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Animal Vectors of Eastern Dwarf Mistletoe of Black Spruce

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CONTENTS

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ANIMAL VECTORS OF EASTERN DWARF MISTLETOE OF BLACK SPRUCE

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INTRODUCTION AND LITERATURE REVIEW

Eastern dwarf mistletoe, *Arceuthobium pusillum* Peck., is a perennial, parasitic seed plant belonging to the family Viscaceae. A summary of its life cycle appears in figure 1. It is the most serious parasite of black spruce, *Picea mariana* (Mill.) B.S.P., in the Lake States (Minnesota, Wisconsin, and Michigan) (Beckwith and Anderson 1956) and southern Canada (Hawksworth and Wiens, 1972). Dwarf mistletoe, the major cause of mortality in spruce stands, also reduces tree growth, wood quality, and seed production.

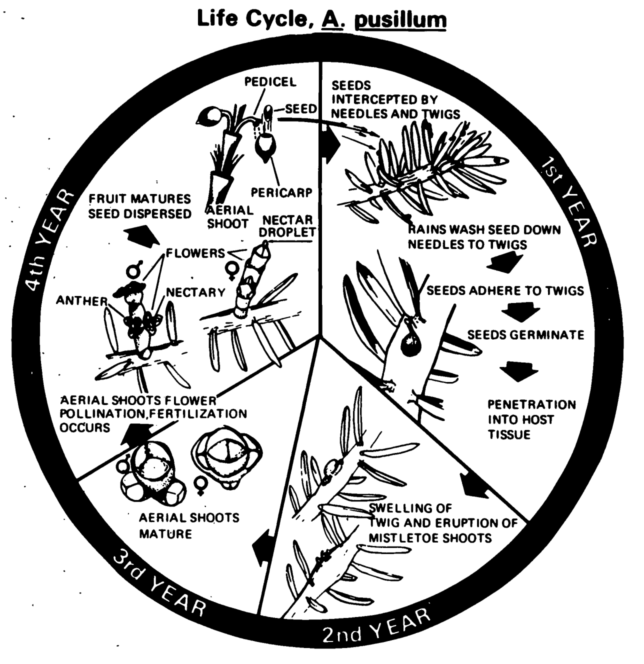

Figure 1.—*Life cycle of* A. pusillum.

Black spruce occupies 890,340 ha in the Lake States. Surveys of black spruce stands on National Forests in the Lake States indicated that 15 percent of the stands were infected with dwarf mistletoe (Anderson and Mosher 1977). In Michigan, 17 percent of the black spruce stands in the Upper Peninsula (Anderson and Mosher 1976) and 1 percent in the Lower Peninsula were infected with dwarf mistletoe (Mathiasen 1979).

A. pusillum is found to a lesser extent on white spruce, *Picea glauca* (Moench) Voss, in the Lake States, although this species is commonly attacked along the Maine coast (Hawksworth and Wiens 1972) and in Manitoba (French *et al.* 1981). The mistletoe is occasionally found on red spruce, *P. rubens* Sarg. (Hawksworth and Shigo 1980), and eastern larch, *Larix laricina* (Du Roi) K. Koch (Tainter and French 1967; Kliejunas 1969).

Rare hosts include blue spruce, *P. pungens* Engelm. (U.S. Department of Agriculture 1960); jack pine, *Pinus banksiana* Lamb. (Laut 1967); (Baker *et al.* 1978), red pine, *P. resinosa* Ait. (Kuijt 1955); and eastern white pine, *P. strobus* L. (House 1935).

Eastern dwarf mistletoe is endemic in North America and, once established, will persist in the stand for as long as the host is present. The most apparent symptom of the disease is the stimulated growth and malformation of infected branches. These bushy masses of branches and twigs are called "witches' brooms" and may grow to 1 to 3 meters in diameter (Anderson and Kaufert 1959). Swelling, positive phototropic response of infected branches, and spike tops are other disease symptoms (Ostry and Nicholls 1976) (fig. 2).

Figure 2.—*Mistletoe-infected black spruce with typical symptoms.*

Figure 3.—*Pistillate fruits of eastern dwarf mistletoe before seed dispersal.*

Most dwarf mistletoe seeds are disseminated by being explosively ejected from the fruit (fig. 3). These seeds can reach as far as 15.24 m (Hinds *et al.* 1963). Discharged seeds of *A. pusillum* were found to travel a mean horizontal distance of 1.65 m and a maximum of 13.7 m (Hudler and French 1976). Recently, a study indicated that *A. pusillum* seeds could be discharged as far as 16.5 m (Baker 1981). The sticky seeds adhere to objects in their flight path. In dense, even-age stands, seeds are intercepted by trees or branches adjacent to the infected tree, reducing dispersal distance.

Establishment of dwarf mistletoe infections beyond the range of their explosive fruits suggests the involvement of vectors. *A. pusillum* is present on islands off the Maine coast and in Lake Michigan, 32 or more km across water from the nearest known infection (Hawksworth and Wiens 1972). Single, isolated infected trees found in a recent mistletoe survey in Michigan were attributed to possible instances of bird-disseminated mistletoe seed (Mathiasen 1979).

