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Pheromone Placement Tracer Test

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Contents

Introduction	1
Statement of Dispersion Problem	2
Project Staffing and Responsibilities	3
Site Description	3
Tracer Program	4
Tracer Array	4
Tracer Release	4
Sample Assay	6
Quality Assurance and Quality Control	6
Meteorological and Turbulence Measurements	6
Canopy Inventory	7
Schedule and Data Targets	7
Data Reporting	7
Appendix A—Site Climatology	8
Appendix B—Safety Plan	9

Introduction

The primary objective of this project is to provide pest managers with information on the effective volume of pheromone flakes applied to forest canopies. The outcome of the field trial will be a dispersion data set that can be used to train pheromone users and evaluate current pheromone application strategies based on dispersion in the canopy and also to validate existing incanopy dispersion models so that a broader range of canopy types can be investigated through simulation.

This is the second year of the pheromone tracer program. In June of 1998, a similar experiment was conducted to measure the dispersion environment in the trunk space of ponderosa pine. The work focused on dispersion from bubble caps that are placed in the trunk space and elute pheromone over weeks to months. The target insect was the pine beetle. Data from this work are currently being analyzed. The study in 1999 will

be conducted in an oak/hickory forest in Virginia. The target insect is the European Gypsy Moth, and pheromone application is usually performed by aerial application of small flakes. The primary difference between this study and the 1998 study is that the dispersion characteristics of a deeper layer of the canopy are of interest. This will require more measurements to be performed at height. 

Statement of Dispersion Problem

It is difficult to design a tracer experiment to investigate pheromone dispersion in the canopy without knowing the exact nature of the pheromone response mechanism of the insect. There is some evidence that response to a pheromone plume is a signal-to-noise ratio detection problem and that the insect follows a plume peak centerline concentration to its source. The female European Gypsy Moth does not fly. The female remains relatively stationary and elutes pheromone, thus acting as a stationary point source. This pheromone is a mating attractant and the male senses the pheromone and apparently follows the plume to the female. The male flight activity is mid-day but many of the canopies that the Gypsy Moth thrives in are closed. Thus, the pheromone plume is not necessarily in an unstable atmosphere, and may actually be in a stable dispersion environment due to canopy shading. The dispersion environment under the canopy will be explicitly measured in this experiment. In the case of a stable plume, the male might follow the plume centerline to the source by flying up-gradient. In some insects, the pheromone might only act as a proximity indicator. Sensing of the pheromone might be combined with an anemotactic response that allows the insect to track the pheromone upwind or with optical sensors that might use infrared wavelengths to sense an objective.

This discussion is guided by studies in the entomological and meteorological literature. These mechanisms will, in all likelihood, be specific to the insect and the pheromone being studied. However, the dispersion of any gaseous scalar quantity under this canopy can be treated generically (assuming chemical passivity) and is largely determined by the dispersion environment which, in turn, is determined by meteorology and canopy density and distribution.

The degree of coupling of the incanopy atmosphere and the 'free' atmosphere away from the canopy will depend on

canopy density and architecture as well as the state of the atmospheric surface layer (ASL). The stem space in a dense, closed canopy can be decoupled from the above-canopy planetary boundary layer (PBL) wind field with exchange between the canopy and the free atmosphere dominated by high-energy, low-frequency downward wind gusts or 'injection' events. The crown space converts mean flow kinetic energy from above the canopy into turbulent kinetic energy (TKE) within the canopy, and much kinetic energy is lost to drag due to canopy elements. Mean wind speeds below the crown space are lower than those above the canopy. In closed canopies, the crowns receive much more direct-beam solar radiation during daylight hours than the stem space and warm more quickly. Thus an inversion layer is likely to form in the stem space in closed canopies during the daytime that further suppresses momentum transfer and turbulence. Local slope-related flows within the stem space and "chimney effects" due to breaks in the canopy may combine with mean motion above the canopy to drive both transport and dispersion within the stem space. In more open canopies, the mean wind speeds are lower incanopy due to a bulk drag effect of the canopy. However, in these canopies, a large amount of sunlight reaches the forest floor and the atmosphere is closely coupled with the free atmosphere because trees may act as individual obstacles to higher energy flows (higher mean wind speeds) causing large horizontal variability in the flow field. Forest canopies range in density from thick tropical jungle canopies, which are completely closed, to widely spaced trees in 'parklands,' typical of much of the high arid Western United States.

