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Using Computer Imaging to Assess Visual Impacts of Forest Insect and Disease Pests

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USING COMPUTER IMAGING TO ASSESS VISUAL IMPACTS
OF FOREST INSECT AND DISEASE PESTS
by
Daniel Rabin

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF LANDSCAPE ARCHITECTURE

Approved:

UTAH STATE UNIVERSITY
Logan, Utah
1989
for Mom and Dad
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Dan Rabin
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ABSTRACT

Using Computer Imaging to Assess Visual Impacts of Forest Insect and Disease Pests

by

Daniel Rabin, Master of Landscape Architecture
Utah State University, 1989

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Department: Landscape Architecture and Environmental Planning

Forest insect and disease pests alter the appearance of trees, thereby impacting visual resources. Because of the complexity of most forest landscapes, the degree of visual impact of pest-infested forest stands is difficult to quantify.

This paper describes a method of measuring visual impacts of pest-infested forest stands. Photographs of healthy Ponderosa pine trees were entered into a computer video-image-processing system. Using this system, images of trees were altered to simulate different degrees of infestation by limb rust, a forest pathogen.

The altered and unaltered images were shown to groups of observers who rated the scenes in terms of "scenic beauty." The great majority of individuals were able to detect a change in the appearance of trees infected with limb rust disease even when only small sections of a tree were altered. There was also general agreement within the groups of observers that the presence of limb rust disease had a detrimental effect on the visual quality of the forest scenes. The tests also suggested that the location of infestation in the tree crown, the
amount of crown mortality, and the number of infected Ponderosa pine in a stand influenced the degree to which visual quality was impacted.
CHAPTER I

INTRODUCTION

Background

The use of our forests for recreation has increased steadily for many years. A recent US Forest Service study predicted that recreation use will continue to increase well into the 21st century (Hof and Kaiser 1983). Given this profusion of recreation-oriented forest visitors, it is clear that the visual quality of our forests is an important resource.

In response to the public's concern for the aesthetic qualities of our forests, Congress has enacted legislation mandating management of visual and other amenity resources. The Multiple Use Sustained Yield Act of 1960 and The National Environmental Policy Act of 1969 required land managers to show concern for intangible forest resources, including aesthetics, wilderness, non-consumptive uses of wildlife, and recreation. The Federal Land Policy and Management Act of 1976 strengthened those earlier laws by compelling land managers to consider scenic resources equally with other resources in management decisions involving public lands.

Statement of the Problem

The management of any resource requires a method of measuring the impact of changes in an environment on that resource. The management of visual resources is no exception. However, unlike water, timber, and other resources for which techniques of measuring impacts
are well established, impacts on visual quality are more difficult to quantify.

Most attempts to assess visual impacts on forests and other wildlands have involved predicting changes to the visual character of a landscape resulting from proposed timber harvests, roads, dams, powerlines, and other man-caused alterations or developments. To aid in this process, a wide range of graphic techniques have been developed to simulate proposed landscape changes. These include freehand sketching, photomontage, rendering on photos or slides, special-effect photography, 3-D modeling, and computer-modified imagery (U.S.D.I Bureau of Land Management 1980b; Orland 1986a, 1986b; personal communication with Ellsworth 1988). Time requirements, need for artistic skills, expense, and realism of the images produced vary greatly for these different techniques (Orland 1986b).

While these simulation techniques have been applied almost exclusively to planned or proposed changes to landscapes, not all impacts on visual resources are a direct result of man's intentions. Natural forces often change the appearance of forest landscapes dramatically.

In forest environments, insects and diseases occur naturally; killing, deforming, defoliating, or in other ways altering the appearance of trees. In some situations forest pests impact tens or even hundreds of acres. In other instances only a few trees in a forest stand are affected. In any case, it is reasonable to assume that some degree of visual impact occurs as a result of the presence of forest pests.

Without a functional method of measuring visual impacts caused by forest pests, land managers are hampered in their efforts to consider
visual quality when making management decisions for pest-infested forests. They must rely on intuition, their perception of public sentiment, or best professional judgement (in cases where trained landscape managers such as landscape architects are involved) if visual resources are to be considered at all. In visually sensitive areas, such as along road corridors or trails and in parks, campgrounds, and other areas where the public is likely to travel, a more reliable method of assessing impacts to the visual resource resulting from pest infestation is necessary.

Objectives

The objectives of this study are:

1. To devise a method of assessing the visual impacts of forest insect and disease pests. Such a method should be directed toward utilization by land managers to insure that visual resources can be given equal consideration with other resources in the management of forest lands. In order that the method be functional, it should have the following qualities:

   a. It should result in a measure of impact that is easily understood. This should be expressed in simple quantifiable terms that are consistent for each application of the method.

   b. It should be repeatable by independent investigators. Though some specialized knowledge may be required for individual applications, high levels of expertise in any one area, such as forest management, pathology and entomology, landscape architecture, statistics, or related
fields, should be unnecessary to successfully apply the method.

c. It should be applicable to different forest pests. Pests affect trees in different ways. Some pests disfigure trees, while others cause a change in foliage color before trees are finally killed. Some pests affect large areas of forests, while others are confined to relatively few trees. The method should have the flexibility to deal with these inherent differences of forest pests.

d. It should be applicable to different viewing situations. Pest damage is often visible over a wide range of landscapes and in different viewing contexts. This includes near-view scenes such as within timber stands, along roads or trails, and in campgrounds. It also includes middle or long views such as scenic vistas or overlooks, which occur along highways, trails, in parks, and in many other locations.

2. To apply this method to assessment of visual impacts of limb rust disease of Ponderosa pine. Limb rust (Peridermium filamentosum Peck) affects Ponderosa pine (Pinus ponderosa) and Jeffery pine (Pinus jeffreyi) in western North America. It infects the stems of trees and spreads both upward and downward from the point of infection at a rate of about 1.5 feet per year (Mielke 1952). Infected branches are killed, one at a time, leaving "gaps" in the tree crowns (Baker et al. 1986). The sizes and locations of these "gaps" are determined by how long a tree has been infected and
the original point of infection in the stem. Limb-rust-infected
trees, randomly scattered throughout a stand, eventually die.

The U.S. Forest Service is currently sponsoring research on the
effects of limb rust on timber production in infected stands in southern
Utah. Since limb rust has been found to occur in several important
recreation areas in both southern Utah and northern Arizona, the
agency is also eager to determine what visual impacts have occurred or
could occur as a result of the presence of limb rust. The research
described in this report, also sponsored by the U.S. Forest Service, will
be included in the limb rust study mentioned above to broaden the
focus of that inquiry.

Achieving the goals outlined above will give land managers a new
tool to predict and measure the extent of visual impacts resulting from
the presence of insect and disease pests on forest stands. Its
application in areas where visual impacts have occurred or are likely to
occur could prove to be a valuable aid to visual-resource managers.
CHAPTER II

REVIEW OF THE LITERATURE

Introduction

This chapter discusses methods that have been applied to assess visual impacts on forests and other wildlands. Procedures for making aesthetic judgments of landscapes are described and applications cited. Finally, graphic simulation techniques that aid in visual impact assessment are discussed.

Methods of determining visual impacts on forests and wildlands are derived from techniques developed within the broader field of visual assessment. Four categories of visual assessment methodology have been identified (Zube, Sell and Taylor 1982). The expert, psychophysical, cognitive, and experiential approaches to visual assessment have different theoretical foundations and vary in their degree of applicability to visual impact assessment.

Expert systems, as the name implies, rely on the skill of trained observers in making aesthetic judgments based on the physical properties of landscapes. Aesthetic criteria, translated from the art and design fields, are used in determining the visual qualities of landscapes. Expert systems are often used by landscape architects and other professionals with expertise in identifying landscape features or conditions that influence aesthetic judgments.

Psychophysical methods generally employ testing portions of the general public to arrive at judgments of aesthetic value. These judgments are often statistically correlated with measurable landscape
features to relate these features to aesthetic judgments. Since this approach applies commonly used procedures of statistical analysis to aesthetic judgements, psychophysical methodology is often favored by researchers from a wide range of disciplines.

The cognitive approach to visual assessment deals with determining the meaning that individuals place on landscapes as a result of the human psychological need to make sense of one's environment. Landscapes are described by attributes such as coherence, complexity, mystery, and legibility (S. Kaplan 1979). Since this approach attempts to explain why humans react to landscapes the way they do, this approach is used by environmental and behavioral psychologists.

Finally, the experiential approach considers the dynamic interaction of humans with the landscape as the primary determinate of aesthetic judgment and landscape value. Because clearly defined analytic techniques to isolate factors influential in determining scenic quality are not well developed, the experiential approach in the study of landscape aesthetics is seldom employed.

Because expert systems and psychophysical techniques often deal with relating individual landscape features to aesthetic judgments by using widely accepted concepts and analytic methods, they are currently the most useful methods for dealing with the pragmatic concerns of land managers. These approaches are used almost exclusively in studies involving visual impact assessment. The expert and psychophysical approaches are reviewed in detail in this section.

