Forest condition assessments and other applications of colour infrared (CIR) aerial photography in Ireland

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Summary

Colour infrared (CIR) aerial photography is a long-established tool for monitoring forest health and condition in Central Europe. Before this technique could be used to classify forest health on a large scale in Ireland, it was necessary to develop photo-interpretation keys for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and lodgepole pine (*Pinus contorta* Dougl.). These were completed as part of an EU-wide programme for investigating methods of monitoring forest condition. With these keys, a trained operator can accurately classify the damage to individual tree crowns in terms of defoliation and discoloration, based entirely on their appearance on CIR aerial photographs. A number of important practical applications of this technique are demonstrated and discussed. These include national and regional forest condition inventories that were carried out using the interpretation keys. CIR aerial photography was successfully used to detect nutrient deficient forest stands on peat sites in midland areas of Ireland, and to monitor the subsequent response of these areas to fertilizer application. The phenomenon of top dying of Norway spruce (*P. abies* (L.) Karst.) was also successfully detected and the extent of damage zoned using this resource. Information on the habit of top dying was gathered from these aerial photographs and this is discussed. Other applications for CIR aerial photography have also been studied and these are briefly described.

Introduction

Monitoring forest condition in Europe

In the early 1980s, a phenomenon later to become known as forest decline was first observed on a large scale throughout the major forest regions of Central Europe. The primary symptoms of this condition were identified as a progressive yellowing and loss of foliage, and, in extreme cases, structural changes in the branching system and crown morphology (Anon., 1991). Although it was not possible to attribute this damage to an individual source, it was widely believed that increased levels of atmospheric pollutants played a central role in its development (Arnt *et al.*, 1982; Lefohn and Mohnen, 1986; Roberts *et al.*, 1989). The widespread manifestation of this damage has now rendered the task of monitoring forest health one of the most important duties of forest inventory.

Following the successful inventory of forest decline in Germany in 1983, the Council of Ministers of the European Community established a Council Regulation (EC Council Regulation 3528/86) specifically designed to develop methods of monitoring the health status (forest condition) of the Community's forests. The primary purpose of this regulation was to establish means of protecting the Community's forests against factors contributing to forest decline.

The first operational measure of this regulation to be introduced by the Council of Ministers was a terrestrial survey of forest condition to be conducted annually in each Member State. The primary objectives of the survey were to describe the conditions of the respective forests of each Member State, and to indicate, where possible, the cause of any damage observed (Anon., 1992). The survey was established at permanent random sample points throughout Europe according to a 16 km x 16 km grid network. The first survey of this type to inventory forest condition throughout the European Community, and the first survey of its kind in Ireland, was completed in 1987 (Keane *et al.*, 1988).

In each country, the survey was carried out using a common procedure where the vitality of individual crowns is expressed by the extent of defoliation and discoloration observed. The field assessment techniques are fully described by Innes (1990). The results of the defoliation assessments are combined with discoloration assessments to give an overall damage score. Each Member State is obliged to carry out a full national inventory of forest condition on an annual basis using this technique. Currently, there are approximately 26,000 forest condition plots located in 35 countries throughout Europe, including 37 plots in Ireland (Anon., 1994). These plots are surveyed annually at different levels of intensity. The main causes of damage identified at these plots have been exposure, nutrient deficiency and insect attack (McCarthy *et al.*, 1993).

Monitoring forest condition by remote sensing

After establishing the terrestrial forest condition survey, the European Commission began to investigate other techniques of monitoring forest condition. Emphasis was placed on methods that would initially complement the terrestrial forest condition survey but which also had the potential to be more cost-effective than the terrestrial survey. Since the main symptoms of forest decline manifest themselves primarily in the parts of the crown visible from above, initial investigations concentrated on identifying a suitable remote sensing medium (Anon., 1991).

Damage symptomatic of forest decline manifests itself as changes in the morphological and physical structure of the crown, and also as shifts in its spectral reflectance properties. Changes in the spectral reflectance are dependent on both the extent and the condition of the foliage. These changes are much more pronounced in the near-infrared wavelengths (0.7 - 1.5 μm) than in the visible wavelengths (0.4 - 0.7 μm). In fact, healthy vegetation may reflect up to ten times as much light in the near-infrared part of the spectrum as visible light. Consequently, the most effective remote sensing medium for monitoring forest condition should have a spatial resolution powerful enough to detect structural changes in individual crowns, and the ability to detect differences in the spectral reflectance of a forest canopy, both in the visible and near-infrared wavelengths.

