TRIP REPORT for TCP/MON/ 2902

Emergency Measures for Control of Siberian Caterpillar and Other Major Forest Pests Mongolia 2003

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United States Department of Agriculture
Forest Service

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Training Courses, September 4 and 6, 2003

The first training course was held at the Ministry of Nature and Environment in Ulaanbaatar, Mongolia. The course focused on forest insect control, modern aerial application technology, backpack sprayer operation, the safe use and delivery of bio-pesticides, and environmental and human health risks associated with *Bacillus thuringiensis* var *kurstaki* (Btk).

The list of participants and their affiliation (if known) are listed below. Mr. Naranbaatar from the Khan Khentii Special Protected Area provided translation for the training session.

A second training session was held at Khan Khentii Protected Area for forest rangers and project techicians. This training session concentrated on backpack sprayer use and spray deposit assessment.

Agenda

The training program agenda was designed to cover the topics outlined in the consultant's Terms of Reference for project TCP/MON/2902. Topics covered in detail during the training session included:

- Treatment Equipment
  - Aircraft types and limitations
    - Airplanes
    - Helicopters
  - Spray Systems
    - Overview of spray system components
    - Atomizers; types and considerations (emphasis on Micronairs)
- Calibration of aircraft spray system
    - Aircraft
    - Backpack Sprayer
- Characterization of spray material
  - Card lines description and layout
    - Interpretation of card lines and determining what is effective swath width
- Process of Pesticide Application
  - Mixing
  - Atomization and consideration of droplet size
  - Transport - environmental considerations and their affect on deposit.
    - Drift and factors affecting deposition
- Meteorology
  - Equipment and its use.
  - Impacts of weather conditions on spray deposition
- Spray timing and phenology
  - Foliage expansion
  - Larval development
- Human Health and Environmental Risks for Btk

Training Sessions - Attendence List

Ulaanbaatar – Ministry of Nature and Environment September 4, 2003

Dulamjav Tumenkhuu	Director Khan Khentii Special Protection Area
Jambalragchaa Byambajav	Director Forest Research Center
Davaa Erdenebulgan	Officer, International Cooperation Department
Batsuuri Gerel	Officer Forest Research Center
Otgonbaatar Naranbaatar	Translator, Officer, Khan Khentii Special Protection Area
Chimeddorj Gambaatar	Officer, Khan Khentii Special Protection Area
Sanjaajamts Bilegsaikhan	Officer, Khan Khentii Special Protection Area
Adiya Nyam	Accountant
Isheekhuu Dorj	
Nyamjav Myagmarjav	
Damdinsuren Enkhsaikhan	
Nyamjav Munkhbat	
Mondoon Sakjiya	
Semjidsuren Ganbat	
Batmunkh Bayasgalan	
Damdin Baatarzorigt	
Damdinsuren Javkhlan	

Khan Khentii Special Protected Area September 6, 2003

Bagaa Altantuya	
Khurlee Buyankhishig	
Sednom gantumur	
Dondog Lochin	
Tseveendorj Ganbold	
Sandagderj Mart	
Khas-Odir Naranchimeg	
Terbish Myagnarsuren	
Purevdorj Narantuya	
Zoyo Oyunsuren	
Sedgerel Brtkhishig	
Tigmed Tsolmon	
Tserennadmid Tsetsegbat	
Batkhishig Ganzorig	Technician
Sandag Bat-Erdene	Technician
Rentsensambuu Munkhbayar	Technician
Baasansuren Oavkhlantugs	Technician

Project Background - TCP/MON/2902

Severe insect pest infestations in forests and urban trees are causing increasing concern both in terms of loss of valuable forest resources and also to the changing face of the urban landscape. Since 1980, 101.1 thousand hectares of forest have been damaged due to insects and diseases and the most economically valuable tree species such as pines and larch are decreasing year by year due to insect pests and diseases. The pine forests of Tuj, Range of Arangat (Selenge aimag) and Duurlig (Khentii aimag) have already been destroyed by insect damage and wildfire and these have now reverted to birch forest.

Forestry provides an essential role in soil protection, water catchment and for socioeconomic productivity. In 2000 it was estimated that the forest fund of Mongolia was 18.2 million-hectares covering 12.9 million hectares of area that occupies 8.2 percent of whole territory. FAO has evaluated Mongolia as one of the poor forest resource countries.

Pest outbreaks usually occur approximately every 10-12 years with increasing intensity but in recent years, the drought conditions have contributed to a reduction in time between cyclic outbreaks. Pest incidence is affected by climatic conditions compounded by wildfires, logging, and permafrost, which all weaken the trees and make them more susceptible to insect infestation. Main forest pests include: *Dendrolimus superans sibiricus, Orgya antiqua, Erannis jacobsoni, Zeiraphera griceana, Dasychira abietis, Dendroctonus micans, Ips subelongatus, Ips sexdentatus, Ips typographus, Tomicus minor, T. piniperda, Monochamus, Urocerus, Sirex spp.*

Recently, many forested areas of Khan Khentii Protected Area Administration (KhKhPA) such as Terelj National Park have been severely damaged by *Dendrolimus sibiricus,* (Siberian caterpillar). In Onon-Balj National Park in Khan Khentii Protected Area, the birth place of Genghis Khan, infestations of *Lymantria dispar* (gypsy moth) are causing severe damage and 30,000 hectares of pines are also infected with yellowing disease caused by *Lophodermium pinastri.*

Because of these infestations there is a reduction of forest quality and negative ecosystem changes are occurring. It is predicted that there will be an environmental catastrophe in Khan Khentii Protected Area, if this trend is not averted. There is increased concern about the impact of these pests in this cultural heritage area.

In total it is estimated that more than one million hectares of larch and to a lesser extent pines in Khan Khentii, Bogd Khan Protected Area and in the city zone areas, in more than 10 Aimags (Provinces) are affected by Siberian Caterpillar *Dendrolimus superans sibiricus*. In 2003 the forest area infested by pests in the northern forest areas in the areas of Selenge, Tuv, Khentii, Dornod, Arkhangai and Bulgan is rapidly increasing.

Surveys carried out in 2002 indicate that 30,000 hectares, mainly *Larix sibirica,* in KhKhPA are in immediate need of treatment to prevent critical losses and a further 12,600 hectares in the mountainous zone of Ulaanbaatar.

According to the forecast for the next decade, Mongolia will lose around 30 percent of (3.6 million hectares) forest fund if immediate action is not taken. The present situation is critical and urgent measures are needed to save the scarce forest resources.

Pest Information

Dendrolimus superans sibiricus is a destructive pest of conifers which is widespread on the Asian continent. This insect not only destroys the trees but also causes health problems to local

populations, particularly children, living close to the trees, due to allergic reactions. Many reports have been made about allergies in children living close to Ulaanbaatar where large infestations of these hairy caterpillars have entered their homes.

The life cycle of *Dendrolimus superans sibiricus* usually takes two years (see chart below). In southern parts of the natural range, however, one generation can develop in a single year, whereas, in northern regions, the completion of a generation can sometimes take three years. Drought, increasing population density, and other factors not well understood cause some of the larvae to have a shorter, 2 calendar-year life cycles. As a result, the adults of two generations emerge simultaneously and the population increases sharply. Competition for food may extend development time of the larvae and may also increase the number of instars.

Adult moths mating

The duration and effect of outbreaks also depends on the forest type. Outbreaks in fir and five-needled pines result in defined focal areas with very high densities of larvae that defoliate trees for 2 or 3 years in succession before the outbreak collapses. Tree mortality is nearly 100 percent in many stands. Outbreaks in larch forests are more prolonged but cause less tree mortality. Moths migrate from defoliated larch to new areas to lay eggs; hence, severe defoliation in successive years seldom occurs and the outbreak population becomes dispersed.

Eggs laid on larch foliage

Late instar larva

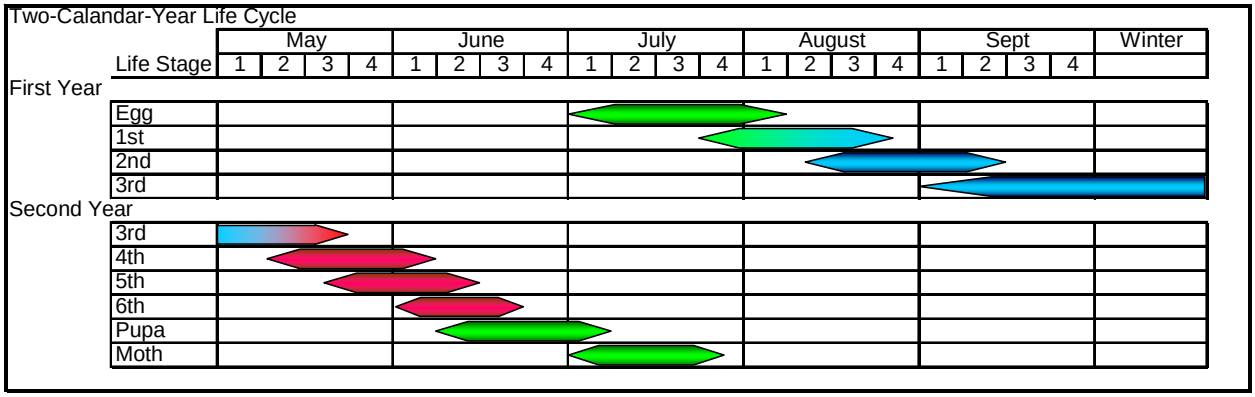


Chart showing typical two year life cycle of Dendorloimus sibericus. Green bars indicate life stages where biopesticides are not effective. Blue bars indicate where Btk is most effective, and red bars indicating where higher doses of Btk would be needed or an insect growth regulator, such as diflubenzuron would be effective.

The target insect for immediate control is *Dendrolimus superans sibiricus* but where *Lymantria dispar* also threatens important forest resources, this insect will also be targeted.

Current Conditions

Continuous attempts have been made by the Mongolian government to control the pest outbreaks but the vast areas, lack of trained personnel and facilities, financial constraints and poor equipment coupled with inadequate coordination and management, make this very difficult to implement. In 2001 the minimum estimated area needing treatment was 400,000 hectares but funds were only available to treat 10,000 hectares. Application technology in use relies on outdated, outmoded Russian spray equipment which urgently needs replacing to enable correct targeting of ultra low volume applications which are more cost effective and less environmentally damaging.

Currently, there is a critical expertise gap with insufficient qualified personnel working in Mongolia on forest health issues, and no nongovernment organizations or private companies to carry out pest management activities.

