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USES OF REMOTE SENSING IN FOREST PEST DAMAGE APPRAISAL

Proceedings of a seminar held May 8, 1981, in Edmonton, Alberta

COMPILED BY

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ABSTRACT

A seminar was held to review experiences and concerns in the application of remote sensing techniques to forest pest damage appraisal. Papers were presented on detection and analysis of vegetative stresses; application of remote sensing to mountain pine beetle management in southern Alberta; practical applications of remote sensing for forest pest damage assessment; some recent developments in remote sensing at the Northern Forest Research Centre; the role, informational requirements, and pest problems of the Forest Insect and Disease Survey (FIDS); FIDS-related remote sensing studies in the Pacific region; and the uses of remote sensing in forest pest damage appraisal.

RESUME

Un séminaire a été organisé pour passer en revue les expériences réalisées et les sujets d'intérêt dans le domaine de l'application des techniques de télédétection à l'estimation des dégâts des ravageurs forestiers. Des communications ont été présentées sur la détection et l'analyse des agressions de la végétation; l'application de la télédétection à la répression du dendroctone du pin ponderosa dans le sud de l'Alberta; les applications pratiques de la télédétection pour la détermination des dégâts des ravageurs forestiers; les innovations récentes dans le domaine au Centre de recherches forestières du Nord; le rôle, les exigences en matière d'information et les problèmes suscités par les ravageurs au Relevé des insectes et des maladies des arbres forestiers (RIMAF); les études sur la télédétection ayant trait au RIMAF dans la région du Pacifique, et les utilisations de la télédétection pour évaluer les dégâts des ravageurs forestiers.

PREFACE

This seminar was organized primarily for the Forest Insect and Disease Survey (FIDS) personnel of the Northern Forest Research Centre (NoFRC). In consideration of the wider potential interests and applications, however, other Canadian Forestry Service staff and personnel from the Alberta Forest Service were invited to attend as well.

The overall purpose of the seminar was to obtain an information base from which could be developed a program plan potentially utilizing remote sensing techniques. Several specialists were invited to address aspects of the seminar objectives, which were

1. to gain an insight into the uses of remote sensing in forest pest damage appraisal;

2. to determine the success of past work by the presentation of several case studies; and

3. to identify potential applications of remote sensing techniques for the FIDS program at NoFRC.

Further, there was an interest in identifying exploratory applications that have research interests in contrast to operational applications that would be immediately useful to federal, provincial, and private agencies. A contribution from the Pacific Forest Research Centre that provides an insight into its program plan provided additional direction and is therefore acknowledged.

Following presentation of the papers, the seminar culminated in a round-table discussion that encouraged interaction among the speakers and participants. Important considerations and recommendations flowing from the discussion and papers are summarized in the final paper of these proceedings.

PREFACE

Ce séminaire a principalement été organisé à l'intention du personnel du Centre de recherches forestières du Nord (CRFN) affecté au Relevé des insectes et des maladies des arbres (RIMAF). Toutefois, en raison de l'ampleur des sujets d'intérêt et des applications susceptibles d'y être d'autres employés du Service canadien des forêts et de l'Alberta Forest Service ont également été invités.

L'objectif global du séminaire était d'obtenir une base d'informations permettant de planifier un programme qui pourrait appliquer les techniques de télédétection. Plusieurs spécialistes ont été invités à présenter des communications sur divers sujets se raportant aux objectifs du séminaire, qui étaient

1. acquérir des connaissances sur les utilisations de la télédétection pour évaluer les dégâts des ravageurs forestiers,

2. évaluer le succès du travail déjà effectués, par la présentation de plusieurs études de cas, et

3. déterminer les applications possibles de la télédétection dans le programme du RIMAF au CRFN.

De plus, on voulait déterminer les applications préliminaires intéressant la rechereche par oppositions aux applications opérationnelles d'utilité immédiate pour les organismes fédéraux, provinciaux et privés. A souligner un article du Centre de recherches forestières du Pacifique donnant un apercu des grandes lignes de son programme, ce qui constituait une source additionnelle d'informations et dont nous le remercions.

La présentation des communications a été suivie d'une table ronde qui a favorisé les échanges entre orateurs et participants. Les considérations et recommandations importantes ressortant de la discussion et des communications sont résumées dans le dernier article du compte rendu.

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WELCOME

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On behalf of Dave Kiil, the A/Director, and the staff of the Northern Forest Research Centre I would like to welcome the visitors to our center, two of whom have come from out of the province.

The Northern Forest Research Centre has been one of the pioneers over the last decade in the use of remote sensing techniques within the Canadian Forestry Service (CFS), mainly through Chuck Kirby's efforts for its use in forest inventory work. Chuck and his staff, formerly Peter Van Eck and now Ron Hall, have assisted or planned numerous workshops, demonstrations, or courses to promote the use of remote sensing in forestry, but this is the first to narrow in on its application in forest pest damage appraisal. This application is not new, as I remember some early work that was directed at identifying insect and disease problems in California back in the late 1950s and early 1960s, and it has long been used to assess such damage in agricultural crops.

This is an opportune time for us to look more deeply into the use of remote sensing. Both recent CFS task forces to evaluate the Forest Protection Program (Sinclair report) and the Forest Management Program indicated that forest protection must be an integral part of management. For instance, one cannot think of forest management in Newfoundland or other parts of Atlantic Canada without considering the damage wrought by the spruce budworm. For management purposes, forest protection must be considered as prevention and suppression--be it fire, insects, or diseases--and this is where we hope remote sensing will have a major role to play. Another problem we have to address in forest renewal and reforestation is that the impact of insect damage on mature forests is much better known than the impact on growth and changes in immature stands and plantations. We have just initiated a project at this Centre to help us look at this problem in young stands.

The CFS has endorsed a major goal of the Canadian Council of Resource and Environment Ministers to increase wood production from Canada's forest land by 50% by the year 2000; however, for the forestry community to have a chance to obtain this goal we must use every available technique to its fullest potential.

I hope this seminar can be a stepping stone in bringing remote sensing and forest pest appraisal closer together in integrated programming in Canada. This center will initiate planning soon for a new 3-year program plan to take us through 1982-85, and I hope that new research or applications using remote sensing will be identified in that plan.

I wish you all a good meeting.

DETECTION AND ANALYSIS OF VEGETATION STRESSES

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ABSTRACT

One of the primary applications of remote sensing technology is the inventory, monitoring, and evaluation of stress to vegetation caused by either biotic or abiotic agents. The understanding of the remote sensing data interpretations for vegetation stresses is based on a knowledge of stress, the effect of the stress on the vegetation, strain symptoms, and the capabilities and limitations of the remote sensing techniques. The remote sensing evidence of vegetation stress is indirect evidence in that it detects strain symptoms or effects rather than the cause. The sequence of strain symptoms displayed by a plant as it responds to stress represents a form of remote sensing signature that can be used to identify an environmental stress or indirectly associate effect with cause. Basic concepts are reviewed, and example interpretations of stresses, including insect, disease, and air pollution, are presented.

1. INTRODUCTION

The overall objectives of this discussion are to show what types of stresses to vegetation can be identified by remote sensing techniques and to indicate how an individual would verify the type of stress involved. To answer both objectives, two questions must be answered: (1) What constitutes remote sensing evidence of vegetation stress? and (2) How is vegetation stress interpreted from remote sensing data in order to identify causal agents?

Before these questions are answered, stress itself must be defined. For purposes of clarity in discussion, the following definitions are presented:

a) stress: any environmental factor capable of inducing a potentially injurious strain on a plant (Levitt 1972);

b) strain: any physical or chemical change in a plant produced by stress (Levitt 1972);

c) injury: any stress on a plant that causes a detrimental strain and that may be noted because of either temporary or permanent syndromes;

d) damage: any loss, either biologic or economic, due to stress;

e) damage type: any syndrome expressed by the plant of either temporary or permanent strain caused initially by stress.

Levitt (1972) gives a detailed discussion of stress and strain and describes strains as either "elastic" (reversible) or "plastic" (irreversible). Most forms of environmental stress cause irreversible strain on the plant; however, some stresses may cause "elastic" strains that are only apparent for short periods of time and from which the plants recover. The task of remote sensing has been to detect, record, and assess both types of strain and simultaneously to identify the stress. The following discussion outlines the relation between strain detection and stress identification.

2. REMOTE SENSING EVIDENCE OF VEGETATION STRESS

To interpret vegetation stress from remote sensing data, the interpreter must be aware of four associated subject areas, namely:

a) the possible environmental stress capable of inducing injurious strain;

b) the possible syndromes indicative of injurious strain, or the manifestation of damage;

c) the effect of the strain on the normal spectral reflectance pattern; and

d) the resulting effects of spectral changes on the air photograph.

2 (a) Possible Stresses

In any given region, the resource manager is acutely aware of environmental agents that could cause injurious strain in a plant. The agents or stress factors vary from one region of a country to another and from one time to another. The heat and drought in the southern USA in the summer of 1980 will undoubtedly have caused strain in certain plant species, and damage syndromes will occur for several years to come. The 1976 drought in central northern Europe caused a wide variety of damage syndromes to appear on many urban and forest trees, and the syndromes were still evident in 1980 (Kenneweg 1980). Similarly, forest pests such as spruce budworm (Choristoneura fumiferana Clem.) are known to be cyclic in population levels and cause varying levels of damage throughout the years (Brown 1970).

Even though environmental stress factors are known to be operative within a region, severe problems in remote sensing are caused by the fact that many stress factors cause a series of widely different strains. Unless associated with identifiable features such as burn patterns from a ground fire (see color photo on cover), floodwaters from a beaverpond, or the typical "ringworm" pattern associated with Phellinus (Poria) weirii (Murr.) root rot, the link between the strain (effect) and the stress (cause) is at best circumstantial. Because of this fact, remote sensing of vegetative stress must depend on detection and evaluation of strain or the changes brought about in the plant by the stress. The manifestations caused by stress therefore are the key to the remote sensing data interpretation.

2 (b) Manifestations of Damage

There are two basic manifestations of injury on a plant. The plant suffers from a detrimental change in either morphology or physiology, or sometimes in both concurrently. Morphological injury involves a change in the shape or form of the plant. Defoliation (either from the entire plant or from one stem or branch), breakage of parts of the plant, or even cellular collapse are examples of morphological change. If the injury has been detrimental and some loss, either economic or biologic, has occurred, then the injury is termed damage.

Physiological injury involves a change in the physiology of the plant, and it can be expressed as a deviation from the normal pattern. The healthy plant has a specific set of functions required for the maintenance of its biology. A change in the functioning of the plant represents the physiological injury. If the change is detrimental, then damage occurs, since biologic loss is generally involved. Examples of such physiologic damage are a decrease in photosynthates, deterioration of chloroplasts, and interruption of translocates, including water, etc. It is the job of remote sensing to detect such changes in functioning. Often the effects are not immediately visually apparent, but a subsequent and related change occurs to emphasize the injury. For example, a plant that has been affected by an outside environmental influence causing a deterioration of chloroplasts is noted as damaged because the plant foliage is yellowed. In the normal functioning of the plant, the chlorophyll absorbs red and blue light and reflects green. A deterioration of the chloroplasts reduces the green reflection and increases the red and blue reflection. Remote sensing devices such as film are sensitive to changes in spectral reflectance. (Spectral reflectance is the reflection of light in a defined spectral region, such as blue, green, red.) Thus, many changes in the functioning of the plant are noted as spectral changes by the remote sensor. These effects are discussed in detail below. Other forms of physiologic change are eventually noted as a morphological change. For example, a plant with a problem that interferes with the translocation of water may not be noted until the cells lose turgidity and/or collapse, thus causing a wilted appearance. In this instance, a morphological change has been effected by a physiological event. Additionally, other physiological damages often result in morphological change such as reduced growth, loss of foliage, top-killing, and necrosis of cells (Dochinger and Jensen 1975).

It is necessary that the remote sensing data interpreter be acutely aware of the strain manifestations of environmental stress. Both types of strain manifestation (morphologic and physiologic) affect the spectral reflectance from a plant. Since passive remote sensing devices respond to either reflected or emitted electromagnetic energy, changes in normal patterns are the key to the detection and interpretation of stress on vegetation.

2 (c) Changes in Spectral Reflectance

Generally, one of the first visual symptoms of physiological injury is yellowing of plant foliage, but this may not be the first change in spectral reflectance. A generalized spectral reflectance curve for a normal (healthy) green leaf is shown in Figure 1(1). The peak visual reflectance (10-20%) is in the green region (500-600 µm), and consequently the eye sees the foliage as green. There is an associated lower (about 10%) reflection in the blue (400-500 µm) and red (600-700 µm) spectral regions. There is also a considerably higher (30-70%) spectral reflectance in the near-infrared (700-900 µm) spectral region (Hildebrandt 1976). Photographic films are produced that are sensitive to these three visual (blue, green, and red) and one near-infrared spectral regions.

The precise levels of spectral reflection from a plant leaf are determined by a complex of factors such as species variety, site, age or maturity of both plant and foliage, nutrient status, and leaf orientation. Within a given area or ecological zone, sampling of the vegetation will give a generalized spectral reflectance pattern that can be considered normal. These data may not necessarily be precisely determined spectral reflectance curves but may be inferred patterns derived from the interpretations of remote sensing data (i.e., air photographs) that have been collected over time. The inference for physiological injury comes from a noted deviation in the normal pattern, either on the same plant when observed over a given time period or from plants of the same species when intraspecific comparisons are made. An example of the deviation from a normal pattern would be the yellowing of the foliage after a deterioration of the chloroplasts. A change in the amount of chlorophyll affects the level of green spectral reflection as well as the absorption level of blue and red light. As chloroplasts deteriorate and the leaf yellows, the green spectral reflectance peak shifts toward the red (Fig. 1 (3)). Thus the relationship between physiological injury and remote sensing is the detection of a change in the functioning of the plant by the remote sensor and the subsequent inference of injury, which in this example would be noted as the presence of yellowed leaves.

