Forestry and the environment: challenges for near infrared spectroscopy

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Introduction

The population of the world is now just over 6 billion and is expected to increase by 80 million per year and reach about 8 billion by the year 2025. The demand for food, especially food which supports and promotes the health of humans, will increase accordingly and place enormous pressure on the agricultural sector.[1] But the increase in population will also place additional burdens on the non-agricultural sectors of the environment to provide food, fibre, minerals, building materials, firewood, medicines and a buffer to change. The environment is also expected to provide attributes, such as scenery, wilderness opportunities, sites of cultural significance, which contribute to human well being (Figure1).

It is clear that there is some urgency to the task of identifying the assets of forests and the environment in general. Technologies are needed that enable us to monitor systems with a view to preserving or improving productivity, or to ensure that they are utilized in an efficient and sustainable manner (Table 1.). Analytical techniques, including NIRS will play an important role in identifying, monitoring and enhancing assets.

Why NIRS?

NIRS is an analytical technique which lends itself to monitoring many aspects of forestry and environmental ecosystems. Its advantages include nil or minimal sample preparation, relatively low cost per sample in routine use, is rapid and non-destructive, does not requires laboratory grade facilities, and makes possible simultaneous multi-constituent analysis. NIRS instruments are available for determinations under laboratory conditions, or in the field using hand-held and remote from sample equipment. The samples size can be in the range from microscopic, through to single plant or crop, to a portion of the landscape.

In this paper I wish to examine some of the applications of NIRS to identifying, measuring and monitoring the basic components of the environment. The assets of forests and the environment in general include the sum of the natural resources, namely rocks / soil, air, water, plants (trees), and microscopic and macroscopic animals. The proportions and the composition of each varies according to the natural history of the region, current evolution and direct and indirect impacts of human activities. With an understanding of the basic resources as the indicators of the health and sustainability of forests and the broader environment decisions are possible as to their future management.

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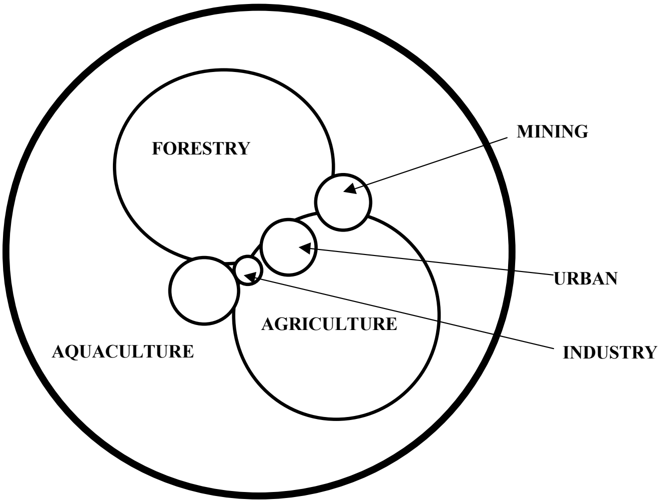

Figure 1. The world environment includes agricultural, forestry and aquaculture systems which frequently overlap

Table 1. Scale of human impact on the environment and a forest ecosystem.

Condition	Environment	Forest
Pristine or Wilderness	World heritage value.	World heritage forest.
Limited utilization	Limited use for fishing, tourism, etc.	Selective economic production.
Utilized	Sustainable use, Aesthetic values maintained.	Sustainable forestry.
Over utilized	Declining productivity.	Opportunistic use, e.g., slash and burn.
Degraded system	Negative aesthetic value. Limited economic returns.	No economic returns
Destroyed	Non restorable system. Blot on the landscape. Threat to productivity of adjoining areas.	Not economical to restore the area. Blot on the landscape. Threat to productivity of adjoining areas.

