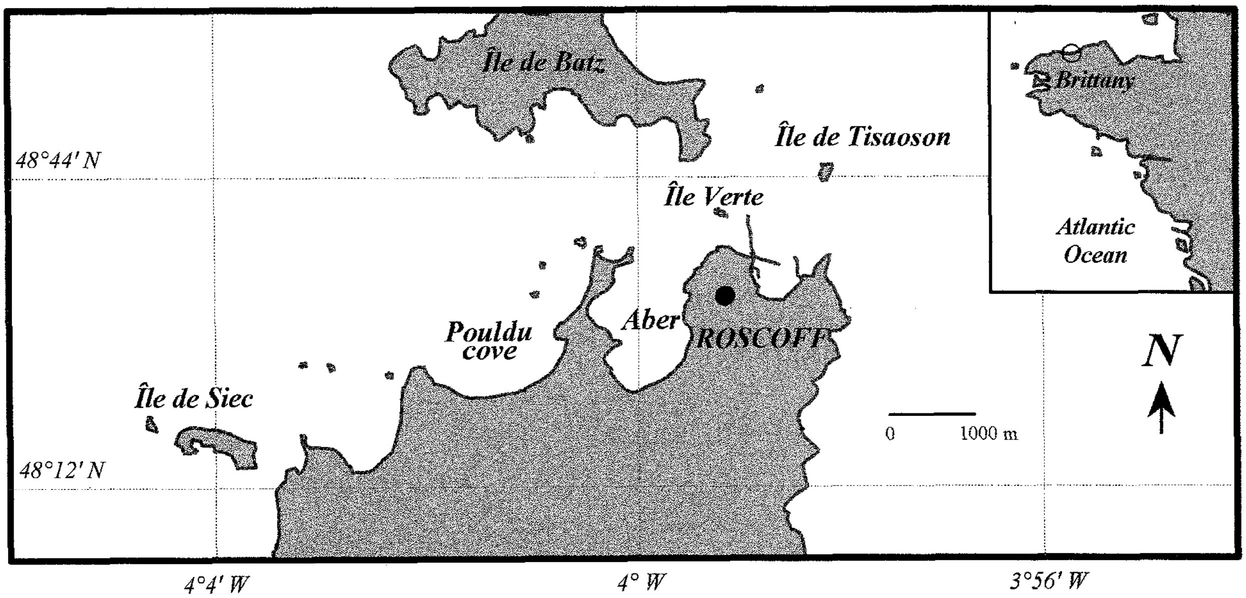

Figure 1. Location map of the site study.

