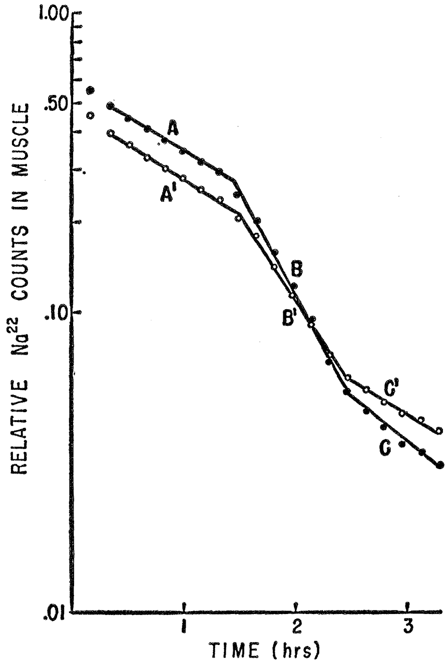

Fig. 2. Semilogarithmic plots of efflux of Na^{22} ions from sartorius muscle cells having elevated contents of sodium. Solid circles refer to a muscle from which the extrusion of sodium was stimulated by the presence of 5-mM potassium in the Ringer fluid (B). Open circles refer to the other of the pair of muscles from which extrusion of sodium was promoted by the presence of 5-mM potassium in the Ringer fluid, with no potassium ions present (B'). Curves A and A' were obtained in the absence of potassium and cesium ions from the bathing medium; C and C', in the presence of $10^{-5}M$ strophanthidin (see text). The primes refer to the curve obtained from the experimental muscle exposed to cesium ions.

gage in strophanthidin-sensitive coupled exchange with sodium ions. It is evident that cesium ions at a concentration of 25 mM have a stimulating effect on the sodium-pumping rate that is very nearly equivalent to the effect of potassium ions at a concentration of 5 mM. Table 2 summarizes the rate constants, for loss of Na^{22}, obtained from the curves of Fig. 2.

These results lead to the conclusion that almost all the movement of cesium into muscle cells is by way of a mechanism that is more or less completely blocked by strophanthidin at a concentration of $10^{-5}M$. Furthermore, cesium ions can stimulate extrusion of sodium against an electrochemical gradient. One is tempted to surmise that cesium ions are actively transported into muscle cells although the data do not prove this point; movement of cesium was not against an electrochemical gradient in our experiments. It is possible that the sodium "pump" generates an electric-potential difference across the muscle-cell membrane (*9*), that pulls cesium ions into the cells. Opposing this possibility is the low permeability of the membrane to cesium ions (*1, 8*). The initial sodium-pumping rates observed when muscles were placed in the 25-mM cesium Ringer solution were around 30 μmoles of Na^+ per hour per gram of muscle. As this rate is several times the rate of inward movement of cesium ions normally observed, considerable hyperpolarization would be required for purely electrically controlled movement of cesium.

These findings suggest that the coupling between extrusion of sodium and inward movement of cesium is mainly chemical in nature rather than electrical. The amount of sodium efflux that is coupled to cesium influx must depend upon the internal concentration of sodium and the external concentration of cesium. Inasmuch as almost all the inward movement of cesium is by way of a mechanism that depends on metabolism, the purely passive membrane permeability to cesium ions is remarkably low—roughly equal to the membrane permeability to sodium ions.

The ability of cesium ions to substitute for potassium ions in the promotion of outward transport of sodium is about the same in squid giant axons as in muscle cells (*10*). This similarity suggests that the ionic transport mechanism may be the same in these two instances.

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Spruce Budworm Mortality as a Function of Aerial Spray Droplet Size

Abstract. *The size and number of aerial spray drops impinging on spruce budworm in its conifer forest habitat were determined by means of a new tracer method that uses fluorescent particles in a liquid spray. Examination of 1113 larvae affected by an experimental insecticide that had been applied to a 5000-acre (2024-ha) test area in Montana showed that 93 percent had not been contacted by any droplets larger than 50 μ in diameter. Small numbers of droplets 50 to 100 μ in diameter were found on 7 percent of the larvae, along with lethal numbers of smaller drops. No evidence was found that significant numbers of drops larger than 100 μ reached the target insects. Because about 95 percent of the spray applied to forests by current methods consist of droplets larger than 50 μ, the biologically effective portion of the drop spectrum is only a few percent. The data foreshadow a major potential reduction in insecticide requirements for the successful control of spruce budworm.*

The mountain forest is a formidable problem to the scientists who must control destructive forest insects in their natural habitat while minimizing adverse ecological changes. The typical mountain conifer forest is a highly complex, three-dimensional environment. Its rugged terrain with deep drainages, steep slopes, and high ridges fosters a complex meteorological situation. From the top of the trees to ground level, the conifer forest itself adds significant vertical dimensions to this environment and provides a habitat with both food and protection for insect pests.

In spite of these complexities, aerial spray techniques have been developed, largely by empirical methods, which successfully control many destructive insects. One of these is the spruce budworm, perhaps the most destructive forest defoliator in the United States and Canada. Until recently, it was controlled by aerial applications of DDT, in a broad-spectrum spray whose droplets ranged from about one or a few microns in diameter to as large as 300 to 400 μ. The persistence of DDT—which was most undesirable from the standpoint of hazard to beneficial insects and other nontarget or-

Table 1. Maximum droplet size found on 1113 larvae. Abbreviation: FP, fluorescent particle.