The research literature seems to indicate that changes occur in the near-infrared (700-900 µm) before visual changes occur. Bawden (1933) provided the first photographic example, and Lillesand et al. (1975) have provided a more-recent example to illustrate near-infrared reflectance changes prior to any visual change. Such changes have been termed previsual and imply that near-infrared changes are always followed by visual reflectance changes. If no visual change follows the near-infrared change, then the near-infrared change could be termed extravisual. Although more research proof should be presented concerning the timing and duration of near-infrared changes, for the purposes of this discussion a near-infrared reflectance change is hypothesized to occur prior to visual changes. Figure 1(2) demonstrates a near-infrared decrease; however, Thomas et al. (1966) reported an increase. Gausman (1977) reported that cellular constituents account for about 8% of the reflected near-infrared, whereas the cell wall:airspace interface accounted for the remainder (25-50%) of the reflection. It is suggested here that the near-infrared reflectance changes reported to occur prior to visual changes are associated with the 8% reflectance from the cellular constituents, whereas changes involving the cell wall:airspace interface occur at a

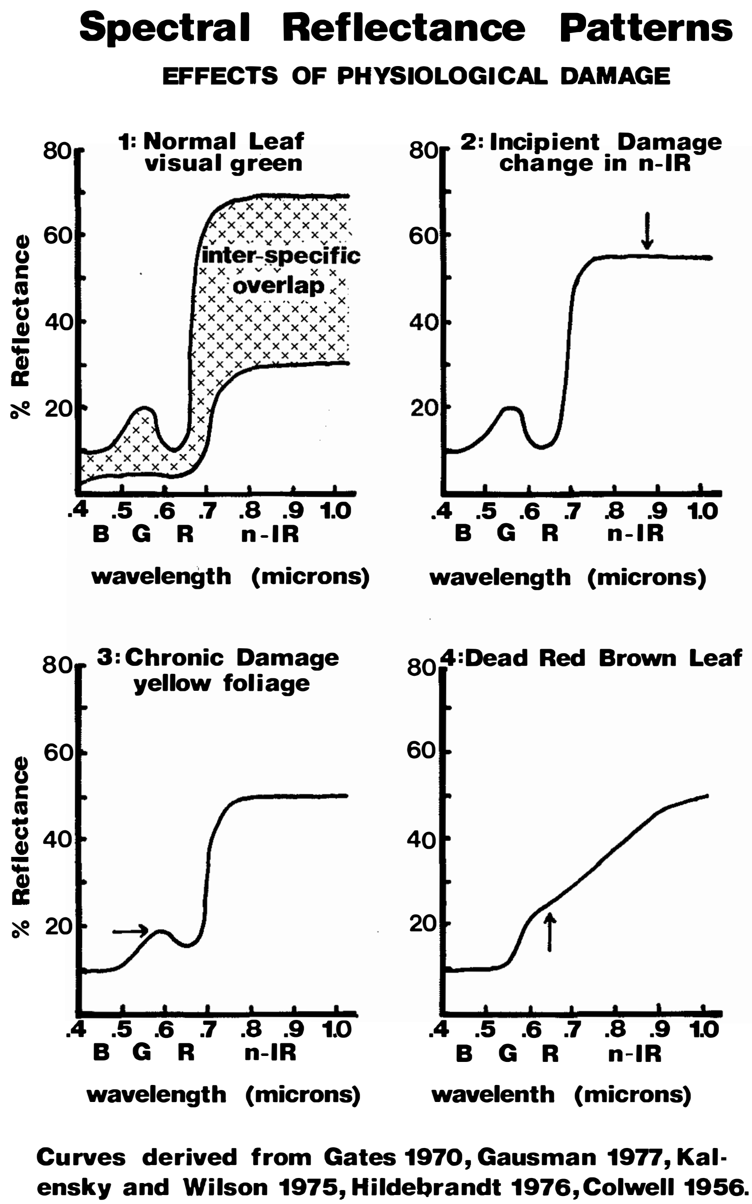

Figure 1. Generalized spectral reflectance patterns for:

(1) a normal green leaf; interspecific overlap indicates the wide variation and the overlapping of spectral reflectance patterns among various species of plants;

(2) a leaf with incipient damage indicated graphically by a change in only near-infrared reflectance;

(3) a yellowed leaf after a period of chronic damage; and

(4) a dead red brown leaf.

Arrows indicate shift in spectral reflectance pattern from previous curve.

later time and are often associated with visual changes. Changes in the cell wall:airspace interface would necessarily be associated with structural changes such as wilting and desiccation caused by drought. Changes incellular constituents are more intimately linked to the physiology of the cell, and chronic injury (i.e., low levels of stress acting over a long period) would be more apt to affect the cellular constituent than the cell wall:airspace interface.

Continuing chronic injury eventually causes a deterioration of chloroplasts and a green to red shift in the visual reflectance (Fig. 1(3)). The final generalized change is the reddening of the dead foliage (Fig. 1(4)). This change is spectrally described as a further shift in reflectance toward the red as well as a noticeable increase in the level of red reflectance. At this point, collapse of the cell walls has usually occurred along with desiccation of the leaf. Air-dried foliage is highly reflective of near-infrared, whereas wet, dead foliage is much less reflective of near-infrared, since water is a poor reflector of near-infrared.

With the collapse of the cell walls, one of the first morphological changes has occurred. Morphological injury affects spectral reflection when new surfaces are exposed or there are changes in the number of contained shadows. Morphological changes are best described on the basis of form, density, texture, and boundary patterns of the plant, whereas physiological changes are best described on the basis of color (hue) or spectral reflection.

2 (d) Effects of Spectral Changes in Air Photographs

There is a direct relationship between spectral reflectance and the final image seen on aerial photographs. The spectral reflectance changes discussed above have their effect on films, and these are represented in Figure 2 for normal color film and Figure 3 for color infrared film. Both types of color film have three dye-forming layers (yellow, magenta, and cyan), and these layers are sensitive to light from the blue, green, and red regions, respectively, for normal color film or to green, red, and near-infrared light,respectively, for color infrared film (Fritz 1967). Thus changes in the levels of spectral reflectance affect the reactions of the spectrally sensitive dye-forming layers and ultimately affect the amount of dye formed. This is usually an inverse relationship, since with high levels of spectral reflectance low quantities of dye are formed and with a low level of reflectance large amounts of dyes are formed.

When a normal green leaf is photographed with a normal color film (Fig. 2(B)1), the blue light affects a small part of the blue-sensitive or yellow dye-forming layer, the green light affects more of the green-sensitive or magenta dye-forming layer, and the red light affects a small amount of the red-sensitive or cyan dye-forming layer. The amount of dye formed is inversely proportional to the exposure, and after reversal development, relatively thick layers of yellow and cyan dyes are formed and a proportionally thinner layer of the magenta dye is formed. The dyes are subtractive, and thus the yellow dye subtracts (absorbs) blue light and the cyan subtracts red, whereas the thin magenta passes more green light than it can absorb. The visual effect is to see the green foliage as green on the normal color photograph. Figure 2 also illustrates why yellow foliage appears yellow and the dead foliage has the reddish hue. It should also be noted that since

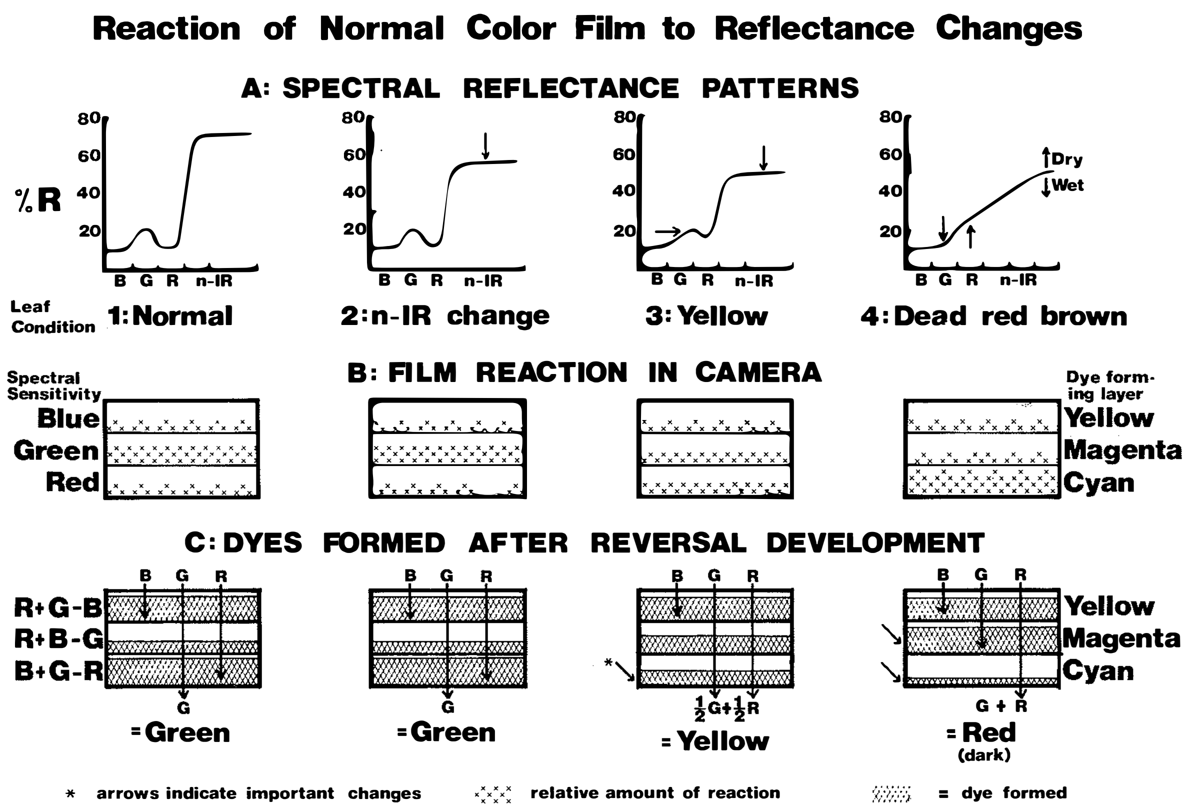

Figure 2. Schematic reaction of normal color film to differences in spectral reflectance, relative amounts of dyes formed, and visual color of image.

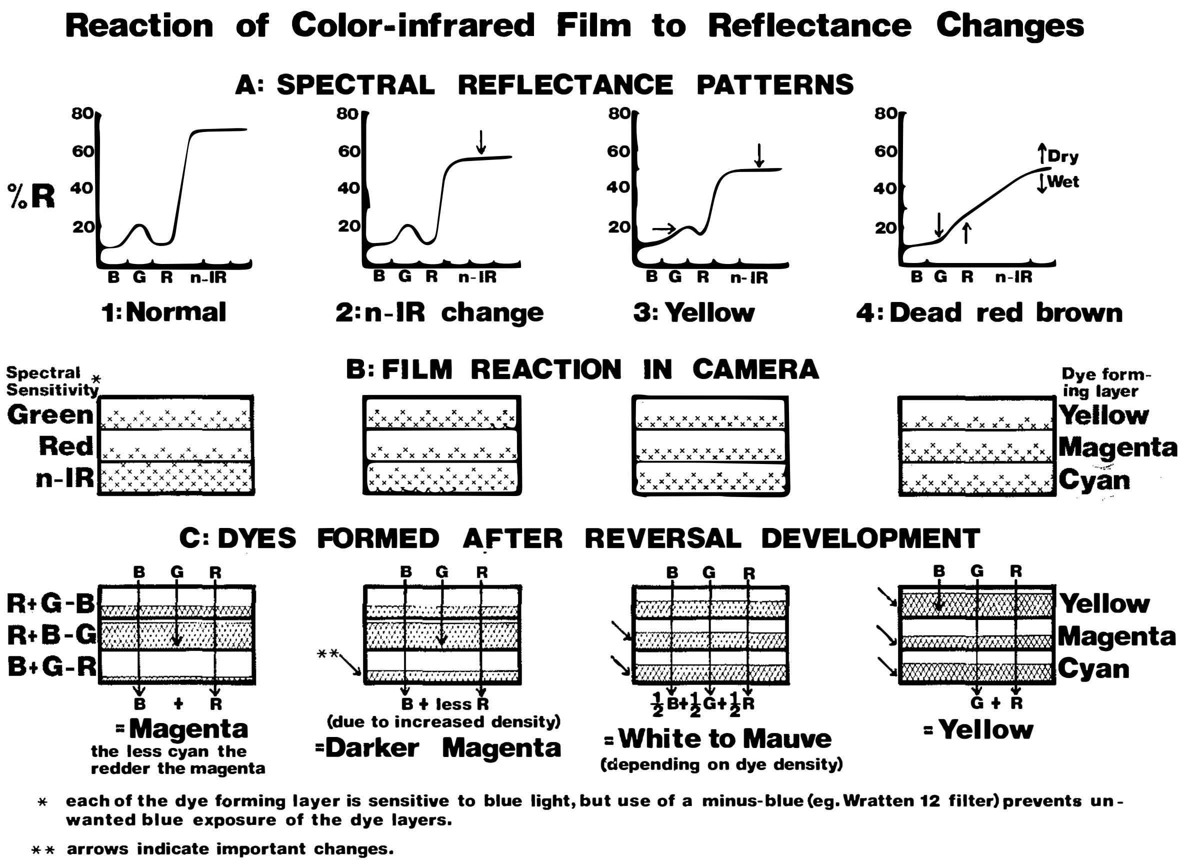

Figure 3. Schematic reaction of color infrared film to differences in spectral reflectance, relative amounts of dye formed, and visual color of image.

normal color film is not sensitive to near-infrared light, it does not respond to changes in near-infrared reflectance. Color infrared film, however, does respond to changes in near-infrared as well as green and red reflectances, and these effects are illustrated in Figure 3.

A normal green leaf is generally seen on color infrared photos as a magenta (blue plus red) hue (Fig. 3(C)1). Because of the relatively high level of near-infrared reflectance, a thin layer of cyan dye was formed. Since cyan subtracts red light and there was only a thin layer of cyan formed, most of the red light is transmitted through the film positive transparency. The reaction of the color infrared film is such that the yellow dye-forming layer responds to green light. Even though there is a lower level of green reflectance than there is of near-infrared, the amount of yellow formed is also relatively thin (Fritz 1967), and consequently blue light is passed through the yellow dye layer. Similarly, the magenta layer is relatively thick, and it absorbs most of the green light. The visual combination of the blue and red light gives the magenta hue (Fig. 3(C)1).

The critical point for the interpreter is to know what happens if there has been a small (e.g., 5%) change in the level of near-infrared reflectance. If there has been a decrease in reflectance, the density of the cyan dye layer increases (Fig. 3(C)2) and the green foliage appears a darker magenta. Conversely, if the near-infrared increased, the image would be a lighter magenta (see color photo on cover). It could be hypothesized that if only a small change (i.e., 5%) in near-infrared reflectance happened, then the changes in reflectance are possibly related to injury of the cellular constituents and not to changes in the cell wall:airspace interface.

Figure 3(C)3 indicates that a yellow leaf appears white to mauve on the color infrared photo, whereas Figure 3(C)4 shows that the dead red-brown leaf will appear yellow. The foliage of a dead tree with dry, green foliage (i.e., a cut Christmas tree) will be seen primarily as a light magenta, since dry foliage is highly reflective of near-infrared, sometimes even more reflective than healthy green foliage. Similarly, if a conifer has been killed by bark beetles and the foliage is air-cured during a hot, dry summer, the greenness will remain and the foliage will become highly reflective of the near-infrared. Such trees will appear as a light magenta hue on color infrared photos, and visually the same tree will appear a faded green. Because dead trees can be green and live trees are green, there have been many problems associated with the photo interpretation of bark beetle-affected conifers.

The above models (Figs. 2 and 3) for the reaction of films to changes in spectral reflectance assume perfect reacting conditions. It is known that the final image on air photos is affected by many things, such as spectral sensitivity variations in the film emulsion, film age, film filtration, exposure, and processing, as well as atmospheric attenuation (Fleming 1978) and scale. Image merging, the apparent coalescing of subjects (i.e., leaves to branches to crowns) as the scale becomes smaller (i.e., 1:1000 to 1:10 000), causes considerable change in the final photo image. Scale changes and atmospheric attenuation are known to override the effect of small spectral changes, and these effects may be sufficient to mask the effect of injury. Thus scale becomes a very important consideration in the interpretation of plant injury in addition to knowledge concerning spectral reflectance changes and their subsequent effect on photographic films. In summary, the presence of strain symptoms representative of injury to plants constitutes remote sensing evidence of vegetative stress. The strain symptoms are interpreted since they represent a detrimental deviation from a normal pattern. The next section discusses how causal agents may be identified from remote sensing data.