Anderson (1949) observed that gray jays (*Perisoreus canadensis),* chickadees (*Parus* spp.), and nuthatches (*Sitta* spp.) may have been responsible for establishing numerous isolated infections of *A. pusillum* in black spruce stands (fig. 4). He speculated that seeds could adhere to birds searching for food in infected trees and these seeds could later be transferred to healthy trees in some manner. Hudler *et al.* (1974) found *A. pusillum* seeds in feathers of gray jays, a robin (*Turdus migratorius),* and a red squirrel (*Tamiasciurus hudsonicus)* in a black spruce stand infected with *A. pusillum.* They concluded that the gray jay or any animal that frequents dwarf mistletoe brooms was a potential vector for the parasite. Gray jays were found nesting in a black spruce witches' broom caused by *A. pusillum* (Warren 1899).

Radio telemetry is a useful technique for obtaining and transmitting information from a living organism and its environment to an observer some distance away. Most early telemetric studies involved large animals such as deer, raccoons, foxes,

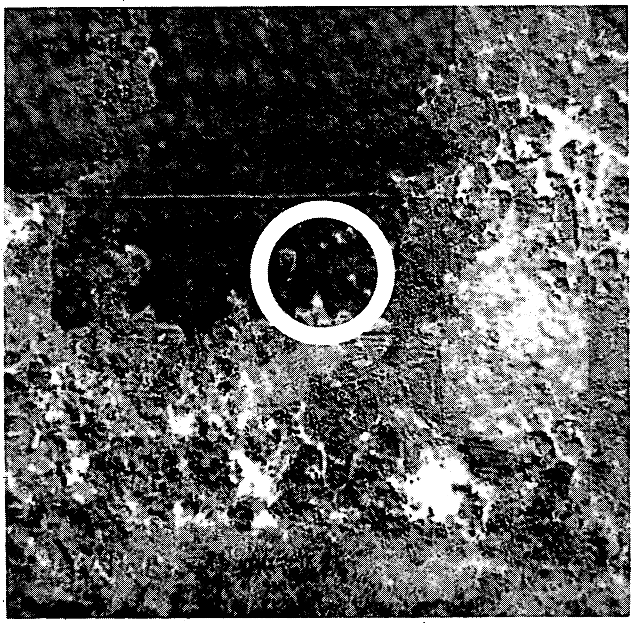

Figure 4.—*Aerial photograph of mistletoe infection center and associated satellite infection centers.*

geese, and ducks that could carry the relatively heavy radio transmitters of that time. By the late 1960's technological improvements resulted in transmitters that were smaller, stronger, lighter, and longer-lived. These new transmitters made it possible to radio-track smaller animals and study birds without significantly affecting their natural behavior (Nicholls and Warner 1966).

Few small birds have been radio-tracked. Starlings (*Sturnus vulgaris)* (Bray *et al.* 1972, 1975), *Hylocichla* thrushes (Cochran *et al.* 1967), robins (Graber and Wunderle 1966), woodcocks (*Philohela minor)* (Godfrey 1970), red-cockaded woodpeckers (*Dendrocopos borealis)* (Jackson *et al.* 1977), and cowbirds (*Molothrus ater)* have been tracked. None of these studies, however, were concerned with birds as vectors of pathogens.

OBJECTIVE

The primary objective of this study was to determine the role of animals in the long-distance dissemination of eastern dwarf mistletoe seed. Long-distance dissemination, as defined in this study, is the movement of *Arceuthobium* seeds more than 16.5 m, the maximum recorded distance. A secondary objective was to adapt and refine radio telemetry equipment and techniques for use in studying the movements and behavior of potential avian vectors of dwarf mistletoe.

MATERIALS AND METHODS

Study Area

Field work was done on the Fond du Lac State Forest (46° 40′ N. lat. and 92° 44′ E. long.) near Cloquet in Carlton County, Minnesota. The forest is near the southern range of commercial black spruce in Minnesota. The lowland organic soil site was occupied by an even-aged stand of black spruce averaging 120 years of age and 12 m in height. Understory consisted predominantly of sphagnum moss (*Sphagnum* spp.), labrador tea (*Ledum groenlandicum* Oeder), and cranberry (*Vaccinium* spp.).

Within the immediate study area, which was approximately 2 km² in size, were one large infection center, 0.87 ha adjacent to Spirit Lake, and several smaller satellite infection centers scattered among otherwise healthy black spruce (fig. 5).

The area was divided into nine sections by using natural breaks in the stand and arbitrarily running compass lines and marking trees with plastic flagging. Each section of the stand was visually evaluated for incidence and severity of mistletoe infection.

