Special Technology Development Program
New Project Proposal

PROJECT NUMBER: R1-2001-04

PROJECT TITLE: Using Remotely Sensed Imagery to Estimate Mountain Pine Beetle-Caused Mortality in Lodgepole Pine Forests of Montana

PROJECT STATUS: New

EXPECTED PROJECT DURATION: 2 years

EXPECTED COMPLETION DATE OF THE PROJECT: 2002

SUBJECT: Biological Control___ Invasive Species___ Methyl Bromide Alternatives___ Models___ Monitoring_1_ Organism Biology___ Pesticides: Microbial ___ Pesticides: Synthetic___ PTIPS___ Population___ Risk and Hazard___ Remote Sensing_1_ Semiochemicals___ Silvicultural Technology___ Social Values___ Spray Technology___ Other_Disturbance_interactions

STATUS OF SUBJECT SPECIES : Native

PROJECT OBJECTIVES: We propose to test the potential of remote sensing technology for quantifying mountain pine beetle (*Dendroctonus ponderosae*) caused mortality in lodgepole pine (*Pinus contorta*) forests in Montana. We predict that the technology developed will provide the capability to 1) quantify mountain pine beetle impact severity at the landscape scale, 2) map spatial patterns of impacted areas, 3) monitor forest changes due to mountain pine beetle outbreaks over time, and 4) quantify the interactive relationships between forest disturbance agents such as bark beetles and fire at the landscape scale. Although spectral signals for impact caused by bark beetle species in other forest types may be different, results of this project will lay the necessary groundwork for extension of the methodology to other forest ecosystems.

BRIEF DESCRIPTION OF PROJECT: An ongoing mountain pine beetle outbreak in the Lolo National Forest, Montana, has impacted more than 20,000 ha of lodgepole pine forest since 1993. Although Aerial Detection Surveys performed by Forest Health Protection map approximate boundaries and impact levels of forest change, quantitative information describing severity and landscape-scale pattern of bark beetle impact is lacking. We propose to test the potential of satellite remote sensing technology to quantify mountain pine beetle impacts over large geographic areas and to monitor these changes through time. The developed technology can then be applied at a larger scale to analyze bark beetle and fire interactions, and to extend bark beetle monitoring into areas typically not flown in current aerial detection surveys.

Year 1: Annual Landsat ETM+ images of a current mountain pine beetle outbreak on the Lolo NF will be acquired for the years 1993 (before), 1999, 2000, 2001 (during). Using change detection techniques, several spectral indices will be developed. On-the-ground surveys will be conducted, using variable radius plots, in the beetle-impacted area of the Lolo National Forest to quantify annual bark beetle caused mortality. Year of beetle attack can be estimated for the three previous years (1998, 1999, 2000) using foliage color and needle retention. Spectral indices derived from band reflectance values will be tested for correlation with observed mountain pine beetle caused mortality as detected in ground surveys and other ancillary data including aerial sketchmaps.

Year 2: Analysis of the relationship between spectral indices and observed mortality will continue, resulting in a landscape-scale change map that identifies severity patterns of mountain pine beetle impact. The methodology will be validated with additional ground surveys. Results and methodology will be posted on the web (FHP and RMRS 4501 web pages) and in a peer-reviewed journal.

FHP LEAD CONTACT:

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
Ken Gibson	Region 1, Missoula, MT	406-329-3278 406-329-3132

kgibson@fs.fed.us

PRINCIPAL INVESTIGATOR(S):

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
Barbara Bentz	RMRS, Logan, UT	435-755-3577 435-755-3563 (fax) bbentz@fs.fed.us
Leslie Brown	RMRS, Logan, UT	435-755-3560 librown@fs.fed.us

COOPERATORS:

Name	Affiliation (Office or Dept.)	Phone, E-mail, Fax
Robert Gillies	Geography and Earth Resources Dept. Utah State University	435-797-2664 435-797-2117 (fax)

COOPERATOR INVOLVEMENT:

Name	Role	Time Commitment
Robert Gillies	Remote sensing expertise and equipment	1 month (see attachment)

