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Effects of ionising radiation on the spectral properties of vegetation

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1. Abstract:

The effects of ionizing radiation on vegetation have been the subject of a great number of studies during the 'Cold war' period. The main objective was to assess the effects of a nuclear war or fallout on ecosystems. The research was essential for comprehending the response of plants to radiation or radioactive fallouts. Many radiobiological studies have found the biological response of vegetation to be a complex problem, and very little has been carried out on the spectral response of vegetation after exposure to ionizing radiation. The objective of this paper is to present the different scientific problems expected to be encountered in the research as well as a presentation of the background of the research itself. A brief review of two preliminary experiments will also be discussed.

2. Introduction:

In order to carry out an experiment involving the change in reflectance of irradiated plants in time and at different dose rates, one must first understand what are the factors controlling radiosensitivity of vegetation. In the case of ionising radiation, work carried out by a number of radiobiologists concludes that DNA amount and interphase chromosomal volumes are highly correlated to radiosensitivity of different species. Sparrow and Miksche (1961) reported high correlations between exposure to ionising radiation and either nuclear DNA or some other closely related character. A linear relation was found between the number of mutations per rad per locus and 1C DNA amount for different species (Abrahamson et al., 1973). Two main facts are to be remembered. Firstly, radiation damage comes from lesions originating from genomic DNA and secondly, the volume of DNA to be affected by ionisation is closely related to species radiosensitivity.

Radiosensitivity of higher plants varies 500-fold and is dependent on nuclear and chromosomal characteristics (Sparrow and Woodwell, 1962). Plants with low chromosomal numbers and large nuclear volumes are highly sensitive. A large nucleus will have higher probabilities of being struck by radiation than a smaller nuclear volume. Having more genomic matter provides a better chance for a cell to repair damage since it has more copies of genetic information. It is also held that plants with slow nuclear division rates are also very sensitive and this is due to their high interphase exposure time. Sparrow and Woodwell (1962) also determined that damage due to radiation highly affects sexual reproduction.

Overall then, there are a number of factors which control the effects of radiation on plants. These factors are usually intrinsic to the plant species (nuclear volume and chromosomal characteristics, level of ploidy, differential shielding i.e cryptophytes, size and shape of the plant dependant on nature of radiation and growth rates) or depend on external factors like dose rates (acute or chronic).

A report issued in 1987 by the U.S. Department of Energy was probably the most serious milestone backing up this type of research. Greatly based on the work of Arnold H. Sparrow, who was an expert in the domain of radiobiology at the National Brookhaven Laboratory, the americans used eight satellite images from Landsat-5 Thematic Mapper (TM),from April 1986 to May 1987 of the Chernobyl area just prior and after the 26 of April 1986 accident. Additional SPOT images were also used as a source of alternative information and higher resolution data. The objective of this study was to demonstrate the feasibility of using satellite image analysis in the assessment of radiation-induced damage in flora, particularly in conifers, due to the Chernobyl accident.
The conclusion of this report is very clear in that it indicates that (i) radiation effects can be detected using remotely sensed data of conifers, and (ii) the cumulative dose surrounding nearby conifers and local dose rates around the accident site can also be estimated using satellite imagery. However, this study failed to generate an explicit understanding of the relationships between irradiation and the change in spectral response of vegetation..

Furthermore, there is extensive scientific data relating to the degradation of biological, biochemical and physical characteristics of irradiated vegetation. At the same time, much work suggests that the degradation of certain aspects of vegetation can be detected via remote sensing techniques. Irradiated plants undergo significant changes in characteristics such as water content, biochemical composition, internal structure and canopy architecture and each of these changes have the potential to result in changes in spectral reflectance. However, this link between irradiation and the spectral response of vegetation has not been explored experimentally.

Therefore this study aims to answer several fundamental questions :
- Is there a quantifiable relationship between dose of radiation and the change in reflectance of plants and what are the limits of detectability?
- What is the physiological/physical basis of the effect?
- Are there differences in response between plant species/community types?
- What are the temporal characteristics of the spectral response following exposure?

Such information will enable us to evaluate the potential for applying satellite remote sensing of vegetation to monitor radioactive pollution that may arise from natural sources, mining activities, accidental releases and larger disasters at nuclear facilities, and even in the identification and surveillance of clandestine nuclear facilities.