3. INTERPRETATION AND IDENTIFICATION OF CAUSAL AGENTS FROM REMOTE SENSING DATA

3. (a) Strain Symptoms Identified

As indicated in the previous discussion, stress to vegetation causes strain symptoms: a detrimental strain is considered an injury, and any subsequent loss caused by the original stress is termed damage. To date, remote sensing has been dependent on the detection of strain symptoms as indicators of stress rather than on the detection of the stress agent itself. Bark beetles are not detected during remote sensing bark beetle damage surveys, but the dead and fading trees caused by the beetle attacks are detected (Klein et al. 1980). Similarly, SO_2 is not detected, but the effects of SO_2 are detected and assessed. Traditionally, entomologists have collected bark beetles in host trees, or environmentalists have recorded the actual presence of the SO_2 gas to identify the causal stress agent. The evidence gathered by remote sensing is circumstantial, or indirect, in that it detects the effect rather than the cause. How much indirect evidence needs to be accumulated before the evidence can be considered direct?

In remote sensing, certain data collected for a plant have been called the plant's signature. If the data were in the form of a spectral reflectance curve, they were called the spectral signature. Changes in the spectral signature form part of the strain symptoms. Strain symptoms indicative of injury and damage are indirect indicators of stress, but these symptoms can have a unique sequence or pattern. The sequence of strain symptoms displayed by a plant as it responds to stress represents a form of remote sensing signature that can be used to identify an environmental stress. The sequence may appear on many host plants over a certain area at any one point in time, or it may be seen as a sequence on the same host plant over an extended period.

There are many strain symptoms that can be caused by one or more stresses, and these symptoms are subject to classification and interpretation. Photo interpretation is facilitated by the use of photo interpretation keys. In 1972, Murtha (1972a) presented a key to the photo interpretation of damage types (strain symptoms representing injury and indicative of damage) for trees and in essence presented a method by which the photo interpreter can describe the strain symptoms as they are perceived during photo interpretation. Kenneweg (1980) compared the damage types of Murtha (1972a) to other European literature and noted that the systematic technique of damage classification was valued, but also noted that there needed to be more flexibility in the key. Noting the sequence of damage types rather than interpreting for a single symptom provides the needed flexibility and an indirect clue to the identification of the original stress. The following discussion illustrates how a sequence of strain syndromes can be used to identify an environmental stress such as SO_2.

The damage types referred to in the discussion are derived from Murtha (1972a, 1978) and are briefly described in Table 1. They are based on strain symptoms interpretable on the air photo-visible portions of the tree crown. The symptoms seen are directly related to photo scale (Carlson 1978, Murtha 1978, Zealear et al. 1971). At very large scales (e.g., 1:1000) virtually all the symptoms are interpretable, but as the scale becomes smaller (e.g., 1:4000), certain symptoms are no longer resolved on the photographs. The first symptoms lost to the interpreter are the finer details in the crown, such as chlorosis or necrosis on individual leaves and exposed tips of small branchlets. (For purposes of this discussion, it is assumed that large-scale (1:1200), color infrared air photographs are being interpreted, since color infrared photos record spectral changes in the near-infrared as well as the green and red spectral regions.)

3 (b) Interpretation of Strain Symptoms: The SO_2 Damage Type Sequence

The sequence of damage types for conifers affected by SO_2 has been modeled in Figure 4, and the pattern for hardwoods has been modeled in Figure 5. (The damage type descriptors are presented in Table 1.) The patterns for Figures 4 and 5 were derived after observations and subsequent photo interpretation of fume-damaged trees in interior British Columbia (Murtha 1971, Murtha and Trerise 1977), coastal British Columbia (Murtha 1978), and northern Ontario (Murtha 1972b, 1973). Additional material examined to model the patterns included reports by Carlson (1974, 1978), Carlson and Dewey (1971), Dochinger and Jensen (1975), Enderlein and Vogl (1966), Jacobson (1970), and Zealear et al. (1971).

Shortly before chloroplast breakdown occurs in a tree injured by SO_2 (Carlson 1974), cellular inclusions are affected and photosynthesis is inhibited (Bennett and Hill 1973). Gausman (1977) has described the near-infrared reflectance resulting from cellular inclusions, and Webster (1967) has compared the continuing effects of SO_2 on the foliage to senescence. Since it is known that near-infrared reflectance changes (usually a decrease) when foliage senesces, it is suggested that an initial decrease in near-infrared reflectance could occur before any visible change. Although this fact has yet to be confirmed by controlled studies, the damage type as recorded on the film and measured by densitometry would be IVA (increased cyan dye layer density) or IVB (decreased cyan dye layer density). When the response has been great enough to be seen (visually on the photos), the damage types are IIIOa (darker magenta), or IIIOb (lighter magenta) (Murtha 1980). The IIIOa and IIIOb syndromes are especially evident when comparisons are made with the same host tree species in the same photo frame, since trees of the same species can be differentially responsive to SO_2 injury. Evidence from numerous plots in SO_2 damage zones suggest that damage type IIIOb is more frequently seen than IIIOa. Damage type IIIOb is considered a more advanced strain syndrome and thus would be evident for longer time periods. Damage type IIIOb is particularly evident in hardwoods in perimeter zones of SO_2 pollution. When interveinal necrosis has occurred and a large number of leaves have been affected and have subsequently bleached to the ivory color described by

Table 1. Coniferous damage types (strain symptoms) used to describe the effects of SO_2, as seen in large-scale normal color or color infrared aerial photographs. Hardwood damage type equivalents are given in brackets (after Murtha 1972a).

Damage type	Description
IA	Tree dead, bark exfoliated, exposed wood bleached whitish through weathering (long-dead tree).
IB (ID)	Tree totally defoliated, limbs and branches maintain bark and are dark toned on the photographs.
IIA (IIB)	Terminal leader or upper branches dead and defoliated, lower crown still retains green foliage.
IIE (IIG)	A thin-crowned tree, premature loss of inner-branch foliage, inner crown branches visible on aerial photographs, current foliage is present.
IIIA (IIIC)	Some foliage yellowed, most of the tree crown is not yellowed, and residual foliage is the normal green hue.
IIIB (IIID)	Entire crown is yellowed; this strain syndrome shows as a mauve hue on color infrared photos.
IIIG (IIIN)	Entire crown shows dead, red-brown foliage.
III I (IIIM)	Terminal portion of a conifer crown or varying amounts of foliage in the upper portion of a hardwood crown display dead, red-brown hues.
IIIOa	Foliage is seen as a darker magenta hue on color infrared photos; the darker-than-normal magenta hue is noted by comparison with other trees of the same species.
IIIOb	Foliage of these trees is seen as a lighter magenta hue on color infrared photos and is noted by comparison with other trees of the same species in the same photo frame.
IVA	Red-filtered optical density measurements on color infrared photos show a greater cyan dye layer density than that shown for a normal tree.
IVB	Red-filtered optical density measurements on color infrared air photos show a lesser cyan dye layer density than that shown for a normal tree.

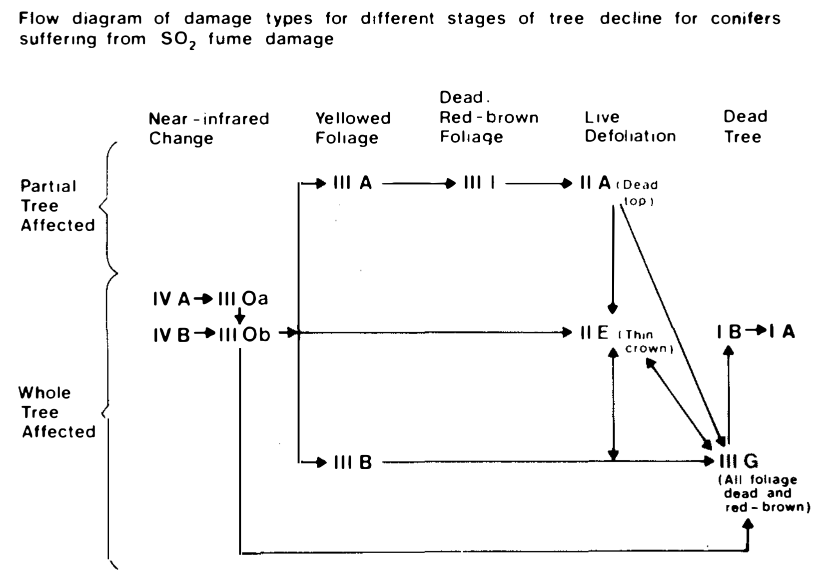

Figure 4. Flow diagram of tree damage types for successive stages of tree decline for conifers suffering from SO_2 fume stress.

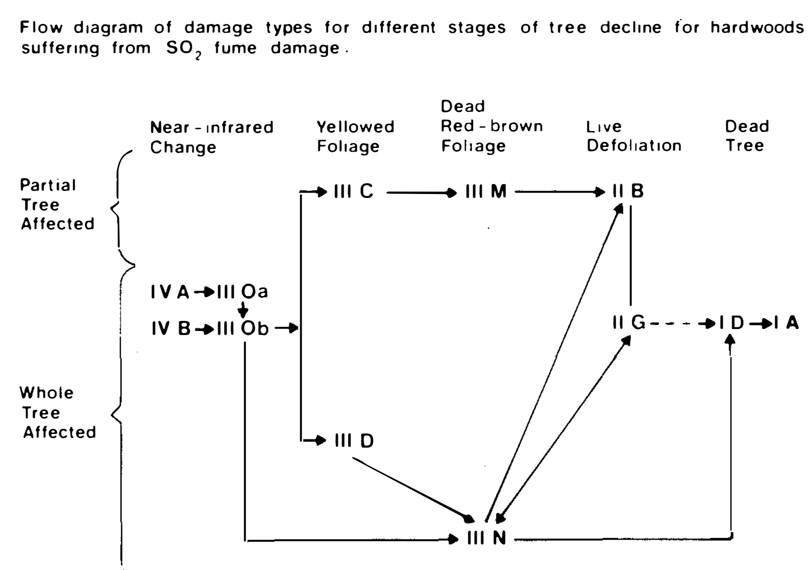

Figure 5. Flow diagram of tree damage types for successive stages of tree decline for deciduous hardwoods suffering from SO_2 fume stress.

Webster (1967), the affected crowns will appear a lighter magenta hue on color infrared photos. Such trees are also classified as damage type IIIOb. Because of image merging, damage type IIIOb is also more frequently seen on smaller-scale (1:3000) than on the very large-scale (1:1000) photos.

When the chronic effects of fume damage persist, chloroplast breakdown occurs and yellowed foliage is perceived and noted as damage type IIIB on conifers. Conifers, especially white pine in perimeter SO_2 damage zones, frequently display such chlorotic foliage (Dochinger et al. 1970). When yellowed foliage is seen on hardwoods it is classified as damage type IIID. After the yellow-foliage stage, the foliage frequently dies, and when the entire crown is seen with dead red-brown foliage, the damage type is IIIG (IIIN in hardwoods). Acute fumigations by SO_2 have killed the foliage of many trees virtually overnight (Murtha 1971), and damage type IIIG will be very widespread, but the trees can recover (Murtha and Trerise 1977).

In some cases the entire crown is not affected and it is only the upper portion or one side of the crown that yellows or blanches, producing damage type IIIA in conifers (IIIC in hardwoods). When the foliage dies, damage type III I (or IIIM) is produced. Trees affected by acute levels of SO_2 frequently show directional damage, with the damage side facing the source of SO_2 (Murtha 1971). In zones of chronic SO_2 stress, directional damage is likely to be noted relative to trees in exposed topographic positions.

When current-year foliage in the upper crown is displaying the red-brown (straw yellow) syndrome it is damage type III I (or IIIM in hardwoods). Dead foliage is usually abscissed relatively quickly, and a tree with dead foliage at or near the top may be seen next as a dead defoliated top IIA (IIB in hardwoods). If needles have been prematurely abscissed and new growth has occurred, the tree is seen with an obviously thin crown, and damage type IIE (IIG in hardwoods) is interpreted. Zones of chronic SO_2 fumigation frequently have many thin-crowned conifers or hardwood with many inner branches showing.

Trees that have died during the previous one or two years (IB or ID) may be interpreted because of the dark appearance of the exposed branches. Trees that have been dead for several years usually have lost some branches, bark has been exfoliated, and the exposed wood has been bleached white. Old dead trees are designated as damage type IA.

The damage types described above are typical of SO_2 strain syndromes; however, because of differential inter- and intraspecific stress responses (Houston 1974), all damage types may be seen on the same aerial photograph. The frequency of occurrence of any given damage type varies with the intensity of the SO_2 fumigation. Damage zones can be delineated based on the frequency of occurrence of damage types. Perimeter zones usually have a higher occurrence of damage type IIIOb, whereas zones of greater damage show more thin-crowned, dead-topped or dead trees.

It is suggested here that the models (Figs. 4 and 5) for the sequential flow of damage types represent unique signatures for the photo interpretation of SO_2

injury (Murtha 1980). The percentage or number of trees displaying a particular damage type will vary with the intensity of the SO_2 fumigation, the distance from the source of SO_2, and the tree species present in the affected area. The compounding factors are the direction of the prevailing winds, climatic patterns such as temperature inversions, air temperature and relative humidity, the influence of topography, and the growing stage of the plant during the fumigation. Although other forms of air pollution (such as fluoride, ozone, etc.) may cause somewhat similar patterns, other stress vectors such as insects, disease, or even poor site conditions do not give the same or even similar patterns of damage types. Most, if not virtually all, insect and disease vectors are host specific, whereas site effects can be evaluated on the basis of terrain analysis. SO_2 injury is airborne, affects more than one or two species of tree, is influenced by winds and topography, and diminishes with distance from the source (Murtha 1973). When trees are affected by SO_2, there is a defined sequence of damage types that have been modeled and can be used by the interpreter to assess SO_2-caused damage.

SO_2-caused strain syndromes are found in complex patterns and, as suggested above, are simply indirect evidence of the SO_2 stress. Even with the strain indicators, however, the literature indicates that positive, direct proof linking the cause and the effect is hard to come by (Webster 1967), and firm guidelines must be established to describe what constitutes absolute proof of air pollution caused-damage.