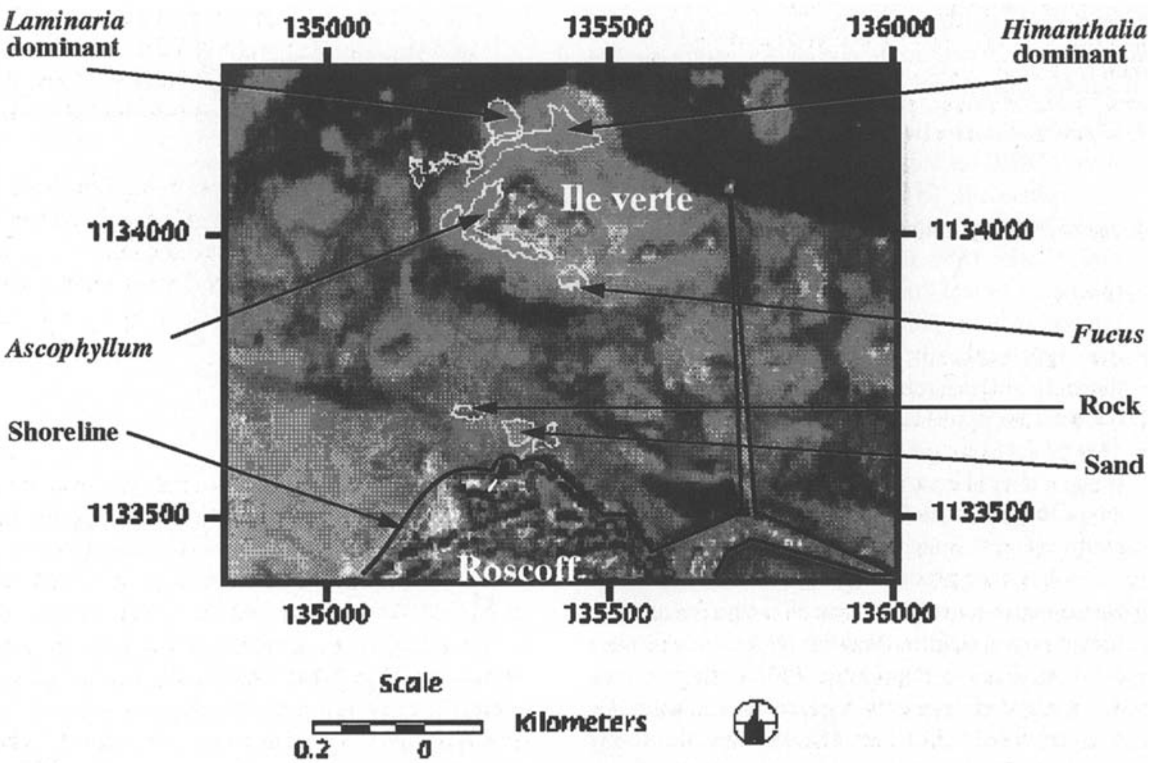

Figure 2. Homogeneous training areas positioned with GPS overlayed on a raw image extract (Lambert 1 projection).

allowed. Bands positions were determined according to *in situ* spectrometry analysis.

Data processing

PV-wave software was used for Spectron 590 data processing. Digital processing was carried out using digi-

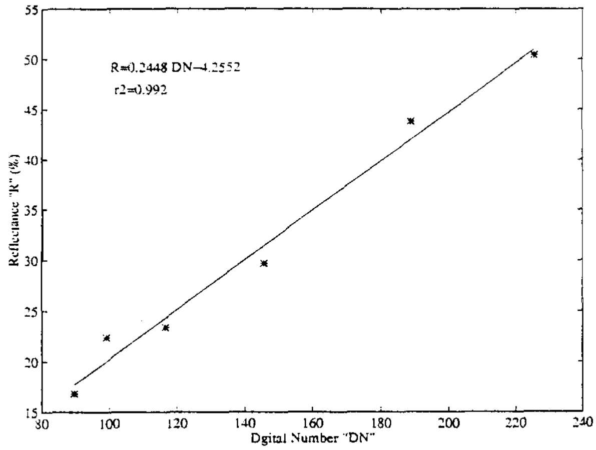

Figure 3. An example of a linear fit between Spectron Reflectance (field data) and digital number (airborne data) established for channel 11.

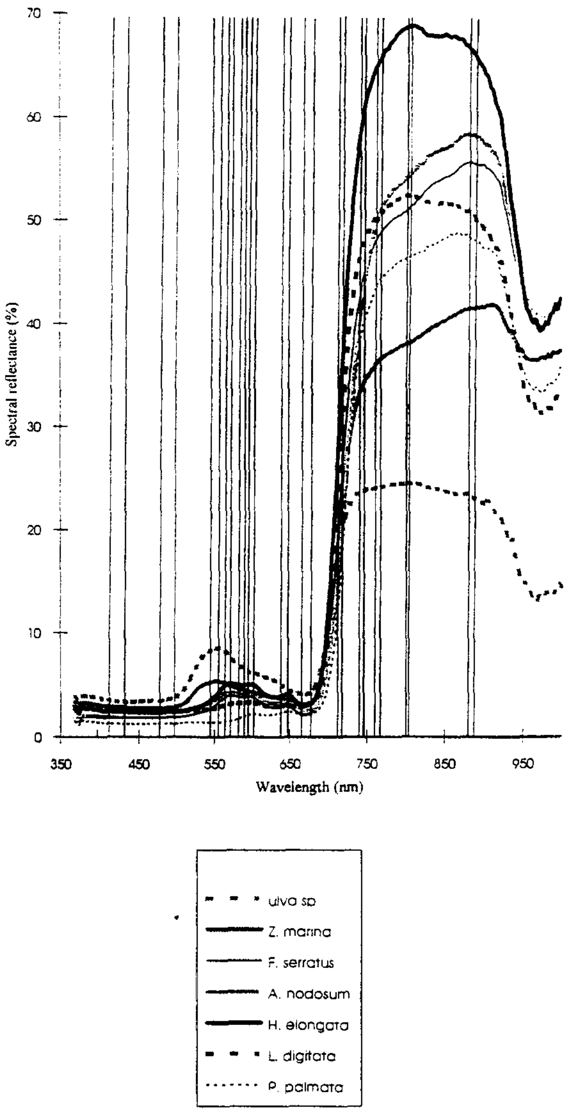

Figure 4. Ground reflectance plots of intertidal seaweed species during low tide. The strokes show the placement of CASI spectral bands.

tal mapping (Intergraph Microstation version 4.1) and image processing (Erdas Imagine version 8.1) softwares running on Sparcstation. Two preliminary procedures were carried out to correct for geometric and radiometric distortions.