JUSTIFICATION: Currently, Forest Health Protection uses aerial sketchmapping surveys to detect and monitor forest change events from an aircraft (McConnell et al. 2000). Aerial sketchmapping has proven to be an efficient and economical method for relating visual events with causal agents. The technology development proposed here is not intended as a replacement for aerial sketchmapping surveys, but as a complimentary tool for use in large-scale monitoring and quantification of the spatial patterns of bark beetle caused mortality using existing, routinely acquired satellite data. The ability to monitor and detect bark beetle caused mortality at a large scale, including wilderness areas which are typically not flown in routine aerial sketchmapping surveys, will be beneficial to many aspects of the forest management decision-making process, including fire risk, wildlife, T&E species and timber resources. This technology will also provide the necessary methodology to analyze landscape-scale interactions of bark beetle caused mortality and other important disturbance agents such as fire. Quantification of the effects of beetle-killed pattern and intensity across a landscape on fire severity would provide land management agencies additional information for evaluation of wildland fuels treatment strategies and schedules.

URGENCY: Knowledge of the role of disturbance agents in forest ecosystems is needed to more accurately manage western forest landscapes. The mountain pine beetle has consistently been a driving force throughout the west, and currently is at epidemic levels in many areas, as are other bark beetle species including the Douglas fir beetle and the spruce beetle. As evidenced by the recent fire season (2000), fire potential throughout the western states is only increasing, especially given warming climates. Quantifiable data describing the landscape scale interaction of these two important disturbance agents (bark beetles and fire) is desperately needed not only for fire risk prediction, but more educated long term forecasting of forest stand dynamics.

NATIONAL FHP TECHNOLOGY DEVELOPMENT PRIORITY:

Priority 1: __ Priority 2: __ Priority 3: _x_ Priority 4: __

TECHNICAL COMMITTEE DEVELOPMENT PRIORITY:

Priority 1: __ Priority 2: __ Priority 3: __ Priority 4: __

Priority 5: __ Priority 6: __ Priority 7: _x_ Priority 8: __

SCOPE OF APPLICATION: This project is targeted at the development and testing of methodology for using transformations of band reflectance values (from Landsat images) to represent physical attributes of lodgepole pine response to mountain pine beetle attack. Results from this project will apply to all similar lodgepole pine forests throughout the west. Other forest types, including lodgepole pine that exists in mixed species stands, may require additional analysis to determine appropriate spectral indices. Other satellite imagery can also be used with the developed methodology, assuming similar band wavelengths are available.

RESEARCH BASIS: Major outbreaks of the mountain pine beetle have killed millions of trees over thousands of acres in the northern and central Rocky Mountains in the past 30 years. As a primary source of downed woody fuel for wildfire, mountain pine beetle outbreaks are important in maintaining both the periodicity and intensity of fire regimes in lodgepole pine ecosystems. Although the important role of both beetles and fire in pine ecosystems is recognized, quantitative information on the interaction of these two disturbance agents is lacking. The lack of studies on forest disturbance interactions is in part due to the paucity of quantifiable landscape-scale data. With recent advancements in satellite-based remotely sensed data, computer-aided processing, and spatial statistics, the time is ripe to further our knowledge in these areas.

Remote sensing instruments are capable of detecting visual, and through the near infrared bands, non-visual physiological changes in vegetation. Numerous studies have investigated the use of satellite-based digital remote sensing for the characterization of forest ecosystems and changes that occur within these systems (see Cohen and Fiorella 1998 and Lunetta and Elvidge 1998 for a review). Spectral change detection techniques rely on the principle that changes in landcover result in visible changes in the spectral signature of the affected landscape. Change detection methods involve some type of pixel-wise transformations designed to normalize or bypass radiometric solar illumination and atmospheric differences between the raw images. The assumption is that multi-temporal data sets are highly correlated and the transformations can be used to emphasize those attributes due to the change between the images. Data from sequential images are used to generate a new image that represents spectral change. This is accomplished through image differencing, a commonly used technique whereby changes in brightness values between two or more data sets are obtained through pixel-by-pixel subtraction (differencing), or image ratioing. The goal of data transformations are to synthesize the information contained in spectral bands of an image into a manageable number of features which can then be associated with physical/biological characteristics of the scene. Changes in these characteristics among multi-temporal images are then detected and can be categorized into levels of severity, or mortality in the case of bark beetles.

