Assessing the Performance of HYPERION in Relation to Eucalypt Biochemistry: Preliminary Project Design and Specifications

Nicholas C Coops[1], Marie-Louise Smith[2], Mary E Martin[3], Scott V Ollinger[3],
Alex Held[4] and Steve J Dury[5]

[1] CSIRO Forestry and Forest Products
Private Bag 10, Clayton South, Victoria 3169, Australia.
E-mail: n.coops@ffp.csiro.au

[2] USDA Forest Service
Northeastern Research Station. P.O. Box 640, Durham, NH 03824, USA.

[3] Complex Systems Research Center, University of New Hampshire
Durham, NH 03824, USA.

[4] CSIRO Land and Water.
GPO Box 1666, Canberra ACT 2601, Australia.

[5] CSIRO Forestry and Forest Products
PO Box E4008, Kingston ACT 2604, Australia.

Abstract*- Vegetation function and dynamics are key parameters in terrestrial carbon cycle models. The strong linkages between foliar nitrogen, photosynthetic capacity and ecosystem productivity makes the development of methods to characterize spatial patterns of canopy bio-chemistry a potentially powerful approach for estimating forest carbon fluxes at a variety of scales. The challenge is to extrapolate results from individual leaves to regional scales to estimate carbon cycles across the landscape using combinations of inverse modeling and remote sensing. Hyperspectral remote sensing methods are advancing rapidly and offer the promise of estimating canopy pigment, bio-chemistry and water content dynamics, which can in turn be linked to carbon assimilation, forest growth and photosynthetic capacity models. This study was undertaken across eucalypt forest near Tumbarumba (Bago-Maragle State Forest), Australia which has a number of eucalypt species, ranging in productivity and age. EO-1 Hyperion imagery has been obtained and a detailed field program undertaken in February 2001. This program involved plot establishment, collected of standard forestry inventory data and the collection of leaf samples. From the sampled eucalypt leaves, individual leaf spectra were recorded, samples dried and a number of foliage bio-physical and bio-chemistry variables analysed. This dataset will form the basis of a comparison with spectral information available from the HYPERION sensor.

I. INTRODUCTION

The carbon and nitrogen cycle in forest ecosystems are linked through a number of common ecological processes [1]. Research in the past decade has demonstrated consistent, strong and generalisable relationships between foliar nitrogen and rates of net photosynthesis and leaf respiration [2]. At broader temporal and spatial scales, canopy nitrogen has been related to annual net primary production, litterfall N and N mineralization [3,4]. As a result, estimates of foliar nitrogen chemistry can provide an insight into terrestrial C and N cycles and thus be an useful indicator of ecosystem productivity [5].

Recent advancements in hyperspectral remote sensing indicate that a variety of independent measures of canopy properties are possible from satellite and airborne sensors including the concentration and total amount of nitrogen in canopies, leaf water content, lignin concentrations and other foliage nutrient status indicators [6,7,8]. Incorporation of these estimates of chemical composition into process models, as input parameters or constraints, will improve predictive capability and enable validation of regional assessments of growth and carbon accumulation. The use of hyperspectral remote sensing to predict canopy properties has been relatively limited, owing in part, to limited availability of hyperspectral data and to large data processing requirements. Nevertheless, interest in the approach has persisted and several new hyperspectral earth-observation sensors, such as NASA's Hyperion instrument, which was successfully launched in November 2000 as part of the NASA New Millennium Program EO-1 satellite platform, are now available.

II. STUDY AREA AND DATA COLLECTION

A. Study Area

The Tumbarumba (or Bago-Maragle) study area (E 148° 15' S 35° 45') is in southern New South Wales, Australia and covers an area of approximately 50,000 hectares of forest (Fig. 1). The study area is largely comprised of gently undulating plateau topography, falling off into deeply incised valleys and escarpments with tall eucalypt forests.

Fig 1: Geographic location of the Bago-Maragle State Forests in Southern N.S.W., Australia (taken from [9]).

Altitude varies from 400m in the north-east to a maximum of 1438m at Granite Mountain. It has a cool to cold moist sub-alpine climate with cold winters (daily range for July 8.2°C and –0.5°C and January 26.0°C and 10.6°C). Mean annual rainfall varies from 680-1800mm.

B. Data Collected

A total of 16 plots were located covering the range of eucalypt species present. These plots consisted of long term growth plots established by State Forest of NSW, research trial plots established by CSIRO Forestry and Forest Products and temporary inventory plots. Table 1 provides a summary of the species located at the plots.