FP'S in drop (No.)	Indicated diameter (μ)	Larvae (No.)	Cumulative percent of total
0	<21	256	23
1	21– 26	596	77
2	27– 30	69	83
3	31– 33	27	85
4	34– 36	18	87
5	37– 38	24	89
6	39– 40	8	90
7	41– 42	6	90
8	43– 44	8	91
9	45– 46	7	91
10– 13	47– 50	22	93
14– 30	51– 68	49	98
31– 85	69– 95	22	99.8
86–115	96–107	2	100
Total		1113	

ganisms—led to a search for new treatments for this and other pests.

A U.S. Forest Service research and development program headquartered at Berkeley, California, has as one objective the development of short-lived, selective insecticide treatments and the development of improved spray application techniques. As a part of that program, a new tracer method using fluorescent particles in liquid sprays has been developed. This method makes it possible to determine what portion of a spray droplet spectrum actually reaches the target insect in its natural habitat (*1*). The method was recently used to determine the size and number of aerial spray drops impinging on spruce budworm larvae in their protective natural habitat.

When a known number of solid, insoluble fluorescent particles (*2*) of micron size are suspended in a known volume of an insecticide spray liquid, the number of fluorescent particles in each spray droplet is a direct measure of droplet size (*1*). As the spray droplet impinges on target (or nontarget) insects or foliage, the liquid in the droplet spreads and is partly evaporated and partly absorbed by the insect or foliage, but the solid, insoluble fluorescent particles remain on the surface in a discrete recognizable pattern for each individual droplet. Illumination with ultraviolet light and inspection under a microscope make it possible to count the number of droplets and to determine the original drop size by counting the number of fluorescent particles in the individual patterns. The method was developed in 1965 and successfully field-tested the same year. In 1966 it was used as a means to determine the effective drop size for spruce budworm control.

The study was carried out on a 5000-acre (2024-ha) pilot spray project on the Bitterroot National Forest near Hamilton, Montana. Zectran (4-dimethylamino-3,5-xylyl methylcarbamate) was used as the insecticide, at a rate of 0.15 lb/gal (18 g/liter). The spray was applied in butyl ether of ethylene glycol plus kerosene at a rate of 1 gal/acre (9.35 liter/ha). A gallon of spray contained 0.16 lb (72.58 g) of fluorescent particles, calibrated as 2×10^8 fluorescent particles per milliliter of spray liquid. The spray spectrum was broad, with the larger droplets ranging up to 300 μ or more in diameter. Spray devices and techniques paralleled present commercial forest spray practice.

A sample of 1113 larvae affected by the spray was collected from trees in the 5000-acre spray area and observed for fluorescent particles. Of these larvae, 810 killed by the spray were collected from drop cloths from seven sampling areas over a 10-day period. The other 303 larvae were caught in bottles as they fell from randomly selected trees soon after spraying. Each larva, illuminated by ultraviolet light, was examined under a microscope to determine, by fluorescent particle count, the size of the largest drop.

No fluorescent particles were present on 256 (23 percent) of the 1113 larvae (Table 1), which indicates that the larvae had been contacted by spray droplets whose diameter was less 21 μ. Droplets smaller than 21 μ have a high probability of having less than one fluorescent particle (that is, zero fluorescent particles) and hence are not visible. The fluorescent particle method is based on the statistical probability of finding K particles in a droplet as a function of the mean number of particles per droplet (*1*). Ninety-three percent of the 1113 larvae had no drops larger than 50 μ in diameter.

To obtain the droplet-size distribution patterns on the larvae, a subsample of 346 larvae was examined to determine the size and number of all visible droplets. Those droplets ranging in size from 21 to 46 μ in diameter constitute 97 percent of the 1024 drops found on these larvae (Table 2).

Table 2. Distribution, by size, of 1024 spray drops found on 346 larvae.

Indicated drop diameter (μ)	Drops (No.)	Cumulative percent by number
21– 30	944	92.1
31– 40	36	95.7
41– 50	17	97.3
51– 60	14	98.7
61– 70	3	99.0
71– 80	2	99.2
81– 90	5	99.7
91–100	3	100

The importance of these data lies in fact that they show, by count of total numbers of drops and maximum drop size, that no significant numbers of spray droplets larger than 50 μ in diameter reached the spruce budworm larvae. A study of the droplet deposition patterns on the trees, on ground-level shrubs, and ground-level spray assessment cards showed that the larger droplets were deposited primarily on the peripheral foliage or fell to the ground level through openings in the canopy. Thus, more than 95 percent of the total volume of most conventional sprays used for spruce budworm control (*3*) contribute chiefly to environmental contamination. The percentage would be somewhat less for sprays produced by low-volume spray equipment (*4*), which may account for the increased effectiveness of such sprays.

This is the first time that data on the upper limits of the biologically effective range of drop sizes have been obtained for this insect in its natural environment. The economic and ecological implications, arising from the high order of magnitude of the potential reduction in insecticide requirements, indicate a need for redesign of spray delivery systems and for a considerable increase in knowledge of atmospheric transport and diffusion of fine drops in the forest. Also, we suggest that similar information should be obtained for other insects controlled with contact spray.

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17 February 1967