Monitoring The Components Of A Forest Or An Environment Using NIRS

Analysis of rocks and soil by NIRS

The composition of rocks determines the physical and chemical properties of soils and, along with the climate, has a major impact on the ecosystem which develops and its stability. NIRS spectra of rock and soil are generally rather featureless but examination of individual constituents of rock or soil indicate contrasting spectra. In the 1970's R Hunt and co workers[2] reported the visible and NIR spectra of many types of rocks. Those and later studies with smectite minerals[3] and hydrotalcites and brucites[4] indicated a high correlation of chemical composition to overtones and combinations of various OH-cation fundamental modes.

The mining sector utilizes NIRS for the analysis of rocks and their weathered products. Examples include differentiation of valuable from uneconomical deposits in bauxite pisoliths[5] and the direct determination of aliphatic carbon in petroleum source rocks by near-infrared microspectroscopy.[6] Satellite and air-borne hyperspectral imaging are also used to detect potential ore-bearing regions.[7]

NIRS calibrations have been reported for a range of soil properties including organic C and N, total humic plus fulvic acids, pH, sand/clay content, CEC and exchangeable cations.[8,9,10] While most of these studies originated in the agricultural sector the calibrations can be extended to forestry and the general environment. Calibrations for the determination of organic C and N appear to be robust[11] but calibrations for other properties, such as available phosphorus, biological activity and mineralisation, may not be reliable outside the population used to develop the calibrations.[9,12,13,14,15] Alternatively, NIRS has proven useful for categorizing soils, as low, moderate, high or very high mineralising potential, in a routine soil analysis laboratory.[16]

The detection of the contamination of soil by hydrocarbons (petroleum products) is an apt use of NIRS, capitalising on the contrasting absorbances of the mineral-dominated soil and the C-H dominated contaminant.[6,17,18] Examples such as these demonstrate that NIRS can make a significant contribution to landscape monitoring and management during remediation (Table 1.).

Analysis of air by NIRS

Air moves between all sectors of the environment and may have positive or negative influences. Of greatest concern are any compounds which threaten the productivity or health of human beings, animals, vegetation or the whole ecosystem.

There are numerous recent reports of detection of several gases at sub ppm concentrations in the air using NIRS, e.g., N_2O,[19,20] CO_2,[19,21] H_2S,[22] methane,[23,24] NH_3,[25] CO,[21, 25] and water.[21] These reports should encourage the development of further calibrations for useful and contaminant gases in the atmosphere. Monitoring of the air at key positions across the globe, using NIRS, could contribute to the management of natural, urban, mining and industrial emissions which impact on the environment and forests.

Analysis of water by NIRS

An NIR spectra of water was published in 1951[26] and absorptions at 1450, 970 and 760 nm were assigned to the first and third overtones of OH stretch and absorption at 1490 to a combination band of OH stretch.[27] The earliest studies of the potential of NIRS to determine water in samples include

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reports cited by Karl Norris in his landmark papers with Hart and Golumbic,[28,29] and other studies.[30,31]

Moisture is now routinely determined using NIRS in samples which have a very wide range in water content. While NIRS can be used to determines sample water content accurately in heterogeneous samples,[32] it also offers an ability to study the forms of water and their interaction with biological samples.[33] Reeves[34,35] examined the effects of water on NIRS spectra of various high moisture content samples. He concluded that *"changes induced by water in the spectra of various materials are very complicated".* Never-the-less, there are sufficient examples of water analysis using NIRS to encourage more applications in environmental situations. The salinity of sea water and sodium chloride solutions can be determined by NIRS, but temperature has a strong influence on the reliability of the calibrations unless measures are taken to eliminate the interference.[36,37,38] Online analysis of ground water salinity using NIRS with an optic fibre probe has been suggested.[39] Detection of contamination of water from aromatic hydrocarbons and organic contaminants has also been reported.[40,41]

A novel application of NIRS is the use of visible and NIR bands from Landsat MSS AND Landsat TM images to model snow melt in the Italian Alps.[42] The model did not adequately predict snow water equivalent.

Applications of NIRS to forest and environmental vegetation

Forests (Table 1.) provide a wide range of wood products which are utilized in almost every society on earth. Timber is used for the construction of houses, bridges, agricultural implements, weapons and ornaments while the wood pulp is used to produce paper products. Forests have enormous importance in stabilising the soil surface and filtering impurities from water and air. Forests are the primary source of food for many communities. Forests are a largely unknown pool of biodiversity.