1. Geometric correction: CASI data were received from ITRES on video tapes. Data were corrected for airplane roll. To rectify the images geometrically, IGN topographic maps (Lambert 1 projection grid, Clarke 1880 ellipsoid) were used. The GCP (Ground Control Point) method consists of selecting conspicuous points in the image and precisely matching them to their geographical coordinates on the map. Map coordinates are assigned to the image data and the pixels are resampled to conform to the map projection grid. In spite of geometric corrections, it should be noted, by overlaying the digitalized shoreline, that distortions remain. Only a well georeferenced image extract, containing training areas, has been processed (Figure 2).
2. Radiometric correction: It is necessary to convert sensor output (Digital Number DN) to values independent of atmospheric conditions, these values are surface radiance or surface reflectance. We have received CASI data in SRU (Spectral Radiance Units). Calibration of imaging spectrometer data to reflectance based on pseudo-invariant features (Miller *et al.*, 1990) can be used for atmospheric scattering and uncertainties in sensor. Relationship between sensor response and *in situ* data was established using six pseudo-invariant features. Thus, for each band, linear fit between airborne data (DN) and field data resulting from Spectron 590 reflectance was determined and applied to the image. Significant correlation coefficients are between 0.87 and 0.99. Figure 3 shows an example for band 11.

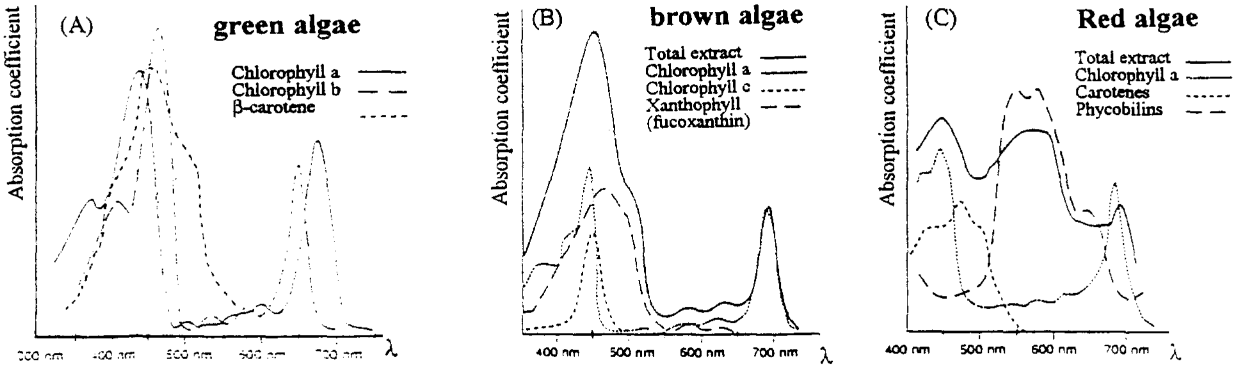

Figure 5. Absorption spectra of algae photosynthetic pigment (In Robert & Roland, 1989).

Results and discussion

Spectroradiometric field measurements

In order to characterize optical properties of denuded substrate and vegetation cover, reflectance data were collected for various homogeneous and emerged targets.

Soils spectra have spectral characteristics related to both their mineral composition and structural properties. The results are similar to those obtained by Guillaumont (1991). In the visible and near infrared ranges spectra show increasing reflectance with increasing wavelength. A slight absorption appears at 690 nm as is the case for vegetation. This absorption may be due to adhering algae and chlorophyll matter detritus.

The visual inspection of typical reflectance spectra of intertidal vegetation (Figure 4) reveals spectral characteristics similar to those of terrestrial vegetation (Gates *et al.*, 1965; Herrmann *et al.*, 1988; Rock *et al.*, 1988). Reflectance is lower in the visible bands, increases significantly in the near infrared and stays high in the entire infrared region.