Although digital remote sensing data captured by multi-spectral scanners from aircraft or from space has been used extensively for forestry purposes, the evaluation of scanner data for monitoring forest damage on a single tree basis has not yet reached an operational stage. The limited spatial resolving power of scanner data, difficulties of geometric correction, and lack of sterescopic evaluation render them unsuitable for assessing the characteristics of individual trees (Anon., 1991). However, the image structure characteristics of analogue photographic film are such that structural details of individual tree crowns can be readily identified on large scale aerial photographs, e.g. 1:5,000.

Aerial photographs have an added advantage in that they can be seen in three dimensions. This is possible using overlapping pairs of photographs viewed through a stereoscope. The condition of the trees can then be classified not only in terms of the colours reproduced on the photograph, but also in terms of the shape characteristics of the tree crown. Severe defoliation and structural changes within individual tree crowns are then readily identified.

In addition to its resolving power, CIR film displays spectral properties particularly suited to detecting changes in the reflectance of both near-infrared and visible light typically symptomatic of forest decline. Stressed or damaged trees loose much of their ability to reflect infrared light and are consequently easily identified on CIR aerial photographs. The combination of its colour characteristics and high resolution renders CIR aerial film more suitable than either digital imagery or true colour photographic film for monitoring forest condition.

Development of photo-interpretation keys for classifying forest damage

Once CIR aerial photography had been identified as a suitable medium for monitoring forest damage, efforts were directed at the development of a technique for conducting surveys of forest condition based entirely on the interpretation of CIR aerial photographs. The desired technique would have to be standardized throughout Europe and be applicable in national and international surveys of forest condition without the need for regional modification.

The technique developed involves photo-interpretation keys for specific species. Initially, interpretation keys were developed for five common European species, i.e. beech, oak, Norway spruce, silver fir and Scots pine (Anon., 1991). A number of these interpretation keys distinguish between different phenotypes of the same species. Each interpretation key describes the appearance of different levels of damage of individual tree crowns when viewed at high magnification using a stereoscope. This damage may be caused by exposure, nutrient deficiency, insect attack or other unknown causes. As the symptoms of forest decline on crown structure are generally similar for the same species, independent of location, this allows the comparison of surveys carried out at different times and in different regions.

Each of the interpretation keys was developed according to a uniform structure and using a standard vocabulary of terms. Each key defines five levels of damage based on the shape and colour characteristics of a tree crown visible on a CIR aerial photograph. The damage levels are analogous to those used in the terrestrial survey of forest condition and describe crown condition in terms of defoliation and discoloration. Supplementary chlorosis classification keys were also developed. These could be used to adjust the overall damage class in cases of severe chlorosis.

Although the pilot projects had resulted in the development of interpretation keys which could be used to assess and monitor the condition of the major forest species of mainland Europe, they were of little value in the Irish context. In order to use CIR aerial photography to monitor the health of Irish forests, it was necessary to develop interpretation keys for Sitka spruce and lodgepole pine, which together constitute approximately 81% of the national forest estate. Independent attempts had been made in Ireland and Denmark to inventory the condition of Sitka spruce using the Norway spruce interpretation key. In both cases, however, the physical structure of Sitka spruce was reported to be very different to that of Norway spruce, and the results of the inventory were deemed to be inaccurate (Dunne, 1993; Jenson *et al.*, 1989).

Following the model of existing keys, interpretation keys were then developed for Sitka spruce and lodgepole pine, using a standard format and glossary of terms. Like the existing keys, both new keys define five levels of damage ranging from negligible or no damage (Level 0) to dead (Level 4).

As part of their development, it was necessary to subject the keys to rigorous testing in order to verify their accuracy. This was carried out by selecting a large number of trees easily identifiable both on the photograph and in the field. The damage level of each of these trees was then assessed, using both the terrestrial assessment technique and the interpretation key. Both assessments were carried out independently. A high correlation between the two assessments was obtained.

