**Special Technology Development Proposal**

**PROJECT STATUS:** New, not previously funded.

**PROJECT NUMBER:** R1-2000-03

**PROJECT TITLE:** Improved risk rating, detection, and impact assessment of balsam woolly adelgid and hemlock woolly adelgid.

**SUBJECT:** Improving detection technology, quantifying the impact on stand structure, remote sensing, *Adelges piceae, Adelges tsugae.*

**PROJECT OBJECTIVES:**
The overall objective of the proposed project is to develop the use of remotely sensed data to improve the detection and monitoring of balsam woolly adelgid and hemlock woolly adelgid infestations. Preliminary risk rating of stands and impact assessments will also be conducted for balsam woolly adelgid in stands of subalpine fir. The four specific objectives of the project are to:

1. Develop the use of hyperspectral and multispectral remote sensing data for detection and delineation of subalpine fir decline and the presence of balsam woolly adelgid in affected stands.
2. Develop GIS-based technologies for the combination of remote sensing and other data types for a preliminary risk rating of stands of subalpine fir for infestation by balsam woolly adelgid.
3. Determine the impact of balsam woolly adelgid on stand structure and regeneration of subalpine fir.
4. Develop the use of hyperspectral and multispectral data for detection and delineation of hemlock woolly adelgid infestations affecting eastern and Carolina hemlock in the eastern United States.

**BRIEF DESCRIPTION OF PROJECT:**
Balsam woolly adelgid (BWA), *Adelges piceae*, is an introduced forest pest of true firs. It is widely established in North America, but is only recently expanding its range into the interior west. Currently, visible and color near-infrared aerial detection surveys are among the primary techniques used to detect and delineate insect infestations within forests. However, BWA damage is often not visible using this technology, even when infestations are in advanced stages. In addition, another introduced adelgid, the hemlock woolly adelgid (HWA), *Adelges tsugae,* is currently causing significant mortality to native hemlocks in the eastern United States. The proposed project will develop methodologies that will allow forest managers to take advantage of two important developments in remote sensing: a) the decreasing cost and greater availability of multispectral data from Landsat 7 and NASA/Earth Observing System (EOS) sensors and b) the ability to obtain low-cost high-resolution imagery in selected narrow bands with digital cameras and digital video systems. Both of these advances in remote sensing technology will be used in developing schemes for early detection and monitoring of BWA and HWA infestations as well as the impact of BWA on stand structure. The monitoring system we seek to develop has two important stages. First, multispectral data sets will be combined with

existing information in a GIS to generate risk maps for large areas. Then, the areas identified as high-risk can be targeted for more detail monitoring with narrow-band remote sensing areal surveys. The methodology for these surveys will be developed using ground and aircraft measurements over controlled plots with various stress factors, and refined and tested under typical conditions for aerial surveys. This technology may allow forest managers to discriminate between various agents that can be involved in fir decline (such as BWA, root rots and western balsam bark beetle), as well as distinguishing between those agents and other plant stresses such as moisture stress. Following the determination and delineation of BWA infestations, ground measurements will be used to examine the impact of BWA on fir regeneration within the infested stands.

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**JUSTIFICATION:**

Balsam woolly adelgid and hemlock woolly adelgid are non-native forest pests that were introduced into the United States and are causing significant mortality to native tree species. BWA has become widely established, but until recently, it was not present in the interior west. The insect is a pest of true firs and is capable of killing a high percentage (up to 90%) of the subalpine fir present within infested stands. Infested trees that survive attack may experience gouting and/or crown dieback. In eastern North America, the understory of infested stands is typically not affected and regeneration is usually plentiful. However, some reports from the interior west suggest that the insect may be negatively impacting fir regeneration on some sites. Subalpine fir is one of the major tree species occurring at high elevation in the interior west

(along with whitebark pine, which itself is being decimated by an introduced pathogen). Therefore, the diversity within these high elevation forests may be severely depleted.