In the visible region (400–700 nm), plant cells contain photosynthetic pigments that intercept light, either reflect or absorb it. Differences in pigments mixture (Figure 5) explain differences in specific spectral signatures. In the blue band, all species are characterized by low reflectance due to chlorophyll and some carotene absorption. Reflectance increases in the green region because decreased absorption by chlorophyll. Another region of high absorption by chlorophyll occurs in the red band.

In addition to chlorophyll *a*, green algae (Chlorophyta) have chlorophyll *b* which exhibits *in vivo* absorption peaks at 470 nm and 650 nm (Figure 5A).

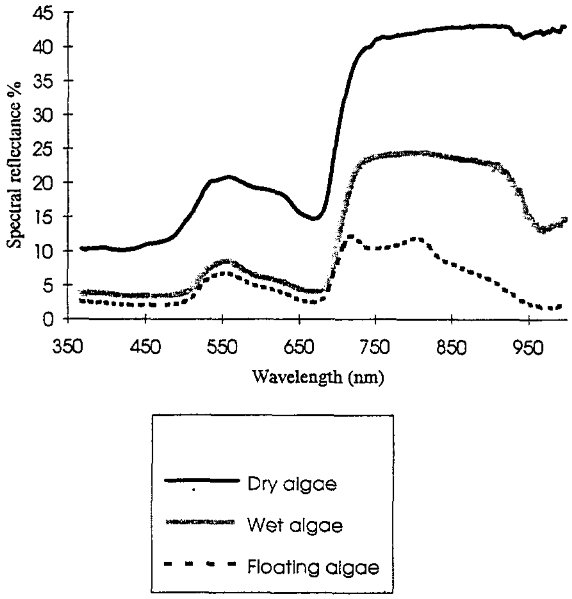

Figure 6. Ground reflectance plots of *Ulva* sp. (Chlorophyta) in various moisture levels.

As for chlorophyll *a*, these absorption peaks are in the blue and red parts of the spectrum, but are closer together. Chlorophyta also contain β-carotene with an absorption peak only in the blue wavelengths.

The colour of brown algae (Phaeophyta) is mainly the result of fucoxanthin (Figure 5B). This pigment causes a relatively high *in vivo* absorption in the spectral range of 500–560 nm (Kirk 1977). That is why Phaeophyta reflectance spectra (*Fucus serratus, Ascophyllum nodosum, Himanthalia elongata and Laminaria digitata*) are lower in the green part of the spectrum than Chlorophyta. In addition to chlorophyll *a*, the brown algae have chlorophyll *c*. Its absorption peak in the blue is lower than the main absorption peaks of chlorophyll *a*. For the red algae (Rhodophyta), the green window in the absorption spectrum of chlorophyll *a* is filled by the water-soluble phycobiliproteins, which have high absorption in the range of 500–650 nm (Figure 5C). That is why the level and peaks of *Palmaria palmata* reflectance are less marked than those of other algae across the visible region.

The spectral response of seagrass *Zostera marina* in the visible region of the spectrum is similar to green vegetation but not as well defined as Chlorophyta or other seagrass like *Talassia testudinum* (Armstrong, 1993).

In the near infrared region (700–1000 nm) the reflectance plots of all algae groups exhibit high values. The mechanisms behind this observation are not completely understood. Two phenomena contribute to the total reflectance in this spectral region : The first one is the surface reflection which can be modified, both in the visible and in the near infrared, by characteristics of the vegetation superficial layer (Grant, 1987). The second one is internal scattering. Inter-cellular spaces are the principal cause of light diffusion. Thus the anatomical organization defines optical properties in the near infrared. (Sinclair *et al.*, 1973; Grant, 1987; Grant *et al.*, 1987).

Other parameters in relation to the intertidal environment can be related to the reflectance. During flooding conditions, due to absorption by water, reflectance decrease principally in the near infrared wavelengths (Ben Moussa *et al.*, 1989; Zacharias *et al.*, 1992; Malthus, 1993; Zibordi *et al.*, 1990). Figure 6 shows the variation of reflectance spectra under various *in situ* moisture and floating condition.