At least 2 plots were located in each forest species type and the plots were measured in February 2001 coincident with a satellite overpass (EO-1). Plot size varied depending on the history of the initial plot establishment but covered a minimum of 0.1 hectares. At each plot diameter at breast height (DBH), and height of the four dominants was measured. In addition basal area, stocking, and average DBH were also calculated. Two dominant trees of each major species were identified and two upper canopy branches excised using a rifle. Current and previous year foliage (if present) were identified on each branch and leaf samples picked and stored in a cool environment. To determine specific leaf weight samples were collected and disks of known area were extracted from each leaf with a metal punch. Five to 7 disks were taken from 3 to 5 leaves per species per sample.

TABLE 1

Eucalypt Species, Authority, Common Name and abbreviation (used in this study) sampled.

Species	Common Name	Abb.
E. delegatensis R. T. Baker	Alpine Ash	AA
E. dalrympleana Maiden *subsp. dalrympleana*	Mountain gum	MG
E. macrorhyncha F. Muell. ex. Benth.	Red Stringybark	SB
E. pauciflora Sieb. ex Spreng. subsp. *pauciflora*	Snow gum	SG
E. albens Benth.	White box	BX
E. viminalis Labill. subsp. *viminalis*	Manna Gum	VM
E. bicostata Maiden, Blakey & Simmonds	Blue Gum	BG
E. *radiata* Sieb. ex DC. subsp. *robertsonii* (Blakely) L.Johnson & D.Blaxell	Narrow Leaf Peppermint	PM
E. mannifera Mudie subsp. *mannifera*	Brittle Gum	BG

Canopy total leaf area was estimated using a number of methods. Using a technique of [10] the species' fractional leaf area was achieved using a camera-based point quadrat sampling technique using a 35-mm camera with a telephoto lens calibrated to distance in meters. The lens is used as a range finder and has a grid of 15 points marked on the focusing screen. At the eight cardinal points of the plots perimeter (and the centre) the camera was directed upward and species and height of the lowest leaf covering each grid point was determined by focusing and recording the calibrated distance [3]. At each location, 15 grid point observations were taken making a total of 135 per plot.

In addition, hemispherical photography was captured at each of the 9 locations using the HEMIVIEW ™ which is a camera, lens and software system that allows information to be obtained on canopy geometry, Leaf Area Index, gap fraction and distribution of gaps in the canopy.

Fig 2: A hemispherical photo acquired at Bago-Maragle State Forests in February 2001.

C. Leaf Reflectance

Leaf reflectance measurements were acquired coincident with the recording of all additional forest inventory data assessments. Leaves from each sample were stacked six layers deep to cover an area of approximately 10 cm x 10 cm. Multiple layers rather than single leaf profiles were used to obtain the reflectance from a layer to approximate an infinite optical thickness [11]. Spectral reflectance measurements of leaves were acquired with an Analytical Spectral Devices (ASD) FieldSpec FR spectroradiometer, which senses in the spectral range 350 to 2500nm with a spectral bandwidth of 1.4 nm., and spectral resolution of 3–10nm. A 150 W halogen bulb and a fibre optic ring were used as the light source to illuminate the leaves. Ten reflectance measurements were averaged to obtain a mean reflectance spectrum. A spectralon panel was used as a "white" reference from which reflectance could be derived.

D. Foliar Chemistry

Once reflectance data had been collected, leaf samples were dried and ground through a mesh sieve and analysed for nitrogen, phosphorus and other nutrients using previously tested methods of near infrared spectroscopy (NIRS) [12,13]. In addition, wet leaf chemistry was undertaken on leaf samples.

E. Remote Sensing Data

A number of EO-1 HYPERION scenes were acquired over the Tumbarumba site, with three images being of good quality with little or no cloud cover. In addition to HYPERION imagery, a number of historical Landsat Thematic Mapper (TM) and Multi Spectral Scanner (MSS) scenes are available as well as a TM scene acquired coincident with the highest quality HYPERION scene (25th December 2001).

Finally, HYMAP™ airborne hyperspectral imagery was obtained over the site on 31st March 2001. HyMap™ is an imaging spectrometer providing coverage in the visible, near, shortwave and middle infrared in 100 - 200 bands with a bandwidth of 10 - 20 nm at 5m spatial resolution [14].