Characterization of Infection Centers

Fixed-wing aircraft were used on two occasions by Northeastern Area State and Private Forestry, USDA

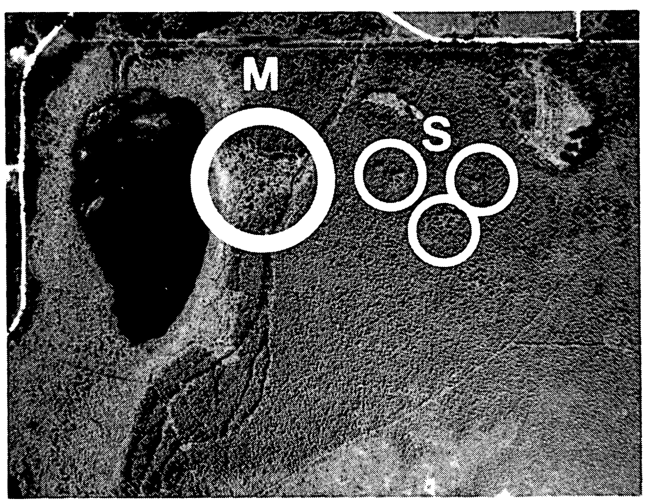

Figure 5.—*Vertical photograph of Spirit Lake study area. (M = Main infection center, S = Satellite infection center).*

Forest Service, to provide the aerial photography of the study area. In April of 1974, 35 mm and 70 mm hand-held cameras provided oblique photos. Black and white, color, and color infrared films were used. In August 1975, vertical 23 x 23 cm infrared transparencies were taken at a scale of 1:6000. In addition, existing 23 x 23 cm black and white photography at a scale of 1:15840 was examined.

All satellite infection centers within the study area were located on aerial photographs and examined on the ground to determine their size and distance from other infection centers. A satellite infection center was defined as one that could not have originated from explosive mistletoe seed dispersal. Size of each center and age of advanced reproduction, if any, were used to determine the relative age of satellite centers in relation to the main infection center.

Trapping, Banding, and Color-Marking

Birds and squirrels were trapped in mistletoe infection centers during seed dispersal each September from 1974-1976 to determine if they carried mistletoe seeds on their bodies. Birds were trapped with nylon mist nets in mesh sizes 30, 36, and 61 mm^2 (fig. 6). Nets were 2.6 m tall and 6 and 12 m long. They were positioned to intercept birds in their observed flight paths. Occasionally, suet was hung in nearby trees to attract birds to nets. During the 3 years of the study a total of 2,916 meters of net were used for a total of 248 trapping hours. Nets were placed throughout the study area including the main infection center, satellite infection centers, and healthy portions of the stand to obtain data on bird populations and movements.

In addition, live traps baited with cracked corn, sunflower seeds, suet, and spruce cones were used to trap squirrels and gray jays. Traps were 20.3 x 20.3 x 66 cm in size and had two compartments. They were made of 16 ga. welded wire cloth with 1.27 x 2.54 cm mesh. Traps were placed in trees and on the ground in infected and healthy areas of the stand. All animals captured were examined for the number and location of mistletoe seeds adhering to their bodies. Seeds were removed and then squirrels and most birds were immediately released. Some birds were held in traps so that fecal material could be collected and examined for mistletoe seeds.

Birds were banded with U.S. Fish & Wildlife Service numbered leg bands (fig. 7). All year-round resident birds such as the chickadees and gray jays also were fitted with colored plastic leg bands for easier identification of individual birds. In addition, some gray jays were color-marked by carefully applying a light coat of fluorescent spray paint to their tail and primary wing feathers (fig. 8). Individual birds and family groups were identified by using various color combinations. Paint was also used to color-mark red squirrels.

Figure 6.—*Gray jay trapped in mist net.*

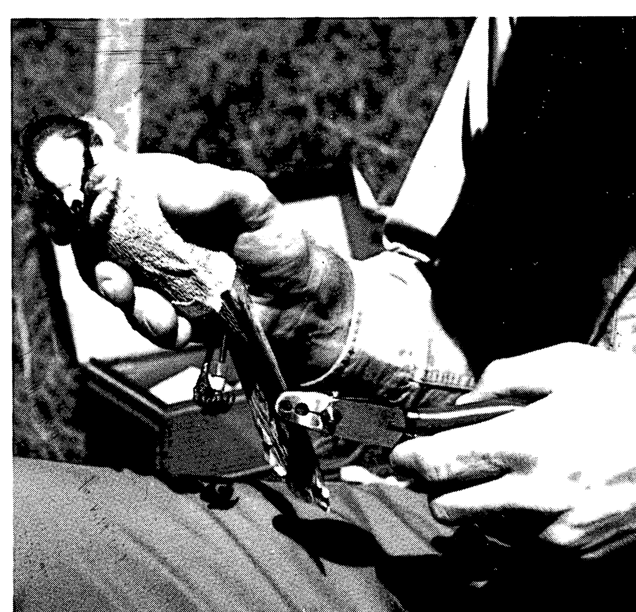

Figure 7.—*Banded gray jay.*

Figure 8.—*Color-marked gray jay.*

Telemetry

Preliminary studies to determine the feasibility of attaching radio transmitters to birds approximately the size of gray jays were done using blue jays (*Cyanocitta cristata*) and radio transmitter mock-ups. We tried to attach radio transmitters directly to the birds' clipped back feathers with eyelash cement or surgical glue. A tail clip mount was also tried (Bray and Corner 1972). In addition, two types of harnesses were designed on which radio transmitters were attached. Both types of harnesses were made from latex penrose tubing, a surgical drainage tubing, 30.5 cm long with a 1.6 cm inside diameter. After a bird had been fitted with a mock-up radio transmitter, it was released into an enclosure for observation. Notes were taken on how the radio transmitter affected the bird's ability to move freely.