Change detection techniques have successfully been used to map and inventory changes in forest canopy cover due to insects (Cohen and Fiorella 1998; Collins and Woodcock 1996; Levien et al. 1999; Macomber and Woodcock 1994; Muchoney and Haack 1994; Price and Jajubauskas 1998; Vogelmann and Rock 1988). For example, a multitemporal Kauth-Thomas transformation (also known as the TM Tasseled Cap technique) (Crist and Cicone 1984), resulted in predictions of bark beetle-caused mortality in mixed stands of California that were highly significant ($R^2 = .73$) (Collins and Woodcock 1996). The Normalized Difference Vegetation Index (NDVI) is another technique which combines several bands, providing a ratio directly linked to leaf area and foliar productivity (Tucker 1979; Green et al. 1997; Nemani and Running 1997). Negative change in NDVI most likely will relate significantly to necrosis in lodgepole needles, and by inference, given the magnitude and time frame of mortality in the infested area, it should therefore indicate the degree of tree mortality caused by beetles. Subsequently, as dead needles drop from trees, NDVI should respond positively to opening of the canopy and enhanced spectral contribution from understory plants.

Image band ratios and other change detection techniques have also proven useful for describing fire severity (Ken and Benson (*In review, a, b*); White et al. 1996; Patterson and Yool 1998). By combining the derived indices of beetle severity (from this project) and previously developed fire severity indices from satellite images, future projects can be aimed at more fully understanding the role of both fire and beetles in lodgepole pine ecosystems at the landscape scale.

METHODS :

Image Processing: TM scenes will be geographically referenced and radiometrically processed to obtain physical units of reflectance. Geographic correction will include registering the images to UTM coordinates and to each other using digital elevation models (DEMs), roads, water bodies, and other fixed, invariant landscape features. The images will then be geographically subset to the study area. Radiometric corrections will include transforming image data to at-sensor radiance values using sensor calibration information contained in the image header (US Geological Survey 1995), followed by conversion to reflectance values which reduces between scene variability by normalizing for solar irradiance. Radiometric matching techniques using invariant features of the scene will be used to account for differences in atmospheric conditions between images.

A number of techniques have been successfully used for detecting vegetation change in forest

ecosystems (see *Research Basis*). We will begin by sampling the reflectance of the six TM bands over known areas of significant beetle infestation within the study area. The locations will be sampled in scenes before (1993 image), and then at least 2 years during the outbreak (1999, 2000, and possibly 2001 images). Differences in reflectance will be calculated per band. Band responses will identify those areas displaying greatest magnitude and variation of change, and indicate which bands might be most useful in discriminating beetle-caused effects. A single band, or more likely a band ratio or transformation of several bands, will then be selected to use as a remote sensing index for differencing. For example, bands 3 and 4 have been combined in the Normalized Difference Vegetation Index (NDVI), a ratio directly linked to leaf area and foliar productivity (Tucker 1979; Green et al. 1997; Nemani and Running 1997). We will also test the validity of the Tasseled-Cap (also called the Kauth-Thomas) transformation for identifying radiometric responses that can be used to quantify beetle-caused mortality patterns within the study area. The Tasseled-Cap is a linear transformation of both the visible and near infrared bands, and concentrates the data variability into three indices of brightness, greenness, and wetness. These indices can be expressed as vectors defining linear transformations of multitemporal TM data. This technique has been used successfully for detecting bark beetle-caused mortality in California (Macomber and Woodcock 1994).

These techniques will result in images for each year whereby the value of each pixel represents a radiometric measure of vegetation status. These derived indices will then be differenced between all scenes, producing a set of 'change images' containing pixel-wise measures of the magnitude of change between scenes. We will attempt to identify the different stages of vegetation change including onset of the red-needle phase, and onset of the dropped-needle phase, with perhaps a gradient of stages between initial attack and downed snags. As change between stages occurs at different rates, various time intervals of differencing may be used to describe the final spatial extent of each phase.

Ground Data: Reference beetle intensity information will be derived from variable radius plots. Plots will be spaced on a grid 1.5 chains apart representing the 30 meter pixel size of the TM data. A grid of plots will be surveyed in areas representing a range of beetle impact, including no impact, as determined from aerial photographs and aerial sketchmaps. Each plot center will be geo-referenced using a GPS. Tree species and the number of beetle-killed trees (annually for at least three previous years) will be recorded at each plot. Beetle intensity in terms of basal area killed will be calculated for each sample plot.

Beetle Intensity Classification of Images: Simple and multiple regression will be used to compare radiometric values from the 'change images' produced using the different techniques (e.g. NDVI and Tasseled-cap) to beetle intensity as measured from ground surveys and aerial sketchmap data. This comparison will provide a statistical measurement of fit that can be used to decide which technique best measures beetle-caused mortality. Once we determine the best technique to use, pixels of the entire change image can be classified into patches of similar level of beetle intensity using the developed rule. The new classified image will be validated with additional on-the-ground observations of beetle impact. Metrics of beetle intensity including diversity of patches for a given area, patch shape, fractal dimension, and average intensity of the patch can then be calculated from the image.