III. CONCLUSION

The challenge to extrapolate from leaf level biochemistry, to canopy and ultimately, forest stands is an important one for the remote sensing community. This project aims to build a strong and measurement-intensive scaling sequence from leaf chemistry to dried-leaf NIR to whole fresh leaf NIR to field-measured canopy nitrogen to airborne and finally satellite reflectance data. Similar work at other sites around the globe allows the findings to be places in context with other biomes and functional types.

ACKNOWLEDGMENT

This work was undertaken as part of a collaborative EO-1 science validation program of CSIRO EOC and NASA. We thank David Jupp, Jill Huntington and Ray Merton (CSIRO EOC) and Jay and Françoise Pearlman (TRW) whose efforts made this joint research program possible. We also acknowledge the considerable research effort already undertaken by CSIRO FFP staff at the Bago Maragle especially Phil Ryan, Heather Keith, John Raison, Partap Khanna, Kris Jacobson, John Smith, Peter Leppert and John Lamour. We thank Kris, John, Peter and John for help undertaking the field work. Guy Byrne and Paul Daniels provided logistical and equipment support.

REFERENCES

[1] S.V. Ollinger, M.L. Smith, M.E. Martin, R.A. Hallett, C.L. Goodale and J.D. Aber. "Foliar Chemistry and N cycling in forests". *Ecol.* (in press). 2001

[2] P.B. Reich., B. D. Kloeppel, D. S. Ellsworth, and M. B. Walters. "Different photosynthesis-nitrogen relations in deciduous hardwood and evergreen coniferous tree species". *Oecol.* 104: 24-30. 1995

[3] J.D. Pastor, J.D. Aber, C.A. McClaugherty, and and J. Mellilo. "Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin". *Ecol.* 65:256-268 . 1984

[4] Scott, N.A., and D. Binkley. "Foliage litter quality and annual net N mineralization: comparison across North American forest sites". *Oecol.* 111:151-159. 1997

[5] M.L. Smith, S.V. Ollinger, M.E. Martin, J.D. Aber, R.A. Hallett and C.J. Goodale. "Direct prediction of above ground forest productivity by hyperspectral remote sensing of canopy nitrogen". *Ecol. Appl.* (in review). 2001

[6] P. Matson, L. Johnson, C. Billow, J. Miller, and R. Pu. "Seasonal patterns and remote spectral estimation of canopy chemistry across the Oregon transect". *Ecol. Appl.* 4:280-298. 1994

[7] M.E. Martin and J.D. Aber. "Estimating forest canopy characteristics as inputs for models of forest carbon exchange by high spectral resolution remote sensing" - In: Gholz, H.L., Nakane, K., and Shimoda, H. (eds) *The use of remote sensing in the modelling of forest productivity*, Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 61-72. 1996

[8] G.M. Smith and P.J. Curran. "The estimation of foliar biochemical content of a slash pine canopy from AVIRIS imagery". *Can. J. Rem. Sens.* 21:234-244. 1995

[9] N.J. McKenzie and P.J. Ryan. "Spatial prediction of soil properties using environmental correlation". *Geoderma.* 89: 67-94. 1999

[10] J.D. Aber. "A method for estimating foliage-height profiles in broad-leaved forests". *J. Ecol*. 67:35-40. 1979

[11] J.A. Howard. "Spectral energy relations of isobilateral leaves". *Aust. J. Biol. Sci.* 19:757-766. 1966

[12] T. McLellan, M.E. Martin, J.D. Aber, J.M. Melillo, K.J. Nadelhoffer, and B. Dewey. "Comparison of wet chemistry and near infrared reflectance measurements of carbon-fraction chemistry and nitrogen concentration of forest foliage". *Can. J. Forest. Res*. 21: 1689-1693. 1991

[13] K.L. Bolster, M. E. Martin, and J. D. Aber. "Interactions between precision and generality in the development of calibrations for the determination of carbon fraction and nitrogen concentration in foliage by near infrared reflectance". *Can. J. Forest Res*. 26:590-600. 1996

[14] T. Cocks, R. Jenssen, A. Stewart, I. Wilson, and T. Shields. "The HyMap Airborne Hyperspectral Sensor: The System, Calibration and Performance". *Proc. 1st EARSeL Workshop on Imaging Spectroscopy* (M. Schaepman, D. Schläpfer, and K.I. Itten, Eds.), 6-8 October 1998, Zurich, EARSeL, Paris, p. 37-42. 1998.