3 (c) Insect and Disease Strain Symptoms

Insects and disease are somewhat easier to identify as causal agents of stress symptoms detected by remote sensing than are SO_2 strain symptoms. An affected plant is readily detectable provided the appropriate film, photo scale, and interpretation techniques are used (Henninger and Hildebrandt 1980). Normal color and especially color infrared films have been found to be more suitable than black-and-white film for strain symptom detection (Heller 1971). Photo scales are dictated by the need to identify the different strain symptoms most frequently displayed by the plant. Image merging (coalescing of image details) occurs at small scales, and with image merging, significant details of strain symptoms are easily lost. The photo scale must be large enough to clearly resolve the strain symptoms. Interpretation techniques range from optical visual analysis to computer-aided image-enhancement techniques, and these techniques may be qualitative or quantitative. Photo interpretation keys are the best aid for qualitative interpretation, and densitometric analyses are suited to quantitative interpretation techniques. The interpreted data are still only inferential, and the positive identification comes from the collection of suitable ground data. It is, however, the remote sensing data that puts the ground data into perspective and helps to indicate the location, extent, and severity of the injury.

Some selected stress agents (Heller 1971) and their most noticeable strain-symptom descriptions are given in Table 2. Relying on specific single indicators (as in Table 2) can lead to erroneous results. Table 2 gives short descriptions for SO_2-caused strain symptoms, yet Figures 4 and 5 indicate the complex pattern of damage types caused by SO_2. In remote sensing data interpretation all strain

Table 2. Selected stress agents and key or most-noticeable strain symptoms

Stress	Key strain symptoms
Abiotic - Environmental	
Water deficit (drought)	- small foliage, wilting
Water excess (flood)	- topography related, discolored-to- dead foliage
Air pollution (e.g., SO_2)	- affects many species, interveinal necrosis and chlorosis, decrease from source
Wind (storm)	- broken stems
Fire (ground)	- burn scar, blackened ground
Acid rain	- top dieback, lower foliage appears healthy
Biotic - Insects	
Bark beetles (Douglas-fir)	- red-brown and faded foliage
Defoliators (spruce budworm)	- bare branches, seasonal red-brown foliage
Terminal feeders (white pine weevil)	- dead leader
Sucking insects (wooly aphid)	- yellowed foliage, thin crown
Leaf miners (birch leaf miner)	- discolored foliage
Biotic - Diseases	
Stem rusts (blister rust)	- dead top or leader
Root rots (Fomes, Poria)	- thin foliage, dead trees in pockets
Leaf wilts (Dutch elm)	- entire or part of crown with no, dead, or discolored foliage

indicators have to be taken into consideration, and in order to do this, the remote sensing data must be acquired with a multiplicity of sensors and sensing scales.

Some selected stress agents and operational scales and sensor types required for detection and interpretation are given in Table 3. The usefulness of the multistage approach is emphasized here. The multistage approach provides the opportunity for an extensive overview at the smaller scales as well as presenting fine detail at the very large scales. In Table 3, airborne multispectral scanner (MSS) data collected in digital format are amenable to computer analysis; however, the data require registration and calibration and lack the stereo view of air photographs. MSS data is somewhat more difficult to qualitatively interpret than the air photos, and consequently strain symptoms must be described in terms of spectral patterns. Thus, in Table 3, MSS data are ranked somewhat lower than air photos. Color infrared photos make use of the important near-infrared spectral region and thus emphasize many spectral changes and provide for easier stereo interpretation (see color photo on cover).

3 (d) Evaluation of Strain Symptoms

With insect and disease strain symptoms and subsequent damage, it is more a case of early detection of damage and subsequent assessment of impact rather than identification of the cause. Murtha (1978) listed the five general approaches to damage evaluation:

i. counting of individuals affected;

ii. delineation of the areal extent of the damage;

iii. multiplying area by ground surveys of crop production estimates to obtain damage volume estimates;

iv. stratification of the area into damage intensity levels; or

v. multiplying area of damage intensity levels by predetermined volumes to get stratified loss volumes.

The above are some of the generalized methods used in inventorying (determining how much is involved and its location) and monitoring (obtaining indications of change). The third and fifth situations are used when some form of economic evaluation is desired. Some recent reports have outlined the multistage approach and given the statistical methodology for evaluation of insect-caused damage (Klein et al. 1980). Henninger and Hildebrandt (1980) have published the most comprehensive listing of papers dealing with damage assessment in forestry and agriculture by remote sensing techniques.

Damage evaluation can also provide indices of impact and provide relationships with normal patterns, especially in chronic stress situations where subjects are being monitored over long periods. In such situations it becomes essential to be able to define the normal plant as well as the stressed plant. In 1969, Murtha and Hamilton related predetermined levels of stress to internal controls. During

Table 3. Ranking of scales and sensor types relative to detection and interpretation to environmental stresses

	SCALES*											
	Large			Medium			Small			Satellite		
Stress	NC†	CIR†	MSS†	NC	CIR	MSS	NC	CIR	MSS	-	-	MSS
Abiotic - Environmental												
Water deficient	2§	3	2	1	2	1	0	1	0	-	-	0
Water excess	3	3	2	1	2	1	0	1	0	-	-	0
Air pollution	2	3	2	1	2	1	1	1	0	-	-	0
Wind	3	3	2	3	3	2	1	1	0	-	-	1
Fire	3	3	2	2	2	1	2	2	1	-	-	2
Acid rain	2	3	2	1	2	1	0	1	0	-	-	0
Biotic - Insects												
Bark beetles	2	3	2	2	2	1	1	1	0	-	-	0
Defoliators	3	3	2	1	2	0	1	1	0	-	-	0
Terminal feeders	3	3	1	0	0	0	0	0	0	-	-	0
Sucking insects	2	3	1	1	1	0	0	0	0	-	-	0
Leaf miners	3	3	2	1	1	0	1	1	0	-	-	0
Biotic - Diseases												
Stem rusts	3	3	1	1	2	1	0	0	0	-	-	0
Root rots	3	3	2	2	2	1	1	1	0	-	-	0
Leaf wilts	3	3	2	1	2	1	1	1	0	-	-	0

*Scales:
- Large 1:500 to 1:2000
- Medium 1:3000 to 1:12 000
- Small 1:20 000 to 1:63 000
- Satellite 1:250 000 to 1:1 000 000 and smaller.

†Sensors:
- NC = normal color film
- CIR = color infrared film
- MSS = multispectral line scanner.

§Utility: 1 = poor; 2 = fair; 3 = good; 0 = not useful.

interpretation of the stress-caused deviation from normal patterns, the comparison should be with plants in the same photo frame or remote sensing data set. More recently, analyses of photo-interpreted tree damage types have shown reduced basal area increment when the damage-type trees were compared to photo-interpreted normal trees (Murtha and McLean 1981). The basal area deviations are presented in Figure 6. For reference, a sample photo set of the study stand can be seen in Murtha and Mclean (1981).

In the example, the stress was caused by a complex interaction of biotic and abiotic factors working over an extended period. The example confirms that remote sensing data can detect stress in a plant community when it is not readily evident on the ground. The stress can be interpreted because of the strain symptom displayed by the plants and because, in a natural stand, defining the normal plants helps to define the stressed plants. Finally, the example indicates that stress detection and evaluation is the first step in stress identification and subsequent management. The usefulness of remote sensing techniques in natural resources management has been confirmed by many research and operational studies. Detection and evaluation of vegetative stresses is probably one of the most important applications of remote sensing to natural resources management. The time for experimentation is past, and the need now is for the widespread acceptance and then operational application of remote sensing to vegetative stress problems. The technology to do it is available, it simply remains to be applied.

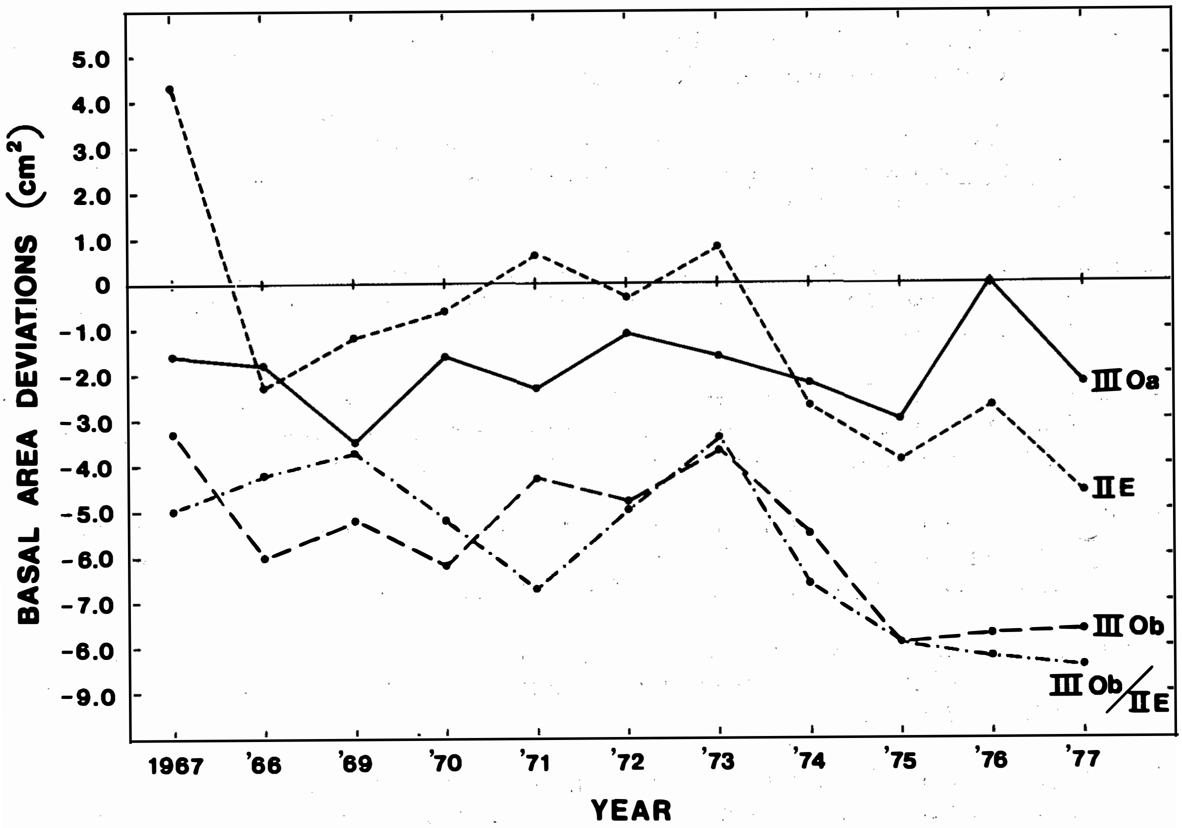

Figure 6. Basal area deviations from normal trees for damage types IIIOa, IIIOb, IIE, and IIIOb/IIE. The negative deviations indicate that the trees photo-stratified as normal are faster-growing trees than the photo-interpreted damage-type trees. (Adapted from Table 4 in Murtha and McLean (1981)).

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APPLICATION OF REMOTE SENSING TO MOUNTAIN PINE BEETLE MANAGEMENT IN SOUTHERN ALBERTA

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ABSTRACT

The mountain pine beetle was first detected just east of the Castle River Station in the fall of 1978 by Alberta Forest Service personnel. Spread of the beetle was continually monitored on the ground, but it was also recommended that the entire foothills area from Highway 3 south to the Montana border be photographed and mapped in the fall of 1979 to assess the extent of the beetle damage. A scale of 1:30 000 (same scale as the forest cover map base) and color infrared film were chosen. When the photography was interpreted, mapped, and compared, it was discovered that several areas that had been interpreted as mountain pine beetle damage were actually overmature white spruce (Picea glauca (Moench) Voss) and balsam and alpine fir (Abies balsamea (L.) Mill. and A. lasiocarpa (Hook.) Nutt.) stands.

The following summer the area was again photographed at a scale of 1:20 000 using color infrared film, and the photography was interpreted and mapped. The Canada Centre for Remote Sensing also flew two flight lines using two separate films at a scale of 1:20 000 in the latter part of July 1980.

Comparing the two films (color infrared and true color), we concluded that true color has a slight advantage over color infrared mainly because we were able to distinguish the infected pine (Pinus contorta Dougl. var. latifolia Engelm.) trees from overmature white spruce and balsam fir timber. In addition, there was less fall-off on the edge of the prints, which assisted us in determining the mountain pine beetle damage.

INTRODUCTION

The mountain pine beetle (Dendroctonus ponderosae Hopkins) has created a situation that the Alberta Forest Service cannot choose to ignore. The beetle has shown the same capability for destruction that has been evident in Montana and British Columbia. There is a tremendous resource value at stake here, and by resource value we are referring not just to timber but also to water, recreation, wildlife, and of course the fundamental resource--soil.

The objective of the Alberta Forest Service is to salvage as much of the beetle-killed and -damaged timber as possible while it still may have some commercial value. If such an effort is not made, not only would the dead timber be wasted, but there is an even greater concern--forest fire. With the present rate of spread of the beetle infestation, this concern becomes even more prominent. Along with the forest fire hazard there is an increased susceptibility of the dead timber to blowdown from the frequent high winds in this area. As with fire, blowdown can result in serious soil erosion problems due to increased mineral soil exposure. Large accumulations of dead timber and debris can result in propogations of further insect infestations of a type not currently being experienced in this area. As well, a much less than optimal environment is created for new forest growth.

HISTORY

The mountain pine beetle is easily the most destructive bark beetle in the west, having ravaged the lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) forests of the northern Rockies since the turn of the century. The progress of mountain pine beetle epidemics in the pine stands can be traced from the beginning in northern Montana in 1909 to full-scale outbreaks that progressed southward through the pine forests of southern Idaho and western Wyoming and into northern Utah. During the past two decades, the infestation pattern has reversed itself (Klein 1978).

Outbreaks are recurring in parts of northern Utah, southern Idaho, western Wyoming, back into Montana, and north into Alberta and British Columbia. Pine stands may be unaffected for many years, then suddenly succumb to attack. Climatic fluctuations are believed to influence insect outbreaks directly by favoring their development and rate of increase and indirectly by increasing susceptibility of the host species. Similarly, a change in climatic conditions may contribute to ending or decreasing the severity of the beetle outbreak (Safranyik 1978).

In combat against the mountain pine beetle, what is the role of the aerial photo interpreter with available technology? To fully appreciate the use of aerial photography in damage evaluation we should first look at the history of this technology.

One of the first reports of foliage damage that was successfully recorded with near-infrared-sensitive film was reported by Bawden (1933). This type of film was used for the first time in Alberta in 1952 in a trial project in Management Unit S-5. Up to 1950, insect damage such as that caused by the spruce budworm (Choristoneura fumiferana (Clemens) and mountain pine beetle and damage caused by forest fires, windstorms, floods, etc., were clearly visible on aerial photographs, and therefore they were used for that purpose. Both the panchromatic as well as the near-infrared films were used, but with different filters. The type of film was the user's choice.

In 1958 it was finally agreed that a photo interpreter was able to make accurate counts of dead and damaged trees using either true color or camouflage-detection film (near-infrared), which was developed in World War II for, as the word implies, detection of areas under camouflage (Pope 1958).

AERIAL FILM SELECTION

In general it was agreed that color was superior to black-and-white film. The choice of true color or near-infrared color was, and in many cases still is, the personal preference of the user. The time of year, terrain, and weather conditions also influence the choice of film. Insect damage, as in our case, also has to be taken into consideration.