Bandset selection and classification algorithm

As was mentioned before, appropriate CASI bandsets can be selected for each application. Of course, the discrimination power is stronger using a high number of bands. In the case of intertidal seaweeds, Zacharias (1992) showed that discrimination between algal genera is possible with a small number of CASI spectral bands. Submerged, floating and emergent vegetation can be clearly distinguished as well (Zibordi *et al.*, 1990; Malthus, 1993). Taking into consideration flight parameters, 13 bands were available. To allow an optimal species discrimination, analysis of the SPECTRON spectra were conducted to determine number, width and placement of the CASI bandset.

Table 1. Spectral CASI bandsets (nm) selected for intertidal seaweed application at 3000 m of aircraft altitude.

Band 1	415.5–434.7
Band 2	480.4–499.7
Band 3	547.7–558.3
Band 4	567.2–574.4
Band 5	585.0–592.2
Band 6	597.5–604.7
Band 7	640.4–649.4
Band 8	667.3–679.9
Band 9	715.8–721.2
Band 10	744.6–750.1
Band 11	764.5–771.7
Band 13	885.7–892.9

CASI bands were placed according to the morphology of the spectral curves and separating wavelengths. The choice took into account pigments and structural species characteristics (Figure 4). Moreover, it was necessary to consider limitations of CASI calibration and sensibility as well as atmospheric and water absorption wavelengths. The resulting bandset is shown in Table 1.

In this work, only homogeneous and dense covers are considered. The first step in image processing is to separate high cover area from the low or middle ones. The vegetation cover index VCI (Guillaumont *et al.*, 1993) was used.

A sequential algorithm was built using either threshold or bands intercomparison (Figure 7) to distinguish between different species. The visible region allows discrimination between green, red and brown algae. This is due to the different pigment mixtures for the three groups. It seems that the infrared spectral region allows us, in addition to detecting emergent and floating algae, to distinguish between seagrass and the two major groups of brown algae: *Fucus/Ascophyllum* and *Himanthalia/Laminaria.*

Preliminary classification of imagery

The overall results obtained from a case study with data taken over the Roscoff area are shown in Figure 8. Reference pixels, for which the class is known, were compared to classified ones. This procedure allows classification accuracy assessment. The results are given in Table 2. 85% of pixels are correctly classified. The two groups *Fucus/Ascophyllum and Himanthalia/Laminaria* are well discriminated. Neither *Ulva*

Table 2. Pixel counts of classes on accurate fieldwork areas and classification accuracy. (Sub =substrate, LC = low cover, F/A = *Fucus* and *A. nodosum*, H/L = *H. elongata* and *L. digitata*, RA = Red algae).

	Image					
In situ	Sub	LC	F/A	H/L	RA	Total
Sub	268 (95%)	13 (5%)				281
LC	11 (7%)	138 (88%)	7 (5%)			156
F/A		36 (10%)	307 (83%)	15 (4%)	12 (3%)	370
H/L		37 (8%)	52 (12)	356 (78%)	9 (2%)	454
Correctly classified = 1069/1261 = 0.85 = 85%						

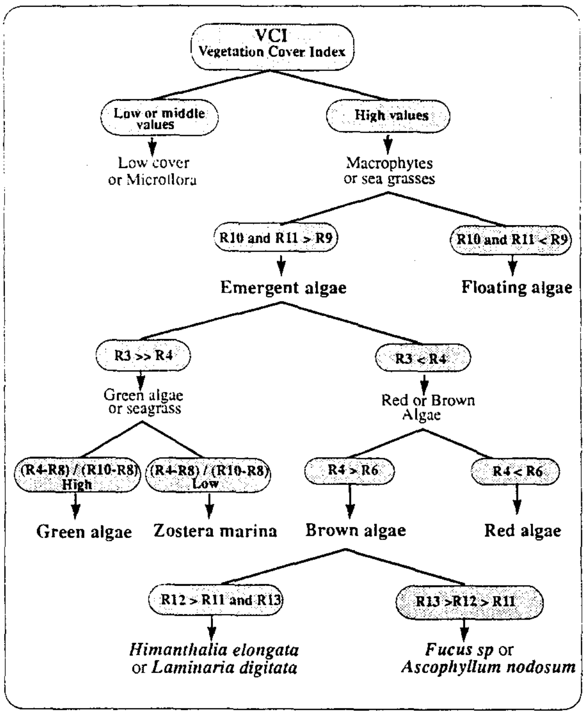

Figure 7. Algorithm for intertidal seaweed discrimination established from SPECTRON 590 spectral signatures (*Rn: Reflectance for channel n).*

nor *Zostera* were revealed. For *Ulva*, there is no patch in the Roscoff zone larger than the pixel size (5.5 m). This genus can probably be detected with a finer spatial resolution. CASI data acquired simultaneously at 1500 meter with a pixel size of 2.8 meter, might reveal these small *Ulva* patches. *Zostera* was consistently classified in the low vegetation cover category because of the soil background (Curran, 1981). Even though it is found in patches larger than the pixel size its low density induces a substratum effect that modifies its reflectance.