When NASA launched the LANDSAT multispectral (visible and near infrared wavelength) recorder into space (altitude 185 km) in 1972 it offered the ability to record variation across the earth's surface due to rock, soil, water and vegetation differences at a spatial resolution of 80 m. This and subsequent developments in airborne and satellite-mounted recorders have boosted interest in spatial analysis of the earth's surface.[43,44]

Analyses of plant material constituents using NIRS were first reported in the 1970's for commercial forage crops [45,46] and subsequently for an increasing range of species and constituents.[47-54] Analysis of plants in the non-agricultural sector and of forest trees using NIRS are logical applications of NIRS.

Recent NIRS applications which should attract the interest of environmental and forestry groups include the work of Foley[55] who has shown that the compound sideroxylonal in leaves of *Eucalyptus* spp determines the acceptability of individual trees to grazing by Koala. This work, and the application of NIRS to predict animal intake patterns,[56] will enhance the ability of park rangers to manage wildlife.

Schultz *et al*[57] have shown that NIRS is a reliable method by which to determine, simultaneously, constituents such as terpenoids, alkaloids or phenolic substances in numerous medicinal and spice plants. This pioneering work should inspire scientists who are seeking health-promoting products from forest species.

NASA, through the accelerated canopy chemistry program sought to determine the carbon and nitrogen budgets of forest foliage. Clearly this is a major challenge due to the diversity of species and ecosystems across the planet and the cost and time required to collect satellite spectra and the ground truth. NIRS calibrations have been published for determining nitrogen, cellulose and lignin concentrations in dry ground native woody plants.[58,59,60] and in fresh whole leaf samples (analysed in the laboratory).[61] It has been suggested [61] that spatial mapping of nitrogen in an ecosystem would require spectral data from airborne spectrometers with a resolution approaching that available in the laboratory (e.g., 2 nm resolution).

Today, almost 10 years later, there are satellites which carry spectrometers, such as Hyperion (or HYMAP), capable of recording from 400 to 2500 nm.[7,43] However, the data from these recorders is either not available due to cloud cover preventing data collection, is not backed up by ground truth data, or the cost to purchase the data exceeds the budgets of potential users.

Commercial forestry

The increasing demand for, and hence increases in value of, forest products has prompted considerable research into how to identify and quality the economically valuable sources of wood and wood products. Trees represent a medium to long term investment so a high growth rate has a significant influence on time to harvest and final yield. Demand for paper products has increase twice as rapidly as the demand for grain and water and some other resources in the last 40 years.[62]

The yield of pulp, defined as the *"percentage of the original mass of wood fibre remaining after kraft pulping to a given content of residual lignin"* can now be estimated rapidly and reliably without destructive sampling, using NIRS and trees with a high individual yield potential can now be identified in a forest. When only the high yielding trees are harvested there are large economic gains in efficiency.[63] The work by Schimleck's group[63,64,65] has 'opened a door' to rapid and affordable forestry. Moisture and the mechanical properties of hard woods are also being determined using NIRS.[66] A major advantage of NIRS, over techniques such as acoustic testing, is that NIRS can also determine the key properties of the wood being analysed.

The Challenge

A brief glance again at Figs 1 and 2 should reaffirm that there is an urgent need to understand and secure the environment. NIRS must be part of that challenge and it is pleasing to see at this conference many papers which take NIRS further into the environmental and forestry sectors.

A challenge for NIRS scientists is to apply the techniques developed during the pioneering phase, mostly with commercial agricultural samples, into the more diverse, and hence more challenging, environmental and forest areas.

NIR spectroscopists, who may have experience mainly from the agricultural sector, need to establish linkages and work together with environmentalists to better define and then solve real world problems. A part of this union is the need to better define the significance of the work, either in terms of tangible monetary costs or no-tangible but equally important, social, aesthetic etc benefits to mankind.

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