Hemlock woolly adelgid is a relatively new invader of eastern forests. It is capable of decimating stands of native hemlock and while these stands have little commercial value, they have considerable value for their biodiversity and wildlife habitat properties. Unlike BWA, HWA is more likely to infest tree crowns, but the results in terms of tree mortality can be just as significant. Hemlocks infested with HWA typically have a dramatically reduced production of new foliage. Early detection and monitoring of HWA infestations may allow treatment alternatives to be considered.

Current aerial surveys are inadequate for detecting early stages of BWA infestations. Advances in remote sensing technology (such as the occassional availability of hyperspectral imagery, the availability of low-cost digital camera and video systems for acquiring data in selected narrow bands), as well the greater availability and lower cost of imagery from Landsat-class sensors, all provide new opportunities for the development of techniques for risk assessment, early detection, delineation and impact assessment. Once developed and tested, these techniques are suitable for operational environments and should improve the ability to both rate the risk of stands to infestation and to detect BWA and HWA infestations at earlier stages of development. This technology may also allow discrimination of potential agents responsible for the fir decline (i.e. BWA versus root rots) and the discrimination between these agents and moisture stress.

**URGENCY:**

Both BWA and HWA are currently expanding their ranges in the interior west and eastern United States, respectively. With BWA in the interior west, the areas being affected (especially at high elevation) may experience a severe loss of biological diversity because subalpine fir is one of the few tree species capable of growing at these elevations. The impact on biodiversity is further compounded because one of the other major tree species found at high elevation in the region is whitebark pine, which itself is being severely depleted by an introduced pathogen. If the regeneration of fir is also being negatively impacted by BWA, it may take decades for trees to reestablish at the higher elevations (if they reestablish at all). Also, while subalpine fir is being severely impacted, other fir species (that are of more commercial value) such as grand fir can also be attacked by the insect and experience the same type of damage (gouting, crown dieback and mortality). A similar scenario is occurring with HWA in the eastern states in that the insect is causing significant mortality to native hemlocks (eastern and Carolina hemlocks) wherever it is found. Like subalpine fir, hemlock has little commercial value, but it is an important component of the eastern forest for its biological diversity and wildlife habitat properties. If eliminated, these hemlock stands may never regenerate.

**LINK TO NATIONAL FHP TECHNOLOGY DEVELOPMENT PRIORITIES:**

The proposed project fits into 2 of the 4 priorities. The project would:

- Develop techniques to quantify the impact of insects and diseases as disturbance agents in forest ecosystems.
- Develop or improve detection, analysis and management of non-native invasive insects, pathogens and plants.

**SCOPE OF APPLICATIONS:**
Balsam woolly adelgid is currently present or a threat to true firs in at least 3 Forest Service regions in the west (1,4 and 6). In addition to subalpine fir, other true firs in the region such as grand fir, silver fir and white fir are also attacked and experience damage ranging from growth loss to mortality. The insect is well established in the eastern United States on both Fraser fir and balsam fir and while the detection and risk rating components of this project would be of little benefit, the impact assessment portion should be readily transferable to the east. After modification, the developed technology should also be readily transferable to systems affected by the hemlock woolly adelgid. The risk rating and impact assessment portions of the BWA work could also be developed for HWA. Further, the potential to discriminate between potential reasons for decline (i.e. insect versus root rot) will be investigated. In addition, development of this type of data for infestation detection should be useful in analyses of other non-foliage feeding insects such as bark beetles and scale insects. All three aspects of the proposed project (risk rating, improved detection and impact assessment) should remain useful tools for forest managers for the foreseeable future. The operational system we envision would involve the use of low-cost, widely available satellite data for creating risk assessment maps for large areas. This would allow forest managers to prioritize areas to be targeted for aerial surveys with narrow band instruments (the procedure for which will also be developed and tested in this work) or for more intense ground measurements.

**RESEARCH BASIS:**

BWA was first introduced to eastern North America about 1908 (Balch 1952) and a separate introduction occurred in the Pacific northwest (Mitchell 1966). There are no males in the North American population of BWA and reproduction occurs parthenogenetically, with as many as 248 eggs per female being produced. Therefore, in theory, a single female could result in an infestation forming. The only dispersal stage of BWA is the first instar larva, or crawler. After the crawler settles and begins to feed, the insect is permanently attached to the host at this feeding site (Atkins & Hall 1969).