In some circumstances during thermally neutral conditions when the wind speeds above the canopy are greater than 5 to 10 m/s, plumes below the canopy follow the mean ASL wind direction. During stably stratified conditions, however, the plume direction in the canopy can be

offset on the order of 45 degrees counterclockwise from the mean wind direction above the canopy. These numbers are specific to the canopy being studied, but they point out that there is a threshold wind event when the air above the canopy mixes with the incanopy air. The mean flow direction incanopy can substantially deviate from the mean flow direction in the free atmosphere.


The degree of coupling will correlate with the temperature structure of the surface layer or the 'stability' of the layer. In stable conditions, cold air is under warm air and vertical turbulence is damped. In these conditions, the stem space may be effectively decoupled from the above-canopy atmosphere. A scalar quantity, such as a pheromone, released under the canopy would tend to stay under the canopy. The pheromone plume would remain concentrated due to the low mixing environment. In the case of an unstable environment, warm air is under cold air. Since the warm air is lighter, it rises through the cold air and mixes the unstable layer. In an unstable atmosphere, pheromone would tend to rise and mix and might leave the target area where the insects are active. The canopy complicates this relationship, because the stability will change with height in the canopy. Often, the upper leaf surfaces intercept the solar radiation. The shaded stem space will remain stable but an unstable layer will develop at the canopy top.

The combination of canopy structure and stability regime will determine the optimum coverage density of the aerially applied pheromone flakes, assuming the entomological parameters and pheromone elution rate are known. The approach used in this study is to know the canopy structure and micrometeorology in detail and measure the gaseous dispersion field. Eventually, a sophisticated atmospheric boundary-layer model will be used to extrapolate the results to other canopies. ☺

Project Staffing and Responsibilities

Harold Thistle, USDA Forest Service, Forest Health Technology Enterprise Team, will be the overall program manager and test director for this project. He will have overall responsibility for scheduling and management of this field measurement program. Mike Huey from the Misoula Technology and Development Center (MTDC) will be onsite providing technical support, and Mark Wiggins (MTDC) will be onsite providing


photographic support. Richard Reardon, USDA Forest Service Forest Health Technology Enterprise Team (FHTET), will provide entomological guidance. **Indaco Air Quality Services, Inc.**, and **their cooperators** will supply the syringe samplers, near-site sample analysis using gas chromatography, and onsite analysis using a real-time SF₆ analyzer. Indaco and their cooperators are an integral part of the study team and their

expertise will be utilized in the experimental design and reporting phases of this work as well. Dave Quilici, University of Nevada-Reno, will perform a Quality Assurance/Quality Control audit, and Pat Skyler, Pacific Southwest Region FHP, will act as data-quality manager. William Massman, USDA Forest Service Rocky Mountain Research Station, will provide modeling support after the data collection. 

Site Description

The site location will be in the Appalachian highlands west of Staunton, VA. This is primarily oak/hickory forest. The site will have a relatively closed canopy with canopy height of

about 70 feet. A relatively open canopy understory is preferred because the human activity associated with the study will trample near-ground vegetation, and could substantially modify air

movement through a thick understory. Generally, this area is comprised of ridges and valleys with elevations ranging from 350 m to over 1400 m at the highest peaks. 

Tracer Program

Tracer Array

There is evidence that plumes for near-instantaneous releases within a Douglas-fir canopy generally range in width from about 30 degrees to over 120 degrees. It appears advisable to instrument sampling arrays covering at least 180 degrees to capture the plume. It is still likely that at least one plume edge may be off the array in any given time period. However, it is also likely that the plume centerline and maximum concentration will be on the measurement array most of the time. In the 1998 field tests, a sufficient number of samplers was available to instrument at least 270 degrees during most of the field tests. The decision as to which portion of the array to decorate for each test will be based on wind-direction forecasts for the period of the tracer test and field observations. A theatrical smoke machine is available to help determine the plume direction and plume spread.