Radio transmitters were designed to be light weight and still achieve a rated life of about 20 days. Radio transmitter packages weighed 3.4 to 5 g, about 4 to 6 percent of the average body weight of gray jays. Each radio transmitter had its own frequency within the range 150.700 to 151.275 MHZ. Antenna lengths ranged from 19.1 to 24.1 cm.

In 1973 one radio transmitter was cemented onto two straps made from the latex tubing. This harness and radio transmitter were placed on a gray jay's back and the four strap ends were sewn together with thread across the breast of the bird. Remaining radio transmitters were attached to gray jays by using a modified harness patterned after the American woodcock back-pack harness described by Godfrey (1970) (fig. 9). The harness was reduced to ensure a proper fit on the smaller gray jay, and a piece of coarse cotton fabric was cemented between the harness and the bottom of the radio transmitter. This harness design and radio attachment was used in all subsequent work in 1974 and 1975 (Ostry and Nicholls 1979b). All gray jays were examined and weighed before radios were attached and after birds were recaptured to determine if there were injuries or weight loss because of the radio transmitter and harness.

Radio receivers and hand-held yagi antennas were used in 1973 to track birds to determine general patterns of their movements. In 1974 and 1975, three receiver stations were set up 0.4 km apart within the study area to permit radio-tracking by the triangulation method using degree bearings obtained from each station. A yagi antenna was mounted on top of an Osborne Firefinder at each station (fig. 10). Aerial photos of the study area were used as map bases on the firefinders. The receiving stations' locations on the photos were centered on the firefinders, and the photos were divided into a square grid with a scale of 2.54 cm equaling 83.8 m (fig. 11). Walkie-talkies enabled observers to record simultaneous fixes on radio signals. Resulting azimuth readings were used to locate the position of each individual bird being tracked. Radio fixes were then plotted on outline maps of the study area. These data represented the movement of individual birds over a specific period of time.

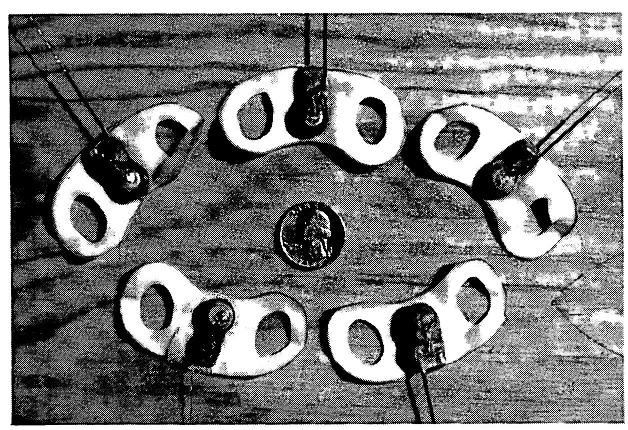

Figure 9.—*Gray jay radio transmitter packages.*

Figure 10.—*Radio telemetry receiving station.*

Animal Behavior

Field Observations

In the 3 years of this study, a total of 49 days were spent observing animal activities, from 0700 to 1700 hrs each day. Animals within infected and healthy trees were carefully observed, especially with reference to the portions of the trees they used and the amount of time they spent in infection centers. The animals were observed by using 7 x 35 binoculars and a 20X spotting scope. Bathing, preening, and feeding behavior of birds received particular attention. Nesting habits of the red squirrel and various bird species known to nest in the study area were also noted.

Captive Bird Studies

It was difficult to observe in the field whether birds ate mistletoe seeds and whether seeds adhering to their bodies were removed through their hygienic habits or other activities and deposited onto trees. These difficulties were overcome by studying birds in captivity. An enclosure with a one-way glass viewing panel was used that allowed us to observe the birds without disturbing them.

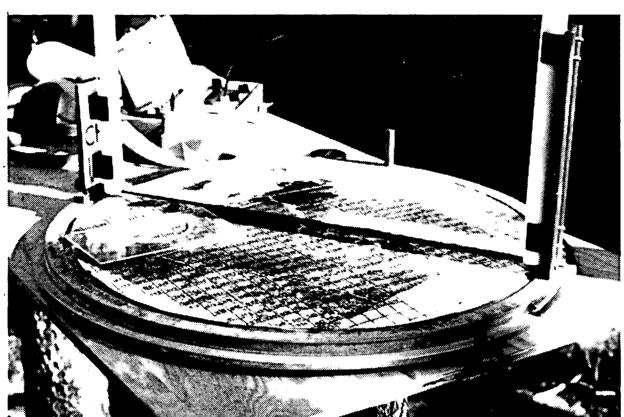

Figure 11.—*Radio telemetry receiving station with map grid used to plot bird locations.*

Food Preference Study

In the laboratory enclosure, dark-eyed juncos (*Junco hyemalis)* and black-capped chickadees (*Parus atricapillus)* were provided with several 0.6 m high potted black spruce trees to serve as perches. Artificial light provided was timed to existing day length.