Moreover, some pixels were wrongly classified. This may be caused by heterogeneous pixels. Further work, particularly a mixing model elaboration, may prove to be suitable to improve the classification.

Conclusions

This study combines ground based spectrometric data and airborne imagery to investigate spectral characteristics of intertidal seaweeds for their discrimination and classification. A theoretical algorithm was established from SPECTRON 590 SE reflectance data and the main results are the following: (a) the visible spectrum region allows good discrimination between green, red and brown algae, (b) the infrared region allows separation of two main types of brown species. The infrared region also permits the identification of seagrass and floating seaweeds.

The CASI instrument gives a high dynamic range. The data navigation system used does not fully eliminate geometric distortions. This effect contributes to difficulties in ground and image data comparison. This will be solved in the future by using differential GPS image navigation. Slight differences occur between ground reflectance spectra and calibrated image data. Other calibration procedures must be tested for radiometric correction. Several CASI improvements are also announced, including direct measurements of incident light and GIS compatibility (Anger *et al.*, 1994).

At the present time not all species with a characteristic ground spectral signature are identified on the image. However, the preliminary results show that in addition to green, red and brown algae identification it seems possible to distinguish between two major groups of brown algae *Fucus/Ascophyllum* on one side

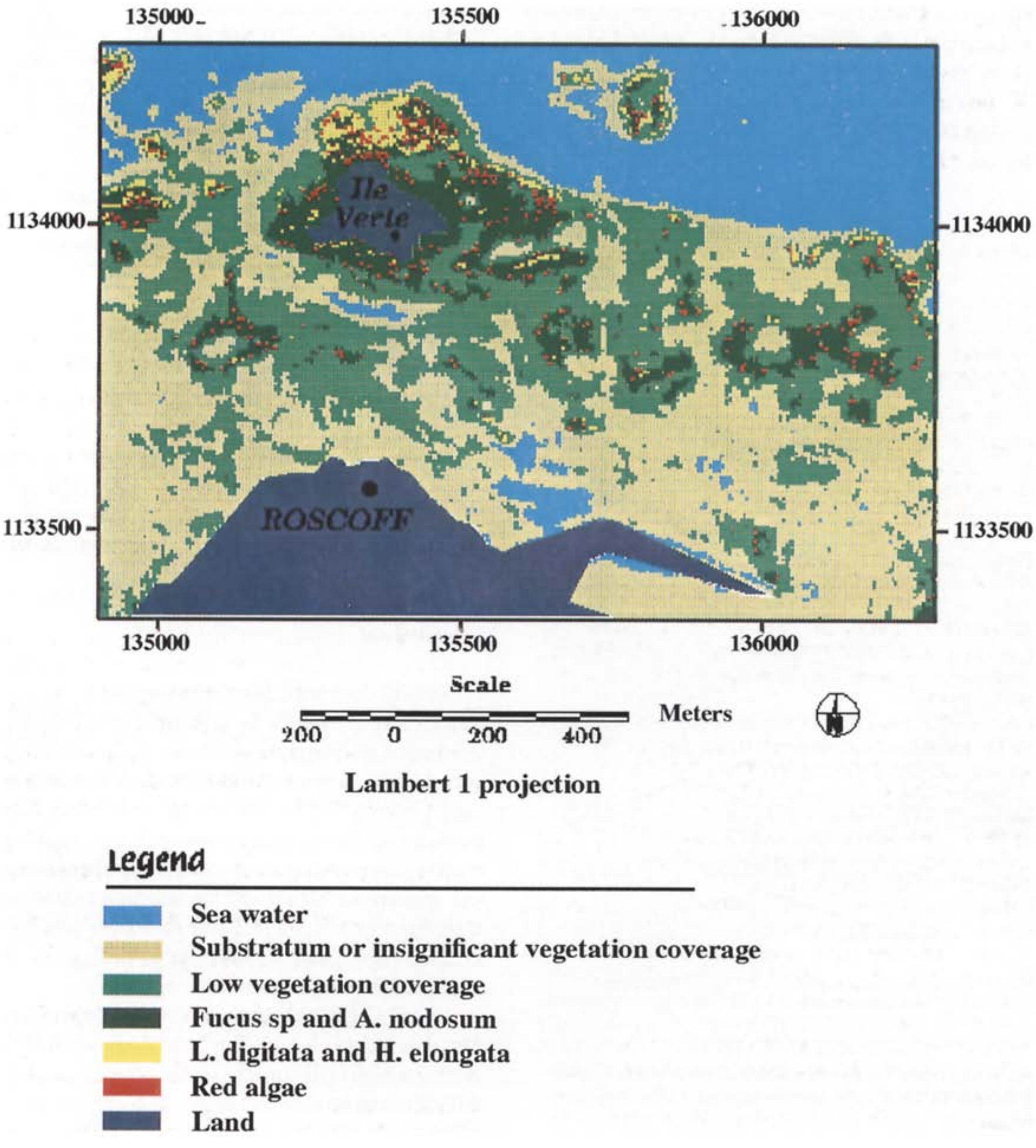

Figure 8. Ile verte preliminary seaweed classification.

and *Himanthalia/Laminaria* on the other side. The comparison of CASI data with mixed pixel simulations of expected composite reflectance spectra may give a more accurate classification. Finer spatial resolution CASI data remains to be tested.

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References

Anger, C. D., S. Mah & S. K. Babey, 1994. Technological enhancements to the Compact Airborne Spectrographic Imager (CASI). Proceedings of the First International Airborne Remote Sensing and Exhibition. Strasbourg, France, 11–15 September 1994: 205–211.