3. Experimental setup and methodology:

Two preliminary experiments were undertaken at Brunel University under the supervision of Dr Peter Hobson and aimed to develop a larger campaign in which we hope to answer the questions mentioned above. The irradiation chamber at Brunel University is equipped with a 2 Curie Cobalt-60 gamma ray ionizing source. The first experiment comprised a community of 50 *Buxus Sempervirens* (Common Box) plants which were divided randomly into three groups (10 controls, 20 chronically irradiated plants, 20 acutely irradiated plants). The controls were kept in the same lighting conditions as the irradiated plants. Temperature and humidity remained constant during the experiment and all three groups were watered evenly. Samples of plants were placed at varying distances away from the source in order to generate a range of doses. The plants were placed on three different rows.in a semicircular fashion around the source so as to obtain similar dose rates on the same row. Using this technique, the plants were irradiated at doses varying from 0.45 Gy to 31.45 Gy (10% accuracy) for the third and first rows respectively. Due to dose rate problems, only the chronically irradiated and control groups were studied. Measurements were performed before (27/4/98) and after (9/5/98) irradiation . The field spectroscopy instrument used was the ASD Fieldspec which measures reflectance in the 350-2500 nm region.

In the second experiment a 50*75cm patch of mixed species grass lawn was used. As the source was in a fixed position, a range of doses were obtained across the lawn. This gave us the possibility of measuring a gradient in effects as well as having a more homogeneous canopy than in the first experiment. The ASD Fieldspec was again used to make measurements of reflectance, this time sampling at a matrix of points, at 5cm spacing across the lawn.

4. Preliminary results:

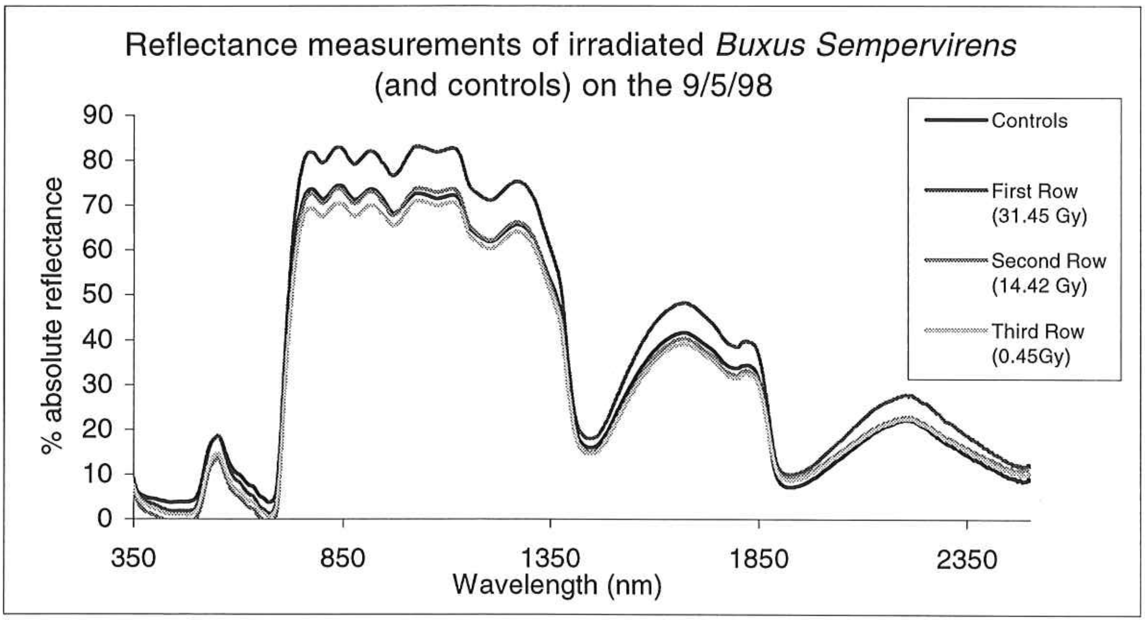

Figure 1

The box experiment yielded promising results in that a change of reflectance was observed for the plants located nearest the source. As figure 1 shows, a general increase in reflectance had occurred for the first row after a total of 31.45 Gy of irradiation. A notable increase in reflectance occurred in the water absorption bands between 1450 nm and 2200 nm and also between 800 nm and 1300 nm which may be accounted for by a change in cellular or canopy structure. A slight increase in reflectance was also found in the chlorphyll absorption peaks which may be indicative of radiation-induced chlorosis.

In the second experiment a much larger range of doses were achieved, from 10 Gy to 300 Gy. The radioactive source is in itself a limiting factor considering it's irradiating capabilities. Being a small source and knowing that the dose rate decreases with the inverse square of the distance from it's location, little room is available for plants which will undergo large doses of irradiation. This is why a patch of lawn was used in order to maximise the plant material and high dose rate ratio. Figure 2 shows variation in reflectance for different parts of the irradiated lawn.