Birds were given cracked corn, sunflower seeds, millet, mistletoe seeds, shoots, and entire mistletoe berries. At other times only mistletoe seeds were provided. A known number of mistletoe seeds were put into the enclosure and the number missing was recorded at various time intervals. Mistletoe seeds offered to the birds included those enclosed by the exocarp, ones that had been expelled and were still sticky (fig. 12), and those that were washed clean of viscin. Birds were occasionally force-fed mistletoe seeds to determine if the seeds would pass through their digestive systems intact and viable.

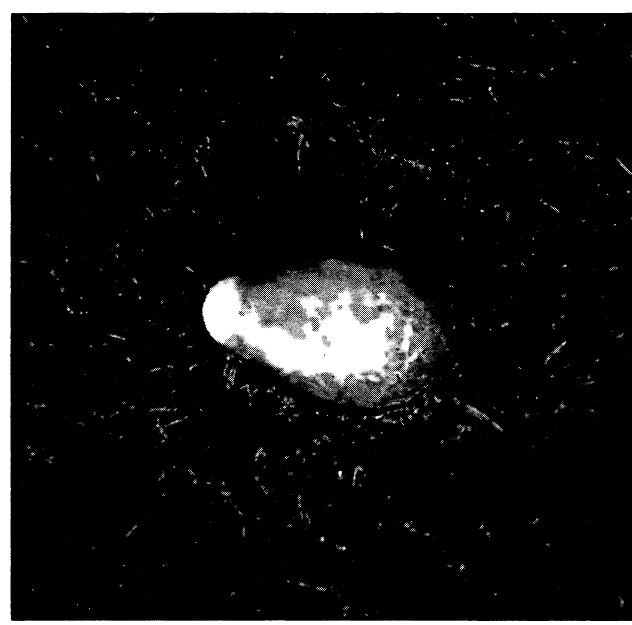

Figure 12.—*Mistletoe seed immediately after being discharged from berry. Note the viscous coating that causes the seed to adhere to objects it strikes (about 30 x).*

Seed Movement Study

To determine if ejected seeds lodged on trees could be moved to other trees by birds, a known number of moistened mistletoe seeds were placed on several branches of two potted trees and allowed to dry. Another tree without seeds on it was placed in the enclosure between these trees. Birds were released into the enclosure without other food to determine if they would search for and eat this seed and in doing so, move seed to adjacent trees.

Bird Preening Study

To observe preening habits of birds and the fate of mistletoe seeds adhering to a bird's body, we placed seeds moistened with a fluorescent brightener on the birds in positions similar to where seeds were found on birds in the field. Seeds removed by the birds could easily be found by using a D.C.-powered black light. Periodically the birds were removed from the enclosure and they, the interior of the enclosure, and the perch trees were closely examined for seeds. The number and position of all seeds were noted and the birds were released back into the enclosure. Birds were observed periodically over several days until all seeds were gone from their bodies. At other times a bird with seeds was released into the enclosure several times a day, and the exact times it took the bird to remove the seeds were recorded.

RESULTS

Characterization of Infection Centers

In addition to the main infection center, 12 satellite infection centers were found within the study area (fig. 13). They ranged in size from a single infected tree, not visible on aerial photographs, to a center 30 by 52 m containing more than 100 infected trees. Centers were randomly located throughout the area and ranged from 72 to 736 m away from the main infection center and from 30 to 250 m away from the nearest other satellite infection center (table 1).

We could not detect small satellite infection centers, but could locate large infection centers using the small-scale and oblique photography. Vertical infrared photography taken in August at a scale of 1:6000 proved best for locating small satellite infection centers. This photography, in contrast to the black and white, allowed distinction between conifers and herbaceous understory visible in infection centers with open canopies.

Figure 13.—*View of a satellite infection center showing the opening created in the canopy caused by the death of heavily infected trees. These openings and associated infected trees attract foraging birds.*

Of 13 areas originally marked on the photos as possible satellite infection centers, one was an area with several wind-thrown trees. This area resembled an infection center on the photos in all respects except it lacked one characteristic of mistletoe infection centers—standing dead trees.

Table 1.—*Characteristics of satellite infection centers*

Center number	Area	Infected trees	Distance and direction from main infection center	Distance from nearest source of inoculum
	m²	*Number*	------------*m*-----------	
1	272	47	250 W	250
2	2	1[1]	72 E	72
3	21	3	191 NE	147
4	1,525	[2]	103 N	59
5	1,362	[2]	206 NW	30
6	326	94	221 N	30
7	1,092	[2]	398 N	162
8	214	31	545 NW	44
9	1,033	[2]	736 NE	74
10	1,308	[2]	707 N	74
11	540	[2]	663 N	30
12	1,071	[2]	545 NE	30

[1] Staminate infection.
[2] Over 100 infected trees.