Armstrong, R. A., 1993. Remote sensing of submerged vegetation canopies for biomass estimation. Int. J. Rem. Sen. 14: 621–627.

Austin, A., & R. Adams, 1978. Aerial colour and colour infrared survey of marine plant resources. Photogram. Eng. Rem. Sens. 44: 469–480.

Belsher, T., L. Loubersac & G. Belbeoch, 1983. Télédétection et variation du phytobenthos intertidal. Oceanolog. Acta, Actes du 17ème Symposium Européen de Biologie Marine. Brest, 1982: 11–14.

Ben Moussa, H., M. Viollier & T. Belsher, 1989. Télédétection des algues macrophytes de l'Archipel de Molène: Radiométrie de terrain et application aux données du satellite SPOT. Int. J. rem. Sen. 10: 53–69.

Borstad, G., 1992. Ecosystem surveillance and monitoring with a portable airborne imaging spectrometer system. First Thematic Conference on Remote Sensing for Marine and Coastal Environments, New Orleans, Louisiana, USA, 15–17 June 1992: 883–892.

Curran, P. J., 1981. Multispectral remote sensing for estimating biomass and productivity. In H. Smith (ed.), Plants and Daylight Spectrum. Academic Press, London.

Davy De Virville, A., 1962. La flore marine de la presqu'île de Quiberon. Rev. Gén. Bot. 69: 89–152.

Floch, J. Y., 1967. Cartographie de la végétation marine et observations écologiques dans l'archipel de Molène (Finistère). Thèse 3ème cycle, Univ. Rennes (France), 135 pp.

Gates, D. M., H. J. Keegan, J. C. Schleter & V. R. Weidner, 1965. Spectral properties of plants. Applied Optics 4: 11–20.

Goedheer, J. C., 1970. On the pigment system of brown algae. Photosynthetica 4: 97–106.

Grant, L., 1987. Diffuse and specular characteristics of leaf reflectance. Remote Sens. Environ. 22: 309–322.

Grant, L., C. S. T. Daughtry & V. C. Vanderbilt, 1987. Variation in the polarized leaf reflectance of sorghum bicolour. Remote Sens. Environ., 21: 333–339.

Guillaumont, B., 1991. Utilisation de l'imagerie satellitaire pour les comparaisons spatiales et temporelles en zone intertidale. In M. Elliot & J. P. Ducrotoy (eds): Estuaries and Coasts: Spatial and Temporal Intercomparisons, ECS 19 Symposium: 63–68.