While the cognitive approach and, to a lesser extent, the experiential approach, have a following among researchers of landscape
aesthetics, they often deal in concepts foreign to the individuals involved in land management decisions and policies. Because a clearly defined method of applying these systems to specific landscape management issues has not been developed, the usefulness of these approaches is limited at this time. Therefore, for the purposes of this study, these two approaches are not discussed in further detail.

**Expert Systems**

The U.S. Forest Service and Bureau of Land Management employ the "expert system" approach to visual impact assessment as part of the Visual Management Systems developed by these agencies (U.S.D.A. Forest Service 1974; U.S.D.I. Bureau of Land Management 1980a). These Visual Management Systems are used to determine the acceptability of visual changes resulting from proposed developments or other alterations to landscapes. These often include planned management activities such as timber harvests, road construction, ski resort development, dams, bridges, pipelines, and powerlines. It can also include unplanned occurrences such as wildfire, pest infestations, and past developments that were insensitive to visual resources.

The Forest Service and BLM systems require that visual impacts be determined for any landscape changes to assure that standards of visual quality are maintained. Both of these agencies employ visual management experts or utilize land managers with visual management training to make aesthetic judgments regarding visual impacts and other visual quality-related issues. Although public input is often solicited regarding specific land management issues, final judgement regarding assessment and management of visual resources rests with those
individuals within the agencies with visual resource expertise. This reliance on skilled individuals as the ultimate decision-makers in the visual management process qualifies the Forest Service and BLM procedures as "expert systems."

To understand how visual impact assessment is implemented in these systems, a brief explanation of their methods is useful. Although some differences in procedures and terminology exist between Forest Service and BLM methodology, within the context of "expert systems" their differences are of minor consequence and the two systems need not be discussed separately.

Lands administered by the Forest Service and BLM are grouped into visual quality classes based on the degree of variety in a landscape in terms of form, line, color, and texture, the four basic design elements. This is known as a "descriptive inventory" approach to quantification of landscape beauty (Litton 1968). Landscapes are also classified according to their visual sensitivity based on the potential number of viewers of that landscape and the perceived concerns of those viewers. The visibility of a landscape, as determined by viewing distance, is also taken into consideration.

These classifications are combined to produce "visual management classes" for all lands. These classifications determine acceptable levels of visual modification. For example, in the Forest Service Visual Management System, changes to a landscape with a "Retention" designation are permitted only under certain conditions.

Under Retention, activities may only repeat form, line, color, and texture which are frequently found in the characteristic landscape. Changes in their qualities of size, amount, intensity, direction, pattern, etc., should not be evident. (U.S.D.A. Forest Service 1974, pg.30)
When development is proposed, or an unplanned alteration to a landscape occurs, the ensuing visual impact is determined by the best professional judgement of visual management experts (often landscape architects). They determine the degree of contrast, in terms of form, line, color, and texture, that will be (or has been) introduced into the existing landscape. The following excerpt from a visual impact assessment of an area in Eastern Oregon infested with mountain pine beetle demonstrates how such a determination might be described.

The visual effect of dead and dying timber, if untreated, will occur predominantly as contrasts in COLOR (especially in middle-ground and background) as follows: First, red, as the needles turn, and then later, grey, as they drop exposing the branches. Some less noticeable changes in TEXTURE will also occur in middleground and background as needles drop and only standing poles remain, then only jack-strawed poles. In foreground areas, because more detail is discernable, some slight contrasts in FORM and LINE will occur as needles fall, then branches and bark, and then jack-strawed poles. The effects described above will be most noticeable in large stands of pure lodgepole and will decrease as the stand size decreases and/or the number of trees of other species within the lodgepole stand increase. (Umatilla National Forest 1974, pg.48)

The report goes on to describe visual impacts that would occur if suggested management activities are implemented.

a. Strong FORM
   --pattern of form created by large numbers and size of patch cuts, strip cuts and shelterwood cuts.

b. Weak to strong LINE
   --temporary and permanent road systems throughout the area.
   --shelterbelt leave-strip rows, especially if viewed at critical observation position.

c. Strong COLOR change
   --heavy earth disturbance necessary to remove large volume of material and create seedbed.
   --significant volume of material left to dead shade and screen.

d. Strong TEXTURE changes
   --heavily thinned shelterwoods due to excessive kill. (pg.48)
Contrast evaluations like this are compared with the acceptable level of alteration permitted for that landscape (as determined by its visual management classification). If the degree of contrast introduced to the landscape does not exceed allowable limits of visual modification for its management class, the proposed management activity meets visual resource management objectives. If allowable limits of contrast are surpassed, the proposed alteration is disallowed or modified until visual quality standards are achieved. In many cases where fire, pest damage, or other unplanned occurrences have drastically reduced the visual quality of a landscape, the area is managed under a temporary "Rehabilitation" classification to bring visual quality up to a more acceptable level.

Psychophysical Techniques

"Psychophysical techniques," most notably the Scenic Beauty Estimation Method (SBE) (Daniel and Boster 1976) and the Law of Comparative Judgement Procedure (LCJ) (as applied by Buhyoff and Leuschner 1978; Buhyoff and Wellman 1979; 1980; Buhyoff et al. 1980; 1982) have been utilized in a wide range of studies dealing with forest aesthetics and visual impact assessment. With these two methods, aesthetic judgments are derived from ratings of visual attractiveness by groups of observers representing either the public or special interests. By measuring physical attributes of the landscapes in question, and using regression analysis, aesthetic judgments have been related to specific landscape features. Comparing ratings of impacted and unimpacted landscapes can provide a measure of visual impact.

The Scenic Beauty Estimation Method and the Law of Comparative Judgement Procedures are similar in their theoretical derivations.
Psychophysical theory, as it relates to landscape aesthetics, contends that "scenic beauty judgments depend jointly on the perceived properties of the landscape and the judgmental criteria of the observer" (Daniel and Boster 1976, pg. 13).

Although the SBE and LCJ methods differ in data collection methodology (Hull et al. 1984), both produce interval scaled scenic beauty ratings for landscapes. Interval scaling reveals the relative differences of scenic beauty ratings. But since interval scales are based on arbitrary zero points, no absolute measure of scenic beauty is expressed (Buhyoff and Leuschner 1978; Hull et al. 1984). Both the SBE and the LCJ methods have been used to assess visual impacts of forest pests.

The Scenic Beauty Estimation Method (SBE). The Scenic Beauty Estimation Method has been used to study the relative attractiveness of forest landscapes exhibiting different physical properties or conditions. In a typical application, observers are shown color slides of forest scenes and asked to rate each scene for scenic beauty using a 10-point scale. Ratings made from photographs of forest scenes have been shown to be similar to ratings made at the sites where photographs were taken (Daniel and Boster 1976). Scores are then transformed using a statistical scaling procedure to eliminate bias resulting from observers using the 10-point scale differently. This procedure produces a Scenic Beauty Estimate for each scene expressed on an interval scale. Using the raw scores (not transformed) often yields the same results as transformed scores (Schweitzer et al. 1976; Benson and Ullrich 1981). However, SBE scores provide a more theoretically sound statistical test.
The SBE method has been used for a wide range of applications: to determine preference for forest stands with different physical characteristics (Schroeder and Daniel 1980, 1981; Brown and Daniel 1984); to determine preference for different silvicultural treatments in forest stands (Daniel and Boster 1976; Schweitzer et al. 1976; Arthur 1977; Benson and Ullrich 1981); to construct scenic beauty maps of forested areas (Daniel et al. 1977); to predict scenic quality of road corridors in forests (Schroeder and Daniel 1980); to test immediate visual effects of prescribed burning and monitor the rate of visual recovery after a burn (Anderson et al. 1982); and to determine visual impacts of infestations of mountain pine beetle (Dendroctonus ponderosae Hopkins) and western spruce budworm (Choristoneura occidentalis Freeman) along the Colorado Front Range (Buhyoff et al. 1982).

The Law of Comparative Judgement (LCJ). The Law of Comparative Judgement has also been used to obtain preference rankings for forest landscapes containing different physical attributes or conditions. Two different testing procedures, pair comparison and rank ordering, are both considered applications of LCJ methodology.

In a typical application of the pair comparison procedure, observers are shown a set of color slides depicting forest landscapes. Slides are shown in pairs and all possible pairs of slides are presented. For each pair, observers are asked to choose the slide they most (or least) prefer. Like the SBE method, results of landscape preference testing can be expressed on an interval scale.

The pair comparison method has been used to test for preference for different "vista type" landscapes (as mentioned in Buhyoff and Wellman 1980); for the effects of seasonal differences on preference.
ratings (Buhyoff and Wellman 1979); for measuring aesthetic losses resulting from infestation of southern pine beetle (Dendroctonus frontalis Zimm) along the Blue Ridge Parkway in Virginia (Buhyoff and Leuschner 1978); and for estimating visual impacts resulting from infestation of a mountain pine beetle and western spruce budworm infestation (Buhyoff et al. 1982).