These keys may be used to monitor the condition of Sitka spruce and lodgepole pine forests in Ireland using CIR aerial photographs, and, with additional verification, should be valid for carrying out forest condition inventories in other countries.

Application of the interpretation keys

Carrying out forest health inventories

Following the development of the Sitka spruce and lodgepole pine interpretation keys, a pilot forest health inventory was carried out on forest stands throughout the country. This survey was limited to a small number of Sitka spruce and lodgepole pine stands for which there was an available resource of CIR aerial photographs (Stanley *et al.*, 1994). A widespread systematic application of the interpretation keys has since been carried out using CIR aerial photography of 20 forest condition plots that are located throughout the country (Stanley, 1996). The location of each of these plots was determined by a 16 km x 16 km sampling grid network and all of these plots are assessed annually from the ground as part of an EU forest condition survey. The results of the aerial survey of these plots were compared with the terrestrial assessments and a strong correlation was observed both on a tree by tree and a plot by plot basis. The aerial survey data was also used to investigate the relationship of the position of a tree relative to the forest edge (i.e. external edge, internal edge or non-edge) with its crown condition. This relationship was found to be non-significant.

Monitoring nutrient application on nutrient deficient sites

Many Sitka spruce crops growing on cutover peat in the midlands of Ireland experience potassium deficiency. A significant proportion of this can be attributed to over-exploitation by agriculture, compounded in many cases by the low levels of potassium inputs from rainfall (OCarroll and McCarthy, 1973). A study was carried out to assess whether the response to potassium application could be detected using CIR aerial photography. Three sites were selected in Longford Forest, of Co. Westmeath and Co. Longford, in an area of known nutrient deficiency. Most of the trees on these sites were between 1.5 m and 2.0 m high, despite being 18 to 22 years old.

Crop description prior to fertilizer application: The study area was photographed using CIR film in September, 1991, prior to fertilizer application. Areas with nutrient deficiencies appeared pale pink to white in colour compared with a dark red or magenta colour for the healthier stands nearby. Foliage samples were also collected from the experimental area prior to application. Percentage foliar nitrogen, phosphorus, potassium, calcium and magnesium were obtained for each of the sites. These confirmed that potassium was severely deficient in all three sites. On average, the sites had only 40% of the threshold level of potassium. None of the other four elements were deficient.

Site fertilization: fertilizer was applied in January and March 1992, as muriate of potash (50% K). Five different treatments were selected and were replicated twice on each of the three sites. The 30 plots each measured 40 m x 40 m. Each plot was brashed (one line in four) prior to fertilizing. Fertilizer was then applied by hand from these brash lines in a broadcast manner. The five treatments were as follows.

- 150 kg K/ha, applied in January, 1992.
- 300 kg K/ha, applied in January, 1992.
- 150 kg K/ha, applied in March, 1992.
- 300 kg K/ha, applied in March, 1992.
- Control.

Crop description after fertilizer application: In the post-application CIR aerial photographs taken in October, 1992, clear distinctions were visible in terms of the intensity of the red colour between the fertilized plots and the control plots. The control plots remained a pale pink or white in colour while the treated areas had changed to a dark red colour (Figure 1). The difference was also evident on the ground, with untreated plots remaining severely discoloured and treated plots having a strong blue-green colour in both the new and older needles. Within the treatment plots, there appeared to be no difference between the various fertilizer rates or between the different timings of application. As expected, the foliage analysis taken during the winter following application showed that potassium nutrient levels had increased from just 40% of the threshold value to between 25% and 40% above threshold.

Due to continuous frost damage to the trees at each site, it was not possible to assess levels of defoliation using the Sitka spruce interpretation key. However, chlorosis levels were assessed using the supplementary chlorosis classification key. The results indicated a considerable reduction in the chlorosis level in all those plots which had received fertilizer. The rates of fertilizer or the timing of application appeared to have little effect on the chlorosis level one year after application.