A set of three concentric circles that are centered on the emission point will be marked for sampler deployment (Figure 1). The circles will have 5-, 10-, and 30-m radii. Sampling locations will be evenly spaced on each circle. The 5-m-radius circle will have 12 possible sampling locations, one each 30 degrees. The 10- and 30-m-radius circles will have 24 possible sampling locations each, one each 15 degrees. Each sampling location will be identified with a circle radius and an azimuth angle. Elevated sampling will be conducted to determine the vertical dispersion coefficient as well as the vertical scalar flux in the canopy. Sampling stations will be deployed at 8 m every 30 degrees on the 30-m arc. These will be positioned above sampling stations at 1.5-m height. The 25-m tower will have sampling stations at 1.5-, 8-, 12.5-, and 25-m heights. The 25-m tower is stationary and will be hung with samplers regardless of wind direction. Each arc will have poles at 0 degrees and 180 degrees.

The pole closest to plume centerline will be hung with samplers at 1.5- and 5-m height. The density of the array may be increased by performing measurements with the real-time SF₆ monitor, as described under *Sample Assay* below.

Table 1 indicates the number of samplers that can be hung during a given trial, based on 50 samplers total. They will be programmed to start simultaneously at all sampling locations. The sampling period will be set for 30 minutes per sample. Because the samplers contain nine sampling stations, this means that each test period will be 4 hours and 30 minutes long. Background concentrations of SF₆ could be above detectable levels, so background concentration levels will be monitored.

Each test will be identified with a separate test identifier letter, and each sampler will be identified with a sampler number. Individual sample syringes will be pre-labeled with a test identifier letter, a sampler number, and a sequential syringe station number (one through nine). A test-deployment log will be recorded with the sampler number and the location identifier as the samplers are deployed. As the samplers are collected, the deployment log will be double checked to ensure there are no errors regarding the recorded sampler locations for each test.

Tracer Release

The real-time analyzer that we plan to use during the tests, and for sample assay, has a detection range of 10 ppt to 10 ppb (6.07 X 10⁻⁷ g/m³). The lower end of the reliable quantification range is probably on the order of 50 ppt (3.04 X 10⁻⁵ g/m³). To stay below the 10-ppb limit at the plume centerline on the 5-m radius circle, the maximum SF₆ emission rate should be in the range of 1 X 10⁻⁴ g/s (Briggs *Small Sources*) to 2 X 10⁻⁶ g/s (SCREEN3 model). Splitting the difference between the two approaches, a nominal emission rate of 5.0 X 10⁻⁵ g/s will be used initially. This emission rate can be adjusted in the field as results become available.

The emission supply cylinder will be equipped with a mechanical flow controller to ensure that the tracer gas is emitted at a constant rate. The flow controller will be adjusted using a primary-flow standard traceable to the National Institute for Standards and Technology, and will be checked following each test. A heat exchanger will be put downstream of the cylinder exit nozzle to eliminate plume slumping due to expansional cooling.

Table 1—Number of samplers that can be hung in a trial, based on 50 samplers total.

Sampler Mounts	Samplers	Height (meters)	Array Position
4	4	1.5,8.0,12.5,25.0	25-m tower, 30-m arc
12	8	1.5	5-m arc
2	1	3.0	5-m arc
24	14	1.5	10-m arc
2	1	3.0	10-m arc
24	14	1.5	30-m arc
11	7	8.0	30-m arc

**Please open 'Figure1.pdf' to view Figure 1.
(11x17-inch format)**

Sample Assay

Sample assaying will be conducted using a continuous, real-time SF₆ analyzer capable of providing concentrations from 10 to 10,000 ppt. This instrument is transportable (weight is 40 lb for the analyzer and 45 lb for the auxiliary battery pack). It will be used to collect real-time (lag time, about 1 to 2 seconds) concentration data during the field tests. A gas chromatograph will be used to analyze the syringe data.