Most studies have concentrated on the detection and evaluation of some variety of forest damage, and usually the interpreter was looking for dead, defoliated, or discolored trees. Forest damage can be defined as any type and intensity of an effect on one or more trees produced by an external agent such as fire, windstorm, flood, frost, and insects. Man also influences changes in the forest, such as by industrial activities including harvesting mature stands and others.

To identify the forest damage on aerial photographs the interpreter must know four factors (Murtha 1969):

1) The possible damage agent. What damage are we looking for? A forest fire, cutover, pipeline, or insect damage? Many more could be mentioned.

2) The manifestation of the damages. Some are easy to detect (such as forest fires and cut lines), while others require more time and knowledge (such as insect damage and disease).

3) The effect of damage on spectral reflectance. For instance, the foliage shape, size, and arrangement influence the spectral reflectance. Young white pine (*Pinus monticola* Dougl.) is more reflective than older mature pine, and reflectance is also generally higher from hardwoods than from coniferous foliage, especially in the near-infrared region.

4) The resulting image on aerial photographs. Anyone who has seen aerial photographs will recognize a cutover, a burned area, a lake, and forested or cultivated land.

In black-and-white photography, forest damage is interpreted from pattern, texture, tone, and shape. In color photography, tone is replaced by color, and damage may be recorded by change of shape, change of color, or both. Color patterns in foliage (which are usually recorded using normal color photography) are dramatically emphasized in near-infrared (false-color) photography. In general, those same changes are masked in black-and-white photography.

The following table indicates the difference between the normal color of an object and its appearance on color infrared photography (false color) (Murtha 1972).

Object	Normal color	False-color appearance
Most hardwood foliage	Green	Magneta
Most coniferous foliage	Green	Magneta to dark-blue magneta
Young conifers	Green	Magneta
Old conifers	Green	Dark-blue magenta
Plant foliage	Light Green	Pine
Sick foliage	Yellow	Mauve
Hardwood foliage	Autumn Yellow	White
Larch foliage	Autumn Yellow	Mauve
Hardwood foliage	Autumn red	Bright yellow
Dead, dry foliage	Straw yellow to red brown	Yellow to yellow green
Defoliated branches	Gray to brown black	Green, blue green, blue
Defoliated branches with exfoliated bark	Whitish	Silvery, silvery green
Wet branches, exfoliated bark	Dark grey	Green, blue green, blue

THE CURRENT INFESTATION

Alberta Forest Service personnel first detected the mountain pine beetle in the fall of 1978 around the Syncline Group Camp Area just east of the Castle River Station. The affected areas were located primarily south of Highway 3 toward the Montana border. The entire area was photographed and mapped in the fall of 1979 using color infrared film at a scale of 1:30 000.

When resulting maps were field checked, it was found that several areas interpreted as mountain pine beetle-damaged forest stands were in actuality overmature white spruce and balsam and alpine fir (Abies balsamea (L.) Mill. and A. lasiocarpa (Hook.) Nutt.) stands. The following summer, August/September 1980, the same area was rephotographed using color infrared film at a scale of 1:20 000. The interpretation and mapping resulted again in the same confusion.

The Canada Centre for Remote Sensing also took two flight lines covering the same area in the latter part of July 1980 using two 9 x 9 inch format cameras. One camera was loaded with color infrared film and the other with color negative film. Photo acquisition scale was 1:20 000.

CONCLUSION

Comparing the two films (color infrared and true color), we concluded that true color has a slight advantage over color infrared for the following reasons:

1) We were able to distinguish the infected pine trees from overmature white spruce and balsam and alpine fir timber.

2) Less fall-off on the edge of the true color prints, which assisted us in determining the mountain pine beetle-affected areas.

3) Better visual penetration of shadows with true color because the valleys in this area (which has high mountains and deep valleys) are too dark with color infrared.

4) This penetration is also important when the photography is used for other purposes such as updating forest cover maps for forest inventories.

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PRACTICAL APPLICATIONS OF REMOTE SENSING FOR FOREST PEST DAMAGE APPRAISAL

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INTRODUCTION

Remote sensing, in particular color and color infrared (IR) aerial photography, has been used for forest pest damage studies quite extensively, as witnessed by the number of publications dealing with this topic. In spite of the amount of knowledge and experience accumulated over the past decades, remote sensing is not yet used to its fullest possible extent in forest damage appraisals.

Remote sensing in general is well suited for the various phases of forest damage surveys. Considering the conditions typical of Canadian forests, the vast extent, and the difficulty or impossibility of access, in many cases remote sensing is the only economical way to collect data.

Remote sensing offers an uninterrupted, vertical view of the forest canopy. The condition of the foliage is a reliable indicator of the physiological state of the tree since all damaging agents, biotic or abiotic, interfering with the normal functioning of the tree will eventually cause changes in the foliage that are recognizable by remote sensing.

All remote sensing methods produce images by recording energy in portions of the electromagnetic spectrum reflected from or emitted by features on the earth's surface. In general, the images offer a vertical view of the earth's surface. As a result, the image is map-like, suitable directly or through some processing for the mapping of ground features. The images are permanent records of the features or phenomena recorded by remote sensing. They can later be studied and analyzed in comfortable working conditions and by means not available in the field. Imagery of the same area can be acquired several times, and the permanent records compiled over a period of time can be used to monitor changes. Furthermore, the images recording the nonvisible part of the spectrum provide information that cannot be collected in any other way.

REMOTE SENSING TECHNIQUES FOR DAMAGE ASSESSMENT

At present--and in the foreseeable future--the most commonly used remote sensing techniques for forest damage assessment are color and color infrared aerial photography. There are, however, other means of remote sensing that may become useful in certain phases of forest damage surveys.

Satellite Imagery

The presently available LANDSAT imagery is characterized by coarse spatial and spectral resolution. The ground resolution of the imagery is about 1.1 acres. As the reflectance value associated with one resolution cell or pixel is the average of all features within that 1.1-acre area, only major changes produce significant changes in the appearance of the pixel. Information is recorded in four relatively broad bands, three 100 nm and one 300 nm wide. Within the limits of each recording band, only the average of the wavelengths present across an individual pixel is detected; therefore, subtle differences are lost in broad-band recording. The great advantage of satellite imagery, however, lies in repetitive coverage, which permits the detection of changes through comparison of multi-date imagery. Future systems with a higher resolution will certainly improve the usefulness of satellite imagery.

At present, the applicability of satellite imagery is restricted to the detection of forest damage in cases where the damage is severe and extensive. Slow, gradual changes are difficult to detect; rapid but short-lived changes may or may not be detected, depending on the frequency with which usable imagery is obtained. The reported successful applications describe cases where the damage had already been detected by other means. Analysis of the satellite imagery only confirmed that, under favorable circumstances, certain types of forest damage may be detected on satellite imagery as well.

Airborne Multispectral Scanners

While airborne scanners retain most of the advantages of the satellite scanners, with the exception of the regular repetitive coverage, the ground resolution can be controlled by acquiring the imagery at various altitudes. The spectral resolution is improved by employing more bands with a narrower band width, over a wider range of the spectrum. In addition, time of image acquisition can be specified. Unfortunately, this imagery is not yet available on a routine basis, and more experience is needed before its usefulness can be fully evaluated.

Airborne Thermal Scanners

Airborne thermal infrared scanners provide imagery showing temperature distribution on the ground. Lack of a clear-cut, logical connection between forest damage and canopy temperature makes the thermal scanner an unlikely sensor for this application. Very little experience has been acquired to date.

Radar Sensors

As in the case of thermal scanners, the nature of the data, i.e., the fact that it is related to surface roughness and to dielectric properties, does not seem to be indicative of the physiological state of forest canopy.

Airborne Video Cassette Recording (VCR)

Although VCR is not considered to be as serious a remote sensing device as those discussed above in that it is not calibrated radiometrically and the distortions in its imagery are not known, for certain applications it has much to offer. In the past year at the Ontario Centre for Remote Sensing, several trials were undertaken to assess its usefulness in crop identification studies and wild rice distribution mapping.

VCR systems are relatively inexpensive to purchase and commercially available on a rental basis as well. Although their resolution is fairly coarse, this can be largely overcome by selecting suitable altitudes. The portable lightweight recording units can be used in helicopters or in fixed-wing aircraft. The recording medium is reusable. Cameras equipped with zoom lenses provide wide-angle coverage for orientation or close-up views of the object of interest. The simultaneously recorded audio track allows for a running commentary of the operator's own visual observations. All of the above factors make the VCR an ideal support system for aerial sketching. Back in the laboratory, the cassette can serve as a permanent record of the mission. Most playback units have the capacity to "freeze" the image, a valuable aid to the mapping of observed features.

REQUIREMENTS OF FOREST DAMAGE SURVEYS

Forest damage surveys are made up of several phases, each of which has requirements regarding the quality and quantity of information. The initial detection of damage requires wide-area coverage but only a low level of information. Delineation and mapping of the already discovered damage area calls for more-detailed information over a limited area. A quantitative appraisal of damage levels and mortality rates requires a medium level of information. For the identification of the damage by its cause, very high levels of information are needed. The same is true for surveys aimed at forecasting damage, usually carried out as a sampling exercise and involving small areas.

The output of remote sensing systems shows a similar relationship between quantity and quality of data produced through approximately identical expenditures. Wide-area coverage is possible with small-scale images having a coarse resolution; for fine resolution and detail, large scales and limited-area coverage must be chosen.

This similarity does not mean, however, that remote sensing may be capable of replacing traditional methods for every task of the forest damage survey. Practical application of remote sensing techniques for any purpose, including forest damage assessment, requires careful consideration, even when research proves to be successful. The following factors should be considered:

1. Ease of application. Research teams often conduct studies under circumstances not readily available outside of the laboratory. The imagery or the equipment used in the analysis may not be routinely available.

2. Compatibility. A newly established remote sensing methodology may be required to provide input into an already existing information system. The remotely sensed data has to be of the same type and format.

3. Reliability. Methods relying on remote sensing data that must be acquired at specific times may be prone to failure because imagery may not be available at that time (e.g., satellite imagery) or may not be obtainable during the required period (e.g., aerial photography in unfavorable weather conditions). It may also be difficult to maintain the uniform image quality that would make consistency of interpretation possible (e.g., color or color IR photography).

4. Cost effectiveness. This factor is difficult to assess, partly because the benefit of conducting the survey by any means is difficult to define, but also because the information derived from remote sensing surveys is different from that derived from surveys carried out by traditional means. Comparison, although not impossible, may therefore be difficult.

AERIAL PHOTOGRAPHY IN FOREST DAMAGE SURVEYS, TECHNICAL CONSIDERATIONS

Aerial photography, the oldest branch of remote sensing, offers a wide selection of cameras, films, lenses, formats, and product sales to choose from. Among remote sensing methods, aerial photography offers the unique feature of stereoscopic viewing of overlapping photography. The advantages of the three-dimensional view over the monocular view need not be elaborated: aerial photographs should always be viewed in stereo.

The format of the photography is dependent on the cameras available. Although in some cases small formats (35 mm or 70 mm) are quite adequate, the smaller number of large-format frames required for the coverage of a given area is a definite advantage as far as flight planning, photo handling, and ease of interpretation are concerned. The advantage of wide-area coverage is especially evident when large-scale photography is used: with large-scale, small-format photography it is very difficult to locate the corresponding area on the ground.

Given the use of a single film type, it is the scale of an aerial photograph that determines its resolution. Within reason, the scale may be controlled by the altitude of the aircraft or by the focal length of the lens used. As a general rule, the smallest possible scale that still provides the required information should be selected. While several combinations of altitude and focal length yield the same scale, extremes should be avoided since they could result in navigation difficulties, unsafe low or high flying heights, a poor stereo effect, uneven exposure, and other problems.

The different kinds of film available have been tested many times, and the consensus is that for vegetation damage studies the color infrared and true color films are the most suitable. From the theoretical point of view, the color IR film is clearly superior for this particular task. In practice, however, consideration should be given to true color film as well.

The main advantages of the color IR film are the inherent high contrast, the increased color contrast, and the ability to record near-infrared radiation, which is the major component of the radiation reflected by vegetation. Blue light, which is prone to atmospheric scattering, is filtered out; for this reason, color IR film penetrates light haze, giving clear, sharp images.

There are major disadvantages to color IR film, however. Color infrared film has a very limited exposure latitude. For consistent quality, exposures must be strictly controlled. The correct choice of lens and altitude combination for a certain scale is especially important, because the exposure across the frame varies with the angle of the rays. To maintain less than a 1-stop exposure difference between the center and corners, the minimum focal lengths for the various formats are as follows:

35 mm format: 35 mm lens

70 mm format: 61 mm lens

9 inch format: 253 mm lens

Alternatively, the use of antivignetting filters, where available, could minimize the problem. The film is very sensitive to storage and handling temperature and to aging. Different batches of this film may also have a different color balance, which must be corrected by appropriate filtering. Using the same film at different altitudes calls for additional compensation by filtering. Because the blue light is filtered out, color infrared film has little or no detail in shadows, where illumination is provided only by scattered light.

Most problems associated with the use of color IR film could be eliminated or at least greatly reduced by careful control of all factors affecting the consistency of the imagery. A detailed discussion of this topic is found in J. Fleming's Standardization Techniques for Aerial Colour Infrared Film (Energy, Mines, and Resources Canada publication, Stock no. SMP-1253B).

Finally, color IR film portrays the scene in unnatural colors, which at first may be difficult to interpret. This is a minor problem, however, and is easily overcome by training and experience.

True color film, on the other hand, while giving a more or less accurate rendition of the scene's natural color, lacks the additional information in the near-infrared range of the spectrum. Color film suffers from the effects of atmospheric haze, but its exposure latitude is considerably wider, giving a fair margin for error without serious effects on image quality. In general, when damage is recognizable on color IR film, it is also visible. The capability of color IR film to detect so-called previsual damage has, however, not yet been proven satisfactorily.

Balancing the advantages and disadvantages of the two color film types, it is fair to say that as long as strict quality control is ensured and sufficient experience in the use of the film has been gained, the color infrared film should be chosen. When the damage to be photographed is distinct and the competence of the operators questionable, the color film will have the greater likelihood of success.

Regardless of the film type chosen, the form of the final product should be selected so as to preserve the maximum amount of information. The original film (the first generation) has the maximum information content. Each subsequent generation, of transparencies and especially of prints, suffers considerable loss in detail and contrast. Both film types should be developed into positive transparencies for the purpose of interpretation. For working copies, prints made from the transparencies are quite adequate; as an alternative, a second camera may be used simultaneously to expose panchromatic film for low-cost working prints.

THE APPLICATION OF AERIAL PHOTOGRAPHY FOR THE VARIOUS PHASES OF FOREST DAMAGE ASSESSMENT

The three major phases of forest damage assessment are detection, mapping, and detailed assessment. The following is an evaluation of the usefulness of aerial photography for each phase.

Damage Detection

For economic reasons, aerial photography is not recommended for this purpose. Because the location of the possible damage is not known and the monitoring of large areas is involved, chances are that a great proportion or possibly all of the exposed film will show no damage. The cost and time involved would be exorbitant. There is as yet nothing better than the keen eye of the airborne observer in the initial detection of damage. With a reduction in the time required to make new imagery available to users, in future the automated analysis of multidate satellite imagery for change detection could possibly be useful.