Unlike pair comparison, the rank order procedure presents a set of color photographs (prints) to observers at one time. Each observer is asked to rank the scenes in order of scenic beauty. Because ranking many landscape scenes can become complex and time consuming, the maximum number of scenes that can be ranked at one time is limited to 15 (Buhyoff et al. 1980). As with the pair comparison procedure, this yields an interval ranking of landscape preference.

The southern pine beetle study (Buhyoff and Leuschner 1978) was repeated using the rank order procedure to determine if different procedures would yield comparable scenic preference ratings. The two tests did yield similar results (Buhyoff et al. 1980). Also, as noted above, visual impacts from mountain pine beetle and western spruce budworm damage were tested using SBE, pair comparison, and rank order procedures with highly correlated results (Hull et al. 1984). This suggests that public sampling techniques are valid for quantifying aesthetic judgments of forest landscapes.

**SBE vs. LCJ.** It may be argued that since SBE tests for "scenic beauty" and LCJ tests for "preference," the results of the two methodologies are not comparable. However, if we assume that people
find landscapes higher in scenic beauty preferable to landscapes lower in scenic beauty, then the results of the two methods are, in fact, comparable. Since the results of both methods are expressed on an interval scale, the results of the two methods show only the rank and relative preference between landscape scenes. Interval scales cannot be used to measure any absolute values of scenic beauty; therefore, both LCJ and SBE are actually tests of preference.

Both the SBE and LCJ methods have proved to be consistent and reliable means of rating the relative beauty of landscapes. When both methods were applied to the same landscapes, they yielded similar results (Buhyoff et al. 1982).

Individuals representing a wide range of professional backgrounds and group affiliations have been used as judges in landscape preference tests. These include college students (with landscape architecture, forestry, psychology, natural resources, outdoor recreation, and other, unrelated backgrounds), church groups, PTA groups, timber industry professionals, Sierra Club members, public school teachers, USDA Forest Service researchers, USDA Forest Service landscape architects, and individuals referred to only as "residents" (Daniel and Boster 1976; Arthur 1977; Buhyoff et al. 1979; 1982; Schroeder and Daniel 1981, Ellsworth 1982). In nearly every study in which groups with diverse interests were used as judges, no significant differences in landscape ratings were observed. This suggests that aesthetic judgments related to landscapes are not biased by professional or other group affiliations. Because scenic ratings made by college students are equivalent to
judgments made by the general public (Schroeder and Daniel 1981), and because students are often available to researchers, they are often used in SBE and LCJ experiments.

For these two methods of testing, Daniel and Boster (1976) found that about 100 slides (or pairs of slides), shown for 5-8 seconds, is the maximum for any one test before viewer fatigue becomes a factor. Because of the way LCJ tests are conducted, tests of landscape preference must be limited to about 15 scenes using either pair comparison or rank order procedures (Buhyoff et al. 1982). Although limited in the number of scenes that can be judged, it is believed that the LCJ methods allow for a finer level of discrimination since each scene is viewed many times along with all other scenes. On the other hand, the SBE method is far less restrictive in the number of scenes that can be judged in one test. However, since each scene is viewed only once, the discrimination between scenes may not be as great (Hull et al. 1984).

Both the SBE and LCJ methods have been used to measure effects of individual landscape features on aesthetic judgments. Using regression analysis, scenic beauty ratings are compared with measurements of physical features of the landscapes to determine the influence of these features on the ratings. Measurements of physical features are made either on the ground using standard forest mensuration procedures or directly from the photographs by enlarging the images and overlaying a grid. In applications involving visual impacts from insect infestation, damage has been measured in terms of
dead trees per acre determined from forest inventory (Schroeder and Daniel 1981) and as square inches of damage measured directly from photographs (Buhyoff and Leuschner 1978; Buhyoff et al. 1982).

Relating aesthetic ratings of forest scenes to individual physical components in those scenes provides the most useful information for forest managers. It is also perhaps the most complex aspect of forest aesthetics research. For one thing, regression can only be applied to measurable physical features. It is difficult to determine the extent to which elements such as sky color, photographic quality, lighting, and other factors that vary between photographs influence scenic beauty ratings, since these factors are difficult to quantify. Also, the number of features that may influence aesthetic judgments is so large that it is impractical to test for each one.

Regression models based on measurements of physical features of timber stands have provided some valuable information about the aesthetic impacts of tree density, ground cover, slash, insect damage, and a host of other features (Daniel and Boster 1976; Schweitzer et al. 1976; Arthur 1977; Buhyoff and Leuschner 1978; Buhyoff et al. 1982; Brown and Daniel 1984; Brown and Daniel 1986). Quantifying these features, whether estimates are made on the site or from photographs, is labor-intensive, and thus expensive.

Finally, measurement of pest damage for use in regression analysis is not an exact science. In some instances pest damage can be measured in terms of number of infected or dead trees. For many pests though, visual impacts occur before trees are killed. While information on numbers of infected trees may be available from inventory data,
infected trees can differ in their visual appearance. Some pests deform trees, cause brooming, or kill only parts of tree crowns. This damage may be static, or it may progress within the crown. In these instances it would be useful to relate visual impacts to damage ratings such as the dwarf mistletoe rating system (Hawksworth 1977) or other pest rating systems currently being developed (Baker et al. 1986).

**Graphic Aids for Simulation of Visual Impact Assessment**

Tests of landscape aesthetics are complicated by the number, complexity, and interactions of all the components that make up a landscape. To accurately determine the effects of individual pieces of a landscape puzzle, it is beneficial to simulate visual changes to individual landscape features while others are held constant (Daniel and Boster 1976). This may mean adding or subtracting visual features or manipulating the degree or condition of visual features already present in a landscape. Freehand drawings created by trained illustrators is probably the oldest method of depicting landscape changes. These drawings can range from quick sketches to intricate detailed renderings. They require individuals able to visualize scenes and communicate those visions on paper (U.S.D.I. Bureau of Land Management 1980b). The greater the amount of detail required, the more time is involved and the greater the skill required of the illustrator. Often, the degree of realism of these images is questionable because of technical quality, and because personal style and artistic bias may be introduced by the illustrator. Special effect photographic techniques and photo-montage, in which images are overlaid, combined, or otherwise manipulated, can
produce highly realistic simulations of certain types of landscape changes. They are especially effective in simulating the addition of buildings or other structures in a landscape. Where it is necessary to manipulate fine details of existing images, these methods are often not practical.

Scale modelling, like special effect photography, can be effective for simulating certain types of alterations to landscapes. However, model construction is very time consuming, and time requirements increase as the level of detail increases. For the level of detail required in most research related to forest pest damage, its applicability is doubtful.

Recent developments in computer video-image-processing hold great promise for research in forest aesthetics. For some time, computer programs have been used to show "seen areas" from any viewpoint, display landforms in perspective view, and simulate textural changes resulting from removal of trees (U.S.D.I. Bureau of Land Management 1980b). These have been put to good use by forest planners and others. Since these programs were designed to deal with large areas, their usefulness is limited when simulating detailed changes.

Recent advances in computer imaging have advanced the role of the personal computer as a graphic tool for individuals involved with forest aesthetics. Now, using desktop computer equipment, it is possible to enter images from videotape, photo prints, or slides; to manipulate these images quickly and in great detail (by adding or subtracting elements or changing the characteristics of existing elements); and to export the manipulated images to videotape, film (prints or slides), or
hard copy (Orland 1986a, 1986b). The ease with which this is accomplished depends upon the characteristics of the particular imaging system in use, but it has been shown that individuals with little computer expertise can produce high quality, realistic images within hours of introduction to a system (Orland 1986b). While it is unlikely that most individuals will become productive this quickly (several days to several weeks may be more typical), user interfaces are continually improving. Coupled with the increasing availability of specialized training, the learning curve for achieving competency with a computer video-imaging system can be expected to decrease.

Because computer video-imaging systems are capable of producing images with such a high degree of realism, the knowledge and experience of the image simulator is of paramount importance. Without a thorough understanding of how a landscape can change visually over time, realistic yet inaccurate images can be produced. The inaccuracies introduced in a simulated image may be at least as misleading as any artistic bias introduced in a hand drawn rendering. In addition to an understanding of the types of visual changes that can occur in a landscape over time, and the ability to use a computer video-imaging system to portray those changes, an understanding of perspective, color diminution, and other tools of the artist is helpful in creating high-quality, realistic video images.

Because this technology has only recently become available and affordable, it has yet to be widely used in visual impact assessment. However, it has already made inroads in such diverse professions as architecture, interior design, landscape architecture, education, medicine, plastic surgery, cosmetology, advertising, and art.
Additional literature concerning the validity, accuracy, and realism of various methods of landscape simulations used in a variety of contexts has been published (cf. Sheppard 1982 for a detailed discussion of these issues). However, a search for literature specific to computer video-imaging simulation, to which the remainder of this document is focused, revealed few relevant sources.

Summary

Results of research mentioned in this report, and other studies, have documented some important findings that can be expanded upon by additional research dealing with visual impact assessment of forest insect and disease pests. Some of the more relevant findings are listed below.