Results from this study clearly indicate that severe potassium deficiency can be successfully treated by fertilizer application midway through rotation. The experiment also demonstrates that CIR aerial photography can be used to detect potassium deficient stands and to monitor their response to fertilizer application. The use of CIR aerial photography is therefore recommended for surveying large forest areas suspected of suffering from nutrient deficiency. The CIR aerial photographs can be extremely useful in determining areas that require sampling for chemical analysis prior to the aerial application of fertilizers, and subsequently in monitoring the effects of any remedial action.

Top dying of Norway spruce

The phenomenon of top dying of Norway spruce has been reported sporadically throughout this century in Ireland, Britain and Continental Europe. It is characterized by a reduction in growth followed by the browning of foliage and eventual crown death.

The health status of a forest block in Allen Forest, Co. Meath was assessed using CIR aerial photography from 1991. The forest was zoned into three regions on the basis of the extent of damage. The trees within each of these zones were assessed using the existing Norway spruce damage interpretation key. It was possible to assess tree health within each zone and draw conclusions about the spatial distribution of top dying of Norway spruce in affected stands. The observations recorded were as follows (also see front cover).

- The highest density of Norway spruce top dying occurred at stand edges where mortality can be four to five rows deep.
- Stand edges on the leeward side were generally unaffected.

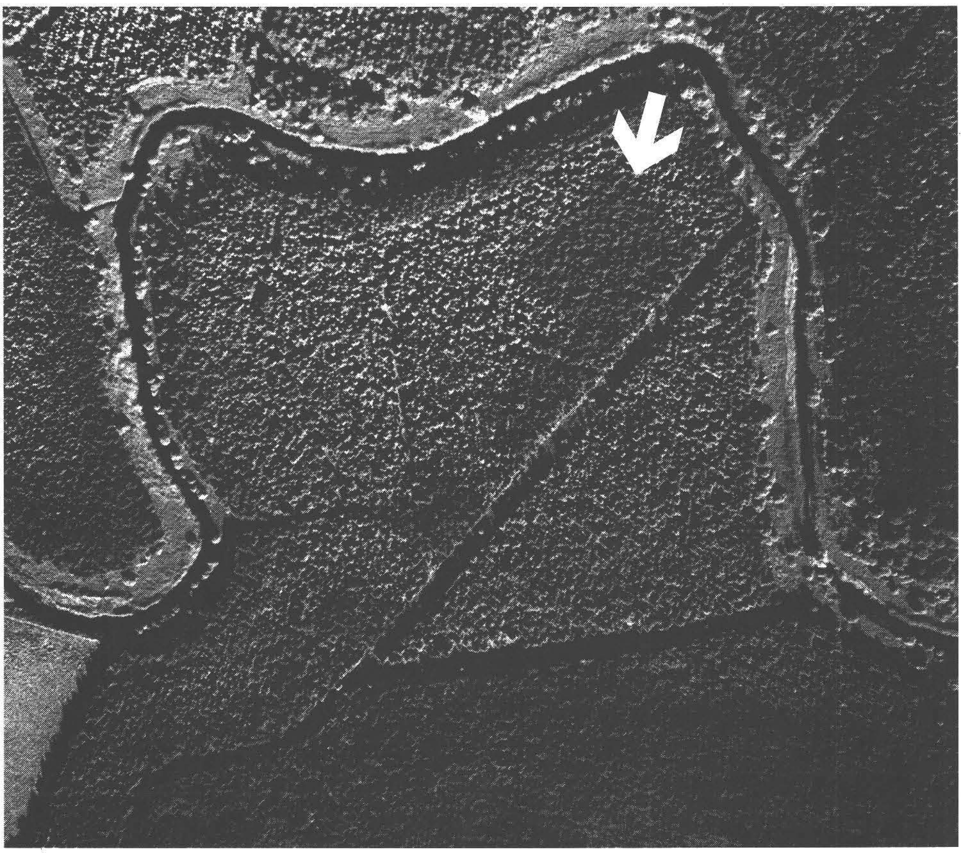

Figure 1. *Black and white reproduction of CIR aerial photograph of The Curragh Property (Longford Forest) showing Sitka spruce with severe potassium deficiency. The dark area indicated by the arrow represents plots where fertiliser was applied in the previous year.*

- Individual trees seem to react differently to the stresses which cause top dying. As a result, trees which have died from the disorder can be found beside healthy trees. Dead trees were found dotted randomly within the stand.