HWA was introduced to eastern North America about 35 years ago. Hemlocks infested with HWA produce almost no new foliage, the preferred food for the insect, and this results in adelgids dispersing from the affected tree (McClure 1991). Tree mortality often occurs following the second such episode which typically occurs during year 3 of an infestation. Wind, birds, deer and humans all contribute to the dispersal of the insect (McClure 1990). HWA eggs and crawlers appear to be adapted for short-term survival off the host and survived in the laboratory for up to 2 weeks without food (McClure 1990).

BWA is capable of infesting all of the true firs found in the western United States, but subalpine fir (*Abies lasiocarpa*) is the most susceptible species. On subalpine fir, BWA infestations typically start high on the tree bole and move down. However, the insect can infest a tree in many locations. Crown infestations are characterized by drooping of the current shoots and gouting of the outer twigs. The crown thins and dieback may occur, resulting in a flat-topped appearance (Amman & Talerico 1967). Stem attacks are readily identified by the woolly, white masses that are produced by and cover the insect. In contrast, hemlock woolly adelgid is a crown-feeding insect. Both eastern hemlock and Carolina hemlock are very susceptible to the

insect. Feeding by HWA typically results in severe reductions in new foliar growth and tree mortality can occur following the second feeding episode which usually occurs during the third year of an infestation (McClure 1991).

BWA typically attacks older, mature trees and mortality usually begins at lower elevations and spreads toward the summit (Johnson et al. 1963, Amman 1970, Witter & Ragenovitch 1986). Damage is usually more severe on dry, well-drained sites (Page 1975) that are also conducive to the development of moisture stress. Heavily damaged trees may have their seed and cone production impacted (Schooley 1975,1976). However, the understory, or regeneration, fir is typically plentiful (Witter & Ragenovitch 1986). HWA does not discriminate against young hemlocks and their foliage is readily infested. *Armellaria* root rot may be associated with adelgid infestation (Hudak & Singh 1970, Hudak & Wells 1974). A useful tool for forest managers would be the ability to determine if trees are infected with root rot or adelgids using remotely sensed data.

Live trees can recover from BWA infestation, especially a crown infestation (Schooley & Bryant 1978). However, stem-feeding by BWA produces a response in susceptible hosts that resembles the formation of premature heartwood (Busby 1964, Doerksen & Mitchell 1965, Mitchell 1967, Puritch & Petty 1971, Smith 1967). Water flow in the sapwood of infested trees is reduced almost to that of heartwood (Mitchell 1967, Puritch 1971). The impact on fluid movement results in reduced photosynthesis and respiration (Puritch 1973). As well as contributing to tree mortality, these attributes of infested trees should result in changes in the spectral signature of the tree's foliage that would be detectable using hyperspectral instrumentation. In contrast, HWA is a crown-infesting insect. Typically, there is a severe reduction in new foliage during the infestation of a tree. The absence of new foliage should create a unique spectral signature from the foliage that is detectable during the second year of the infestation when uninfested trees are producing new foliage.

Current methodologies for risk assessment in balsam fir use site and stand characteristics to develop a hazard risk rating. We propose to derive from multispectral remote sensing data several stand characteristics which affect the vulnerability of an area for infestation (for example, stand density). These characteristics will be combined with other data in the framework of a GIS to produce maps of risk rating for BWA infestation. This will be a preliminary risk rating system, taking advantage of the opportunity to collect data at the same time that the remote sensing data is obtained. Additional plot work and analysis to refine the risk rating would be needed in the future as part of a separate project proposal in the future. Several researchers have demonstrated success as well as limitations in deriving forest stand parameters from remotely sensed data (for example, Cohen and Spies 1992; Danson 1987; DeWulf et al.1990; Franklin 1986). Several of these studies have demonstrated that there is a threshold above which reflectance is no longer very sensitive to basal area. Some of the most succesful schemes for deriving stand characteristics involve the use of both multispectral and higher spatial resolution panchromatic data. The addition of the 15m resolution panchromatic band on Landsat 7 Enhanced Thematic Mapper (ETM) will allow this type of analysis at much lower cost than was previously possible.