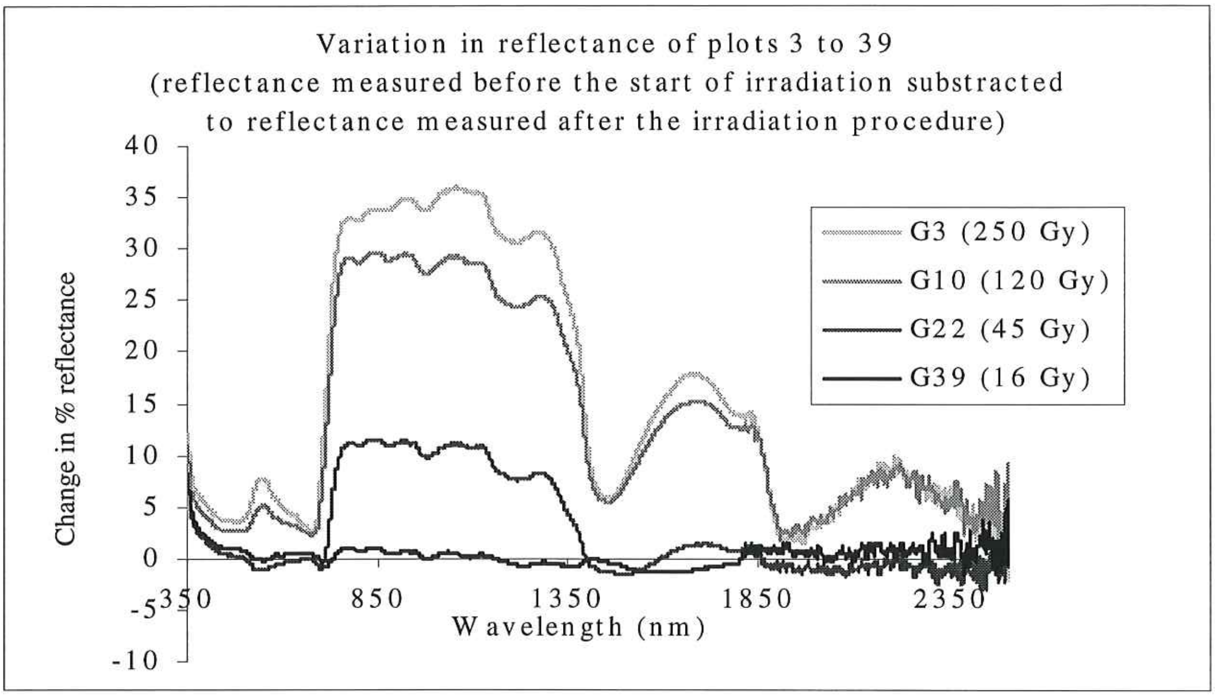

Figure 2

G3, G10 , G22 and G39 represent different parts of the patch in which reflectance was measured. The doses calculated for these four plots were 250, 120, 45 and 16 Gy.
Again, a large increase in reflectance for the plots nearest the source (G3 and G10) was noted, whereas no significant changes occurred for the furthermost plot (G39). Data in the 1800-2500 nm region showed significant increase in reflectance although a lot of background noise could be seen. The overall increase in reflectance can be attributed to canopy structure change as the closest lawn plots showed wilting and visible signs of chlorosis. It seems that vegetation reflectance variation greatly depends on dose rates as one can observe on figure 2.

5. Conclusion:

The two preliminary experiments show that changes in reflectance properties occur when vegetation is irradiated. These changes can be measured with conventional means and we are confident that a generally applicable model of the relationships between irradiation and spectral reflectance of plants can be derived from further experiments. It seems that the use of species that present homogeneous canopies simplifies the measurements and interpretations of results thereafter Future work will include other species of plants and hopefully a larger radioactive source to increase the statistical population of plants in each upcoming experiment. As dose rate decreases with the inverse square of the distance from a radioactive source, a 30-Curie source, for example, will enable us to irradiate the entire volume of the facility using high dose rates. This will allow us to expose much larger (older) plants and collections of plants uniformly over much shorter periods of time than possible with the existing source, thus we will be able to undertake a larger number of experiments and simulate more accurately medium-to-large pollution events in the field situation.

6. Acknowledgements:

We would also like to thank the NERC equipment pool and David Emery for the field spectroscopy instrument (ASD Fieldspec).

7. References:

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