1. College students' scenic judgments of forest landscapes are comparable to judgments made by the general public (Daniel and Boster 1976; Arthur 1977; Buhyoff and Leuschner 1978; Schroeder and Daniel 1981).

2. Aesthetic ratings of landscapes are not significantly affected by observers' professional orientation or group affiliations (Buhyoff et al. 1979; 1982).

3. Aesthetic judgments of forest scenes based on photographs of those scenes accurately reflect how the same observers would judge the scenes if on-site (Daniel and Boster 1976).

4. Computer imaging systems can create realistic simulations of landscape changes without introducing artistic bias (Orland 1986a, 1986b).
By using these findings as a foundation; and by extrapolating, modifying, and otherwise adapting previously tested sampling, graphic, and statistical techniques; and by incorporating new techniques where necessary; it should be possible to develop a new method of assessing visual impacts of forest insect and disease pests.
CHAPTER III

THE TESTS

Introduction to Methodology

Placing an absolute rating of scenic beauty on any given landscape is a difficult, if not impossible, task. However, using psychophysical testing procedures, methods have been devised to assign landscapes ratings of relative attractiveness (see previous chapter). If a rating is derived for a particular scene, and another rating derived for that same scene in which some feature has been altered, it is reasonable to assume that the difference in ratings will describe some degree of visual impact resulting from that alteration. Differences in testing procedures or conditions may also influence ratings to some degree.

Because of the complexity of most forest landscapes, isolating individual landscape features for study presents many problems. The ability of investigators to hold some experimental variables constant while altering others would greatly aid landscape research. This has been very difficult in studies of forest aesthetics.

Regression analysis has helped reduce this deficiency. By relating measurable attributes of forest landscapes to aesthetic ratings of those landscapes, researchers have been able to determine the visual importance of some physical features of forest stands with reasonable, but not complete, accuracy. The major problems with this type of analysis are 1) measurement of physical features of forests is costly and time consuming, and 2) many features likely to influence aesthetic judgments are difficult or impossible to quantify.
A method of addressing these problems is described in this chapter. Using a computer video-image-processing system to manipulate pictures of forest scenes, only parameters of interest are altered while all other landscape variables are held constant. This allows for the design of experiments to evaluate aesthetic losses resulting from changes in forest landscapes. In this study, the method is applied to measure the aesthetic losses caused by the disfigurement of trees resulting from the presence of limb rust, a forest disease.

It is reasonable to assume that the visual impact resulting from the presence of a forest pest is a consequence of both the number of infected trees (i.e. incidence) and the extent to which the pest has deformed individual trees (i.e. severity). The nature of the scene in which an infestation occurs, the horizontal and vertical angle and distance from which it is viewed, and other factors may also serve to lessen or increase the degree of visual impact in a forest landscape. The interaction of these factors further complicates the assessment of visual impacts.

The proposed method for assessing the visual impacts of limb rust consists of three parts:

1. Manipulating photographic images of forest scenes to simulate different levels of pest incidence (the number of infected trees) and severity (the visual extent of pest damage) while all other aspects of the scenes remain unchanged.

2. Obtaining scenic beauty ratings for original and manipulated forest scenes.

3. Comparing ratings of scenes with no visible pest damage to scenes with varying levels of pest incidence and severity to arrive at a
measure of visual impact attributable only to pest damage (since that is the only difference in the images). By relating visual impact to changing levels of pest incidence and severity, results become useful to forest managers.

To evaluate visual impacts of any one landscape feature, categories that describe levels of occurrence must be defined. The number of categories defined for each feature will depend upon the physical properties of that feature, increments of change visible to the human eye, and the maximum number of images we can use in any one test. The range of categories should reflect the range within which that feature occurs, or is likely to occur.

Incidence, described as a percentage of infested trees per stand, can easily be converted to a number of damaged trees per presented scene. Testing different levels of severity is more complex. The visual manifestations of pest damage, at different severity levels, vary for different forest pests. Therefore no one severity classification system is appropriate for all pests.

The most useful approach would be to relate visual severity ratings to an existing rating system that is not based on visual impact but on physiological damage. This would allow for more direct, and thus less costly, integration of physiological and visual impact assessment. Rating systems now exist for dwarf mistletoe, mountain pine beetle, and a few other pests. A six-class rating system similar to the dwarf mistletoe rating system (Hawksworth 1977) has been developed for limb rust disease (Baker et al. 1986), and its relationship to growth loss is being evaluated.
In its present form, the limb rust rating system works on the premise that the higher in the tree crown an infection occurs, and the greater the amount of crown mortality, the greater the degree of damage. A rust rating is derived for an individual tree by assigning a score of:

3 if rust is in the top third of the crown
2 if in the mid-third
1 if in the lower third

and adding to this:

1 if 1-30% of the crown has been killed
2 if 31-60% of the crown has been killed
3 if > 60% of the crown has been killed

A tree is rated a 1 if rust is present but no branch mortality has occurred. Adding the location and mortality scores yields six severity classes (seven if the 0 or uninfected tree is included). However, these six severity classes can produce twelve visual manifestations. For example, 3 + 1 or 2 + 2 are both rated as class 4 trees, but the first tree may have a dead top, while the second may be missing half of its crown in the middle of the tree (see figure 1).

It would be convenient, and consistent, if the existing 6-class system could be used for visual severity classes. However, since trees within a class may appear differently, a separate experiment was conducted to 1) define levels of visual impact of limb rust disease based on the severity of infection, and 2) determine the applicability of the existing limb rust rating system as a system of rating visual severity in individual trees.
Limb Rust Rating (LRR)

0,1*  
0  

2  
1 + 1 1 + 1

3  
2 + 1

4  
3 + 1 3 + 1 2 + 2 2 + 2

5  
3 + 2 3 + 2

6  
3 + 3 3 + 3

*A tree is rated a 1 if rust is present but no mortality has occurred.

LRR = Highest position of infection in crown + Mortality rating
3 = rust in top 1/3 1 = 1-30% crown killed
2 = rust in mid 1/3 2 = 31-60% crown killed
1 = rust in lower 1/3 3 = > 60% crown killed

Figure 1. The twelve visual manifestations of the six-class limb rust rating system.
Methods. Approximately two hundred photographs were taken in limb-rust-infected Ponderosa pine stands in three locations in Southern Utah in September 1986 (see figure 2). The photographed sites represented a range of physiographic conditions, stand characteristics,

Area #1 - Boulder Mountain, Dixie National Forest
Area #2 - Pine Lake Road, Dixie National Forest
Area #3 - Just west of Bryce Canyon National Park

Figure 2. Location map showing three areas where limb rust-infected Ponderosa pine stands were photographed.

and incidence of limb rust disease. Not all photographs showed diseased trees, although all were taken within infested stands. The number of slides produced (200) was probably excessive for the requirements of this first test. However, this same set of slides was used in a second experiment. This second experiment, described later in this chapter, required images depicting a greater range of conditions in limb-rust-infected stands.
From this set of photographs, one image was chosen for computer manipulation. The selected image displayed one prominent foreground tree surrounded by several slightly smaller trees atop a small rise and silhouetted against the sky (see figure 3). Because of the solid sky background, the entire crown of the prominent tree was clearly visible. No trees in the scene displayed any signs of limb rust disease.

Figure 3. Photograph chosen for simulation of different levels of limb rust severity.

Using a computer video-image-processing system to modify the crown of the prominent tree, images simulating the twelve possible visual manifestations of the six-class limb rust rating system were created. Except for the changes made to the one tree, all other aspects of the scene remained unaltered for each new image. The twelve images were output to 35mm slides (see figure 4). The original slide was also processed through the computer system and a new slide created although the tree in question remained unaltered. This was done to ensure that all slides used in the test were of comparable graphic quality and resolution (see appendix A for description of video-image-processing system). The actual image processing was performed by
Figure 4. Twelve images simulating the visual manifestations of the six-class limb rust rating system (LRR = limb rust rating).
Figure 4. (continued)
Figure 4. (continued)
Elaine Campanella, a skilled computer artist employed by the Merrill Library at Utah State University.

The pair comparison method, described in the previous chapter, was used to obtain aesthetic ratings for each scene. The pair comparison method was used because it allows for the finest degree of discrimination between scenes (Hull et al. 1984).

The twelve different images were arranged in all possible pairings, resulting in sixty-six pairs of slides. Identical slides were spaced as far apart as possible. The sixty-six pairs of slides were shown to a total of fifty-six college students in two landscape architecture classes at Utah State University.

Before viewing the slides, the students were informed that they were taking part in a study of forest aesthetics. They were told they would be viewing pairs of slides of forest scenes and were to indicate on a response sheet (see appendix B) the one scene in each pair that they felt contained the least amount of scenic beauty. The students were asked not to base judgments on the photographic quality of the images (imaging systems obscure fine details due to limitations of resolution and color) but to base their judgments on the actual content of the images being viewed. They were also asked to reserve questions not related to the testing procedure until the test was complete.