There is much evidence from the work of a number of researchers that stressed forest vegetation exhibits spectral changes that can be detected with hyperspectral remote sensing data (for example, Rock et al. 1986; Rock et al. 1988; Guyot et al. 1989; Kleman 1986; Vogelman et al. 1993; Koch et al. 1990; Ruth et al. 1991; Carter 1993; Cibula and Carter 1992; Hoque and Hutzler 1992). One of the major challenges in using hyperspectral data to detect forest plant stress is separating the effects of different types of stress, such as root rot, insect infestation, or moisture stress (Koch et al.1990). For the case of infestation by defoliating insects, the spectral changes occurring because of defoliation can be subtle compared to the spectral changes due to changes in stand characteristics and to terrain variations (Ekstrand 1994; Koch et al. 1990). However, for the case of BWA in sub-alpine fir, there are a number of factors which favor the development of successful procedures for detecting and delineating infestations: 1) At the elevations for which infestations are most likely, species diversity is very low (in the areas to be studied in the interior west, there are only two main species which occur); 2) BWA is non-defoliating insect, so the impacts of soil background and understory will not be changing as infestation occurs. By working with plots known to be experiencing various types of plant stress, we hope to separate the spectral changes associated with BWA infestations at the canopy and foliar level. We will seek to minimize the effects of stand and site characteristics as much as possible through band ratioing techniques and, possibly, through change detection techniques using multi-temporal images from the same sites. Recent advances in GPS-based aircraft positioning and the low cost of data storage devices makes change detection techniques more feasible for operational settings. It has been demonstrated that narrow band remotely sensed data acquired in selected bands with digital cameras and video systems can be useful to detection of plant stress (Carter and Miller 1994; Everitt et al. 1997),

**METHODS:**

During Year 1, the focus will be on: 1)the development and validation of the GIS-based risk assessment methodology for BWA using a combination of remotely sensed and other data types; 2) ground and foliar-based spectral characterization of trees with varying degrees of BWA infestation and other stresses and 3) identification of narrow bands which contain the most information about infestation.

To accomplish this, ground measurements will be made on known infestations of BWA located in northern Idaho. Transects will be set up to run through the infestations from lower elevations toward the summit. Ground measurements to be acquired include information on stand characteristics and on individual trees. The stand measurements will include habitat type, stand composition including percentage of fir in the stand and soil moisture regime. The measurements of individual trees will include physical parameters such as height, dbh, crown class rating. Each tree will be examined for infestation location and infestation characteristics. Measurements of BWA density on the stem and crown will be taken. Root samples will be taken to determine the presence/absence of root rot in the trees. Nearby, uninfested stands will also be examined and similar measurements taken.

In conjunction with these ground measurements, spectroradiometer measurements (400-2500 nm) of various tree components (needles, stems, bark, etc) will be acquired. Through the Upper Midwest Aerospace Consortium, University of Idaho team members have been eligible to

request that aircraft-based hyperspectral data be acquired with the NASA AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) instrument once per year in this region. A request will be made to acquire image data over portions of this transect. If successfully acquired, these data will be used to help select the narrow bands that would be most useful in detecting and delineating infested areas in digital camera or digital video aerial surveys. If AVIRIS data are not successfully acquired, we will investigate the possibililty of obtaining foliar level spectral measurements in helicopter surveys.

A hazard risk rating scheme will be developed using the balsam fir stand rating system as a guide. The balsam fir rating system uses elevation, soil moisture regime, percentage fir in the stand basal area and stand age at breast height as the primary variables. Three elevation classes are used. Within an elevation class, the other variables are used to rate individual stands for infestation and potential damage. We will derive and validate stand characteristics for the study area using multispectral remote sensing data. Maps for other risk factors will be generated by interpolating commonly available point-based meaurements. The remotely sensed data and ground data will be integrated within a GIS, which will be used for the risk rating mapping. The accuracy of the maps will be assessed using ground data.