MEASURES OF SUCCESS:

Standard of Success: Development of technology which will enable comparisons of agents of change in forested environments.

Expected Outcomes: Ability to use remote-sensing imagery to quantify impacts of forest change over time and space.

Implementation of Products/methods: Methodology, when implemented could become operational throughout Forest Service and cooperating agencies.

PRODUCTS AND DUE DATES: Classification of beetle severity using remotely sensed imagery can be overlayed with existing GIS layers to produce a map of bark beetle intensity on the Lolo National Forest for the years 1998 – 2001. However, long term use of the developed remote sensing methodology for mapping the temporal and spatial progression of mountain pine beetle disturbances in lodgepole pine will be the major product of the project. Given multi-temporal TM images of a mountain pine beetle affected area in lodgepole pine, users could apply the techniques derived here to classify bark beetle severity across a landscape. We anticipate the map and developed indices to be completed by Fall 2002.

PUBLICATIONS : At least one manuscript will be published in a peer-review journal. Web-based products will also be developed.

TECHNOLOGY TRANSFER: An appropriate and rapid approach to facilitate the transfer of technology to users is through the web. RMRS RWU-4501 currently has a web page where results of this project will be posted. Web-based RMRS publications are also an avenue. Additional analyses will be required to develop appropriate spectral indices for bark beetle species in other forest types. Results of the current project will be directly applicable to the task of more fully understanding the interactive relationship between mountain pine beetle caused mortality and fire in lodgepole pine ecosystems.

LONG-TERM BUDGET REQUEST:

	Item	Requested FHP STDP Funding	Other-Source Funding	Source
FIRST YEAR				
Administration	Salary	15,000	12,000 2,000	RMRS FHP
	Travel	5,600		
Procurements	Contracting		2,000	RMRS
	Equipment			
	Supplies	1,300	650	RMRS
RMRS Overhead (12%)		2,556		
Year Totals		**24,456**	**16,650**	
SECOND YEAR				
Administration	Salary	32,550	7000 2,000	RMRS FHP
	Travel	2,600		
Procurements	Contracting	2,000		
	Equipment			
	Supplies	500		
RMRS Overhead (12%)		4,206		
Year Totals		**41,856**	**9,000**	
PROJECT TOTALS		**66,312**	**22,650**	

Budget Justification: Salary listed is for Leslie Brown, RMRS GIS Technician. First Fiscal Year salary includes 10 pay periods full-time at the GS-9 rate. Bentz and 2 field technicians salary is contributed. Also contributed by RMRS are funds for GIS Lab use at Utah State University. FHP contributed salary for Gibson. Travel costs during first year include travel to and from the Lolo National Forest. One satellite image has been purchased by RMRS, one image will be acquired for free through the Forest Service MLRC database, and two images will be purchased with STDP funds. Second Fiscal Year salary for Brown is 16 pay periods at full-time and 10 pay periods at half-time. Travel includes funds for additional ground data collection. Overhead (12%) is charged only on those funds coming to RMRS.

BENEFIT AND COST

-Expenditures of $88,962 of which $66,312 are requested STDP funds.

-Funds to be expended over a two-year period including preparation of work plan, execution of project, evaluation, analysis and report writing.

-Assumptions include methodologies used to conduct annual aerial surveys and remote sensing capabilities.

-Economic calculations (see attached) include project costs and prospective savings using developed technology.

LITERATURE:

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Crist, E.P, and R.C. Cicone. 1984. A physically-based transformation of thematic mapper data-the TM tasseled cap. IEEE Transactions on Geoscience and Remote Sensing, vol. GE-22: 256-263.

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Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment 8(1):127-150.

US Geological Survey. 1995. TM fast format document for digital products, version C. USGS EROS Data Center, Sioux Falls, SD 57198. Informational Brochure, 12 p.

Vogelmann, J.E. and B.N. Rock. 1988. Assessing forest damage in high-elevation coniferous forests in Vermont and New Hampshire using thematic mapper data. Remote Sensing of Environment 24(2):227-246.