Guillaumont, B., L. Callens & P. Dion, 1993. Spatial distribution and quantification of *Fucus* species and *Ascophyllum nodosum* beds in intertidal zones using Spot imagery. Hydrobiologia (Dev. Hydrobiol. 85): 260/261: 297–305.

Gower, J. F. R., G. A. Borstad, C. D. Anger & H. R. Edel, 1992. CCD based imaging spectroscopy for remote sensing: The FLI and CASI programs. Can. J. Remote Sens. 18: 199–208.

Herrmann, K., B. N. Rock, U. Ammer & H. N. Paley, 1988. Preliminary assessment of airborne imaging spectrometer and airborne thematic mapper data acquired for forest decline areas in the Federal Republic of Germany. Remote Sens. Environ. 24: 129–149.

Jacobs, R. P. W. M., 1979. Distribution and aspects of the production and biomass of seagrass, Zostera marina L., at Roscoff (France). Aquat. Bot. 7: 151–172.

Joubin, M. L., 1909. Recherches sur la distribution oceanographique des vegetaux marins dans la region de Roscoff. Annales de l'Institut Oceanographique 1: 1–17.

Kirk, J. T. O., 1977. Thermal dissociation of fucoxanthin-prothein binding in pigment complexes from chloroplasts of *Hormosira* (phaeophyta). Plant Sci. Lett. 9: 373–380.

Malthus, T. J., 1993. Remote sensing of macrophytes in lakes. Proceeding of the NERC Symposium on Airborne Remote Sensing, West Parque Centre, University of Dundee, 20 and 21 December 1993: 57–69.

Miller, J., C. Elvidge, B. Rock & J. R. Freemantle, 1990. An airborne perspective on vegetation phenolgy from the analysis of AVIRIS data sets over the Jasper Ridge Biological Reserve. Proceedings of IGARSS 90, Washington, D. C., May 20–24, 1990: 565–568.

Perez, R. & J. Audouin, 1973. Repartition des grands champs d'algues brunes sur les côtes françaises de la Manche Occidentale entre l'île Grande et l'île de Siec. Science et pêche, Bull. Inst. Pêches marit. 226: 1–12.

Robert, D. & J. C. Rolland, 1989. Biologie Végétale. I - Organisation Cellulaire. Doin ed., Paris, 265 pp.

Rock, B. N., T. Hoshizaki & J. R. Miller, 1988. Comparison of *in situ* and airborne spectral measurements of the blue shift with forest decline. Remote Sens. Environ., 24: 109–127.

Rollin, E. M. & E. J. Milton, 1991. U.K. Natural Environments Research Concil (NERC) Equipment Pool for Field Spectroscopy (EPFS). In the Proceedings of 5th International Colloquium on Physical Measurements and Signatures in Remote sensing, Courchevel (France), 14th-18th Jan. 1991. ESA SP-391, May 1991: 837–839.

Sinclair, T. R., R. M. Hoffer & M. M. Schreiber, 1973. Diffuse reflectance hypothesis for the pathway of solar radiance through leaves. Agron. J. 65: 276–283.

Sournia, A., J. L. Birrien, B. Douville, B. Klein & M. Viollier, 1987. A daily study of the diatom spring bloom at Roscoff (France) in 1985. I. The spring bloom within the annual cycle. Estuar. coast. shelf Sci., 25: 355–367.

Viollier, M., T. Belsher & L. Loubersac, 1985. Signatures spectrales des objets du littoral. Proceedings of the 3rd International Colloquium on Spectral Signatures of Objects in Remote Sensing, Les Arcs, France, 16–20 Dec. 1985. ESA SP 247 (Noordwijk: ESA, ESTEC): 253–256.

Zacharias, M., O. Niemann & G. Borstad, 1992. An assessment and classification of a multispectral bandset for the remote sensing of intertidal seaweeds. Can. J. Remote Sens. 18: 263–274.

Zbinden, R.M., 1985. Les réflectances des sédiments d'estran: Résultats de mesures *in situ* et d'une simulation Spot en Baie du Mont Saint Michel. Proceedings of the 3rd International Colloquium on Spectral Signatures of Objects in Remote Sensing, Les Arcs, France, 16–20 Dec. 1985. ESA SP 247 (Noordwijk: ESA, ESTEC): 257–263.

Zibordi, G., F. Parmiggiani & L. Alberotanza, 1990. Application of aircraft multispectral scanner data to algae mapping over the Venice Lagoon. Remote Sens. Environ. 34: 49–54.