Impacts on stand structure by BWA will also be evaluated by using both remotely sensed data and on site measurements such as habitat type and FHM visual crown rating indicators (as well as other variables). These data will be correlated with fir regeneration within the affected stands.

During Year 2, the emphasis will be on field testing the detection of BWA infestations using narrow band filters in combination with an aircraft mounted digital camera or digitial video system. The Potlach Corporation is beginning to investigate the use of these types of techniques for detection of bark beetle infestations in northen Idaho. Both to minimize costs and to stay focused on the development of an operationally-feasible system, we will as much as possible coordinate our data acquisition with theirs, and with other surveys done by state and federal agencies.

During year 3, we will extend the work done on BWA detection and delineation in the west to HWA in the eastern U.S. Site selection and assessment will be coordinated with Rusty Rhea of the FHP office in Asheville, North Carolina and Fred Hain at North Carolina State University.

**MEASURE OF SUCCESS:**
Our workplan includes the acquisition of ground data regarding aldelgid infestations. These data will be used to assess the accuracy of the risk assessment maps, and the degree of success in detection and delineation of infestations with narrow band remotely sensed data.

**PRODUCTS:**
The proposed project would produce :

- Spectral characterization of fir foliage impacted by several potential agents involved in subalpine fir decline, but concentrating on BWA.
- Spectral characterization of hemlock foliage infested with HWA.
- Impact assessment of BWA on stand structure and regeneration.

- Two theses projects – one each in the Departments of Geography and Forestry Resources/entomology.
- A preliminary hazard risk rating scheme for BWA infestation of subalpine fir stands in the interior west.

**PUBLICATIONS:**
Anticipated publications in mainstream referred journals such as *Environmental Entomology* for entomology, *Forest Science* for forestry and *Remote Sensing of Environment* for remote sensing. Publications will be geared to the main audiences for the respective journals. Results will also be presented at regional forest entomology conferences such as the annual Western Forest Insect Work Conference as will as national society meetings.

**TECHNOLOGY TRANSFER:**
The goal of this work is to develop techniques that can be applied on an operational basis by FHP personnel and/or district foresters. If the techniques described above prove useful, workshops will be held at the regional Forest Insect Work Conferences or other venues to familiarize Forest Service personnel with these techniques. Additionally, we will work closely with RSAC and FHTET personnel (Jim Ellenwood) to help make these techniques widely accessible and well understood, including assistance with the development of training materials.

**PROJECT DURATION:**
Three years.

**LONG TERM BUDGET:**
The amount requested from FHP for FY2000 is $49,704. During the second and third years of the proposed project the funding requested from FHP will also be approximately $50,000 per year. The contribution from the University of Idaho includes the spectroradiometer that will be used throughout the three year duration of the project (valued at $40,000), the hardware and software for conducting the image analysis (approximate value of $10,000) and the deferred overhead (31.5% of $49,704 is $15,657). Potlatch Corporation will be sharing imagery, but their major concern is not with BWA and their exact contribution to the project is still being negotiated. Other sources of funding are also being pursued by the principal investigators.

**FY2000 BUDGET REQUEST:**

| | FHP |
|---|---|
| Salaries | $36,222 |
| Fringe | $ 3,382 |
| Travel (domestic) | $ 6,500 |
| Supplies, general | $ 2,000 |
| 4 Landsat images | $ 1,600 |
| hardware/software | $ 0 |
| Equipment | $ 0 |
| | |
| TOTAL FY2000 | $49,704 |

PRODUCTION FUNCTION

Background Data:

- Ski areas are located in high elevation sites where whitebark pine, subalpine fir and Engelmann spruce are the primary species that occur.
- In the Northern Rockies whitebark pine has been severely reduced as a result of white pine blister rust. BWA could have a similar effect on subalpine fir
- Esthetics and recreation values are reduced
- The value of a RVD is $55.00 according to RPA figures for winter recreation (this figure is conservative since downhill skiing is a high-end cost compared to sledding, skating. X-country skiing, etc)
- Other values related to wildlife habitat, water yield are affected by the loss of subalpine fir, especially when looked at with the existing loss of whitebark pine. Some of these sites don't support Engelmann spruce, therefore forest conditions are radically altered.