White, J.D., K.C. Ryan, C.C. Key, and S.W. Running. 1996. Remote Sensing of forest fire severity and vegetation recovery. Int. J. Wildland Fire 6(3):125-136.

STDP PRODUCTION FUNCTION (Enclosure 1)

PROJECT NUMBER: R1-2001-04

PROJECT COST: $88,962 ($66,312 STDP Funds; remainder donated)

PROJECT OBJECTIVE: Test the potential of remote sensing technology for quantifying mountain pine beetle-caused mortality in lodgepole pine forests in Montana. We predict that the technology developed will provide the capability (1) quantify MPB impact severity at landscape level, (2) map spatial patterns of impacted areas, (3) monitor forest changes over time, and (4) quantify interactive relationships between various disturbance agents—such as MPB and fire.

ASSUMPTIONS:
- Currently, only feasible means of recording "agents of change" in forested areas is by annual aerial detection surveys.
- Technology needed to monitor and quantify spatial patterns of forest change at a landscape level, as complimentary information to be used with aerial survey data, is lacking.
- Technology is needed to enable the analysis of landscape interactions between agents of change, for example, bark beetle outbreaks and fire histories.
- Technology—satellite imagery, for example—exists which must be evaluated to determine its usefulness in providing a means of quantifying these interactions.
- Ground-collected data is necessary to validate remotely collected information as it relates to forest change.

BACKGROUND DATA:
- Costs of satellite imagery :$1,300 for 2 images + $1,500 for analysis = $2,800
- Costs of collecting ground survey information: Salaries, travel, equipment (2 years)--$32,200 (of which $19,00 is donated)

CALCULATIONS

EXPENDITURE & OUTPUT VALUES (EOV) WITHOUT PROJECT:

- Without project (and developed technologies), we will continue to conduct annual aerial surveys; however, we will not have the capability of making long-term and broadscale comparisons between various agents of change. Currently we budget (in R-1) about $120,000 yearly on aerial surveys (aircraft, seasonal salaries and travel). Without project, those costs will not change.

EXPENDITURE & OUTPUT VALUES (EOV) WITH PROJECT:

- Development of the technology will require a one-time expenditure, over two years, of $88,962. If project is successful and technologies developed, the cost to a user would be approximately $2,800. We will still conduct annual aerial surveys. However, the additional Landsat technology for bark beetle impact detection will increase our ability for temporal and spatial monitoring and analyses. In addition, we will be capable of extrapolating data to areas which we do not routinely fly because of budget constraints—such as wilderness areas and national parks. Too, there is on occasion the need for more than one survey per year where outbreaks exist, are building, or insects have more than one generation per year. Real savings of as much as the cost of additional surveys might be realized from time to time and place to place.

BENEFIT (CHANGE IN EOV) ATTRIBUTABLE TO PROJECT (with – without):
B = ($120,000 + ($2,800)) - as much as $240,000 in any given year

BENEFIT/COST RATIO:

$$B/C = \frac{\$(w/o) - \$(with)}{\$(STDP\ cost) + \$(treatment\ cost,\ where\ applicable)} = \frac{\$240,000 - 122,800}{\$88,962} = \frac{\$117,200}{\$88,962} = \mathbf{1.32}$$

BENEFIT ATTRIBUTABLE TO STDP:
Benefit attributable to STDP funds = $88,962 x 1.32 = $117,423

PNV OF PROJECT:
PNV of project = $117,423 - $88,962 = $28,468

PNV OF STDP:
Same—but could be more in any particular year, depending on need and future expenses.

September 29, 2000

Barbara Bentz
RMRS
Logan, UT

Dear Barbara:

This letter is to confirm my enthusiastic support for your project entitled, "Using Remotely Sensed Imagery to Estimate Mountain Pine Beetle-Caused Mortality in Lodgepole Pine Forests of Montana." As we have discussed, this is a valuable opportunity to apply state-of-the-art remote sensing and geographic information systems (GIS) tools.

As you know, Utah State University is designated as a Center for Excellence in Remote Sensing (RS) and GIS. The University is equipped with 5 RS/GIS labs which reside in the Colleges of Natural Resources, Agriculture and Engineering. As one of the administrators that oversees the activities of these labs, I will ensure that the RS/GIS computing facilities are made available to their fullest capacity in the implementation of this project.

I look forward to this interdisciplinary project in which we apply RS/GIS tools to Forest Service studies.

Sincerely,

Robert R. Gillies, Ph.D.
Assistant Professor