Damage Mapping

This task is traditionally performed by aerial sketching, a method that possesses all the advantages of the vertical or oblique view from the aircraft but does not produce the permanent record of forest conditions that is provided by remote sensing. Aerial sketching is a low-cost technique that works well as long as there are enough landmarks recognizable both on the map and on the ground. Where the land is relatively featureless or visibility is limited, the accuracy of sketch mapping deteriorates.

Aerial photography is the ideal tool. Medium-scale (1:20 000) to small-scale (1:120 000) photography permits highly accurate mapping of the damage. The detail is sufficient for stratification of the damaged area.

Detailed Damage Assessment

For the next step, a more-detailed study of the damage, medium- to large-scale aerial photography is recommended. The determination of defoliation levels and the assessment of mortality requires a scale at which individual trees can be recognized or identified. The suggested scales range from 1:10 000 to 1:5 000. The 1:5 000 scale offers a minimal gain in information content for a large increase in cost. The recognition of certain types of light damage, such as the loss of the current foliage of conifers, would require larger scales up to 1:1 500. Because of the small ground coverage per frame, these very large scales should only be used for sampling purposes.

The identification of specific damaging agents is often difficult even on the ground, so remote sensing should not be used alone for this purpose. Specific damage patterns visible on the imagery, however, could be reliable clues for identification. The main value of remote sensing for damage identification is in pinpointing the exact location of the damage so that field work can be carried out with a minimum of effort and cost.

Specific examples of the application of aerial photography for forest damage assessment conducted by the Ontario Centre for Remote Sensing are described in the following section.

CASE STUDIES

Since its establishment, the Ontario Centre for Remote Sensing (OCRS) has been involved in practical applications of remote sensing in various areas of resource management. Three OCRS projects dealing with forest pest damage assessment are described below in detail.

1. Hemlock Looper Damage Assessment and Monitoring

In 1978, an outbreak of hemlock looper (Lambdina fiscellaria fiscellaria Guenee) occurred in the North Kawartha Lakes area in southern Ontario. The infestation was first reported by cottagers; subsequently, an aerial sketch map of the defoliation was prepared. Because hemlock looper infestations are rather short-lived, the OCRS decided to obtain aerial photography of the damage in spite of the late season. A flight plan based on verbal information was drawn up, and the photographic flight took place in November 1972. Both color and color IR films were used at a scale of 1:8 000. Although the entire damage area was not covered, ample evidence of the infestation was found on the excellent-quality imagery.

To obtain complete coverage, the boundary of predominantly hemlock stands in the vicinity of the damage was determined from 1:15 840 scale panchromatic photography, and a second flight covering this area was flown in December 1978. Because the damage was so evident at the 1:8 000 scale, this time the scale was changed to 1:20 000. In spite of the lower quality of the photography, the damage was clearly recognizable. Two damage classes, heavy and light, were mapped on the basis of the photography. Comparison of the map and the aerial sketch showed considerable differences both in extent and location of the damage. To monitor the infestation, the area was rephotographed in October 1979. Careful comparison of the 1978 and 1979 photography revealed no changes, indicating the collapse of the infestation, and the mortality of defoliated trees.

Although the size of the totally defoliated pure hemlock stands was far larger than the theoretical resolution of LANDSAT imagery, comparison of 1976 and 1978 satellite images did not show the damage.

Aerial photography proved superior to aerial sketching for damage delineation. Repeated photography was demonstrated to be a reliable way to monitor forest damage. Color IR film greatly facilitated damage recognition, although the damage was visible on true color film as well. The damage map was used in planning salvage operations.

2. Aerial IR Surveys of Conifer Plantations

This program was initially aimed at the detection and identification of Fomes annosus (Fr.) Cke. damage in red pine (Pinus resinosa Ait.) plantations in southern Ontario from 1974 to 1979. The OCRS has experimented with several formats and scales. The scale found to be most useful was 1:8 000. The 35-mm cameras originally used were later replaced by 70-mm cameras. In 1977 and 1978, a photographic survey company was contracted to obtain coverage using 9-inch-format cameras with 12-inch lenses. Of the three, the large-format camera with the long focal length gave the best results.

Throughout the years color infrared film was used. The film was always developed to positive transparency for interpretation. The interpretation results were marked on black-and-white prints made from panchromatic negatives obtained simultaneously with the color IR photography. Use of the small formats made it necessary to prepare a key map showing the location of the individual frames. The wide-area coverage of the large format eliminated the need for the key map, as the flight index maps (supplied by the contractor) were sufficient.

In view of the difficulty in reliably identifying trees infected with Fomes annosus, all dead trees and all trees showing color different from the color of healthy specimens were marked during the interpretation phase, regardless of the probable cause. Identification of the specific damage was left to field checking. The black-and-white prints were used as maps for the field check. The photo scale and the regular pattern of the plantation made the location of suspect trees an easy task.

In this project, damage detection was not needed, because all plantations were photographed in the district requesting the survey. For mapping purposes, aerial photography again proved to be an excellent tool, providing the precise location of all stressed trees. The main advantage of the remote sensing approach lay in minimizing the fieldwork.

3. Spruce Budworm Damage Studies

This multiyear project started in 1976. Damage detection was considered because spruce budworm (Choristoneura fumiferana (Clemens)) is found practically everywhere in Ontario, where the host species occurs. The main purpose of the project changed several times over the years.

In 1976 and 1977 two flight lines were flown in north-central Ontario covering a well-established infestation. Color IR film was exposed at scales of 1:2 600, 1:4 800, 1:10 000, and 1:16 000. Total defoliation was recognizable at all scales, but moderate or light damage was detected only at the two largest scales. On both occasions the films were handed over to the client for field checking and for a trial run of an automated analysis method.

In 1978 a relatively new infestation was reported in northern Ontario in Clavet Township near Geraldton. The study area, about 40 square miles in size, included several stands of mature and overmature balsam fir and white spruce, scheduled for harvesting within the next 15 years. A program of spraying was planned to keep the stands alive until harvest. In this case, remote sensing was employed to identify and map infested stands without giving any detailed assessment of the damage. To this end, aerial photography was acquired using 70-mm cameras and color and color IR film at scales of 1:30 000 and 1:60 000. In August 1978 the presence of damage was clearly recognizable on the 1:80 000-scale color IR photography, which was used to map the damage on 1:50 000-scale topographic maps, which were used for planning the aerial spraying operation.

The combination of large area and small format gave a large number of frames even at the small scale used. In similar cases the use of 9-inch cameras is highly recommended for ease of interpretation, photo handling, and mapping.

A second study area photographed in 1978 was located near Temagami, Ontario, within a well-established old infestation. In this case, 70-mm color and color infrared photography was taken at scales of 1:14 000, 1:7 000, and 1:3 000. The object of this study was to determine which scales were suitable for the assessment of damage levels. Two scales were found to be sufficient: approximately 1:8 000 for detailed assessment and approximately 1:20 000 for damage delineation and mapping. An optional third scale of approximately 1:50 000 may be included if a photomosaic is needed as an up-to-date mapping and planning base. The actual scales would largely depend on the available camera equipment. In an economical multicamera operation, different focal length lenses provide all the necessary scales in one flight.

In 1979 a reportedly undamaged area between two old infestations in northern Ontario was surveyed by aerial photography. This buffer zone was too large for complete coverage. To stratify the area, forest resources inventory maps and photo interpretation were used to locate areas of potential budworm damage. Few such stands were found: the area appeared to be a natural buffer zone. Seven flight lines were drawn up to cover the selected stands. Color infrared photography was obtained at a scale of 1:24 000. The interpretation indicated heavy or moderate damage in all stands.

The Temagami site was rephotographed in 1979 using the same scales and films as in 1978. The 1:7 000-scale coverage proved to be suitable for monitoring changes in the appearance of damaged individual trees and stands.

In 1980, monitoring of the Temagami site was continued. The aerial photography was carried out according to the previous specifications. The main effort was directed toward a remote sensing-based method for determining cumulative damage. According to the Ministry of Natural Resources policy for protection spraying, spray permits are issued for an area only if certain requirements are met. For example, the damage must be such that only by spraying could the stand be kept alive until harvesting. To determine the damage level, the following method was devised. Medium-scale (1:7 000) color and color

IR photography is taken over the stands considered for spraying. With the aid of a transparent overlay, randomly distributed circular samples are delineated on the photograph for each sample area. A count is made of trees falling into six damage categories determined by the appearance of the crown. The damage classes were developed in accordance with the criteria used in ground surveys. The aerial method allows for more randomly distributed samples.

SOME DEVELOPMENTS IN REMOTE SENSING AT THE NORTHERN FOREST RESEARCH CENTRE

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ABSTRACT

Rapidly rising costs of conventional forest inventory are contributing to a renewed interest in methods to reduce costs. I think that remote sensing has the kerosene to light some fires that will help obtain forest inventories at reduced cost.

This reminds me of a story about a young geologist, just out of graduate school with a fresh Ph.D., who was sitting in on his first wildcat oil well. His client was a hard-crusted, bitter, tough guy who worried about the money and knew little geology and certainly no scientific nomenclature. At two o'clock in the morning the graduate called his client and said, "We just penetrated the Miocene with a drill bit." The next night he called his client and said, "We just penetrated the Oligocene." The following early morning he called his client and said, "We just penetrated the Eocene." The old man responded, "Son, don't call me any more until you reach Kerosene."

Over the past 10 years, research and development in remote sensing have been carried out at the Northern Forest Research Centre (NoFRC) in the following areas:

1. multistaged and multiphased inventory approaches,
2. digital and optical satellite image interpretation,
3. small-scale color infrared aerial photography,
4. large-scale photo sampling, and
5. computer mapping and data base management systems.

MULTISTAGED AND MULTIPHASED INVENTORY APPROACHES

The first Canadian test of multistaged inventory was on the P-6 management unit in Alberta. This study indicated that highly efficient estimates of merchantable softwood volume could be made for large areas at low cost. The approach involved using estimates of merchantable softwood volume obtained from LANDSAT imagery and digital tapes to guide subsequent sampling.

Subsequent sampling was made proportional to the aerial occurrence of softwood as determined in the first stage based on LANDSAT. This focused the sampling on the areas with softwood timber and required only one-third of the samples that would have been required for simple random sampling. The approach used for the P-6 test site (Kirby and van Eck 1977) was also used by the Simpson Timber Company for its lease area at Whitecourt, Alberta. Inventory costs were reduced, and the results were found to be satisfactory. Multistaged sampling design should be suitable for insect and disease damage surveys but may require aerial photography in the first stage to detect the damage. The only successful detection of forest damage on LANDSAT by NoFRC was of red belt (Kirby et al. 1975).

DIGITAL AND OPTICAL SATELLITE IMAGE INTERPRETATION

Both optical and digital satellite image interpretation techniques are available at NoFRC. In our work with satellite imagery we have found that both approaches give similar results in many cases. The digitally produced pictures usually produce the best-quality picture at greater cost when only small areas are involved, but when themes for large areas are to be interpreted, digital techniques may be the most economic approach. At present NoFRC has an unsupervised classifier for digital image classification developed by Goldberg and Shlien (1976). This software was put on the PDP 11-60 at NoFRC with assistance from the Petawawa National Forestry Institute. Preliminary evaluation indicates the classifier works well on our system, so that it will be possible to integrate image classification with computer mapping techniques that will be available at NoFRC in 1982.

SMALL-SCALE COLOR INFRARED AERIAL PHOTOGRAPHY

Considerable savings in forest inventory cost may be achieved with the use of small-scale aerial photographs. On the P-6 test site it was demonstrated that color infrared photography at a scale of 1:100 000 could produce similar results to an inventory obtained from 1:20 000 aerial photographs in infrared black and white. The use of a small scale requires good interpretation equipment such as the Zeiss-Jena Interpretoskop available at NoFRC. With this equipment and the color infrared photographs previously described, it was possible to detect forest damage where the trees had been turned red by flooding in patches as small as 0.1 ha on the original positive transparencies. The quality of color infrared aerial photography is greatly reduced when printed on paper.

LARGE-SCALE PHOTO SAMPLING

NoFRC has pioneered the use of large-scale aerial photographs taken from helicopters (Kirby 1980). This approach greatly reduces the cost of ferrying aircraft to various sites. The camera system consists of a Honeywell radar altimeter, two 70-mm Vinten cameras, and an intervalometer built in-house. Height of aircraft above ground is recorded digitally on each exposure taken.

With large-scale photographs at a scale of 1:400 it is possible to detect coniferous forest regeneration as small as 0.3 m, and with photographs at a scale of 1:1000, timber volumes of individual trees may be determined and tree heights estimated to an accuracy of 1 m. The system is being upgraded so that it may be mounted with MOT approval on a Bell 206 or Cessna 172 using a pod developed by the U.S. Air Force for the Department of Environment. The cameras in the pod may be rotated to correct for drift as detected on the television tracking camera. The system will have a microcomputer for controlling the cameras and recording readings from the radar altimeter and the tip and tilt indicator.

COMPUTER MAPPING AND DATA BASE MANAGEMENT SYSTEMS

At present the technological developments in this area are far ahead of applications in forestry, and there is a need for demonstrations of various approaches. A computer mapping system is being developed for this center that will have the capability to integrate map and satellite information so that inventories may be speedily updated for changes resulting from fire and clear-cutting. Thematic maps in color may be produced by the system.

CONCLUSION

The transfer of technology in remote sensing has not been as quick as was first thought possible. The continuing work at NoFRC is now beginning to provide some tangible results that are being used to improve approaches to forest inventory.

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THE ROLE, INFORMATIONAL REQUIREMENTS, AND MAJOR PEST PROBLEMS OF THE FOREST INSECT AND DISEASE SURVEY

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ABSTRACT

The Forest Insect and Disease Survey (FIDS) of the Northern Forest Research Centre, in conjunction with provincial forest services, conducts annual surveys to detect and monitor the activities of forest pests. Data collected during these surveys are used by federal and provincial resource management agencies in their pest management programs. Described here are the major role and informational requirements of FIDS aerial survey techniques, including type and uses of data collected and major forest pests of the region. The possible role of remote sensing products and the interpretation techniques for standardizing and improving survey methods are discussed.

INTRODUCTION

Forest pest surveys in Alberta, Saskatchewan, Manitoba, and the Northwest Territories are conducted mainly by the staff of the Forest Insect and Disease Survey (FIDS) of the Northern Forest Research Centre, Canadian Forestry Service, in Edmonton. Cooperation and assistance are provided by personnel from many federal, provincial, and municipal agencies.

Various surveys are undertaken annually and include those that detect and assess tree damage from the air. Damage is seen as discolored trees with needles damaged or missing. Special surveys of damaged trees are done in more detail on the ground, but the extensive forests of the region require aerial surveys. The FIDS group has used aerial sketch mapping surveys for a number of years. These surveys, in which areas of damaged trees are sketched onto maps by observers in aircraft, permit an overview of tree damage and may be augmented by detailed ground surveys or observations.

Although aerial photography has been used occasionally to supplement aerial observation, the potential use of this method to refine present FIDS survey techniques needs to be investigated. Before this can be accomplished, the role and informational requirements of FIDS, the major tree-damaging agents, and existing surveys must be identified and stated.