They were not informed that they would be viewing a scene in which pest damage was present, but it quickly became evident that the only difference between scenes was the degree of deformity in the one prominent tree. The groups were shown four sample slides showing forest scenes similar to the one being tested before the actual test slides were shown. This was done to familiarize the viewers with the
general nature of the test slides and to demonstrate the amount of time each pair of slides would be displayed.

Each pair of test slides was shown for about five seconds. After all slides were shown, the participants were given a chance to comment freely on the aesthetic criteria they used in making their judgements and on their reaction to the testing procedure.

**Data Analysis.** Data analysis consisted of two procedures. The first was designed to measure the amount of agreement within the group of viewers and to identify those individuals whose judgments departed most from the group. The second procedure was to construct an interval scale showing both the order of preference for the images and the relative degree of preference between images.

The procedure for creating an interval scale in pair comparison testing uses a routine that averages the percentage of times viewers prefer one item over all other items. A problem with this type of averaging technique is that it assumes that individuals within the group will use similar criteria for making aesthetic judgments. As disagreement within the group increases, the results become less meaningful.

For example, if a scene produces a strong negative reaction in half of the group and a strong positive reaction in the other half, the rating for that slide will likely fall in the mid-range of the interval scale. Now consider another slide which is perceived as only slightly unattractive by half of the group and slightly attractive by the other half. Like the first slide, this slide will likely produce a rating in the mid-range even though viewers' feelings regarding its attractiveness are far weaker than for the first slide.
To measure the amount of agreement within the group of viewers tested, and to isolate those individuals in the group whose ratings deviated most from the group, a commonly-used statistical procedure was performed on the responses generated by the tests. This deviation test, described below, is extremely useful in determining the degree of consistency of responses within the group.

For each individual, the slide chosen as least attractive in each pair was assigned a score of 1. The difference between 1 and the percentage (%) expressed as a decimal) of the total group that chose the same slide as least attractive was squared. Adding the sum of the squared differences for all sixty-six pairs of slides for an individual gave a measure of that individual's departure from the group as a whole.

For example, if viewer #1 chose slide "A" in pair #1 as being least attractive, and 75% of all viewers also chose slide "A" in pair #1 as least attractive, the amount of departure for that individual for that pair of slides would be 0.0625 \((1-.75)^2=0.0625\). If only 25% of all viewers had chosen slide "A" as least attractive, the amount of departure for that individual for that pair of slides would be 0.5625 \((1-.25)^2=0.5625\). When an individual's departure scores for all pairs of slides are totaled, the lower the amount, the greater that individual's agreement with the group.

The results of this test of deviation show that fifty of the fifty-six viewers (about 90%) fall within a moderately tight group (i.e. their ratings are in general agreement) with the remaining six viewers (about 10%) showing a higher degree of departure from the norm (see figure 5). Since a stronger consensus yields more meaningful ratings,
Figure 5. The degree of deviation of scenic beauty ratings by fifty-six individuals who viewed sixty-six pairs of slides.

the test scores of the 10% of the viewers with the most deviant scores were not used in the rating procedure.

Two important findings are demonstrated by this test of deviation. First, that 90% of the group fell within a reasonably tight range of deviation shows there was general agreement regarding aesthetic judgments of the test slides. Second, that a small yet significant percentage of the group exhibited a relatively large degree of deviation suggests that either this small group was not following instructions properly or that genuine disagreements do exist regarding aesthetic judgments.

An interval scale depicting the ranking and relative attractiveness of the twelve test slides was created using a procedure based on the law of comparative judgment as explained in Nunnally (1967). The
procedure consisted of constructing a table showing, for each pair, the percentage of viewers who selected one slide as being less attractive than the other (see table 1).

The percentages were converted into normal deviates and a new table was built. The normal deviates for each slide were summed and averaged to produce a rating. To eliminate negative numbers from the ratings, and to make the scale easier to comprehend, the scores were reversed so that slides judged more attractive received higher scores than lesser-liked slides. This was done by finding the difference between the least-liked slide (slide L, rating=0.63) and all other slides and adding that difference to 0.63 to produce a scaled rating for each slide (see table 2).

For example, the difference between the scores of slide L and slide F is 0.62 (0.63-0.01). Adding 0.62 to 0.63 results in a scaled rating of 1.25 for slide F. It is important to note that adjusting the scores this way did not change either the relative ranking of slides or the relative difference between scores. Because this is an interval scale, the actual values are of little use; however the rankings and relative distance between scores are meaningful.

**TABLE 1.** Percentage of times each slide was selected as least attractive in comparison to all other slides.

<table>
<thead>
<tr>
<th>Slide</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
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<td>0.74</td>
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<td>0.18</td>
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<td>0.20</td>
<td>0.50</td>
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<td>0.20</td>
<td>0.50</td>
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<td>0.50</td>
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<td>0.22</td>
<td>0.14</td>
<td>0.20</td>
<td>0.26</td>
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</table>
TABLE 2.
Percentages converted to normal deviates, averaged, and scaled for each slide.

<table>
<thead>
<tr>
<th>Slide A</th>
<th>Slide B</th>
<th>Slide C</th>
<th>Slide D</th>
<th>Slide E</th>
<th>Slide F</th>
<th>Slide G</th>
<th>Slide H</th>
<th>Slide I</th>
<th>Slide J</th>
<th>Slide K</th>
<th>Slide L</th>
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<td>1.75</td>
<td>1.28</td>
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<tr>
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<td>0.00</td>
<td>0.64</td>
<td>0.92</td>
<td>0.20</td>
<td>0.92</td>
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<td>0.92</td>
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</table>

Results and Conclusions. Figure 6 shows the ranking and relative rating of the twelve images used in the pair comparison test. The limb rust rating for each image is also shown. Some interesting findings emerge from the results of this test.

The uninfected tree, with a rust rating of 0 (this tree could also be rated a 1 since trees with a 1 rating are infected but have no visible mortality), emerges as, by far, the most preferred image. The next most preferred image is slide B, a tree with a limb rust rating of 2. This tree contains a small amount of mortality (≤30%) located in the lower one-third of the crown.

The next most liked image, slide E, has a limb rust rating of 4. E contains a small amount of rust (≤30%) in the upper one-third of the tree. It is interesting to note that slide F, also containing a small amount of rust (≤30%) in the upper one-third of the tree, scored substantially lower than slide E. Visually, the difference between the two images is that in slide F the tree has a dead top whereas in slide E the tree top remains alive. We may speculate that, at least in cases
where the amount mortality is small, a dead top is more visually disruptive than mortality elsewhere in the crown. That slides B, C, and D, displaying small amounts of mortality lower in the crown all rate higher than slide F supports this hypothesis.

It should also be noted that the mortality in slides C and D is lower in the crown than slide E, yet they rated lower for scenic beauty than slide E. This works opposite the limb rust rating system which considers infections more severe the higher in the tree they appear. Perhaps, due to the pyramidal form of Ponderosa pine, the same vertical measure of crown mortality actually produces a greater volume of crown mortality when it appears lower in the crown. With small amounts of mortality (measured vertically), an infection high in the crown (but with a live top) results in a small volume of crown loss and minimal visual disturbance. However, with a greater volume of crown loss lower in the
tree, the natural form of the tree is more distorted, producing a greater
degree of visual impact.

As the amount of crown mortality increases from <30%, the
resulting ratings show some interesting trends. When the mortality is
confined to the bottom two-thirds of the crown, as in slides G and H, the
ratings are slightly lower than for the least-liked trees with less
mortality (slides D and F). However, when that mortality reaches the
upper third of the tree, whether the amount of mortality is moderate or
large, the ratings fall significantly. Ratings for trees with moderate or
large amounts of mortality in the upper one-third of the tree form a
tight grouping at the low (least-liked) end of the scale.

This implies that in trees with a greater amount of dead crown,
the higher in the crown the mortality appears, the greater the visual
impact. This is opposite the findings for trees with small amounts of
dead crown. It seems that once a tree surpasses a certain threshold of
crown loss, and that crown loss reaches the upper part of the tree, the
natural form of the tree is distorted to such an extent that the actual
amount of mortality becomes secondary and the maximum degree of
visual impact has occurred.

Some interesting conclusions can be drawn from the results of
test #1. Since the tree with a limb rust rating of 0 (or 1), with no
visible mortality, rated substantially higher than the next most-liked
image, it seems clear that observers were able to detect even a small
amount of rust damage in a tree, and that any damage was perceived as
being aesthetically detrimental. It also appears that the limb rust
rating system, devised to provide a method of quickly judging the loss
of timber production as a result of the presence of limb rust, correlates
well with aesthetic ratings only at the extremes of the scale but not within the middle range of the scale. A possible explanation for this occurrence is that, although the location of dead crown is important in both growth loss and aesthetic loss, the influence of location in aesthetic loss appears to reverse itself as crown mortality increases.