Assumptions:

- The value of an RVD is reduced by 1% and 5% as a result of dead and diseased trees. The two values are shown to demonstrate the relative magnitutde. I don't have any citable data to indicate how much it would be affected. I think the 1% estimate is fairly conservative.
- With early detection and monitoring of spread, treatments can be applied before they reach a ski area to protect the values.
- The calculations below are conservative because they only reflect two ski areas there are others that will be affected over time and the effect will be longer than 5 years.

Calculations:

ECONOMIC ANALYSIS FOR 1% REDUCTION IN VISITOR USE

| | |
|---|---|
| LOOKOUT SKI AREA | 22,400 |
| SILVER MOUNTAIN SKI AREA | 120,000 |
| DISCOUNT RATE | 0.04 |
| RPA VALUE/RVD-WINTER SPORTS | $55.18 |
| SKIER DAYS/RVD FROM RPA | 2.4 |
| PERCENTAGE REDUCTION IN SKIER USE | **1%** |

| YEAR | COST | P.V. | LOST SKIER DAYS | RVDs | VALUE | P.V. |
|---|---|---|---|---|---|---|
| 1 | 50000 | $48,076.92 | | | | |
| 2 | 50000 | $46,227.81 | | | | |
| 3 | 50000 | $44,449.82 | | | | |
| 4 | | | | | | |
| 5 | | | 1424 | 593 | $32,740 | $26,910 |
| 6 | | | 1424 | 593 | $32,740 | $25,875 |
| 7 | | | 1424 | 593 | $32,740 | $24,880 |
| 8 | | | 1424 | 593 | $32,740 | $23,923 |
| 9 | | | 1424 | 593 | $32,740 | $23,003 |

| | | | | | |
|---|---|---|---|---|---|
| 10 | 1424 | 593 | $32,740 | $22,118 | |

TOTAL P.V. COST $138,754.55 TOTAL P.V. LOST VALUE $146,709

**PROJECT TOTAL PRESENT NET VALUE** **$7,954.00**

**PROJECT BENEFIT/COST RATIO** **$1.06**

**PNV of PROJECT = PNV of STDP**

ECONOMIC ANALYSIS FOR BALSAM WOOLY ADELGID - WITH 5% REDUCTION IN SKIER USE

| | |
|---|---|
| LOOKOUT SKI AREA | 22,400 |
| SILVER MOUNTAIN SKI AREA | 120,000 |
| DISCOUNT RATE | 0.04 |
| RPA VALUE/RVD-WINTER SPORTS | $55.18 |
| SKIER DAYS/RVD FROM RPA | 2.4 |
| PERCENTAGE REDUCTION IN SKIER USE | **5%** |

| YEAR | COST | P.V. | LOST SKIER DAYS | RVDs | VALUE | P.V. |
|---|---|---|---|---|---|---|
| 1 | 50000 | $48,076.92 | | | | |
| 2 | 50000 | $46,227.81 | | | | |
| 3 | 50000 | $44,449.82 | | | | |
| 4 | | | | | | |
| 5 | | | 7120 | 2967 | $163,701 | $134,550 |
| 6 | | | 7120 | 2967 | $163,701 | $129,375 |
| 7 | | | 7120 | 2967 | $163,701 | $124,399 |
| 8 | | | 7120 | 2967 | $163,701 | $119,614 |
| 9 | | | 7120 | 2967 | $163,701 | $115,014 |
| 10 | | | 7120 | 2967 | $163,701 | $110,590 |

TOTAL P.V. COST $138,754.55 TOTAL P.V. LOST VALUE $733,543

**PROJECT TOTAL PRESENT NET VALUE** **$594,788**

**PROJECT BENEFIT/COST RATIO** **$5.29**

**PNV of PROJECT = PNV of STDP**

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