The basic problem that the current FAO project addresses is sufficient resources are not available to carry out an extensive spray operation and that existing facilities are outdated and inappropriate, coupled with the lack of personnel trained in aerial application techniques.

Larch Defoliation in Khan Khentii Special Protected Area.

Backpack Sprayer

In forested residential/urban areas, where trees tend to be widely spaced or in small groups, it is not practical to treat such stands using aircraft. Environmental conditions during spraying often make it difficult to control the deposit of the released spray cloud and effectively treat such open grown trees. To met this need, backpack sprayers equipped with Micronair AU8000 spray heads were acquired.

The backpack sprayer holds approximately 14 liters and produces droplet sizes that are equivalent to those produced by the aircraft's Micronair AU5000 atomizers. The small droplet size produced, estimated to be 100 µm in size, is best suited for coniferous foliage, but is still large enough to contain a toxic dose for early instar larvae (second and third instar).

Four backpack sprayers were calibrated with water using the smallest restrictor size (#1). Each unit yielded a different flow rate. Table 1 shows the average flow rate for each sprayer.

AU8000 Backpack sprayer with Khan Khentii Special Protected Area Director - D. Tumunkhuu

Table 1. Individual Backpack sprayer flow rates.

Backpack Sprayer	Water ml/min (Restrictor No. 1)
1	190
2	200
3	270
4	120
Average	195

Field trials were conducted to determine backpack sprayer lateral swath width, the vertical height the spray plume could reach, and droplet sizes produced. Card lines using water sensitive paper were placed parallel to the wind. The applicator sprayed two lines, one with the wind and one against the wind. Wind speed was approximately 2.5 m/s. This wind speed aided the down-wind deposit with approximately 8 meters receiving good coverage with greater than 20 drops/ cm^2. When spraying into the wind, the small droplets were limited in deposit to less than 4 meters. **When winds exceed 3 m/s, it is advisable to spray in only the downwind direction.**

A vertical card line was established along a rock wall, with spray cards spaced every meter along a string. The applicator stood approximately 6 meters from the base of the card line. Deposit was recorded at a height of 8 meters with light winds (1 m/s). This is viewed as the maximum vertical distance for the sprayer under favorable conditions. Vertical height will be reduced with wind.

To determine applicator speed, a 100 meter spray course was established in part field and part forest. The applicator walked at a slow speed, moving the AU8000 spray head both up and down, and

laterally from side to side to insure even coverage of the foliage. Water sensitive spray cards were hung in the trees to evaluate coverage and depth the spray could reach within a tree.

Results of the field spray indicated that a slow ground speed of approximately 3 kph provides good coverage. The distance reached by the lateral spray is reduced by tree foliage, indicating that the swath width of sprayer can vary with foliage density. **In dense forest, swath width should be reduced to insure good coverage**.

During field trials using Foray 76B, it was discovered that the formulation, being somewhat more viscus than water, flowed at a slower rate. To meet application rates of 4 to 5 l/ha, the sprayer's restrictor was increased to size # 4. This resulted in the desired 200 ml/min flow rate for Btk.

Calibration of backpack sprayer

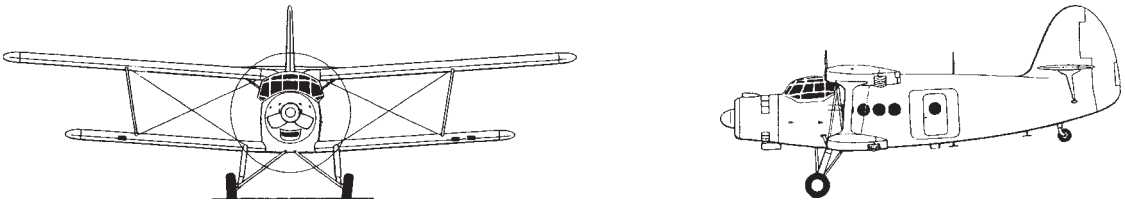
Verticle cardline to check sprayer height

Testing sprayer deposition during field trials

Water sensitive card. Blue dots are spray droplets deposited from backpack sprayer.

Antonov An-2

This aircraft in all its variations may well be the most common utility and agricultural aircraft in worldwide deployment. Over 12,000 have been produced in the Ukraine and Poland since 1949. They are also produced by the Shijiazhuang aircraft Plant (SAP) in China. Originally designed to meet a USSR Ministry of Agriculture and Forestry specifications, this aircraft has been extensively used in aerial application. The piston engined AN-2 aircraft can be fitted with a 1,350-kilogram capacity epoxy resin dry material tank, or a 1,400-liter liquid chemical tank.

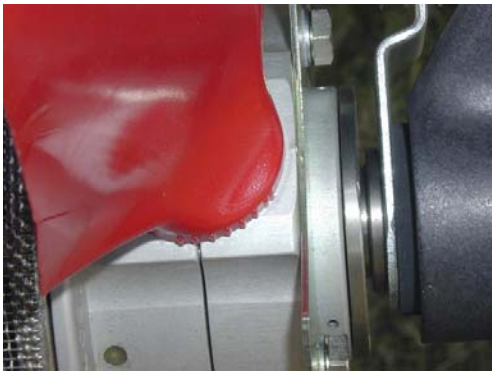


Front and side view of Antonov An-2 aircraft

Two An-2 were equipped with Micronair AU5000 atomizers. Each aircraft is outfitted with 10 atomizers, evenly distributed along 75% of the trailing edge of the lower wing.

Micronair units have adjustable blade angles which allow the user to select the desired droplet size. For Foray 76B, the optimum droplet size that contains a toxic dose and provides good deposition in coniferous foliage, is a volume median diameter of 100 µm. (A human hair is approximately 90 µm in diameter).

Using an aircraft application speed of 140 kph, the Micronair users manual indicates that the desired blade angle is 35 degrees to produce droplets of 100 µm. **All blade angles must be set to the same setting to avoid excessive vibration during flight.**



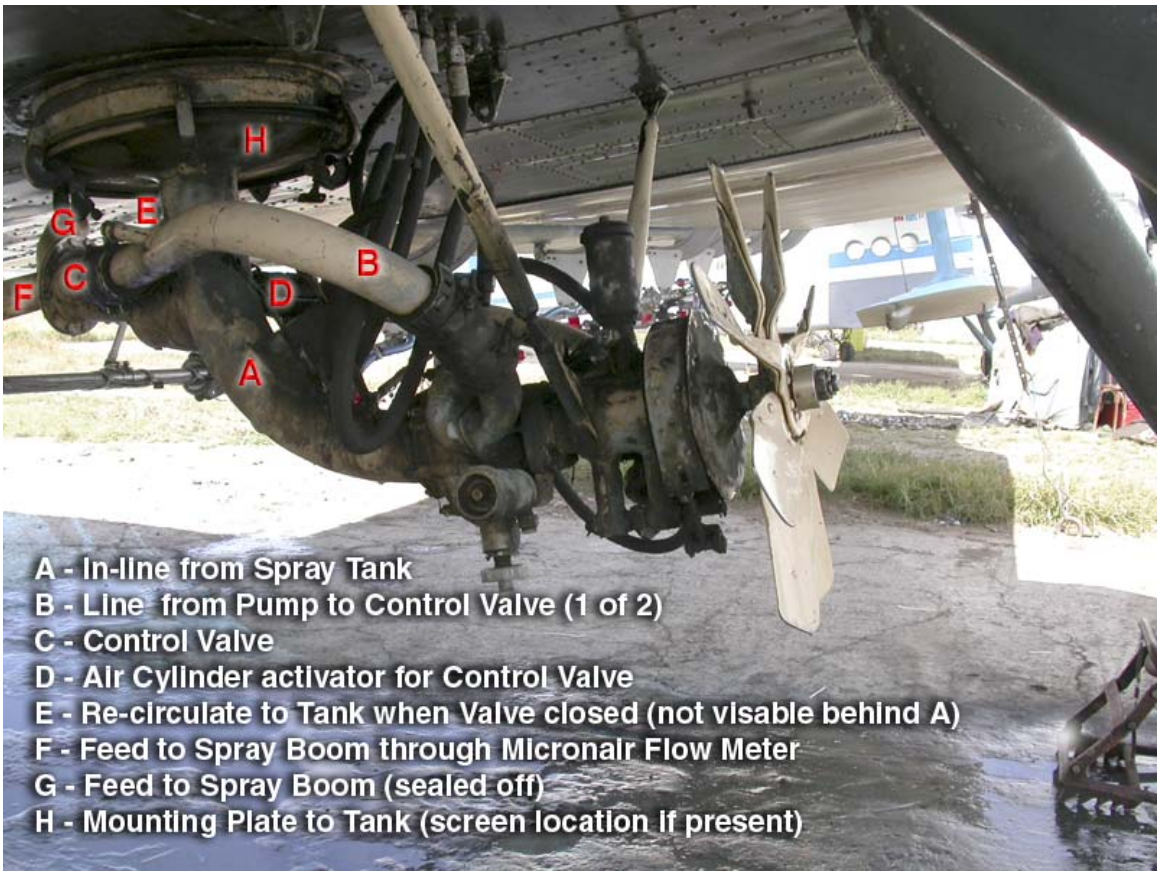
Micronair blade showing 35º setting.

When not in use, the spray boom and atomizers should be removed from the aircraft and stored in a secure location to avoid any damage. **It is recommended that the booms with the Micronairs attached be hung from the ceiling**.

A complete record of the spray system setup, including AU5000 variable restrictor units (VRU) settings, has been provided by Mr. Tim Sander during installation and testing. **These settings should be confirmed prior to spraying in the spring.**

The air driven centrifugal pump, with a nonadjustable blade, is typical of An-2's. During calibration of the aircraft, the spray pump's fan had to be reduced in diameter to avoid excessive pressure in the spray system.

On inspection of the aircraft's spray system, it was noted that there is no filter between the spray tank and atomizers. Ideally a 50 mesh screen should be place between the spray tank and the boom to prevent debris from clogging small openings in the Micronair VRUs. The biopesticide Foray, has some detergent activity, and will loosen scale or dried sediment present in the tank, pump, or pipes of the spray system.



An-2 spray pump and plumbing.

During the first few loads of Foray, it is possible that the small VRU ports msy become blocked by sediment or scale dislodged by the insecticide. Applicators should be aware of signs of diminished or blocked spray from the Micronairs. All atomizer can be affected, but it is usually the outer most units that first show signs of problems.

As clogging may occur, those treatment blocks closest to the airfield should be treated first. In the event of a clogged spray system, the return distance to the airport would be minimized.