A project is currently underway to monitor the multi-temporal progression of the top dying of Norway spruce on a number of sites.

Other applications

Ireland's geographical isolation makes it very difficult for insects and diseases to enter the country. Strict plant health guidelines combined with regular port inspections have been largely successful in excluding exotic pests. As a further line of defense for forest protection, forests in the vicinity of ports are being flown, using CIR aerial photography. This survey should act as an early warning system of pest establishment, thereby allowing the prompt deployment of necessary control measures.

Another one of the most important features of aerial photographs is that they can be used to obtain reliable measurements of height, distance and area. This is possible using overlapping stereo pairs of photographs. Information taken directly from the photographs can be referenced to known ground points to provide data for geographic information systems (GIS). Forest inventories throughout the world are commonly conducted using this technique. Results from pilot projects in Coillte have shown that CIR aerial photographs have the potential to substantially increase the efficiency and accuracy of forest inventory work. If applied correctly, forest inventories based on aerial photography should be quicker and less expensive to carry out than ground only surveys, while providing more accurate information in many cases.

Investigations have also taken place into the potential application of large scale CIR aerial photographs for assessing the survival rates and establishment success of young plantations. This system has shown promise in its ability to identify the exact number of live stems of trees as young as three years old.

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REFERENCES

Anon. 1991. Remote sensing applications for forest health status assessment. Directorate General for Agriculture. Commission of the European Communities.
Anon. 1992. Convention on long range transboundary air pollution. Manual on methodologies and criteria for harmonizing sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Unpublished. United Nations Environmental Programme and the United Nations Economic Commission for Europe.
Anon. 1994. Forest Condition in Europe – Results of the 1993 Survey. United Nations Economic Commission for Europe/European Commission.
Arnt, U., Seufert, G. and Nobel, W. 1982. Die beiteilung von ozon on der komplexkrankheit der tenne (*Abies alba* Mill.) - eine prufenswerte hypothese. *Stanb*, 42:243-247.
Dunne, S.P. 1993. The use of colour infrared aerial photography in monitoring the health of Irish forests. Unpublished Masters thesis. Department of Crop Science, Horticulture and Forestry, University College Dublin.
Innes, J. L. 1990. Assessment of tree condition. Forestry Commission Field Book 12. HMSO.
Jenson, J. S., Oleson, H. H. and Poulsen, J. K. 1989. IR-photos and satellite images for forest health monitoring. Unpublished report. Ministry of the Environment, Forest and Nature Agency, Denmark.
Keane, M., Hogan, J. and McCarthy, R. 1988. Forest Health Report, Ireland. Coillte Teo. Research and Development, Sidmonton Place, Bray, Co. Wicklow.
Lefohn, A. S. and Mohnen, V. A. 1986. The characterization of ozone, sulphur dioxide and nitrogen for selective monitoring sites in the Federal Republic of Germany. *JAPCA*, 36:1329-1337.
McCarthy, R., Hogan, J. and Delaney, M. 1993. Forest Condition Surveys – Ireland 1993. Coillte Teo. Research and Development, Sidmonton Place, Bray, Co. Wicklow.
OCarroll, N. and McCarthy, R. 1973. Potassium supplied by precipitation and its possible role in forest nutrition. *Irish Forestry*, 30(2):88-93.
Roberts, T. M., Steffington, R.A. and Blank, L. W. 1989. Cause of type 1 spruce decline in Europe. *Forestry*, 62(3):179-216.
Stanley, B. 1996. An Assessment of the Level 1 Forest Condition Survey in Ireland using Aerial Photo-interpretation – Final Report on Project Number 94.60.IR.003. Coillte Teo. Research and Development, Sidmonton Place, Bray, Co. Wicklow.
Stanley, B., Dunne, S. and Keane, M. 1994. Monitoring Forest Condition using Colour Infrared Aerial Photography – Final Report on Project Numbers 90.60.IR.004 and 90.60.IR.005. Coillte Teo. Research and Development, Sidmonton Place, Bray, Co. Wicklow.