The analyzer will be calibrated with three audit standards before and after each test series is analyzed. Once per hour during the analysis, the analyzer will be challenged using a known high-concentration sample (span gas). If the span gas concentration differs more than 10 percent from the nominal concentration, the analyzer will be recalibrated using all three standards, and the samples analyzed since the previous span check will be reanalyzed.

The concentrations will be entered into a spreadsheet program that will be used to record the sampler number, syringe number, and concentration. All sample syringes will be held for reanalysis until the test director has reviewed the test results and release the samples. ☞

Quality Assurance and Quality Control

An independent auditor will review this experiment and make recommendations directly to the project manager. Operating and calibration procedures to ensure quality and accuracy for the analytical sample-analysis system will be designed and conducted by Indaco AQS, Inc. Field procedures will include:

- 1—Hanging calibration gases in the array and processing them blind in the sample analysis stream.
- 2—Reshooting four of the highest 10 samples from the previous day's data stream at the outset of each analysis session.
- 3—Reshooting four zeroes or low samples from the previous day.

- 4—Analyzing offsite (background) syringes.
- 5—Reshooting spatial outliers recognized in preliminary data analysis.
- 6—All meteorological systems will be bench tested before field deployment and calibrated as necessary. ☞

Meteorological and Turbulence Measurements

The meteorological data collection has two objectives:

- 1—To identify the dispersion environment the pheromone is released into, so that guidance can be given to pest managers on pheromone placement and coverage.
- 2—To collect the necessary data for detailed modeling to extend this work into other canopies through simulation.

Meteorological data collection consists of two parts:

- 1—Three 7-m towers that will collect mean meteorological data, both under and outside the canopy. The towers have two levels of temperature, humidity, wind speed and direction, and one net radiometer. These data will be processed to yield 1-minute averages.
- 2—Three three-axis sonic anemom-

eters that will be used to collect both mean and turbulence statistics. These instruments will provide both momentum and heat flux, as well as mean-wind vectors and turbulent covariance statistics. The sensors will be arrayed vertically on an 80-foot triangle tower and will be collocated with tracer gas samplers. These data will be collected at 20 Hz, though flux data will be reduced to 15-minute averages. ☞

Canopy Inventory

Canopy density will be measured on a regular grid pattern across the site. The method of measurement will

rely on a direct optical measurement and on processed hemispherical photography. Tree trunks in the instrument array

will be surveyed and mapped. Vertical profiling of canopy density will be attempted using the high tower. ☞

Schedule and Data Targets

The field program will be conducted during August 1999. The field crew will arrive onsite beginning on August 16 and will leave on or before September 5. A total field period of 20 days is anticipated. A period of 3 days is estimated for field setup of the meteorological and tracer field equipment, and 2 days for tear down, packing, and shipping, leaving 15 possible operational days.

To conduct a test, the tracer samplers must be charged (6 hours) and loaded with sample syringes (1 hour). The sampler array must be decorated with the samplers (2 hours). If a set of nine 30-minute-average samples are collected in each test, the test duration will be 4 hours and 30 minutes. It will take approximately 2 hours to retrieve the samplers and another hour to remove and cap the syringe samples. Not including charging time and transit time to the field site, each test will take about 10 hours to conduct. Sample assay and concentration data entry (at one sample

per minute) will require 7.5 hours after each test. Additional analysis time will be required for instrument calibration and periodic quality-control samples. Sampler charging will be done between tests. Preliminary data analysis will be done in the field to identify experimental problems. If a real-time analyzer is used both in the field for the tests and for sample assay, two 8- to 10-hour work shifts will be needed to conduct and analyze each test.

Data targets are established by using the total length of time available for the field experiment, the number of samplers available, and the historical data capture for this equipment. The maximum rate of emergence, and probably the maximum period of flight for gypsy moth males, is midafternoon. Because of the time required to conduct a test, one test per operational day will be planned. Night, early morning, and evening tests will be considered, based on logistics.