If clogging of Micronairs does occur, the aircraft should return to the airfield and all the VRUs should be unassembled and cleaned. Usually after one or two loads, the system is sufficiently cleared of scale and further clogging of atomizers is not generally a problem.

Economics of Aerial Application

The Mongolian Ministry of Nature and the Environment has previously used a Russian produced Btk formulation – Lepidocide. The material is produced both as a dry powder and a liquid. The powder is applied at 2 kg product in 25 liter water per hectare, and the liquid is formulated at 3 liters product in 22 liters water per hectare. The Btk potency level (expressed in international units) of either formulation is not provided by the manufacture. The application volume of 25 l/ha and product concentration was recommended from field research results.

Product costs of Lepidocide are approximately $30.00/ha for the powder and $22.32/ha for the liquid.

FAO, based on results of previous spray programs, recommended the use of the high potency Btk formulation - Foray 76B, produced by Valent BioSciences. This material is formulated to be applied undiluted at the low volume rate of 3 L/ha. Foray 76B contains approximately 20 Billion International Units (BIU) per liter, for a total application rate of 60 BIU/ha. Product cost of Foray is $23.91/ha.

A comparison of costs between the various products must also consider the application cost. Determining individual aircraft productivity and project production needs will vary with the size and number of treatment blocks, and the location of airports in relationship to the treatment blocks. To simplify this analysis, a single hypothetical treatment area of 320 hectares (800 meters x 400 meters), located 30 km from the loading site was evaluated.

Foray 76B shipping container containing 6-50 liter containers with Director of the Forest Research Center - J. Byambajav

The "Baltin-Amsden Formula" (1959) describes a method for estimating the cost of an aerial spray operation. In order to predict time and cost elements of an aerial spray operation, specific data are required. These include: application rate, aircraft tank capacity, flying speeds, hourly costs, insecticide cost, turning times, and the number and lengths of spray paths flown.

Application rates for each insecticide product was used to determine total spray operation time. These data (values used are in right column) were use in the Baltin-Amsden formula:

$$t = 10^4 \left(\left(T_r * Q / Q_f \right) + \left(1 / v*b \right) + \left(T_w / b*L \right) + \left(2*a*Q / V*Q_f \right) + \left(C/V*F \right) \right)$$

Where:

t = total aerial spray operation time (sec/ha)	
T_r = loading time (sec)	1200
Q = application rate (l/m^2)	0.025 and 0.003
Q_f = spray material applied per spray cycle (l)	1200
v = spraying speed (m/s)	39
b = swath width (m)	40
T_w = turning time (sec)	60

L = spray length (m)	800
a = ferrying distance (m)	30000
V = ferrying speed (m/s)	39
C = distance between spray blocks (m)	0
F = spray block area (m^2)	320000
Aircraft hourly flight rate =	$255

From these inputs the spray productivity and spray efficiency was calculated for a single 320 ha treatment bock. Spray productivity is the area sprayed per hour and is the quotient of the area sprayed divided by the total operational time (take off to landing). Spray efficiency is the ratio of the actual spray-time to the total operational time (take off to take off).

Results

For both application rates, the aircraft and treatment area parameters are constant. The difference in the application rate, 25 l/ha versus 3 l/ha, accounts for the differences in the total operational time and therefore the overall cost of the project.

Assuming an aircraft spray tank holds 1200 liters, at a 25 l/ha application rate each aircraft flight could treat 48 ha (1200 L/25 L per ha = 48 ha). With a treatment area of 320 hectare a total of 7 (320 ha/48 ha per load = 6.7 loads) round trip ferries between the treatment area and the airport would be required to complete the block. Using a distance of 30 km and ferry speed of 140 kph, a single round trip ferry takes approximately 0.43 hrs. At an aircraft hourly rate of $255, each round trip would cost approximately $110, with a total of $770 in ferrying costs being required to treat the block.

For an application rate of 3 l/ha, using the same criteria above, only one round trip ferry would be required (1200 L/3 L per ha = 400 ha), for a total of approximately $110 in ferrying costs. Using this example, the Foray 76B material give a 86% reduction in ferry costs.

The cost of the actual treatment of the block, which includes the 10 flight lines and the turn time between lines would be the same for both application rates.

If aircraft fueling and insecticide loading times are assumed to be 20 minutes, the total application costs (material and application) per hectare for the 25 and 3 liter per hectare rates using the Baltin-Amsden formula, would be $17.71 versus $2.13 per hectare, respectively.

Table 1 shows a breakdown of insecticide cost, application expenses, and the total cost of treatment by hectare. These values are calculated based on the above assumptions. The total cost/ha will change based primarily on the ferry distances. In this example, **Foray 76B gives a total treatment saving of 45 percent over the Lepidocide formulations.** If ferry distances were longer, the differences in costs between products would be greater.

Table 1. Comparison of two Russian formulations of Lepidocide and Foray 76B.

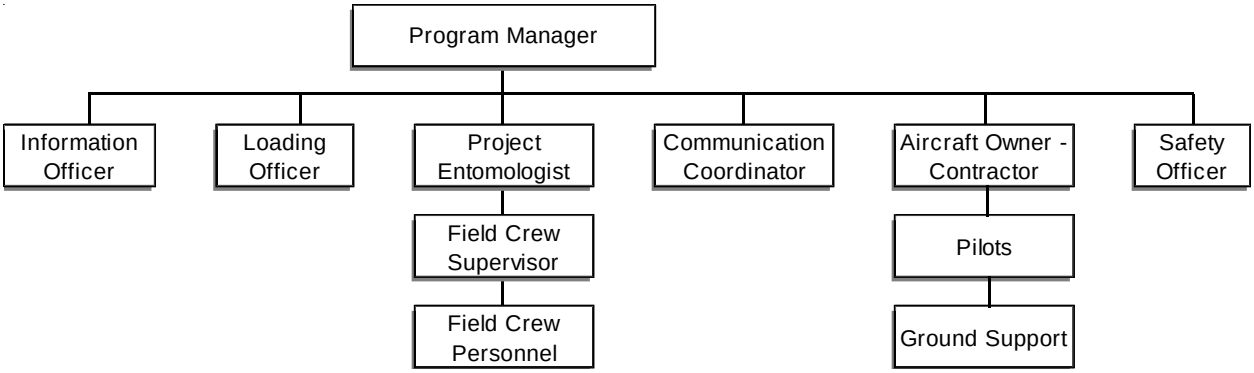
	Cost	Insecticide Cost/ha	Application Cost/ha	Total Cost/ha
Lepidocide (powder)	15.00/kg	30.00	17.71	47.71
Lepidocide (liquid)	7.44/L	22.32	17.71	40.03
Foray	7.97/L	23.91	2.13	26.04

Project Organization and Responsibilities

In the United States, aerial suppression projects are implemented under the Incident Command System (ICS), the same system that is used by emergency response agencies and for forest fire suppression.

An example of an organization flow chart and position descriptions are given below. It is important that each person is to report to the person in the block directly above them with any problems or concerns. Staffing for these positions may include one or more persons filling the duties of the following positions. One of the benefits of implementing the ICS is that positions and personnel can be flexible according to the projects needs.

Based on project size and proximity of treatment blocks to airstrips, it may be feasible to conduct the suppression project simultaneously from two airstrips or staging areas. If so, a technical specialist may be designated by the Project's Program Manager to oversee the spray operations at a staging area while conducting spray operations at another staging area.



Organization Chart for an Aerial Applicaition Project

Program Manager – Has the responsibility for the overall spray program. The manager is responsible for meeting with the contractor at least one week in advance of the project starting date and calibrating and inspecting all aircraft. The manager has the authority to stop all spray activities if a contract dispute arises. The program manager has the authority to prioritize and schedule block treatment, brief pilots on treatment blocks (briefings held each morning and evening), and terminates spray sessions when weather is unfavorable or other problems arise.

Project Entomologist – Reports directly to the Program Manager and assists with the logistics of the spray operations. Other duties includes coordinating the field activities of the Field Crew Supervisor, and releasing blocks for treatment based on larval and foliage development and desirable weather conditions.

Field Crew Supervisor – Reports directly to the Project Entomologist. Has the responsibility of training field crew personnel for the spray operations, obtaining needed supplies, and acquiring and assigning equipment (radios, wind gauges, RH gauges, thermometers, etc.). Also responsible for contact radio communication with field crews within the blocks during treatment, collecting information on weather conditions, and for reporting pertinent information to the Project Entomologist.

Field Crew Personnel – Reports directly to the Field Crew Supervisor. Has responsibility of collecting larvae and foliage development data, monitoring weather conditions during treatment sessions, and informing the Field Crew Supervisor of "no spray" situations (for example, nozzles are plugged, not spraying in the right area, no deposit in treatment area, etc.)

Communications Coordinator – Reports directly to the Program Manager. Has the responsibility of establishing an effective communication system. This should include ground to ground (field crews), ground to airport (Field Crew Supervisor to Program Manager) and airport to pilot communication (Program Manager to spray pilot). All communication equipment should be tested prior to the start of the project to ensure that communication from all treatment areas to airbase can be reached. No flights will be made without satisfactory air to ground communications. During the spray operations, the communication coordinator assists in troubleshooting radio-related problems.

Safety Officer – Reports directly to the Program Manager and is responsible for making sure project personnel and the contractor following all pertinent safety guidelines. This position investigates any misuse or misapplication of insecticide, aircraft accident, or an insecticide spill. The Safety Officer is also responsible for not allowing any non-essential personnel in the loading and fueling area.

Mixing/Loading Officer – Reports directly to the Program Manager and has the responsibility of maintaining accurate records of amount of spray material loaded into each aircraft, which aircraft is treating in a block, logging takeoff and landing times of each aircraft, and submitting this information at the end of each treatment day for signature by both pilot and Program Manager. See attached Daily Flight Record data sheet

Information Officer – Reports directly to the Program Manager and is responsible for handling all incoming telephone calls or news media representatives. Also responsible for updating the media on the status of the treatment operations.

Aircraft Owner - Contractor – A contractor representative must be present at all times during the project and reports directly to the Program Manager. The contractor representative must have the authority to direct the on-site operations of the contractor, resolve operational problems, and represents the company in contractual matters. All contract specifications concerning acceptable aircraft, pilots, aircraft maintenance, spray systems nozzles, ground personnel, and ground equipment must be met.