Trapping, Banding, and Color-Marking

A total of 250 birds and squirrels (not including recaptures) representing 45 species were captured during this study (table 2).

Table 2.—*Birds and mammals sighted or captured in or near a mistletoe-infected black spruce stand in September 1973-78*

Species	Number captured[1]					
	1973	1974	1975	1976	1977	1978
Ruffed grouse (*Bonasa umbellus*)						
Marsh hawk (*Circus cyaneus*)		1				
Sharp-shinned hawk (*Accipiter striatus*)		1	2	1		
Red-tailed hawk (*Bueto jamaicensis*)						
Broad-winged hawk (*Bueto platypterus*)						
Rough-legged hawk (*Bueto lagopus*)						
American-Kestral (*Falco sparverius*)						
Hairy woodpecker (*Dendrocopos villosus*)	1	2				
Downy woodpecker (*Dendrocopos pubescens*)	1					
Pileated woodpecker (*Dryocopus pileatus*)				1		
Black-backed three-toed woodpecker (*Picoides arcticus*)						
Northern Three-toed woodpecker (*Picoides tridactylus*)						
Yellow-bellied sapsucker (*Sphyrapicus varius*)						
Common flicker (*Colaptes auratus*)		2	1			1
Traill's flycatcher (*Empidonax traillii*)			2			
Blue jay (*Cyanocitta cristata*)	5	3	1	3		
Gray jay (*Perisoreus canadensis*)	7	12	4	2	2	4
White-winged crossbill (*Loxia leucoptera*)						
American goldfinch (*Spinus tristis*)						
White-throated sparrow (*Zonotrichia albicollis*)			2	1		
Swamp sparrow (*Melospiza georgiana*)			1			
Dark-eyed Junco (*Junco hyemalis*)		5	4	1		
Solitary Vireo (*Vireo solitarius*)						
Tennessee Warbler (*Vermivora peregrina*)			6			
Yellow Warbler (*Dendroica petechia*)			1			
Yellow-rumped Warbler (*Dendroica coronata*)	6	34	37			
Magnolia Warbler (*Dendroica magnolia*)			1			
Blackburnian Warbler (*Dendroica fusca*)			2			
Pine Warbler (*Dendroica pinus*)		1	1			
Yellow Palm Warbler (*Dendroica palmarum*)			12	1		
Connecticut Warbler (*Oporornis agilis*)			8			
Wilson's Warbler (*Wilsonia pusilla*)			1			
House Wren (*Troglodytes aedon*)						
Brown Creeper (*Certhia familiaris*)	1	1	1			
Red-breasted Nuthatch (*Sitta canadensis*)		1				
Black-capped Chickadee (*Parus atricapillus*)						1
Boreal Chickadee (*Parus hudsonicus*)	4	8	8			
Golden-crowned Kinglet (*Regulus satrapa*)		1	3			
Ruby-crowned Kinglet (*Regulus calendula*)		2	2			
Swainson's Thrush (*Hylocichla ustulata*)			3			
Hermit Thrush (*Hylocichla guttata*)	2	1	2			
Robin (*Turdus migratorius*)						
Northern Flying Squirrel (*Glaucomys sabrinus*)		6				
Red Squirrel (*Tamiasciurus hudsonicus*)	3	3	6	4		2
Least Weasel (*Mustela rixosa*)				1		
TOTALS	30	84	111	15	2	8

[1]Does not include recaptures of previously banded birds.

In the 2 years of trapping during seed dispersal period, we found that 28 animals of seven species had a total of 45 seeds on their bodies (tables 3-4). In 1973, presumably due to a sudden and severe

Table 3.—*Number and location of mistletoe seeds on individual animals trapped during September, 1974*

Date	Animal species	Seeds	Seed location
		Number	
9/17	Gray jay	1	Top of left wing—between 10 and 11 primary feathers
9/18	Red squirrel	1	Right rear leg
9/20	Flying squirrel	2	Right rear leg
		2	Left front leg
		1	Belly
		1	Left rear leg
		1	Right front leg
		1	Left cheek
		1	Right side of rump
	Yellow-rumped warbler	1	Underside of right wing
	Yellow-rumped warbler	1	Belly
	Dark-eyed junco	1	Left cheek
9/22	Gray jay	1	Right cheek
	Dark-eyed junco	1	Underside of left wing
		2	Belly
9/23	Flying squirrel	1	Tail
9/25	Gray jay	1	Top of left wing
TOTALS	10 animals	20	

frost, most seeds either discharged or aborted one night, and no animals were captured with seeds during this short peak period of seed dispersal. Peak seed dispersal was when seeds were being forcibly discharged from most brooms. Only a few brooms discharged seeds during early and late dispersal periods. Post dispersal was after all brooms had ceased discharging seeds. During peak seed dispersal in 1974, we found seeds on 12 percent (N=58) of the birds and squirrels we captured (fig. 14). One dark-eyed junco with three seeds on its body was captured 142 m from the nearest infection center (fig. 15).