THE ROLE OF THE FIDS GROUP

The main responsibilities of the FIDS group are as follows (Hiratsuka et al. 1981):

1. Contribute to a national overview of important pest conditions in the region and their implications;
2. Map, evaluate, and report on important forest pest infestations in the region;
3. Provide advisory services concerning forest insect and disease problems;
4. Conduct plant quarantine-related activities;
5. Conduct specific surveys of unresolved or potential problems; and
6. Provide an ornamental and shade tree pest extension service.

INFORMATION REQUIREMENTS

An annual national overview of important forest pest conditions would require the following information:

(a) distribution and general location of infestations within a province

(b) causal agent(s) and population level

(c) tree species affected and type of injury and/or damage

(d) area affected

(e) broad mortality volume estimates

(f) broad growth-volume loss estimates where available

(g) further breakdown of forest losses by maturity classes, broad cover types, accessibility, etc.

(h) forecast of pest and host conditions for next year

(i) control options.

MAJOR FOREST PEST PROBLEMS

The first step in designing a program to monitor forest pest damage should be a clear understanding of the pest(s) involved, especially the type of damage to the trees and the period of occurrence. Brief descriptions of some major pests and their damage are discussed in the following section.

DEFOLIATORS

Spruce budworm, Choristoneura fumiferana (Clemens):

Outbreaks of the spruce budworm usually occur in mature forests of white spruce and balsam fir but may infest black spruce and larch in the prairie provinces and Northwest Territories. The spruce budworm has one generation per year. In late July or August the female moth lays over 100 green eggs in clusters of 15-20 on the underside of needles. Eggs hatch in about 10 days, and the young larvae spin silken hibernation shelters (hibernaculae) on the twigs and bark where they overwinter.

The small larvae emerge in early May and first mine old needles, male flowers, or unopened buds. After a few days the larvae begin feeding on the developing needles within expanding buds. As the new shoots grow, the larvae spin fine silk among the needles and between shoots. During periods of high budworm populations, larvae may consume all current-year needles and then feed on the older needles. Heavy feeding causes trees to take on a red-brown appearance that can be readily seen from an aircraft in midsummer. When larvae are fully grown they change to pupae in the feeding sites. The pupae become moths from late June to early August.

Successive years of heavy spruce budworm attack result in repetitive removal of all new foliage and in extensive back-feeding of older needles once the new needles have been devoured. Extensive top-killing and tree mortality occur following a number of years of such defoliation. It will usually take from 3 to 5 years of severe infestation to kill a balsam fir and longer to kill white spruce.

Jack pine budworm, Choristoneura pinus pinus Freeman:

The jack pine budworm, a close relative of the spruce budworm, is the most important insect defoliator of jack pine forests and pine plantations in Manitoba and Saskatchewan. While its main host is jack pine, it also attacks red, Scots, lodgepole, and eastern white pines and occasionally spruce.

The budworm has one generation each year. Small larvae overwinter in their hibernaculae. The larvae commence feeding in late May to early June. They prefer the staminate (male) cone clusters and developing buds as their initial food source. Initial mining of old needles does not occur as in the case of the spruce budworm (Kulman and Hodson 1961). Later, the larvae migrate to the new foliage to complete feeding and development. Older foliage may be fed upon before completion of larval development.

Jack pine budworm larvae are wasteful feeders and rarely consume entire needles. Numerous clipped-off and partly chewed needles accumulate larva excrement and remain attached to the branches with silk webbing. This material turns reddish-brown as it dries in July and, when viewed on the whole tree, provides the basis for judging severity of defoliation during aerial or ground surveys. Defoliation typically spreads from the top of the tree downward, so that, top-kill and reduced annual growth are the most common effects.

Aspen defoliators, primarily Malacosoma disstria Hubner, Choristoneura conflictana (F. Walker), and Operophtera bruceata (Hulst):

Trembling aspen is subjected to severe defoliation periodically by the forest tent caterpillar, M. disstria, and less frequently by the large aspen tortrix, C. conflictana, and the Bruce spanworm, O. bruceata. The forest tent caterpillar is the major defoliator of trembling aspen and other hardwoods in the prairie provinces. This insect overwinters as a small larva in the egg and emerges in the spring to feed in large clusters on the developing foliage of aspen and other hardwoods. The larvae feed for 5 to 6 weeks, during which they pass through five stages or instars. Cocoons are spun about mid-June among the leaves of trees, shrubs, or other vegetation, and the moths emerge 8 to 10 days later.

In heavy infestations, infested trees in vast areas are completely stripped of foliage by about mid-June. If defoliation has been complete, trees may remain bare as late as August, but in general, by mid-July hardwood trees that have less than 60% defoliation begin to refoliate.

BARK BEETLES

Mountain pine beetle, Dendroctonus ponderosae Hopkins:

The mountain pine beetle is a major insect pest of the mature pine forests of western Canada: an outbreak exists in lodgepole pine forests in southern Alberta and may extend into southwestern Saskatchewan. Usually the beetle attacks pine trees older than 60-80 years and with stems over 20-25 cm diameter at breast height; however, when abundant the beetle may attack and kill younger trees.

The adult beetle is 5-7 mm long, black, and attacks live pine trees by boring through the bark. During its life cycle of one year it passes through egg, larval, pupal, and adult stages. All stages are spent under the bark of infested trees except for a few days in late July or August when adult beetles emerge and fly to attack new trees.

Beetle-infested trees are readily recognized from the air except in the earliest stages of infestation. Green trees are attacked by the mountain pine beetle in midsummer. The first noticeable foliage color change usually occurs in May and June of the following year, but occasionally crowns begin to fade in late fall of the attack year. The crowns fade first to yellow usually by June and July, then to red-brown in July and August. The tree is essentially dead at this point, about one year after initial beetle attack.

Trees killed by agents other than the mountain pine beetle usually show the same color changes; therefore, a ground survey is necessary, to confirm the causal organism. On the ground, infested trees can be recognized by reddish brown foliage, pitch tubes on the bole, boring dust at the base of the tree, and by the vertical egg galleries that have a slight hook at the bottom and are constructed by female beetles in the inner bark.

Outbreaks begin in infestations of individual trees or small groups scattered throughout the stand and tend to spread progressively from these centers. In active infestations older than 2 years, grey-topped trees that have lost their foliage may be scattered among red and fading crowns (Safranyik et al. 1974).

Dutch elm disease, Ceratocystis ulmi (Buisman) C. Moreau:

Dutch elm disease (DED) so far has been found only in Manitoba. The disease occurs on American elm but can affect Siberian (Manchurian) elm. Native stands of American elm are not common in Saskatchewan and do not occur in Alberta; however, both elm species have been introduced into all three prairie provinces, where they are widely planted as ornamental, shelterbelt, and shade trees.

Dutch elm disease is caused by the fungus Ceratocystis ulmi. Tiny spores of the fungus are carried by two species of bark beetles, Hylurgopinus rufipes (Eichh) and Scolytus multistriatus (Marsh.). The fungus invades the sapwood, and its spores rapidly spread through the tree's water conducting system, causing wilting and death of the elm tree. Early signs of the disease appear from mid-June to mid-July and include wilting and curling of the leaves on one or more branches. Later, the leaves shrivel and turn brown but may remain on the tree. By mid-August to early September, leaves on one or more branches become yellow and droop (flagging) and affected leaves drop prematurely.

Infected elms leaf out in the spring with smaller than normal leaves on one or more branches or over the entire tree. Some small branches may be dead. These signs indicate that the tree was infected with DED the previous year, but too late for signs of the disease to appear that year. Also, early and late signs may be present at the same time, and in late summer it is not possible to distinguish between autumn coloring and the late-season signs of DED.

Dwarf Mistletoes, Arceuthobium americanum Nuttal ex Engelmann and A. pusillum Peck:

Two species of dwarf mistletoes are widespread in the region and infect jack pine, lodgepole pine, black spruce, and white spruce. Only A. americanum on jack pine and lodgepole pine causes significant damage. The disease is caused by a parasitic green plant that may be easily recognized by its aerial stems growing from infected swollen branches. The most conspicuous indicator of infection is a proliferation of distorted branches on the host, called witches' broom. Because brooms can also be caused by other factors (rusts and genetic or stimulation factors), the presence of the small greenish yellow aerial shoots of the mistletoe is an important identifying character.

Dwarf mistletoes are seed-producing plants with limited spread potential, and their occurrence tends to be spotty but locally concentrated. All ages of trees are susceptible and losses are usually gradual, persistent, and progressive with time since infection. Little annual fluctuation occurs once the disease is established in a tree stand. For this reason, annual surveys are not necessary.

AERIAL SKETCH MAPPING PROGRAM

Most aerial surveys of forest pest damage involve sketch mapping, which is the principal technique used in the region. Observations are made by one or more persons in a fixed-wing aircraft or helicopter of the infestation boundaries and intensity of damage, which are marked onto maps. Prior to the flight, a plan is prepared indicating the flight lines and the observations to be made. Selection of the areas to be visited is usually based on earlier ground or aerial surveys. The aerial survey is primarily concerned with detecting and monitoring the more serious and economically important forest pests that produce symptoms that can be classified by aerial observations. The annual aerial surveys conducted by FIDS at NoFRC are listed by pest and location in Table 1.

Table 1. Annual aerial sketch mapping surveys conducted by FIDS at NoFRC

Pest	Location	Time	Outside cooperator[1]	Report
Mountain pine beetle	Southern Alberta Southwest Saskatchewan	June and August	AFS, Parks Canada, prov. parks	File reports with distribution maps
Spruce budworm	Manitoba	June-July	MDNR, Parks Canada	"
	Alberta	June-July	AFS	"
	NWT	July	NWTFS	"
Jack pine budworm	Manitoba	June-July	MDNR	"
Aspen defoliators	Alberta	June	AFS	"
	Saskatchewan	June		"
	Manitoba	June		"
Red belt survey	Alberta			As required

[1] AFS = Alberta Forest Service.
MDNR = Manitoba Department of Natural Resources.
NWTFS = Northwest Territories Forest Service.

Forest pests are classified in broad categories according to their method of inflicting damage.

Defoliators: Defoliation estimates in most surveys are based on ocular examination of defoliated trees and are, therefore, usually subject to considerable error and variation. To adopt a more standard measurement for reporting, the following classifications have been used.

For deciduous trees, measurement of infestation is based on the total foliage eaten or defoliation classes as follows:

From the ground	From the air
Nil: no foliage eaten	Nil
Moderate: 21-60% foliage consumed	Moderate to severe: 30-100%
Severe: 61-100% foliage consumed	
Complete: all foliage on tree completely eaten	

For coniferous trees, ground survey measurement of infestation is based on percent defoliations of new foliage or old foliage. For aerial surveys, infestation is measured by the intensity of discoloration perceptible and rated as follows:

Moderate: redness of foliage evident at about 300 m, but some green foliage mixed with it;

Severe: new foliage completely red-brown, no green foliage visible

Bark Beetle: Classified according to the numbers or proportion of susceptible trees currently displaying yellow or red-brown foliage (dead trees).

Application of Aerial Sketch-Map Survey Data

Sketch-map data are used for a variety of purposes by provincial and private forestry agencies and public resource management agencies. Some of the main purposes of aerial surveys are the following:

(a) detecting unknown pest problems

(b) identifying and mapping the boundaries of known infestations

(c) planning damage appraisal surveys and control operations

(d) planning salvage operations

(e) planning egg mass surveys for forecast

(f) assessing spread rate and estimating damage or impact of pests on the forests

(g) evaluating control measures, and

(h) providing a historical record of infestation.

CONCLUSION AND DISCUSSION

Difficulties in FIDS aerial pest surveys include: the irregular occurrence of pest problems or damage, the time lag between pest attack and tree mortality (1 year for bark beetles and 5 years for the spruce budworm), variability and discrepancies in the subjective estimates of tree counts, and the necessity for ground checks to confirm identifications of pests and to obtain limited mensuration data.

Because of cost, size of forests, and limited capability for determining causal agents, aerial photography is not well suited for detection surveys; however, after initial detection of an infestation is made by such means as aerial observation, aerial photography is recommended for more-accurate delineation of the infestation to provide a permanent record and as evidence of conclusions reached.

The aerial sketch-mapping technique used by FIDS will probably remain the best detection method because it is the most economical means of obtaining the information. Nevertheless, several proposed refinements to the present aerial surveys should be considered for future surveys by FIDS. Aerial photography could be used to supplement sketch-mapping and ground surveys of pests in high-value forest stands.

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FIDS-RELATED REMOTE SENSING STUDIES IN THE PACIFIC REGION

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A brief contribution was solicited from the Pacific Forest Research Centre (PFRC) to provide an insight into its projects utilizing remote sensing techniques in the Forest Insect and Disease Survey (FIDS) program. The objective was to use the PFRC program as an example to assist the project in development at the Northern Forest Research Centre. According to G.A. Van Sickle, Head of FIDS, PFRC, with the recent addition of a scientist from the Petawawa National Forestry Institute (PNFI), PFRC is embarking on an enlarged program plan in this area. As such, its contribution consists of a brief description of the information needs followed by two abstracts describing current studies.

The most immediate need of the FIDS program at PFRC is to provide the best possible estimate of current-year and 1977-81 periodic tree mortality caused by the mountain pine beetle. FIDS and the B.C. Ministry of Forests have similar requirements for an annual general survey for estimation of bark beetle-caused tree mortality. The goal is to provide by October 1981 a regional (Nelson, Kamloops, Cariboo, etc.) and province-wide estimate by area, infestation intensity, number, and volume of trees recently killed by bark beetles. Measures of reliability, costs in effort and dollars, and suggestions for continuing and gradual testing and phase-in of improvements are to be included.

Two scientists in this program area will be providing continuing guidance to the field staff in the development and documentation of efficient methodology.

A Technique for the Evaluation of Mountain Pine Beetle Damage using Aerial Photography in the Flathead River Valley

A low-budget, multistage sampling procedure was applied in 1980 to a 14 750-hectare area in the Flathead River Valley in southeastern British Columbia, where lodgepole pine (Pinus contorta Dougl.) is suffering from increasing mountain pine beetle-caused mortality (Dendroctonus ponderosae Hopkins). Damaged areas were sketch mapped, and 0.25-hectare ground subplots were established. Additionally, 1:5000-scale photos were obtained using Kodak MS Aerochrome 2448 true color positive transparency film with photo plots subsequently located following a grid pattern.

The numbers of dead trees counted on all air photo plots combined were modified by each of nine subplot ground/air-photo count ratios. The average of the nine modified total counts was then expanded by multiplying it by the ratio of total affected area/total plot area to obtain total estimated killed trees for the area affected. The average volume/tree was determined for each ground subplot from volume tables, volumes were calculated for the nine modified total tree counts, and the average of the nine volumes was expanded to obtain total estimated volume loss for the total area.

In the attacked area, over 5.2 million trees had been killed since 1976, mostly resulting from 1979 attack. Volume losses were about 1.3 million m^3, and 93% of the volume loss was in trees 15-cm dbh or larger. Sampling error was 5% for tree counts and 21% for volume. Study costs were about 85¢/ha. An improved sampling scheme based on this experience is described.