MINISTRY OF NATURE AND ENVIRONMENT Daily Aircraft Record		DATE	
		CONTRACTOR	
		PILOT	
REGION	PEST	LOCALITY(S)	AIRCRAFT NO.
LOADING SITE			

	MATERIAL	Rate/HA	Volume/HA	Solvent: Type and Vol.	Additive: Type and Vol.	Liters Sprayed by Material
A						
B						
C						

Blocks completed	Blocks Partial

Location	Block(s)	Material	Take-off	Landing	Min	Spray Timer Take-Off	Spray Timer Landing	MIN	Liters
								TOTAL	

Weather:

Notes:

Operation Shutdown Time and Reason

Signature of Record Keeper	Signature of Pilot
	Flight Time: Hrs:

Example of a Daily Aircraft Flight Record. Documented take-off and landings will verify aircraft usage. Insecticide loads and spray time (booms on) will document calibration and indicate any problems with the spray system.

Aircraft Calibration and Characterization

Introduction

The objective of calibration of the spray aircraft is to set up the aircraft so that it can deliver the correct volume of insecticide per minute through its application system under normal operating conditions. Calibration is vital for effective spraying. Unless the precise flow rate of the spray system is known, it is not possible to apply the required dose rate of insecticide.

Calibration

Why Calibrate?

1. So the correct, predetermined amount of material will be applied uniformly over a given area to achieve maximum control of the target insect.
2. To ensure the safety of workers and the environment
3. To ensure that all equipment is operating properly
4. To ensure the smooth operation of the spray project
5. Comply with label recommendations

When Do I Calibrate?

1. At the start of each program.
2. Anytime you change chemicals or formulations
3. When faulty equipment is replaced
4. After equipment has been used on another job.
5. ALL treatment aircraft on your program should be calibrated

What Determines Flow Rate?

1. Nozzle or restrictor unit orifice size
2. Boom pressure
3. Type and viscosity of formulation

Flow Rate Changes are Made By:

1. Large adjustment to flow rate: change the orifice size and/or number of nozzles
2. Small changes in flow rate: adjust pressure

Things to Check Before Calibration

1. Check in-line and nozzle screens for cleanliness
2. Check the pressure gauge for accuracy. Use liquid filled mounted on boom in clear view of pilot
3. Check for clean nozzle tips and replace worn ones.
4. Check for clean tank
5. Check hoses and clamps
6. Check pump to make sure it turns freely.
7. Fill with water and run system at pressure you will be operating. Check proper pump operation and check complete system for leaks.
8. Drain system of water and then add spray material for start of calibration or correct flow by material specific gravity.

Types of Calibration

1. Ground - Conducted with aircraft on the ground. Aircraft must have hydraulic or electrical pump. You can check each individual nozzle as well as overall output.
2. In flight - Conducted in the air for aircraft equipped with wind driven pumps. This will give overall output only and will not tell flow variability between individual nozzles.

Calibration Process

Nozzle selection and number

A. Compute Hectares per Minute (HPM)

$$\text{HPM} = \frac{\text{(air speed in kph) x (swath width in meters)}}{600}$$

$$\text{Example: } \frac{\text{(240 kph x 30 meters)}}{600} = 12 \text{ HPM}$$

B. Compute aircraft flow rate in liters per minute (LPM)

LPM = (HPM) x (Liters per Hectare (LPH))

Example: HPM = 12 and application rate is 5 LPH

12 hpm x 5 lph = 60 LPM

C. Desired nozzle size is known, how many nozzles will be required?

$$\text{Number of Nozzles} = \frac{\text{Aircraft Flow Rate (LPM)}}{\text{Flow Rate per nozzle (LPM)}}$$

Example: The 8004 Flat Fan nozzle has a flow rate of 1.5 LPM at 40 psi.

Flow Rate is 60 LPM.

$$\text{Number of Nozzles} = \frac{60 \text{ LPM}}{1.5 \text{ LPM}} = 40 \text{ nozzles}$$

Field Check the Application Rate

Ground Check Method if Possible

1. Fill spray tanks of the aircraft with a quantity of water adequate for charging of the system (approximately 100 liters). Request that the pilot run the spray system until the pump breaks prime (loses pressure). At this point, any air within the system should have been replaced by liquid. Check for any leaks or clogged nozzles and repair as necessary.
2. Add a predetermined quantity of water to the spray tanks. This should normally be between 110 and 160 liters. If metering of liquids is not possible, a plastic container, pre-calibrated and marked should be used.
3. With a stopwatch, measure the amount of time required to empty the spray tanks from beginning to the nozzle discharge.
4. While measuring discharge time, check that the pressure shown on the boom pressure gauge is within the specified limits, and for evidence of clogged or improperly operating nozzles.

$$\text{Discharge Rate (LPM)} = \frac{\text{Liters of water added to spray tank}}{\text{Discharge time in seconds}} \times 60$$

5. Calculate discharge rate:
6. Compare discharge rate to desired application rate. This discharge rate should be within plus or minus 5% of the desired application rate.

$$\text{Percent of Error} = \frac{\text{Discharge rate}}{\text{Application rate}} \times 100\%$$

7. If the discharge rate is higher than the desired application rate:

   a. Check the nozzles for oversize orifices, replace, if necessary, and repeat calibration procedure, or
   b. Adjust for proper boom pressure, if this was too high, and repeat calibration procedure, or
   c. Remove sufficient nozzles to bring application rate within the allowable range, and repeat calibration procedure.
8. If the discharge rate is lower than the desired application rate:

   a. Clean nozzles and repeat the calibration procedure, or
   b. Adjust for proper boom pressure, if this was too low, and repeat calibration procedure, or
   c. Add sufficient nozzles to bring application rate within the allowable range, and repeat calibration procedure.

9. Proper calibration should normally be obtained within three or less attempts. If more than three trials are required, or results are erratic, the following possibilities should be investigated:

a. Aircraft spray system pump defective.
b. Dirt or other foreign material present in aircraft spray system, batch truck, or in calibration solution.
c. If used to measure calibration solution into aircraft spray tanks, batch truck meter may be defective.

10. Check the spray system calibration in flight as soon as possible after obtaining acceptable ground calibration.

$$\text{Pesticide application rate (LPH)} = \frac{\text{Liters sprayed}}{\text{Hectares covered}}$$

CALIBRATION PROCEDURE FOR ROTARY ATOMIZER

A .Calculate the flow rate from the basic flow rate equation as described previously in Flat Fan calibration.

B. Determine the orifice setting and number of rotary atomizers that delivers the desired flow rate.

1. Obtain manufacture's rotary atomizer catalog.
2. Determine the flow rate for a single nozzle.

$$\text{Single Nozzle Flowrate} = \frac{\text{Flowrate from Basic Flowrate equation (LPM)}}{\text{Number of rotary nozzles}}$$

3. Select orifice setting from manufacture's catalog at selected boom pressure.
4. Adjust blades or RPM for desired droplet size using manufacture's procedure.

C. Field check the application rate using the refill method.

1. Fill hopper with water and operate system to fill sump, booms, and nozzles. For wind driven pumps, this will require the pilot to fly until spray is emitted from all nozzles.
2. Refill hopper with water and mark level
3. Request pilot to spray for 3 minutes at selected boom pressure.
4. Have aircraft return to same location that water level was previously measured and measure amount of water required to refill hopper to marked level. Use calibrated containers to measure amount refilled.
5. Calculate discharge rate:

$$\text{Discharge rate (LPM)} = \frac{\text{Liters required to fill hopper}}{\text{Minutes application time}}$$

6. Compare discharge rate to desired application rate. The discharge rate should be within plus or minus 5% of the desired application rate.
7. If discharge rate is not within an acceptable limit, adjust pressure or change orifice setting.

Spray Characterization

Introduction

The objective of characterization is to determine the proper swath width or lane separation for the application aircraft. Characterization insures that the material to be sprayed is: 1) deposited evenly across the treatment area and 2) the spray cloud is composed of a droplet sizes and density that will be effective for control of the target pest. Spray with a lane separation too large may result in skips or stripping, while lane separations to close will result in excessive deposit and wasting material and time.

Aircraft Swath Pattern

The swath pattern of an aircraft should ideally be trapezoidal in shape. For the kind of low-volume applications being performed in forest spraying, the spray deposit should be as even as possible across the main part of the swath with sloping edges on either side. Such a trapezoidal shape will give good overlap characteristics of adjacent swaths. It enables a safety margin to be built in for situations where wind effects or aircraft positioning errors result in imperfect overlaps of swaths. Under-treatment or over treatment of areas will thus be minimized.

An ideal even swath pattern should show a uniform distribution of spray volume (active ingredient) across most of the swath. Droplet density should only be used for pattern estimation in the absence of techniques that measure dose directly. Droplet densities can give misleading dose representations at the extremes of the swath pattern where densities are high but doses are low because of the small droplet size.

An even swath pattern should show a uniform distribution of where spray is directed into a light head- or tail-wind. Any crosswind component will tend to distort the shape of the pattern leading to a tailing effect in the direction of the wind. This will be most pronounced with the smaller droplets, which are able to drift longer distances.

Lane Separation

The lane separation for any particular aircraft spraying forests at the required application rate of between 5 and 20 liters per hectare will already have been established based on past operational experience and characterization trials. A common misconception of the purpose of swath testing is that it is performed primarily to establish the lane separation that will be used operationally. What can happen is that turbulent or crosswind conditions result in a swath pattern that appears to be much larger than it typically is, resulting in the choice of too wide a lane separation to guarantee uniform coverage in most operating conditions and, consequently, under-dosing of forest areas.

Since work rates and profits for a given aircraft depend on the lane separation, make sure that you specify the lane separation distance for each aircraft in the bid proposals to ensure fair bidding by each operator.

Procedures

Preparation

When performing a swath pattern assessment, you should already have established a lane separation for the aircraft and calibrated the aircraft on the basis of that value. (For a given airspeed, increasing the lane separation by a certain margin would entail increasing the flow rate also by the same margin, if the application rate is to remain constant). Before going to the air-field, make sure that you have the items listed below and that all equipment is functioning. (Avoid as much of the measuring or marking as possible during the actual characterization trial by advance preparation.)

1. Adequate supply of spray cards. Spray cards are typically made from photographic paper, commonly called Kromekote paper. Pre-mark these cards with an indelible pen, showing a spray run number and card number.

2. Boxes or specially made collectors to hold sprayed cards until data analysis. (Many spray formulations, especially those containing oils, do not readily dry, so, cards must be kept separate to avoid cross contamination and smearing of the deposit.)

3. Weather equipment. Calibrate meters this before the trial. Take spare batteries and cables where appropriate. Take a good compass, preferably, a sighting compass.