Tests will be run on a forecast basis to fulfill the data targets and avoid periods with precipitation. Precipitation periods will be avoided, both because insects do not fly during rainy periods, and because the field sampling equipment may become unreliable during the rainstorms.

Assuming 3 days will be used to stand down for weather or other operational reasons, 9 test days are planned as a target. Fifty samplers will be available, each with nine syringes. Planning on ninety-percent data recovery for the syringe samples, this will result in 3,645 valid 30-minute average syringe concentration samples (9 tests X 50 samplers X 9 syringes per sampler X 90-percent data recovery) to meet the data target, plus additional real-time sampling (if conducted), and "grab samples." ☞

Data Reporting

A spreadsheet will be developed that shows syringe sample code vs. SF₆ concentration. The syringe sample code will include the time and position of the syringe during the test. This information will be used to develop maps of concentration isopleths overlain on array diagrams (Figure 1). A stem map

will also be overlain. Meteorological data will be stored in datalogger format and processed for both mean information and model input.

A project data report will be published as a Forest Service report in calendar year 2000. The technical team is encour-

aged to publish results in the peer-review literature. Funding sources must be acknowledged when presenting or publishing this work, and the core technical team should be listed as coauthors on published work when practical. ☞

Appendix A—Site Climatology

NORMALS and MEANS

ROANOKE, VA (ROA)

LATITUDE: 37° 19' 01" N LONGITUDE: 79° 58' 27" W ELEVATION: GRND, 1149 BARO, 1193 | TIME ZONE: EASTERN (UTC -5) WBAN: 13741

| [Degree Days](#) | [Relative Humidity](#) | [Sunshine](#) | [Wind Information](#) | [Barometric Pressure](#) |

Average Degree Days

ELEMENT	Period of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Normal Heating Degree Days	30	646	776	564	289	105	5	0	0	39	282	525	828	4360
Normal Cooling Degree Days	30	0	0	0	7	78	200	329	298	120	20	0	0	1052

Average Relative Humidity

ELEMENT	Period of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Normal Relative Humidity (Percent)	30	61	60	58	57	66	69	71	73	74	68	64	64	65

Average Wind Data

ELEMENT	Period of Record	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Mean Wind Speed (MPH)	37	9.4	9.5	9.9	9.6	7.6	6.7	6.4	6.0	5.9	5.7	7.9	8.5	7.8
Prevailing Wind Direction (tens of degrees)	21	30	30	30	30	30	30	30	30	30	30	30	30	30

Average Barometric Pressure

Appendix B—Safety Plan

The safety plan will be distributed to all onsite personnel with the experimental design. Details will be presented at tailgate safety meetings in the field. Any problems or concerns that arise in the field will be addressed at that time.

Travel To and From Site

Travel to and from site will be performed in accordance with all local, state, and local Forest Service regulations. Traffic laws will be followed at all times.

Medical Emergencies

Directions to the nearest medical facility, and hospital and emergency-room phone numbers will be made available at a kickoff tailgate session onsite.

Fire Hazards

Standard precautions following Forest Service regulations will be followed while onsite. Firefighting tools will be onsite at all times. This project is not high risk for fire, but there will be electronic equipment, extension cords, and so forth, onsite that pose some risk.

Heat Stress and Dehydration

The weather at the test site can be hot and humid (Appendix A). The crew will be warned about dehydration and heat stress. Drinking water will be available onsite.

Elevated Instruments

Some instruments will be mounted from the ground using pulleys. The main meteorological instrument tower is made for climbing. Three certified climbers will be onsite. Only trained personnel are authorized to climb this tower. Climbing will be kept to a minimum and will always be performed on belay from the ground so the climber is never free climbing.

Overhead Hazards

This experiment is taking place under the canopy. Forest Service clothing requirements, including hardhat requirements, will be followed onsite at all times. All onsite personnel will be made aware of overhead work or suspended instruments at the site. ☺