--J.W.E. Harris

Application of Remote Sensing to Forest Damage Detection and Appraisal at PNFI in 1980-81

In response to the request of the Task Force for the Review of CFS Research on the Eastern Spruce Budworm, the Petawawa National Forestry Institute agreed to investigate the usefulness of remote sensing technology for the inventory of damaged forest stands. In April 1980, a new study (Application of Remote Sensing to Forest Damage Detection and Appraisal) was initiated within the Pl-3 (Remote Sensing) Project. While the long-term study was intended to investigate detection and quantification of all major types of forest damage, the efforts during the first two years (1980-81 and 1981-82) were to concentrate mainly on the volumetric assessment of tree mortality caused by forest pests.

For 1980-81, over 40% of the Pl-3 Project resources was alloted to this study: $18,000 operating budget and 3.7 P/Y, which included 0.7 P/Y of Pl-3 Project Leader P. Gimbarzevsky as Study Officer, 0.7 P/Y senior photo interpreter, cartographic technician, 0.7 P/Y photogrammetrist, and 0.6 P/Y airborne system technician. In addition, all available PNFI equipment (airborne, photo interpretation, photo measuring, plotting) and digital ARIES system was made available to this study.

A tentative study plan was prepared in April 1980 with the following main objectives:

a) Assess present attempts at the practical application of remote sensing technology for the detection and appraisal of forest damage, particularly those concerned with forest pests.

b) Investigate the use of large-scale aerial photography for a volumetric assessment of tree mortality in forest stands.

c) In cooperation with the CFS regional centers, select representative areas and conduct pilot surveys as operational trials to evaluate suitability of various sensors for the quantification of tree damage and mortality.

d) Describe, illustrate, and document the appraisal procedures and recommend the most suitable practical techniques to inventory damaged tree volumes in forest stands using aerial photography and other sensors.

Progress in 1980-81:

1. In consultation with the Maritimes Forest Research Centre, Nova Scotia Forest Service, and the Canada Centre for Remote Sensing (CCRS), several demonstration areas were selected in Nova Scotia (about 70 km^2 each) for a systematic resource survey and quantification of spruce budworm infestations.

2. Base maps at 1:10 000 were compiled for two areas (Baddeck Lakes and Cheticamp River), and available background information (existing aerial photography, resource maps, digitally processed LANDSAT imagery, etc.) was acquired.

3. In August 1980, complete photo coverage was acquired of the two areas with 1:10 000 color infrared (IR) photography, and partial coverage was acquired along selected flight lines with 1:2400 and 1:1000 color IR and color photography. Conventional Zeiss RMKA-30 air survey cameras (300-mm lens) and two 70-mm Vinten and two Hasselblad 500 EL cameras were used.

4. For Baddeck Lakes (Cape Breton Highlands) and Barnes Lake (Cape Breton Lowlands) areas, simultaneous coverage was obtained with the CCRS multispectral airborne scanner (MSS) and color IR aerial photography from two altitudes (25,800 and 6,800 ft ASL).

5. Field reconnaissance of the selected areas was conducted in October 1980 by the study staff to observe and document typical ground conditions for air-photo analysis, classification of damage, damage intensity, and photo measurements on large-scale photography.

The analysis of collected data and systematic photo interpretation work planned for the remainder of 1980-81 had to be discontinued because on November 1, 1980, all resources of the PI-3 Project were transferred to the Forestry Statistics and Systems Branch.

Some work was carried on in January and February of 1981 on the analysis of MSS airborne imagery in cooperation with the PNFI. Digital tapes for the Baddeck Lakes area were analyzed on the ARIES system to determine if partial defoliation of conifers could be mapped by the combination of 11 MSS bands, particulary the importance of the 1.55-1.75 micron region for defoliation detection. Preliminary results, when compared with photo interpretation of conventional infrared color photography, are quite encouraging. This work is still in progress. The Baddeck Lakes area, with about 60-90% of defoliated conifer stands, is probably not the best area selected for this experiment. The work will continue on the Barnes Lake area, which contains forest types showing different degrees of damage, and in the Newcastle area, New Brunswick.

--P.G. Gimbarzevsky
(formerly with the Petawawa
National Forestry Institute)

USES OF REMOTE SENSING IN FOREST PEST DAMAGE APPRAISAL: SUMMARY AND DISCUSSION

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ABSTRACT

Presentations on the fundamentals of remote sensing interpretation for damage appraisal, the practical aspects of forest pest damage assessment, and information needs resulted in a well-rounded seminar. A synopsis of those presentations is provided. Additionally, a summation is presented of the major points and recommendations that arose from the presented papers and the discussion session.

INTRODUCTION

One of the 1981 project goals of the damage appraisal program at the Northern Forest Research Centre (NoFRC) was to assess the feasibility of using remote sensing techniques for forest pest detection and damage assessment. To assess this need, a seminar was organized on behalf of the Forest Insect and Disease Survey (FIDS) to acquire an information base from which to develop a program plan. The seminar was conducted in a logical sequence, starting with aspects of damage interpretation, followed by the success or failures of case studies, and ending with a description of informational requirements. The term damage as used here includes both dead and infected vegetation.

Three primary aspects of remote sensing were addressed by the seminar. These included the capabilities of remote sensing for the detection, assessment, monitoring, and mapping of pest conditions; the capability to identify damage-causing agents; and the concept of previsual detection and its use to acquire advance knowledge of pest conditions. It is the purpose of this paper to merge the major findings of the seminar.

SYNOPSIS OF PRESENTATIONS

Dr. P A. Murtha presented a paper on the theory of detection and analysis of vegetation stresses using aerial photographs. Among the important points mentioned were four associated subject areas an interpreter must be aware of in interpreting vegetation stress from remote sensing data. In addition, in using remote sensing to assess damage it is necessary to understand not only the effects of stress on vegetation but also the film reactions to spectral reflectance changes in the vegetation caused by the stress.

A conceptual problem that was outlined and is supported by Fox (1978) is the use of the term previsual detection. This term is correct only when the interpreted symptom eventually becomes visible. Previsual detection implies that near-infrared changes are always followed by visual reflectance changes; however, alterations in the near-infrared are not necessarily followed by visual changes and, some previsual symptoms may never become visual because of vegetation recovery. Consequently, the term extra-visual detection is proposed (Murtha 1978, 1981).

A strong recommendation was that the scale and film type must be related to the objective of interpretation. There is a direct relation between the scale of the photo and the amount of detail available. For example, a small-scale photo affords a broad view of the terrain but is useless for interpreting damage on individual trees. A suggestion was also made to first identify the information that would be useful and then to develop keys or lists of what to look for. Additionally, use of interpretation keys such as that outlined by Murtha (1972) can be valuable.

The second presentation was by E. Winquist and J.H. Vandenbrink of the Alberta Forest Service (AFS) on their experiences with color and color infrared photography for monitoring the mountain pine beetle (Dendroctonus ponderosae Hopkins) infestation in southern Alberta. A main concern has been to salvage as much of the beetle-killed timber as possible before it degrades and to reduce the the fire hazard. They expressed a preference for color film because of the difficulty they had in distinguishing mountain pine beetle-infested stands from overmature white spruce (Picea glauca (Moench) Voss.) and balsam fir (Abies balsamea (L.) Mill.). Color film also permitted better shadow penetration in the mountainous areas, but there was a problem with haze penetration at the higher altitudes.

A.P. Jano of the Ontario Centre for Remote Sensing discussed the practical considerations of using remote sensing for forest pest damage assessment. The major benefits of using aerial photographs include an overview of large forested areas, a reduction of ground work, and a permanent record of forest conditions at a specific time. This permits monitoring and mapping by photo comparison if photos are acquired in successive years. Additionally, interpretation can be performed in a comfortable office with the benefits of three-dimensional viewing using a stereoscope.

For practical operational use, some criteria need to be developed to judge how and when to apply remote sensing for assessment. This is an important point, because the assessment objectives determine the informational requirements and therefore the appropriate remote sensing techniques. With regard to cost effectiveness, assuming aerial photography is used for both detection and mapping, Mr. Jano recommended prestratification using forest cover maps or photos to identify areas that have a higher potential for damage. This would reduce the total amount of photo coverage otherwise required. He also emphasized that remote sensing is actually better suited for accurate mapping of known damaged areas than for detection of unsurveyed areas.

Two additional concerns that can affect the ease of remote sensing application are the equipment available for both photo acquisition and interpretation and the staff expertise. It is difficult to be committed to using remote sensing imagery if you cannot get a continuously high-quality product. This is especially true for color infrared film with its narrow exposure latitude. It was therefore recommended that a private firm be contracted to facilitate receiving good results.

Support was given to the critical selection of photo scale since it must be in relation to the detail that is required. It was also noted that, although aerial sketch mapping is fast and efficient, it is only good if the terrain features are easily related to the map or photo.

A discussion of the general information needs, functions, and pest problems of the Forest Insect and Disease Survey unit at NoFRC was given by Dr. B. Moody. Federal and provincial agencies require detection and monitoring of damage conditions for their pest management programs, and this information is primarily acquired through aerial surveys that may be augmented by ground surveys. Of particular importance is the regional contribution to the national overview of forest pest conditions. Annual reports such as those by Hiratsuka et al. (1981) and Sterner and Davidson (1981) are produced to describe current conditions and to provide predictions. The regional data currently consist of numbers of trees, areas affected, and volume loss estimates when available; however, the trend is for more-accurate estimates of volume loss for inventory purposes.

No presentation was made by the Pacific Forest Research Centre (PFRC), but a written contribution was provided briefly describing the current PFRC-FIDS program position. Planning is under way for expansion of the remote sensing damage appraisal program.

DISCUSSION

Role of Remote Sensing

An important point that was not emphasized at the seminar is that remote sensing is a tool with which to acquire information for some end purpose. As such, remote sensing must be viewed in terms of what it can and cannot provide. For example, several damage causing agents will result in the same morphological damage on a tree or forest stand. Does this mean that we rule out the use of remote sensing because we cannot readily identify the causal agent? I would like to think not. Using remote sensing could tell us that something is wrong and would provide some idea of the pattern of damage. It is, then, the essential use of other information--maps, photos, historical data, ground information, air-photo interpretation keys, and a priori knowledge--that will provide the basis for the identification of the causal agent.

Aerial Sketch Mapping vs. Photography

Sketch mapping involves flying over preplanned flight lines with an aerial observer sketching the damaged areas onto maps. This is the principal technique used in the prairie region and in British Columbia (Harris and Dawson 1979). Two of the major problems are that accuracy is hard to assess and that single and small groups of trees are hard to distinguish. Furthermore, the success of aerial sketch mapping is highly dependent on the observer's abilities and experience (Harris and Dawson 1978). An additional problem for the aircraft observer is that there is little time for verification, except by recircling the area.

The use of aerial imagery is also not without problems. Knowledge and experience are required to specify the correct aerial photo parameters to facilitate successful acquisition of photography. Failure to specify optimum parameters can result in high interpretation error, loss of needed data, and inefficiency (Ciesla 1978). One of the major considerations is selection of the correct time of year during which to survey the damage-causing agent of interest. Additionally, the selection of photo scale and aerial film must be in relation to the information to be interpreted from the photos. In retrospect, the best approach appears to be a combination whereby aerial photos are used to supplement sketch mapping. Possibly, a double sampling scheme providing a means for correction could then be employed, with minimal ground sampling constituting the secondary sample. Murtha advocated aerial surveying for detection, not sketch mapping. He also encouraged the use of multistage sampling utilizing remote sensing techniques for the actual assessment. Along the same line, an excellent documentation of a double sampling approach utilizing aerial photographic techniques for estimating damage by insects is given by Wear et al. (1966). In summary, Safranyik et al. (1974) conclude that an efficient appraisal method based upon aerial photography and limited ground sampling can considerably reduce the cost of a survey and increase its precision.

Interpretation and Identification of Damage

Photo interpretation of forest damage requires knowledge from several subject areas. One must also realize that an interpreter can only interpret symptoms or manifestations of damage (Murtha 1978). These manifestations are changes in morphology or physiology of the vegetation or a combination of both. A knowledge of the morphological and physiological characteristics of normal healthy plants and their alterations with stress is therefore essential to the proper understanding and interpretation of reflectance characteristics (Puritch 1981).

It is also critical that an interpreter have a knowledge of interpretation elements and know what to look for. Too often the emphasis has been on detecting changes in the color or tone of the vegetation alone. Here, the use of a priori knowledge in the interpretation process cannot be underemphasized. This is especially true if one of the objectives is to identify the possible causal agent(s).

There is a common misconception in expecting the capabilities of remote sensing to include the means for identifying the damage agent. This problem would be compounded in stands of mixed conifers, where different mortality causing agents produce the same result (Ciesla 1978). One should remember that a dead tree is a dead tree, and even on the ground further analysis is often necessary to determine the cause. Here again, the use of a priori knowledge cannot be underemphasized.

Survey

Greater significance needs to be placed on the intensity of a survey. Accuracy requirements and budgetary limitations play key roles in survey design. Most important is that different intensities of surveys are required for different information needs. Where appropriate, sampling and statistical considerations should be input variables in planning the survey.

Interest was expressed in performing surveys to acquire advance lead time for mountain pine beetle control. Dry foliage is highly reflective of near-infrared, however, and it is for this reason that bark beetle-infested trees are so difficult to interpret on aerial photographs before the foliage turns red brown (Murtha 1978). At this time, then, the best use of remote sensing may be limited to the monitoring and mapping of the infestations and in determining the pattern of damage. This is, of course, no small feat in itself. There are encouraging studies at the University of B.C. comparing optical density values of the images of healthy and attacked trees, which may warrant consideration for feasibility in an operationally oriented program. In the future, as more knowledge is obtained about the sequence of physiological changes that occur in the host tree after infestation it will be possible to focus remote sensing techniques more precisely on what to sense and when to sense it (Puritch 1981).

CONCLUSIONS AND RECOMMENDATIONS

The theoretical and practical considerations of using remote sensing for forest pest damage appraisal were presented in the seminar, with the major points summarized in this paper. The need for qualification of terminology was outlined, with emphasis on uniform usage of the term previsual detection.

With regard to photo acquisition, it was stressed that selection of photo scale and film type must be in relation to the objective of the aerial survey. Knowledge of the terrain and photographic conditions is also valuable in facilitating achievement of the objectives of the photography. Prestratification is recommended to guide flight-line location for improved efficiency. Aerial photography was recommended as a supplement to an aerial sketch-mapping program. Murtha subsequently recommended the use of remote sensing wherever possible with surveys using traditional techniques.

Emphasis was placed on remote sensing as an information tool, and that information could best be derived with the essential use of a priori knowledge in photo interpretation. Additionally, one must be familiar with the elements of interpretation and know what to look for on an aerial photograph. As well, interpretation requires a knowledge of host plants and the effects of stress.

Greater care in survey planning is also recommended, particularly if statistical procedures are to be employed. One final note is to encourage literature searches and/or use of a bibliography such as that by Henniger and Hildebrandt (1980), as they can be of tremendous value in the preparatory stages of a project when developing methodology.

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