4. Radios. Ensure that batteries are charged, and brief the pilot on the frequency to be used and the procedure for flight and for aborting spray runs

5. Collector stands. Make sure to have collector stands to hold the collector cards off the ground. Pre-mark the sampling area to help locate the spray line quickly in the case of changing wind directions.

6. Smoke bombs. Use 3- to 4-minute duration smoke bombs to help the pilot locate the center of the card line and to judge the direction and turbulence of the wind

7. Miscellaneous supplies, such as pens and notebooks. Make plenty of notes about weather conditions at application time (e.g., was there an overcast) and on observation of the way the spray cloud settled out. (An example might read “seemed like the cloud fell side of card line. Wind changed direction before small droplets fell. Check for extra wide pattern width. Looked like unfilled spray pattern beneath fuselage.”) These kinds of comments are invaluable evidence when you later trying to interpret the shape and width of the patterns observed. Notebook use also encourages observations on causative factors influencing spray patterns and the resulting effects.

8. Micrometer - A specially designed magnifier with a micrometer scale etched in the view field. This is used to determine the diameter of selected droplets.

9. Spray material - Whether water or the actual operational tank mix is used to perform a spray pattern characterization depends on the nature of the material. In cases where an emulsifiable concentrate mix made up with more than 2 volumes of water is used, water may be used for the runs. However, if viscous materials (such as Btk undilute), particulate, or concentrated materials whose volatilities differ markedly

from water are being used, then the final tank mix should be used. Generally, it is better to work with the tank mix, as long as the material is not very toxic and not in short supply.

10. Dye - In order to visualize the deposit, a dye (usually colored) is added to the tank mix. If water-sensitive or oil-sensitive papers are being used, no dye need be added. Dyes that are soluble in both aqueous and oil-based formulations do not exist. In most cases, aqueous formulations are used in gypsy moth control, so, an aqueous dye should be added. Remember that Bt oil-based formulations are aqueous in nature when mixed with water, although they will not dissolve water-soluble dyes when in the undiluted state.

Card Line

Collector array: length and spacing. There are two questions to be considered: “How long should the card line be to catch the whole spray pattern and “How wide should the cards be spaced to get an adequate measurement of the shape of the pattern These questions are answered below.

When spraying from 15 meters (a typical spray height for single engine aircraft), even a slight crosswind component of 3 KPH (0.83 m/s) will drift droplets of 100 mm a considerable distance (52 meters) and larger droplets greater than 200 mm by up to 15 meters. Therefore, it is necessary to extend the cards well to either side of the centerline of the aircraft to make sure that the entire swath is caught (Into wind diagram)

As a guide, card line lengths for aircraft involved in forest spraying are usually ten (10) times the application height. This formula is quite generous. For single-engine aircraft, a 122 meter line is adequate when a flying height of 15 meters is used. For multi-engine aircraft, the line should be increased to 185 to 245 meters or further if a 30 meter flying height is used.

Collectors should be placed in a straight line at 2-meter intervals in order to obtain a good resolution of the pattern. A 3.5-meter spacing gives a coarser picture. This spacing should be used only for the wide patterns from multi engine aircraft.

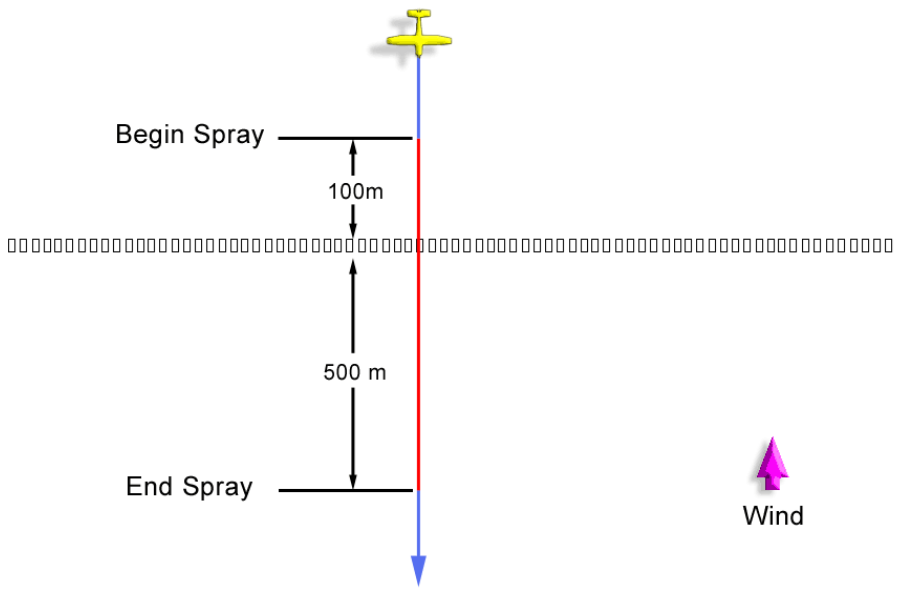
The orientation of the target line should be perpendicular to the wind. Getting the direction right is often not easy when trials are conducted early in the morning. As the sun rises and heats up the ground, the wind direction may veer considerably as vertical mixing in the atmosphere takes place. In such cases, collector lines can be laid out to anticipate changes in the wind direction or the crosswind spray technique used (Cross wind diagram).

Spray characterization trails are best conducted under reasonably steady meteorological conditions. The best spray deposition patterns are usually obtained during the early-morning and late-evening hours when the wind speeds are low, humidity high, and the thermal stratification is neutral.

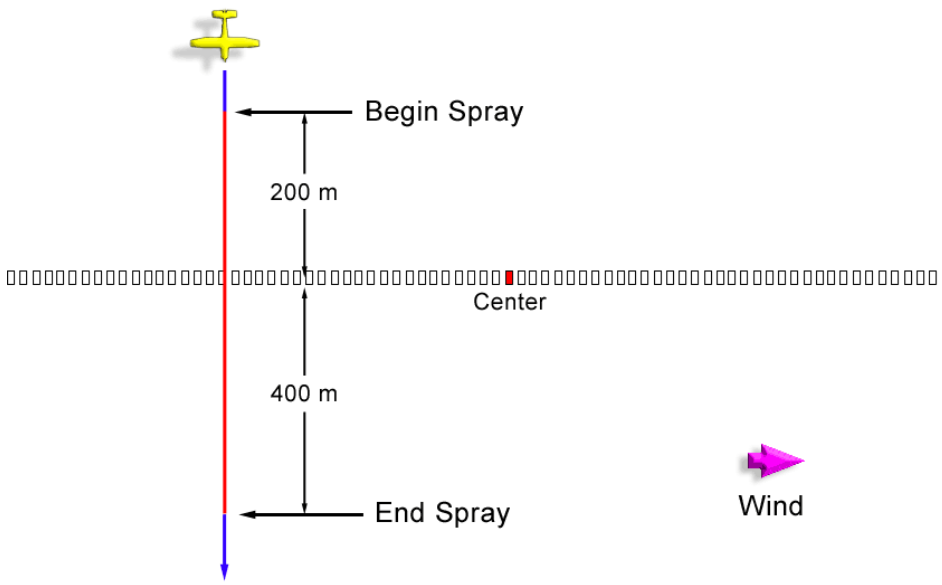
Meteorological monitoring

Wind speed and wind direction at 2 meters should be constantly monitored. Wet and dry bulb temperatures should be measured at 10-minute intervals, and at the time of aircraft overflight.

If temperatures increase beyond 27°C, or the humidity falls below 50 percent with temperatures higher than 16°C , the spray trials should be suspended until conditions become more favorable for spraying aqueous sprays.



Into Wind diagram of card line layout for single pass. Card line length is approximately 10 times release height for a single engine aircraft. Be sure to leave spray on well pass card line to allow for spray moved by wind.



Cross Wind diagram of card line layout and offset of center line due to cross wind. The higher the wind speed the further the planes flight line should be moved.

Equipment for monitoring ranges from the simple and inexpensive to elaborate and expensive. A list of the minimum equipment required includes: a wet and dry bulb sling psychrometer; sighting compass and ribbon on a stick; and hand-held wind measuring equipment.

Replicates.

How many times should the aircraft be tested? Experience has shown that there is considerable variation between spray runs. They literally change with the weather. Because of this variation, numerous runs would be needed to provide any level of confidence in assigning a swath width. A single card line represents the deposition under the environmental conditions under which was sprayed. A change in wind direction, wind speed, temperature, relative humidity, and release height all affect spray deposition. The swath pattern obtained after one run should not be considered as sufficient to establish the true pattern Putting out two or more collector lines for each pass is only worthwhile if sufficient resources are available to analyze each of the card lines. Remember that these do not constitute an independent replicate.

The question, "How adequate is the shape of the pattern—is it even or does it have problems?", can be quickly answered with a single run, changing the nozzle positions as necessary between runs. When satisfied that the pattern meets requirements, make additional runs with the same configuration to build an average or typical pattern for that configuration.

Spray trial procedures

Make sure the pilot is well briefed on what has to be done. This is especially important if there is no ground communication between the aircraft and ground crew. In such a situation, agree for clear signals to be made to the pilot by the flaggers in case an abort due to poor wind conditions is required. The ground crew should continually monitor the weather while the aircraft is airborne and advise the pilot when a run is possible.

If a nontoxic product is being sprayed, position flaggers 60 meters on either side of the spray card line, in line with the wind. If toxic products are being sprayed, position flags in the same areas. Using smoke bombs is useful to indicate current wind conditions, since both ground crew and pilot can see changes in the smoke quickly.

Spray switch-on and switch-off should be done, bearing in mind the passage of small droplets due to wind drift. Flying height and wind strength directly affect the droplet distances from the centerline. Switch-on should be made 60-90 meters away from the target line when flying into wind at 15 meters. Switch-off should be made at 90 meters in still wind conditions, but should be extended according to the strength of the fresh wind. As a rough guide, in 15 kph winds, the aircraft should fly about 305 meters past the card line. Characterization trials in high and variable winds should not be conducted, as the results are difficult to interpret.

After a run has been made, wait at least 5 minutes before picking up the cards. It takes this much time for the small droplets to settle out and allows the droplets time to dry on the cards. During this time do not walk around or upwind of the cards.