The ratings also demonstrate that in trees with equal amounts of crown mortality, a tree with mortality beginning at the bottom of the crown is not as aesthetically displeasing as either a tree with mortality in the mid-crown (with live crown both above and below the mortality), or a tree with a dead top. In comparing trees with equal mortality in which one has a dead top and the other has live crown both above and below the mortality, no clear pattern of preference emerged. The viewers' candid responses following the tests tended to confirm this lack of consensus. When asked which form of mortality they found most aesthetically detrimental (dead top, dead bottom, or dead mid-crown), about half the group chose dead top, half chose dead mid-crown, and a very small number indicated that a dead bottom crown was most aesthetically displeasing.

We may speculate that since trees with dead lower limbs retain more of the natural pyramidal form of the species than do dead-topped trees or dead mid-crown trees, their deformities are not as visually disruptive and therefore not as aesthetically damaging as the other visual manifestations of limb rust damage. It is possible that dead-topped trees are associated with stunted growth, which may affect aesthetic judgments. It is not clear why individuals appear divided as to which type of mortality is more aesthetically displeasing, dead-topped trees or dead mid-crown trees. When asked to explain why they felt
one particular type of mortality was more aesthetically detrimental than the other types, individuals indicated that the type of mortality they found to be most aesthetically displeasing made the tree look "less natural" than the other types. This was the case no matter which type of mortality they felt was most aesthetically displeasing. However, it is clear that once crown mortality reaches a level where there is substantial deformation of a tree's natural form, aesthetic value is severely affected no matter where in the tree, and in what form, the mortality occurs.

Test #2

Methods. Test #1 measured the reaction of viewers to a scene in which different levels of limb rust infection were simulated in a single Ponderosa pine tree. Using the results of this first test to define a range of visual severity levels, test #2 measured visual impacts in scenes in which trees were infected with limb rust disease in different degrees and combinations of severity and incidence.

From the same set of slides used in test #1 of limb-rust-infected Ponderosa pine stands photographed in Southern Utah, four images were selected for computer manipulation. These images displayed near to middle-view forest scenes. The four scenes were photographed along or within several minutes walk of roadways, and were typical of what might be viewed along a trail, roadway, or within a campground, picnic area or other recreation sites. None of the trees visible in the four scenes showed signs of limb rust infection (see figure 7).

Using a computer video-image-processing system, a set of simulations was created for each scene. The new images were identical to the original image except that simulations of limb rust damage were
Figure 7. Four images selected for simulation of different levels of limb rust incidence and severity.
introduced. In order that a reasonable number of slides be tested for each scene, four levels of visual impact, as defined in the first test, were chosen for simulation in test #2. These four levels, representing three different degrees of infection plus a fourth, uninfected level, appeared almost equally separated in terms of visual impact on the scale derived from the first test. In other words, the four rust levels depicted four stages of visual impact with near-equal amounts of impact separating adjacent levels. These four levels of impact are represented by slides A, B, F, and L in the first test and represent limb rust levels of 0, 2, 4 and 6 (see figure 6).

By simulating three levels of infection (the fourth level, representing uninfected trees, needed no simulation) in first one, and then two trees in each scene, a set of ten slides per scene was created. As with test #1, the original slides used in this test were also processed through the computer system to ensure graphic consistency between all images. Each set consisted of one slide in which no trees were infected, three slides in which one tree was infected at three different rust levels, and six slides in which two trees were infected at different combinations of the three rust levels (see figure 8).

The ten slides from each scene were arranged in random order and all four scenes were combined so that each scene would appear every fourth slide. The slides were shown to a total of thirty-seven individuals which included undergraduate and graduate students, faculty and staff from the School of Natural Resources at Utah State University during two viewing sessions in August 1987. Different individuals were used in test #2 than in test #1 to ensure that no biases were present
Figure 8. Forty images showing simulated limb rust infection in four scenes. Four levels of infection in two trees per scene give ten combinations per scene. Key to limb rust level:
0 = none, 2 = low, 4 = moderate, 6 = high
Figure 8. (continued)
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during testing resulting from a knowledge of the nature of the experiment. The slides were rated for scenic beauty using a procedure described by Daniel and Boster (1976).

The viewers were told that they were participating in a study dealing with forest aesthetics. They were informed that they would be viewing forty slides of forest scenes and that they were to rate each slide for scenic beauty on a scale of 1 to 10, 1 being the lowest scenic beauty rating and 10 being the highest (see appendix C). They were also informed of some variation in the photographic quality of the slides but they were to ignore this and concentrate only on the content of the images. The viewers were then shown four sample slides typical of the test slides. The sample slides contained none of the actual test scenes though several of the sample slides did contain limb-rust-infected trees.

Slides were viewed for eight seconds at the beginning then, midway through the test, when viewers were familiar with the procedure, viewing time was decreased to five seconds in order to maintain the observers' concentration. After all slides were viewed and rated, the viewers were given a brief description of the nature of the study.

_data analysis._ As in test #1, data collected from the thirty-seven viewers in test #2 was analyzed both to produce scenic beauty ratings and to determine the degree to which each individual in the group agreed with the assignment of those ratings. However, because the methods of data collection were different in the two tests, the methods of data analysis also differed.

A potential problem with using a rating system such as the ten-point rating system employed in test #2, is that viewers with similar
perceptions may use different strategies for assigning scores to slides. Some viewers may favor the high end of the scale while others may favor the low end. Still others may use a wide range of the scale. Using only the raw values of the scores, it is impossible to know whether a difference in ratings among viewers is due to true perceptual differences or merely to differences in use of the scale.

Daniel and Boster describe a method of adjusting ratings to eliminate the effects of different uses of a scale among observers. Using this method, raw ratings are transformed to standardized scores (called z-scores) by the following formula:

\[ z_{ij} = \frac{(R_{ij} - R_j)}{s_j} \]

where:
- \( z_{ij} \) = z-score for the \( i^{th} \) rating of observer \( j \)
- \( R_{ij} \) = \( i^{th} \) rating of observer \( j \)
- \( R_j \) = mean of all ratings by observer \( j \)
- \( s_j \) = standard deviation of all ratings by observer \( j \).

(Daniel and Boster 1976, p. 10).

Each of the ratings for the forty slides by all thirty-seven observers were transformed to z-scores using this formula. To find the degree to which individual observers were in agreement with the group as a whole, an analysis of deviance, similar to the procedure used in test #1, was performed.

For each rating by each observer, the difference between an individual’s z-score for a slide and the mean of all z-scores for that slide was found. Squaring the differences and summing the results for all forty of an individual’s ratings resulted in a measure of that observer’s deviance from the group.

The results of this procedure are shown in figure 9. As in test #1, the deviance scores for the vast majority of observers form a fairly
tight grouping. Also similar to test #1, a small number of observers show a more pronounced degree of departure. The scores of the four individuals with the most deviant ratings in test #2 (as in test #1, about 10% of the group) were not used in the final compilation of scenic beauty ratings for the forty slides used in the test.

As described earlier, the forty slides shown in test #2 consisted of ten slides each of four different scenes. The ten slides of each scene consisted of ten different combinations of limb rust infection in two trees per scene. Each of the four scenes contained slides depicting the same ten combinations of limb rust infection.

An aesthetic rating for each slide was produced by finding the mean of all z-scores for each slide. To make the results easier to comprehend, the mean ratings were first multiplied by one hundred to eliminate decimal ratings. Then, one hundred was added to each score.
so that all scores would have positive values. While this scaling procedure changed the numeric value of the scenic beauty scores, the rankings and relative distance between scores remained unchanged.

While the resulting ratings are useful for comparing slides of the same scene, it is not possible to compare ratings of different scenes using these scores, since each scene has different inherent scenic qualities. To arrive at a cumulative rating for each limb rust level, the average ratings for each limb rust level from each of the four scenes were added. This resulted in ten different scores representing the ten levels of limb rust infection.

It should be stressed here that this method of averaging z-scores to produce scenic beauty ratings deviates from the procedure described by Daniel and Boster (1976) and adopted by other researchers in recent years. The procedure these researchers devised for obtaining scenic beauty ratings is based on analyzing the frequency of similar responses for a small number of unique scenes viewed many times from different viewpoints ("unique scenes" here refers to a landscape that, although viewed many times by observers, has no physical changes introduced to it between observations). In this test, each unique scene was viewed only once by each observer (since a physical change, i.e. limb rust infection was introduced, each slide became, in essence, a "unique scene").

For the purposes of this test, it was important to obtain ratings for many unique scenes. Because the nature of this experiment differed from previous experiments designed to obtain scenic beauty ratings for landscapes, the methods of data analysis used in previous experiments were not applicable in this situation. Though the term "scenic beauty
rating" is occasionally used to describe the results of the computations, it is used only in a generic sense. The scenic beauty ratings that were derived are in no way meant to imply that the statistical procedures that were employed are the same as those applied by previous researchers.

Results. Figures 10 and 11 show two representations of the results of the data analysis described above. Figure 10 shows how the scenic beauty rating for each scene at each limb rust level contributes to the combined scenic beauty rating for the ten limb rust levels. The four patterns that each of the ten combined scores are composed of represent the individual ratings of the four scenes for a particular limb rust level.