In 1975 we found seeds on 20 percent (N=64) of the animals we captured (fig. 16). Several animals captured in 1974 and 1975 had more than one seed adhering to their bodies (tables 3-4). All seeds found on animals appeared to be viable. The viscin on most seeds was still sticky. Some seeds were, however, dried and deeply embedded in the birds' feathers.

In 1974, most birds captured with seeds were warblers (*Dendroica* spp.) that were migrating through the area (fig. 17). In 1975, however, birds most often captured with seeds were gray jays (fig. 18). Red and Northern flying squirrels (*Glaucomys sabrinus*) (fig. 19) also were captured with seeds on their bodies.

Table 4.—*Number and location of mistletoe seeds on individual animals trapped during September, 1975*

Date	Animal species	Seeds	Seed location
		Number	
9/9	Gray jay	1	Underside of left wing
9/10	Yellow-rumped warbler	1	Back
9/10	Gray jay	1	Left side of neck
9/10	Gray jay	1	Right side of breast
		1	Under tail coverts
9/10	Gray jay	1	Underside of right wing
		1	Lower breast
9/11	Gray jay	1	Crown
		1	Underside of left wing
9/11	Red squirrel	1	Left rear leg
9/11	Gray jay	1	Upper right leg
9/11	Gray jay	2	Under tail coverts
9/11	Palm warbler	1	Chin
9/11	Gray jay	1	Belly
9/12	Gray jay	1	Left flank
9/12	Gray jay	1	Underside of left wing
9/13	Gray jay	1	Breast
9/13	Gray jay	1	Upper breast
		1	Left flank
9/14	Gray jay	1	Left side of neck
9/16	Yellow warbler	1	Right flank
		1	Left flank
		1	Under tail coverts
9/16	Gray jay	1	Breast
TOTALS	18 animals	25	

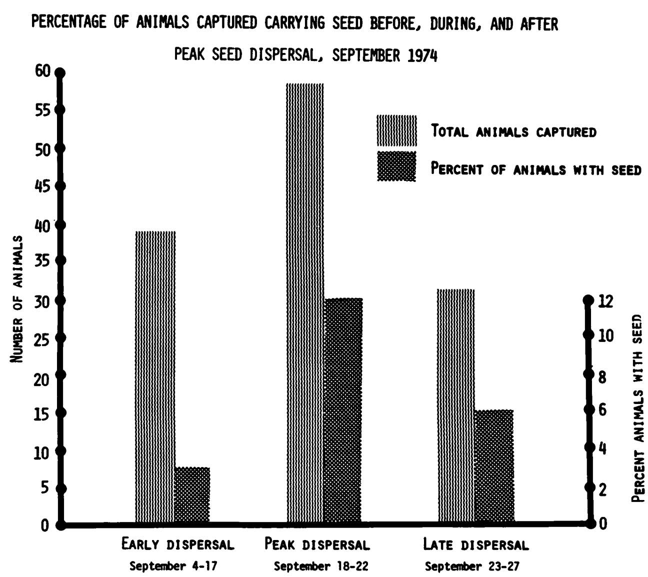

Figure 14.—*Percentage of animals captured carrying seed before, during, and after peak seed dispersal, September 1974.*

Figure 15.—*Dark-eyed junco with 3 seeds on its body captured 142 m from the nearest mistletoe infection. NOTE one seed adhering to neck.*

Figure 17.—*Yellow-rumped warbler with seed adhering to its side captured in infection center.*

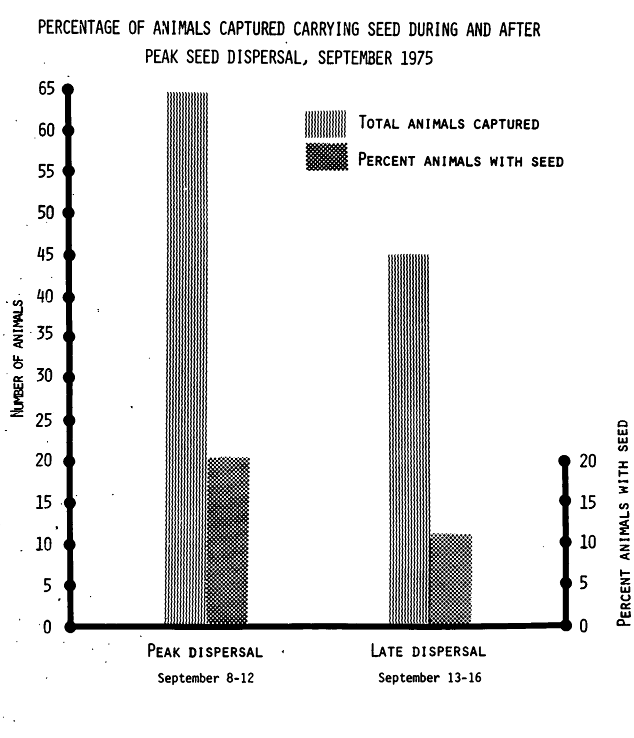

Figure 16.—*Percentage of animals captured carrying seed during and after peak seed dispersal, September 1975.*