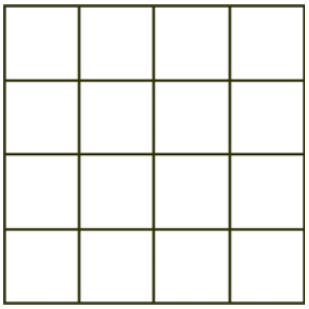
Field Characterization of Card Line

The procedures described below for determining swath width, drop density within the swath and volume-median diameter are designed to provide in-the-field characterization of the aircraft spray. For example, these "quick-look" procedures are intended to provide aircraft spray engineers with the information required to make immediate decisions regarding necessary changes in nozzle types, nozzle configurations, flow rate and to make other mechanical adjustments in the dissemination system to improve spray characteristics. These procedures are also intended for

use in determining any changes required in the aircraft flight altitude, separation distance of the card samplers and other features of the test plan to achieve better results.

Plastic Template for Sizing and Counting Drops

The analysis procedures described here require the use of clear plastic templates to overlay the exposed sample cards. Since continued use of the templates will eventually result in their becoming scratched and unusable, it is necessary to provide replacements. This can best be accomplished by creating a template of square centimeter grids (see graphic below) and making a photo copy on transparency film. Be sure to measure the finished product to insure that it maintained proper scale when copied.



Example of grid template to evaluate drop density. Each square is 1 cm^2

Swath Width and Drop Density

The spray project entomologist is interested in obtaining the widest swath width in which droplet density exceeds a specified amount known or thought to produce the requisite insecticide effectiveness. Each insecticide will have its own effective swath width since each insecticide has a different effective dose. A “quick-look” estimate of the minimum swath width and drop density within the swath width can be obtained by following the simple procedures described below.

After the visible spray cloud has settled or dispersed, proceed on foot from one end of the exposed card line until spray deposition on the sampling cards becomes visible to the naked eye. Visually inspect the next few cards and note the position of the first card on which the drop density appears to be uniform. After inspecting this card to be certain that the stains have dried, estimate the spray drop density on this card using the following step-wise procedure:

1. Remove the card from its holder.
2. Place the grid template over the card and fasten the card and template to the clipboard.
3. Use the large hand-held magnifying glass to count the number of stains in the small (1 square centimeter) square in the upper left-hand corner. Note the number of stains on scratch paper.
4. Continue to the next square moving down the extreme left column of squares on the template. Count the stains in the square and add the number to the number of stains determined for the first square (step 3). If the total number of stains exceeds 100, no more squares need be counted. If the total number of stains is 100 or less, continue

to count the stains in squares until the total number of stains exceeds 100 for all squares counted.

5. Enter the card number, total number of squares counted (area in square centimeters) and total number of stains on a separate data sheet.

6. Divide the number of stains by the area (area in square centimeters) and record the drop density. Do this for each card in the line.

If the drop density on this first card is less than the density required to produce the requisite insecticide effectiveness, use the density just measured as a guide and walk along the card line towards cards showing greater densities and attempt visually to select a card showing the requisite density. For example, if the first card shows a density of 10 drops per square centimeter and the required density is 20 drops per square centimeter, proceed along the card line and select a card showing twice the density of the card just measured. Follow the same procedure for counting the stains to obtain drop density. If the measured drop density on the selected card is greater than or approximately equal to the required density, the edge of the swath can be obtained by linear interpolation. As soon as this edge of the swath is defined, walk to the other end of the card line and use the same procedures to define the other edge of the swath.

After defining the swath width, use the procedures for counting stains outlined above to estimate the drop density of the card near the swath center visually indicating the greatest density. Estimate the drop density on at least two other cards. If the drop density distribution along the card line is uniform or Gaussian (bell-shaped), select a card halfway between the swath end and swath center on either side of the card showing the greatest density. If the distribution is slightly asymmetrical, which can occur when the aircraft does not fly directly into the wind, select the additional cards for analysis from the side of the distribution with the longest “tail. “ When the distribution appears highly asymmetrical such as with a cross wind, an additional trial must be conducted to estimate the swath width..

The analysis of drop density on 5 cards is usually more than sufficient to define the swath width for field use and provide the necessary information to allow aircraft engineers to make necessary adjustments in spray equipment and assist the project entomologist in making a preliminary estimate of the spray system performance. In many cases, measurement of the drop density at the swath edges may provide sufficient information in the field.

It should be noted that the drop density analysis and the volume median diameter analysis described below is best accomplished using two people, one to count the drops and the other to record the information.

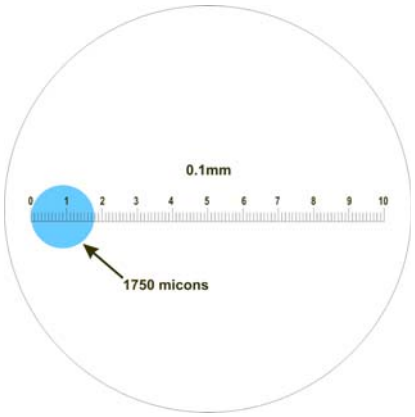
Field Estimation of Volume Median Diameter

The procedures outlined in this section for the field estimation of the volume median diameter (VMD) are based on the approach suggested by Maksymiuk (1964). Although Maksymiuk tested his approach using propeller-driven slow and medium speed aircraft and oil-based sprays, recent experience in applying the method with helicopter equipment and oil- and water-based sprays indicates the method is also adequate for the field estimation for this type of equipment and sprays.

The determination of drop sizes can only be done if a spread factor is used to convert stain sizes to drop sizes. For a general estimate of VMD, the D-max method can be used with a hand

magnifier and graticule. The procedure for determining the VMD :

1. Allow at least 10 minutes for the droplets to spread and dry on the cards before measuring the spots; allow more time for very large droplets or for spray formulations that evaporate slowly..
2. After the spots stop spreading, select and measure the diameters of the five largest spots. Measure the stain diameter to the nearest 50 micrometers (µm) using the measuring magnifier graduated in 100- µm intervals (See graphic below).



View of Micrometer with 0.1 millimeter scale. Distance between whole numbers is 1000 microns.

3. Convert the spot diameters to spherical droplet diameters by dividing the spot diameters by the proper spread factors (either 2.2 or 2.5, depending on the speed of the aircraft as noted in the form (see attached sample data sheet). Enter the card number and stain diameter(s) on the form.
4. Select the D-Max droplet. The D-max is the largest droplet diameter in the continuous droplet spectrum with not more than a 32-µm difference between it and the next largest droplet – going from the smallest droplet size up.

As an example of the application of the D-max technique, assume that the aircraft speed was 230 kilometers per hour and the five largest drops diameters measured on the cards in ascending order were 263, 286, 286, 321 and 335 micrometers. The VMD for the trial is calculated as follows:

VMD = 286 / 2.2 = 130 micrometers

FIELD CHARACTERIZATION OF VOLUME MEDIAN DIAMETER (VMD)

Trial Number	_____	Spray Material	_____
Time/Date	_____	Flow Rate	_____
Line Number	_____	Aircraft	_____
Altitude	_____		
Speed	_____	Stain Factor	_____

Largest Stain and Drops

Card Number	Stain Diameter	Drop Diameter
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Five Largest Drops

Card Number	Drop Diameter
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

DD = Drop Diameter

VMD = DD/2.2 (125-195 kph) or DD/2.5 (> 195 kph)

VMD = _____

Sample data sheet for determining volume median diameter (VMD)

REFERENCES

Maksymiuk, b. 1964. a rapid method for estimating the atomization of oil-base aerial sprays. J. Econ. Entomol. 57:16-19

Weather and Spray Operations

Introduction

At the time of a spray application, it is important to recognize that weather conditions have a direct effect upon spray deposit and hence spray effectiveness. Five conditions to be aware of are:

- Low humidity and high temperatures causing evaporation of volatile components of the spray.
- Insufficient wind or turbulence resulting in a hanging spray cloud.
- Inversion layer resulting in poor settling of smaller drops.
- Thermals caused by the heating of an unstable air mass.
- Rain or wet foliage causing spray runoff.

Low Humidity - High Temperatures

If an insecticide formulation contains evaporative components or is diluted in an evaporative carrier such as water, then the size of droplets reaching the target and their behavior will vary with time of flight and be influenced by temperature and humidity. When spraying a forest, evaporation is a problem more so than in agricultural spraying because the aircraft's height above the forest canopy is at least 15 meters. According to calculations reported by Ciba-Geigy, at 29° C. a water-based droplet 100 microns in size can evaporate by 40 percent after falling only 0.6 meters whereas an oil-based droplet of the same size can lose only 28 percent of its weight after 9 meters. Most insecticide formulations contain additives to impede evaporation. However, among insecticide formulations, a variation in evaporation rate can be expected. Sundaram and others, have demonstrated different evaporation rates for three water-based formulations, each sprayed with VMD's less than 100 microns:

Futura XLV.....(1.65 percent/minute)
Thuricide 48LV .....(1.75 percent/minute)
Dimilin WP-25 .....(2.45 percent/minute)

Note the evaporation rate of Dimilin is 40 percent higher compared to the two Bt products. This is due to the fact that the majority (98%) of the Dimilin formulation is water.

For water-based formulations the greatest influence on evaporation rate was initial droplet size (the larger the initial droplet, the less the influence of evaporation) and relative humidity the next most important influence. Oil-based formulations showed a negligible effect from changes in relative humidity. Ironically, for both water- and oil-based formulations, the influence of temperature was considered small in comparison to other factors. One of those other factors is surface tension of the droplet. Surface tension increases the resistance to small droplet formation and it's the small droplets that have the highest evaporation rates. Surface tension is a function of the formulation.

For gypsy moth aerial spray operations in the eastern United States, the temperature/humidity thresholds at which spraying are stopped:

- Aqueous formulations—temperatures in excess of 27° C. and/or relative humidity less than 60 percent.

- Btk formulations without water added—temperatures in excess of 27° C. and/or relative humidity less than 40 percent.

The 60 percent relative humidity rule for aqueous formulations is based upon the observation that the rate of change of an aqueous formulation is dramatic below 60 percent relative humidity. These thresholds are particularly important when using small droplet sizes (less than 100 microns) and as explained above, relative humidity should be of most concern.

Temperature and humidity should be measured at the spray block or in a geographically similar area close to the block. Measurements should be made at least 2 meters above the ground. Relative humidity is the amount of water vapor in the air relative to the maximum amount the air could hold if it were saturated at the same temperature. It is always expressed as a percent. The psychrometer or sling psychrometer is the most accurate method for determining relative humidity. A sling psychrometer must be spun for 90 seconds to arrive at an accurate reading of depression of the wet bulb. The wet bulb reading is used in conjunction with dry bulb reading to estimate relative humidity.