Figure 11 is a three-dimensional portrayal of the ten cumulative scores. The X-axis of the graph portrays the visual impact level of one tree in a scene while the Y-axis depicts the visual impact level of the second tree in the scene. The Z-axis represents the cumulative scenic beauty rating for each combination of tree damage. While the first graph shows the degree of variation among the scenic beauty ratings for similar limb rust levels among the four scenes, the second graph shows the net result when limb rust damage and incidence are depicted in different combinations.

Figure 10 reveals that the degree of change in scenic beauty ratings at different limb rust levels varies among the four scenes. Scenes A and B show a relatively greater degree of variability among the ten limb rust combinations than scenes C and D. It is interesting to note that scenes A and B have generally lower scenic beauty ratings for all rust levels (including scenes where no rust is visible) than scenes C
LEVELS OF INFECTION FOR EACH PAIR OF TREES

0 = uninfected
L = low degree of infection
M = medium degree of infection
H = high degree of infection

Figure 10. Scenic beauty ratings for ten levels of limb rust disease. The contribution of each of the four scenes comprising each rating is also shown.

Figure 11. Three-dimensional portrayal of the ten cumulative scenic beauty ratings.
and D. This implies that scenes A and B have inherently less scenic beauty than the other two scenes. That scenes A and B should have more variability in their scenic beauty ratings suggests that the aesthetic quality of less scenic landscapes is more severely impacted by the presence of limb rust than landscapes with more inherent scenic qualities.

It is evident from figures 10 and 11 that the scenic beauty ratings for the ten limb rust combinations fall into a three-tiered pattern. Figure 11 demonstrates how the combination of infection severity and number of infected trees determines the level of scenic beauty.

Not surprisingly, the combination of two uninfected trees (0,0 on the graphs) rated the highest for scenic beauty. The combination of one tree infected to a low degree and one uninfected tree (0,2) rated only slightly lower. The next four scores down the scale show a substantial drop in scenic beauty ratings and form a tight grouping. This group of four limb rust combinations consists of two limb rust combinations in which one tree is infected to a medium or high degree (scenes 0,4 and 0,6) and two combinations in which two trees are infected with one tree having a low level of infection and the second tree having a low or medium degree of infection (2,2 or 2,6).

The third group, possessing the lowest level of scenic beauty, consists of the remaining four limb rust combinations. All four ratings in this group represent combinations in which two trees are infected. This includes the combination of one tree with a low degree of infection paired with a tree with a high degree of infection (2,6). It also
includes the three scenes in which each tree is infected to either a medium or high degree (4,4 and 4,6 and 6,6).

It appears from these results that the loss in scenic beauty resulting from the presence of limb rust disease is influenced by both the degree to which individual trees are infected and the number of infected trees that are present in a scene. It also appears that these two factors are about equally influential in scenic beauty loss although more combinations would have to be tested in order to verify this conclusion.
CHAPTER IV

CONCLUSION

The experiments described on the preceding pages were intended to test not only the degree of sensitivity of a group of viewers to aesthetic losses in Ponderosa pine stands infested with limb rust disease, but also to test the applicability of using computer image processing technology as a tool for measuring aesthetic losses. The success of these tests should not be judged solely by the insights gained from analyzing the statistics generated by the tests themselves, but also by the insights gained by applying this emerging technology to the field of visual impact assessment.

Visual Impacts Resulting from Limb Rust Disease

Although specific results and conclusions of the tests have been discussed in the preceding chapter, it may be appropriate at this point to discuss the test results and their implications in a more general framework. Since the ultimate goal of this and similar tests is to provide land managers with information useful in making management decisions, we need to determine to what degree the information we've acquired is applicable in real-world situations.

The first, and perhaps most important conclusion we can draw from the tests is that people are able to perceive the presence of limb rust disease even when it occurs to a small degree; and the great majority of people find the presence of limb rust to have an aesthetically detrimental effect in Ponderosa pine stands. The presence of limb rust should therefore be a factor of consideration in the
management of Ponderosa pine stands. In visually sensitive areas, the presence of limb rust may be among the primary factors influencing management decisions.

One of the more pragmatic goals of the experiments was to test the applicability of the limb rust rating system for rating visual impacts in limb-rust-damaged Ponderosa pine stands. If the correlation between limb rust ratings, based on physiological damage, and visual impact ratings, based on visual damage, were strong enough, measurement of both physiological and visual damage could conceivably be derived from the same forest survey data.

It was found that limb rust ratings and visual impact ratings correlated strongly at the extremes of the scales and less strongly in the mid-range. It was speculated that this discrepancy in the mid-range scores was due to a difference in the influence of location of crown mortality on aesthetic ratings and physiological ratings. This being the case, the limb rust rating system is not a flawless system of rating visual impacts, especially where a fine degree of discrimination in visual impact classification is desirable. However, until a more precise system is devised, the limb rust rating system seems to be a reasonable and efficient means of determining whether a large degree of visual impact has occurred in limb-rust-infected Ponderosa pine stands.

Factors outside the landscape in question must also be considered to determine visual impacts in any location. For example, a damaged or distorted tree may be determined to have a negative impact on visual quality based on test results derived from experiments similar to those described previously in this report. However, if that tree were located amidst an otherwise uniform forest stand, by breaking up the monotony
and adding variety to the landscape, it may in fact have a positive influence on visual quality that is not reflected in the ratings generated by the testing procedure. On the other extreme, if test results indicate a pest-infested forest stand has a low to moderate degree of visual impact, and that forest stand is located near or adjacent to an exceptionally magnificent landscape, the damaged stand, by contrast, may produce more visual impact than indicated by the tests than if it were located among less spectacular scenery. A professional judgment will ultimately be required to make that decision.

It is important to realize that no testing procedure can or should take the human element out of visual impact assessment. Impact ratings derived from sound scientific testing procedures should be one of a number of tools used by skilled professionals to plan strategies for visual resource management. An understanding of landscape aesthetics coupled with an intuitive feel for visual quality should not be ignored when determining visual impacts in a landscape.

Analysis of Methodology

To evaluate the methodology used in the two tests, it is important to refer back to the original objectives to see to what extent these objectives have been met. One measure of a method's applicability is its ability to produce meaningful and consistent results over different applications. The statistical procedures applied to the responses generated by the two tests described in this report were used to formulate interval scales. Keeping in mind that interval scales have no predefined base point (i.e. there was no predefined level of scenic beauty on which the ratings were based), the scales derived from both tests appear to be an effective method of describing both the order of
preference for the presented images and the relative attractiveness for images used in any one test.

The weakness of using interval scales is that, lacking an absolute measure of scenic beauty to use as a base point, results of different tests are not directly comparable. In the case of the two tests described in this report, while we may conclude that certain factors produced a measurable difference in aesthetic quality, we cannot say that the difference in aesthetic quality between any two images in test #1 is any more or less than the difference in aesthetic quality between any two images in test #2.

If the same method used in this limb rust study were applied to testing for visual impacts caused by bark beetles, dwarf mistletoe, or other forest pest infestations, the results of any of these tests would not tell us anything about the relative visual impact of limb rust vs. bark beetles or bark beetles vs. dwarf mistletoe, etc. In order to compare the visual impacts resulting from one pest with the visual impacts resulting from other pests, it would be necessary to display images depicting damage caused by different forest pests in the same experiment.

Such an experiment might be extremely useful in helping forest pest managers make decisions on where their pest management efforts could be best applied. A limitation with this type of test is that, given the maximum number of images that can be presented to viewers before fatigue becomes a factor, the number of images that could be presented for any one pest would have to be decreased. This would limit the images within a range of incidence and severity that could be presented.
Another measure of the applicability of a methodology is its repeatability by independent investigators. Due to the interdisciplinary nature of the limb rust tests, individuals with expertise in computer video-image processing, forest pathology, landscape architecture, and statistics all contributed to the design, execution, and analysis of the tests. The degree of expertise required, and thus the ease with which the procedures could be duplicated, differed for each stage of the experiments.

The stage of the experiments that required the most specialized knowledge involved determining the content of the simulated images. A thorough understanding of the visual changes resulting from the forest pest being studied, and the nature and progression of the pest infestation was necessary to accurately depict visual changes caused by the pest in real-world situations. As discussed previously, the images created by a computer video-image-processing system can be so realistic that inaccuracies introduced in the simulated images will likely go unnoticed by most viewers but could severely effect the validity of a test.

The actual creation of the images used in the tests was performed by a skilled computer artist who was familiar with the specific computer video-image-processing system that was used. The process of creating the new images was implemented in such a way as to ensure, as much as was possible, that the simulated images displayed a reasonable representation of limb rust infection as it occurs in real world conditions.

First, the computer artist was shown a number of photographs of limb-rust-infected trees to familiarize her with the visual nature of the
pathogen. Second, a cut-and-paste technique, in which sections of video images of limb-rust-infected trees were transferred into images of uninfected trees, greatly reduced the need for freehand drawing or other interpretations on the part of the computer artist. Third, the artist's work was closely monitored to insure accuracy and consistency between images. Finally, the completed images were presented to a number of forest pathology experts familiar with limb rust disease for their reactions. None expressed any reservations as to the images being reasonable surrogates of limb rust in real conditions.