Insufficient Wind or Turbulence

Wind provides energy to move a spray cloud and should be used to help target spray deposition. For this reason, the best wind conditions are organized in one general direction and steady. Ideal wind conditions range from 5-16 kph (1.5-4.5 mps), without gusts. Winds less than 5 kph, are usually variable and hence less dependable.

Smaller spray droplet sizes (20-100 microns), because of their lower fall velocities, are greatly affected by wind. Wind distributes droplets over and around the foliage by turbulent diffusion. It is the essential mechanism whereby droplets are spread out after they are out of influence of the aircraft wake. Without wind, turbulent mixing will be negligible and the droplets will stay in a relatively dense cloud falling very slowly and moving with the predominant airflow. Spraying in near-calm conditions is common and successful in agricultural spraying when applying large (>250 micron) droplets. Agricultural aircraft also fly close to the target (1-3 meters), with downwash or wake causing penetration of the spray deposit. Most forest sprays, however, are released too high above the canopy to be effectively distributed by wake effect alone. For this reason, it is advantageous to have some wind energy and turbulent forces to help move the spray cloud along and into the canopy.

When a spray cloud reaches the top of the canopy, its penetration into the canopy is a function of air turbulence and sedimentation of the droplets. Turbulent eddies within the canopy are important because they carry the small droplets into the foliage (Fig. B). The sedimentation speeds (that is, droplets falling by gravity alone) of 30- and 50-micron drops are about 0.03 and 0.07 m/s, respectively. In a forest canopy, windspeeds of 5-16 kph can greatly augment dispersion of droplets.

When spraying in near calm conditions, droplet density is primarily controlled by aircraft wake effect and droplet sedimentation. The aircraft should fly as close to the target as safety permits (usually 10 to 15 meters). Downwash decreases with increasing aircraft speed; therefore, the aircraft should also fly somewhat slower. If these calm conditions will predominate during spraying, the aircraft should be recalibrated for the slower air speed.

In general, near calm conditions should be avoided. The basic concept is to cover large amounts of foliage with a maximum amount of insecticide. It is generally recognized that large drops (larger than 100 µm) contain over 50 percent of the spray mass. Consequently, an attempt should be made to use smaller droplets released into a 1.5 - 4.5 m/s steady wind. The turbulence associated with these winds will aid in distributing the droplets throughout the canopy.

At the other extreme, high winds (over 16 kph) can result in increased drift. Windspeed measurements should be taken only to insure that they fall within the acceptable operational range of 2 - 16 kph. As with temperature and humidity, windspeeds outside these limits should serve as caution zones. Windspeeds above 16 kph are not necessarily detrimental to effective spray deposit, however, above this threshold spray deposit should be closely monitored for off target movement. Of particular importance at higher windspeeds is the assurance that gusting winds will not cause patchiness in the spray deposit.

Wind direction should also be observed to insure that it will not result in spray drift outside the spray area. Wind direction should be used to help target the spray cloud, with aircraft flying perpendicular to its direction. Spraying perpendicular to the wind direction uses the energy of the wind to help spread the cloud across and into the target, resulting in a more even application as successive swath patterns overlap.

Windspeed and direction estimates should be made as close to the spray area as possible. Cup anemometers provide a reliable method of estimating windspeed. They should be used in an opening at least four to five tree-heights across and at least 2 meters above ground cover. Windspeeds should be estimated using the Beaufort speed categories shown in Table 1. In general, windspeed increases with height above open ground level. For a windspeed measured at 2-3 meters above the ground, add 50 percent (multiply windspeed by 1.5) to more closely reflect windspeeds in the canopy.

Table 1. Simplified Beaufort wind speed scale

Beaufort Number	Wind Description	Visible Sign	Windspeed (kph)
0	Calm	Smoke rises vertically	0 – 1
1	Light air	Direction is shown by smoke drift; barely moves tree leaves	1 – 5
2	Light breeze	Leaves rustle, wind felt on face; small twigs move	5 – 10
3	Gentle breeze	Leaves and small twigs in constant motion; blows up dry leaves from ground.	10 – 18
4	Moderate Breeze	Small branches move; raises dust and loose paper	18 – 29
5	Fresh breeze	Large branches and small trees in leaf begin to sway	29 – 40

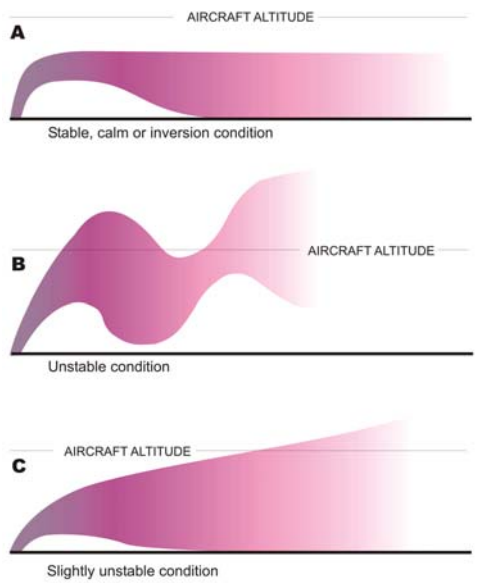
Inversion Layers

Droplet deposition on the forest canopy occurs mainly by impaction and sedimentation. A common reason for lack of deposition of small droplets is the existence of a temperature inversion. An inversion layer is a band of air that underlies a warmer air mass. In flat areas, this is usually caused by radiation or radiational cooling of the ground during cloud free nights, and in mountainous areas by drainage of cool air into lower elevations. If small drops are sprayed above this layer, they will hang suspended and tend to move horizontally with the air mass. In the inversion region, turbulence is also lacking, as inversions are usually stable calm conditions (Fig A). Large droplets fall easily, and are not moved out of the spray area. Be aware, however, that the small droplets can drift a long way, and will not be substantially dispersed under such conditions.

Maximum temperature inversions usually occur when a high daytime ground temperature is followed by radiation cooling to cloudless sky. The cold-sky radiation cooling produces an inversion that starts in early evening continues through the night reaching a peak in the early morning and is the usual pattern for inversion establishment in relatively flat areas.

Spraying that begins too early (at daylight) may be less likely to distribute small droplets within the canopy simply because of inversion conditions and lack of turbulent eddies. Spraying in a cloudless evening, after a sunny day, may also show poor small droplet distribution in the canopy due to the reestablishment of a temperature inversion. In both cases, the wake of the aircraft is the principal energy source distributing small droplets.

With overcast skies, temperature gradients above and within a forest are too small to influence droplet dispersal within a canopy. Under clear skies, temperature gradients are greater. Generally, temperature inversions above the forest crown disappear by 8:00 a.m., and within the canopy by 9:00 a.m. By 7:00 p.m. on clear days, inversions can again be established in the canopy.



Schematic diagram showing smoke plume diffusion under (A) stabe, calm, or inversion conditins, (B) unstable conditions, and (C) slightly unstable conditions.

One of the best indications of an inversion is smoke rising a short distance vertically, then hanging, forming a horizontal layer (Fig. A). Figure C represents ideal conditions for spraying. While spraying, another common indication of a hanging spray cloud is droplet deposit on the windshield and fuselage of the aircraft. On the ground, "cool spots" in the low areas along the roadway may be detected. Typically occurring conditions to expect an inversion are:

- A high-pressure area has been centered over the region for at least one day.
- Warm days followed by clear, cool nights.
- Visibility shows a marked decrease without the presence of precipitation.

Thermal Updrafts

There are certain unstable air conditions that result in air parcels near the earth warming and rising, then being replaced by cool air from above. These form vertical eddies bringing cool air down from aloft and carrying warm air away from the ground. These eddies provide one of the ways by which the solar energy that is absorbed at the ground is carried aloft. This process becomes very noticeable in spring and summer particularly in dry areas. Pilots know these vertical eddies as thermal updrafts that cause a bumpy ride as the aircraft passes through.

A spray released into these thermal updrafts will be entrapped in a rising bubble of air and will not reach the canopy. The best ways to recognize thermal updrafts is through pilot reports, raising columns of smoke, dust whirls, and usually the appearance of fair weather cumulus clouds. Fair weather cumulus clouds are white and have flat bases with rounded tops resembling cauliflower. This is a cloud formation that usually appears in late morning or early afternoon and is produced by upward rising currents of air. The clear areas between the clouds are areas in which the predominant air motion is downward.

Spraying should be stopped whenever thermal updraft conditions appear. Use the appearance of fair weather cumulus clouds as the indication that thermal updrafts are established.

Rainfall and Wet Foliage

The precise effect of rain upon spray deposition has not been well documented for forestry applications. However, rainfall is known to have an adverse effect on spray deposit retention and residual levels of *Bacillus thuringiensis* var. *kurstaki* (Btk.) on foliage. Therefore, a spray sticker is recommended when using diluted Btk. Undiluted applications of some formulations that contain stickers may not require additional sticker to be added.

Spraying should not take place when rain is imminent (definite rain is less than 2 kilometers away, or there is more than a 75 percent chance) or when foliage is dripping wet. After the spray material is dry (3 to 4 hours), rain will have less of an affect on the deposited material.

For Foray (Btk), rainfall is generally considered a problem when it is in excess of 2.5 centimeters and occurs within a couple of hours after the spray application. Rain before the application may leave foliage too wet for Btk. to stick to it or it may adversely alter surface tension of the leaf or drop. Foliage conditions should be checked on a walk through the planned treatment area. If the foliage is wet or if water can be shaken from it, spraying should be delayed until conditions are drier.

Weather observers should observe and note rainfall in treatment areas. The easiest and most reliable method of estimating amount of rainfall is to place rain gauges in representative areas within the general spray area.

Ecological Risk Assessment of Btk

Introduction

The pathogenicity of *Bacillus thuringiensis* var. *kurstaki* (Btk) derives primarily form the presence of a crystal containing delta endotoxin produced by the bacteria. When crystals are ingested by an organism that has an alkaline gut and a receptor site specific for delta endotoxin, that organism is subject to the toxic effects of Btk. This generally limits the susceptible organisms to certain invertebrates such as some Lepidopeterans (butterflies and moths). Vertebrates are not susceptible to Btk toxicity. The mode of action precludes any concern for dermal and inhalation routes. Phytotoxicity (the ability to poison plants) from Btk has never been observed at field rates of application.