While I have little doubt that, given enough time, comparable images could have been produced by a non-expert in image processing, by using a professional computer artist, substantial time was saved on training and familiarization with the particular computer system. As computer video-image-processing systems become more user friendly, the need for image processing specialists to create simulated images is decreasing. With some training and practice, the use of these computer systems by non-experts for image processing applications is becoming an increasing reality.

Once the images were created, the psychophysical testing procedures, which are straightforward and well documented (Daniel and Boster 1976), were employed to generate responses from viewers. While no particular skills or expertise are required to display the images and generate responses, some differences between past experiments and the experiments described in this report may warrant some modification to the testing process if similar tests are conducted.

Past testing has usually involved displaying a variety of scenes or a few scenes from a variety of viewpoints. Since the point of the
limb rust tests was to isolate one factor for study, it was necessary to display images of a small number of scenes (one in the first test, four in the second test) shown many times from the same viewpoint. It is likely that viewer fatigue becomes a factor more quickly when the variety of scenes is limited than in a test where there is more variety in the images displayed. There was no evidence of viewer fatigue being a factor in test #2 in which four scenes were presented a total of ten times each. However, in test #1, in which one scene was displayed sixty-six consecutive times, some individuals did appear restless in the later stages of the viewing sessions. In the free responses following test #1, one individual expressed becoming increasingly bored as the test progressed. This opinion was likely shared by other participants. Even though the total viewing time was under six minutes, it appears that more variety is necessary if viewers' interest is to be maintained for this period of time. Although it may mean limiting the number of images within a range of conditions that can be displayed, this may be an advisable tradeoff in pair comparison testing where it may not be possible to increase the variety of images.

Another possible consequence of using a limited number of scenes shown from the same viewpoint multiple times is that individuals may be more likely to key on the one changing variable than they would in a real-life situation in which viewing context and stimuli are constantly changing. Though difficult to quantify, if we assume this to be true, we may conclude that ratings derived in the tests produce somewhat exaggerated measures of visual impact.

Those procedures dealing with statistical analysis that were adopted from other studies involving psychophysical testing were, like
the testing procedures themselves, straightforward and well documented. Other procedures, such as the deviation tests, suggested by an advisor to this project (personal communications with Charles Romesberg 1987), were also easily implemented and could be duplicated by non-experts with little difficulty. It should be noted that the relative ease with which the statistical procedures were implemented were, in part, due to the use of a computer spreadsheet which eliminated the drudgery of performing numerous mathematical calculations manually.

Need for Future Research.

Mitigation of the aesthetically detrimental effects of limb rust disease is desirable in locations where visual sensitivity is great and maintaining aesthetic values is a priority. The type of management necessary to achieve this goal is an important topic for investigation. Concurrent research suggests that it is possible to change people's perceptions regarding forest pathogens (Baker and Rabin 1988). Individuals informed that pest-infected trees provide wildlife habitat appear to make vastly different aesthetic judgements than uninformed individuals.

The images displayed in the two tests included near to mid view scenes of pure Ponderosa pine stands photographed in early fall. While these may be considered typical viewing conditions for many visitors to these and similar Ponderosa pine forests, they are by no means the only viewing conditions where limb rust has or may occur. It would be valuable to conduct similar tests which include different viewing conditions. Such tests could help determine what effect these different conditions have on visual impacts. Among the viewing conditions that may be of interest to investigators are seasonal variations where snow,
The experiments described in this report suggest that the presence of limb rust has an aesthetically detrimental effect in stands of Ponderosa pine trees. However, due to the inherent weaknesses of interval scaling techniques, these tests were unable to compare the visual impacts caused by limb rust to other tests dealing with visual impacts caused by other forest pathogens. To make this type of comparison using this methodology, it would be necessary to conduct tests in which images displaying tree damage caused by more than one pathogen appeared in the same test. Only then could this testing procedure be used to compare the relative visual impacts of limb rust, bark beetles, dwarf mistletoe, and any other pathogen likely to degrade the visual quality of a landscape. The results of this type of test could help forest pest managers decide where management efforts may be best applied.

The range of tools available in most computer video-image-processing systems provide great flexibility in modifying captured images. Because of this flexibility, creating images which simulate visual changes to forest stands infected with pests other than limb rust should present no particular difficulties. The "cut-and-paste" technique used to create many of the limb rust images would also be applicable to dwarf mistletoe and other pests that cause brooming (nest-like clumps) in tree
branches. Brooms could be captured in a video image and pasted into images of uninfected trees at various concentrations.

Most computer video-image-processing systems also include tools to manipulate colors. This would prove valuable in simulating many insect infections including bark beetles, which cause the needles of infected conifers to turn red before finally dropping off. After needles fall off, the trees appear gray from a distance. Images of conifer stands with varying numbers of red or gray trees could be simulated depicting different concentrations of bug kill per stand.

Finally, the issue of costs vs. benefits is vitally important to researchers and their sponsors. For computer video-image-processing to become an accepted tool in visual impact assessment, it must be shown that the benefits of applying this technology are worth the expense. A comparison of the expenses involved in applying this technology versus other approaches to visual impact assessment, including the relative benefits and drawbacks of the different approaches, would be a valuable aid in determining the feasibility of applying this technology on a wide-scale basis.

Perhaps it is a fortunate coincidence that as the need to quantify visual impacts to our increasingly popular forest landscapes intensifies, a new tool which appears to have great promise in aiding this endeavor is rapidly emerging. The computer video-image-processing system should never become the ultimate decision-maker in any judgments involving something so closely linked to human values as visual quality. However, having the ability to accurately and realistically depict potential changes to a landscape can only help land planning
professionals make better-informed decisions regarding the management of our visual resources.
REFERENCES CITED


APPENDICES
Appendix A  The Computer Video–Image–Processing System
The computer video-image-processing system used to produce the images used in the tests described in this report was an Artronics PC 2000 system Version 3.1 manufactured by Artronics, Inc. of South Plainfield, N.J. The system consisted of a combination of hardware and software which performed three specific tasks required to produce the images.

The first task consisted of inputting or "grabbing" existing photographic images through a video camera into the computer. Special hardware and software was used to transform each video image into a format that could be displayed on the computer screen, manipulated with software and stored on a disk. It was important that the quality of the captured images remained as close to the original images as was possible. This was necessary to insure that the realism of the images was not sacrificed. While the sharpness and color range of the captured images was decreased to some degree, the images still retained a high degree of realism after they had been input into the computer.

The second task consisted of editing the images to produce a new set of images simulating different degrees of limb rust damage. This consisted largely of merging parts of images of limb rust damaged trees with images of uninfected trees to simulate limb rust damage in the uninfected trees. This technique of merging parts of different images is called "cutting and pasting" and is crucial to the creation of realistic landscape simulations. Other editing tasks included copying and scaling parts of images, drawing or "painting" with pre-defined textures and patterns, and blending and otherwise altering colors. The resulting images were also saved to files.
The third task was to output the new images to 35mm slides. This was done using a special film recorder designed to record computer-generated images on film. The quality of the slides produced by the film recorder was comparable to that of the images displayed on the computer screen.

Of the three steps involved in image processing for the purpose of visual impact assessment of forest pest infestation, image editing is perhaps the most critical. Sophisticated editing capabilities are required to create realistic simulated images. A system that allows flexible and detailed editing of images is a prerequisite for individuals involved in visual impact assessment.

Although a dollar figure was not available for the value of this computer video-image-processing system, the original cost was most likely in excess of $20,000. With the rapid advances in this technology over the past few years, a system with similar or more advanced capabilities could be purchased today for approximately $20,000.
Appendix B
Test #1 Response Form
Please indicate the one slide in each pair that you feel has the least amount of scenic beauty.

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Appendix C
Test #2 Response Form
Please rate each slide for scenic quality on a 1 to 10 scale.

1 indicates very low scenic quality and 10 indicates very high scenic quality.

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VITA

Daniel Rabin

Master of Landscape Architecture

Thesis: Using Computer Imaging to Assess Visual Impacts of Forest Insect and Disease Pests

Major Field: Landscape Architecture

Biographical Information:


Professional Experience: Crew supervisor - forest inventory crew for private contractor on Dixie National Forest; Urban Forestry Assistant - conducted tree inventory on Utah State University campus; Residential and commercial landscape design and construction - design/build firm, Rockland, Maine; Biological Technician - conducted forest pest research, US Forest Service, Rocky Mountain Region; Teaching assistant for plant materials and computer applications in Landscape Architecture at Utah State University; Research Assistant - visual impact assessment, Utah State University; Product Developer for computer software company specializing in software for land planning disciplines, Franktown, Colorado; Lecturer on computer applications in Landscape Architecture, University of Colorado at Denver.

Professional Publications:
Rating the Severity of Limb Rust in Ponderosa Pine Stands, (Western International Forest Disease Work Conference), 1986.
Drawing on High Tech...Software Innovations for the Landscape Profession (Landscape Design Magazine), 1988.