Among the terrestrial insects affected by exposure to Btk, lepidopteran larvae are most likely to be adversely affected. Susceptible caterpillars include the following taxa: noctuid moths, geometer moths, pyralid moths, tortricid moths, tussock moths, notodonid moths, tiger moths, silk moths, tent caterpillars, bagworm moths, sphinx moths, swallowtail butterflies, and pierid butterflies (Faust and Bulla, 1982). Btk is relatively nontoxic to honeybees (Atkins and others, 1981). Direct toxicity of Btk to terrestrial insect predators and parasites has not been noted in any studies except some low-level mortality in a laboratory study at doses higher than would occur at the highest recommended rates of application (79 BIU/ha) of Btk (Haverty, 1982).

Most aquatic insects are not affected by Btk. Immature and adult stages of mayflies, caddisflies, dragonflies, damselflies, beetles, midges, and dobsonflies are all unaffected by Btk. Aquatic lepidopteran larvae, however, might be susceptible. Some species of black fly larvae, and two species of stoneflies in the families Leuctridae and Taeniopterygidae were found to be susceptible to Btk at field application rates (30 BIU/ha) for gypsy moth (Eidt, 1985, Lacey and others, 1978; Kreutzweiser and others, 1993; Kreutzwieser and others, 1992).

Terrestrial Field Studies

Lepidoptera

Btk treatments designed to eradicate or suppress target lepidoptera will also have negative consequences for nontarget moths and butterflies eating sprayed foliage, although the susceptibility to the toxic effects of Btk varies widely with species (Peacock and Schweithzer, 1993).

Applications of Btk significantly decrease the numbers of adult and larval Lepidoptera the year of spray (Miller, 199a; Miller 1990b; Rodenhouse and Homes, 1992; Crawford and others, 1993; Peacock and others, 1994; Sample and others, 1995). Both macrolepidoptera and microlepidoptera are affected (Peacock and others, 1994, Sample and others, 1995; Butler and others, 1995). Reductions of adult populations of Lepidoptera in general, and the larvae of some groups in particular (Noctuidae), are routinely noted the following year as well (Miller 1990a and b; Peacock and others, 1994; Sample and others, 1995). The delayed effect of Btk on adult populations is expected in species whose susceptible life-stage occurs the year previous to the appearance of the adult (Sample and others, 1995). Despite the nearly universal reductions in total lepidopteran biomass suggested by these studies, most investigators have not found reductions in

overall species diversity (Miller, 1990a; Crawford and others, 1993; Peacock and others, 1994; Sample and others, 1995). However, some species appear to be particularly susceptible to Btk, as evidenced by their total, or nearly total elimination from treated sites (Crawford and others, 1993; Peacock and others, 1994). Such results are expected given the variable susceptibility to Btk noted among several species (some in the same genus) of Lepidoptera tested in laboratory experiments (Peacock and Schweitzer, 1993). A number of species Peacock and Schweitzer tested had little or no mortality. Even in controlled laboratory situations for most species some treated larvae produced normal adults. Miller (1990b) noted significant reductions in species richness of Lepidoptera larvae collected in sprayed areas the year of treatment and one year after treatment, but not two years after treatment.

Parasites

Field studies on the effects of Btk on the parasites of gypsy moth (*Lymantia dispar*), spruce budworm (*Choristoneura fumiferana*), and Lepidoptera in general have yielded somewhat variable results. The direct toxicity of Btk to parasitic Hymenoptera is low (Flexner and others, 1986). Laboratory tests on several species of wasp parasites of Lepidoptera have shown that only a few were susceptible to Btk (Hamed, 1979; Muck and others, 1981). In addition to the two laboratory studies showing toxic effects of Btk on beneficial wasps, one field study showed that two species of wasp parasitoids of the western spruce budworm (*Choristoneura occidentalis*) "not uncommonly" acquired lethal Btk infections from their hosts. Parasite larvae appeared to develop normally and emerged from their hosts, which had been brought into the laboratory after exposure in the field, only to die before pupation (Thompson and others, 1977). The studies, however, show no adverse toxic effects of Btk on parasite populations, thus the effects noted below are assumed to be indirect ofor this group, as well as for the parasitic flies.

Three field studies found no change in rates of parasitism (that is, the proportions of parasitized larvae per sample) by most species of wasp and fly parasites on gypsy moth aor spruce budworm larvae due to the application of Btk (Dunbar and others, 1973; Buckner and others, 1974; Abrahamson and others, 1979). A decrease in the rate of parasitisim on treated plots was noted for some species of parasites in one study (Ticehurst and others, 1982). Moth larvae poisoned by Btk suffer lethal or non-lethal gut paralysis and feed at lower rates than unaffected larvae, thus prolonging the larval period of the host and allowing greater time for the development of the parasite. Ovipositing females preferentially seek smaller or younger larvae, of which there are more on treated plots due to their slower rate of development. Thus, the rate of parasitism increases on treated plots because there are more suitable hosts (Weseloh, 1985). The same mechanism operates to increase the rate of parasitism on Btk –poisoned gypsy moth larvae for an introduced parasitic wasp, *Rogas lymantriae* (Wallner an dothers, 1983).

Spray programs will also reduce the number of potential hosts for parasites, thus a reduction in trap captures of adult parasites in treated areas would be expected, as found by Readon and others 91979). The same effect might account for the lower numbers of Ichneumonidae (of which many species parasitize lepidopteran larvae) caught in plots treated with Btk in another study (Sample and others, 1995).

Other Arthropods

Field studies of insects other than Lepidoptera and their parasites and predators have found

few other species or groups that are affected. Sample and others (1995) found no effects on sawfly larvae (Hymenoptera: Tenthredinidae and Pergidae), which are similar to caterpillars in appearance and diet. Sawflies were lumped and caterpillars in collections of larvae from foliage in another study (Rodenhouse and Holmes, 1992), so the effect of Btk on this group cannot be distinguished from the general decline in caterpillar abundance. Btk did not affect the overall abundance of other "clinging" arthropods, which included Coleoptera (beetles), Homoptera (sucking insects such as aphids, leaf-hoppers, cicadas), and Araneida (spiders) (Rodenhouse and Holms, 1992).

The effect of Btk treatments on predatory ground beetles (Carabidae) was studied in woodlands with heavy gypsy moth infestation in southwestern Pennsylvania (Cameron and reeves, 1990). A weak trend suggested that beetles were more likely to feed on gypsy moth caterpillars in untreated plots than in treated plots, a trend perhaps easily explained by the greater availability of gypsy moth larvae on untreated plots. Btk-sprayed plots did not affect the number of individuals per species trapped on treated and control plots (Cameron and Reeves, 1990). In another study, numbers of ground beetles caught in pit-fall traps declined six days after treatment in treated plots, and continued to decline 30 days post-spray (Buckner and others, 1974). However, catches on control plots also were lower on day 30 which suggests that factors such as phenology, and factors other than Btk treatments were responsible for the reduced trap catches. This same study noted no effects on the foraging behavior, pollen collection, or colony growth, of bees in hives placed in treated areas; and no negative effects were noted on other arthropods collected in pit-fall traps or from foliage, including insects in the order Hemiptera, Homoptera, and Hymenoptera (Buckner and others, 1974).

Several studies report on effect of Btk spray on other beneficial predatory insects of crop pests (reviewed by Melin and Cozzi, 1990). Among the hemiptera, or true bugs, predators such as spined stiltbug (*Jalysus spinosus*), Nabidae (damsel bugs, *Mabis* spp.), or Lygaeidae (big-eyed bug, Geocoris spp.), Anthocoridae (minute pirate bugs, *Orius* spp.), or Reduviidae (assassin bugs), and Penatomidae (spined soldier bug, *Podisus maculiventris*). Among beetles, Coleoptera, several important predators in the family Coccinelidae (ladybird beetles) were unaffected by Btk applications.

No effect was noted on ground dwelling spiders in a spruce-fir forest in west-central Maine tow weeks after an application of 20 BIU/ha; fluctuations in trap catches before and after spray on treated sites were matched on control plots (Hilburn and Gennings, 1988).

Soil Organisms

A study of the effects of Btk application on soil microflora found that application of Btk to soils resulted in a moderate increase in numbers of soil bacteria, actinomycetes, fungi, and nematodes compared to control (Petras and Casida, 1985). In a review of the effects of Bt on other soil organisms, Btk applications were found to reduce populations of species of predatory mite that is closely related to a soil-dwelling species (Addison, 1993).

Some species of earthworms were unaffected by Btk applied to ash-maple forest soils at 6000 mg/m^2, 100 times recommended rates (Benz and Altweg, 1975), however, whether or not the earthworms were actually exposed to the Btk was not clear in the study (Addison, 1993).

Birds

The following field studies examine the effects on insectivorous birds, including neotropical migrants, when food resources are reduced by the application of Btk. These studies show that the effects of reduced food levels on birds resulting from applications of Btk are subtle.

In sprayed plots, Rodenhouse and Homes (1992) found significant reductions in the number of nesting attempts per bird per year, and in the number of caterpillars in the diets of black-throated blue warblers (*Dendroica caerulescens*, a notropical migrant). Nestling growth, nestling mortality and starvation, and fledgling success (measurable aspects of nesting birds that could be negatively affected by food reduction) did not differ between treated and control plots; the production of young per year (number of young produced per territory per season) was not significantly lower despite fewer nesting attempts by birds on treated plots.

Gaddis (1987) and Gaddis and Corkran (1986) studied the reproductive success and feeding activities of chestnut-backed and black-capped chickadees in control and Btk-sprayed sites near Portland, Oregon. In two years of study, caterpillars constituted a significantly smaller proportion of the nestling diet in treated sites compared to controls, but the time between prey deliveries was not different between spray and control sites. In the first year they found no difference between treated and control sites in reproductive success or nestling growth measures. In the second year they found a significantly lower fledgling success at treatment sites. This was due to three nests that were abandoned in one of the treatment blocks near the third spray of the season. The relationship between the application of Btk and the nest failures is uncertain. Prior to failure all of the nests contained nestlings that appeared healthy, and all failures occurred within 7 days. One nest in a control site was similarly abandoned the same week.

Mammals

As with birds, some bats might be affected indirectly by reductions in food abundance. Sample and other (1993b) found that Btk applications to oak/hickory woodlands in West Virginia resulted in reduced abundance and biomass of moths the year following application. Although effects on bats were not measured, some effect is possible. This study also showed that defoliation by gypsy moth also reduced populations of adult native Lepidoptera and could affect bat foraging as well.

Belloq and others (1992) found increased emigration of adult male masked shrews out of treated areas, and diet shifts among females and young on treated areas. Diet of adult males was unchanged on treated plots. The abundance of shrews on treated plots was unaffected as juveniles replaced adult males. The masked shrew is a generalist predator, thus the effects of Btk applications were not great.

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