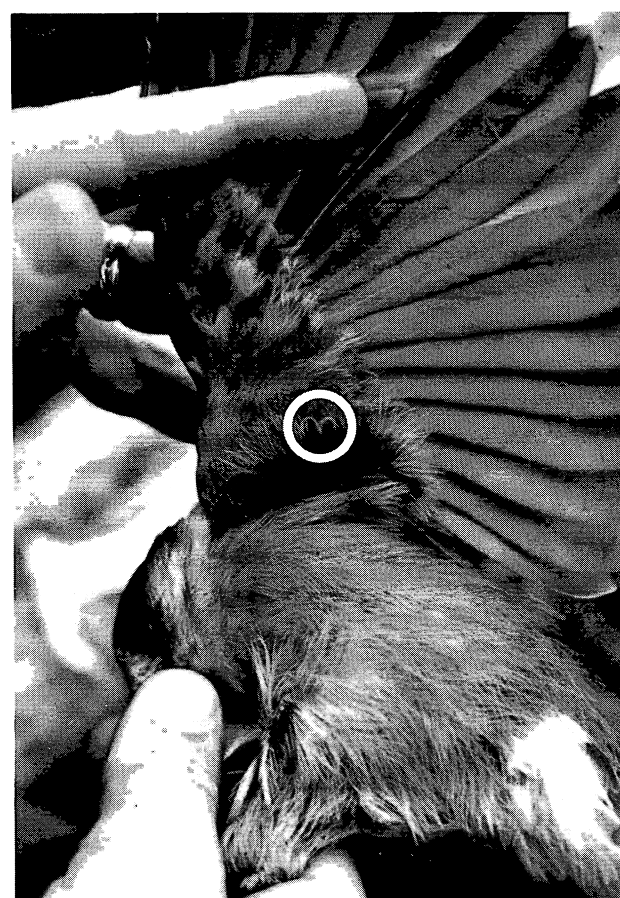

Figure 18.—*Gray jay with a seed adhering to down feathers under its wing.*

Figure 19.—*Flying squirrel captured in infection center with nine seeds adhering to its body. Three seeds are visible in this photo.*

During 1973-1975, 19 gray jays were banded within the study area. In addition, four gray jays banded in 1972 were recaptured and color leg bands were added. These 23 gray jays were recaptured within the study area a total of 126 times during the 3-year study.

Banding and color-marking techniques greatly enhanced identification of individuals and family groups of gray jays. These birds frequently visited infection centers and healthy areas of the stand, indicating that their home range included all or most of the study area.

Three family groups of gray jays were active within the main infection center and two additional groups were active adjacent to it. Although some overlap did occasionally occur, each group maintained its own territory and remained in it most of the time.

In 1975, six red squirrels were color-marked and retrapped several times within the area. Visual observations and marking and trapping data showed that red squirrels occupied a relatively small home range of 0.4 to 0.8 ha.

Telemetry

When radio transmitters were attached with eyelash cement, surgical glue, and tail clip mounts, they easily dislodged. The strap harness used in 1973 was discontinued because it was difficult to put on birds and did not fit properly. However, the modified woodcock back-pack harness was easily put on a bird, fit well, and was used successfully throughout the study on several birds (figs. 20-22). There was no evidence of chafing or other injury to birds due to the harness or radio transmitter. Birds quickly adjusted to the radio transmitter packages, their social and feeding behavior did not appear to be adversely affected, and they did not lose weight.

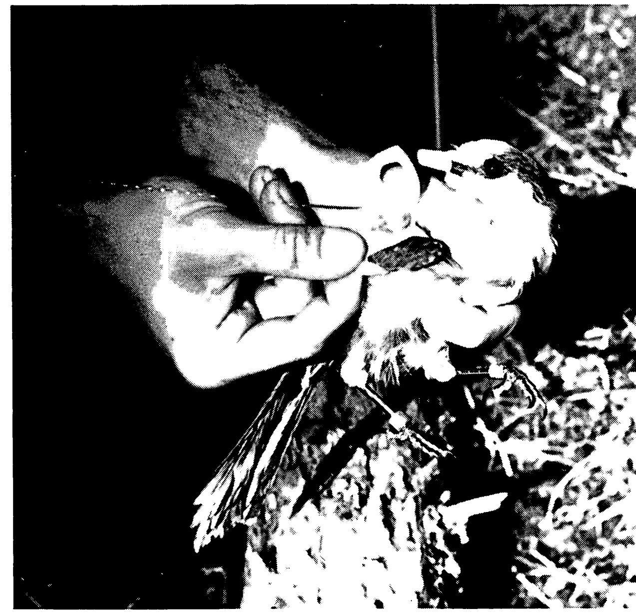

Figure 20.—*Placing radio transmitter onto back of gray jay.*

A total of 115 data days were obtained on the 14 birds with radios. Comparisons of visual sightings with radio fixes on the same bird at a given time indicated that the tracking system using the firefinders was accurate to ± 83 m.

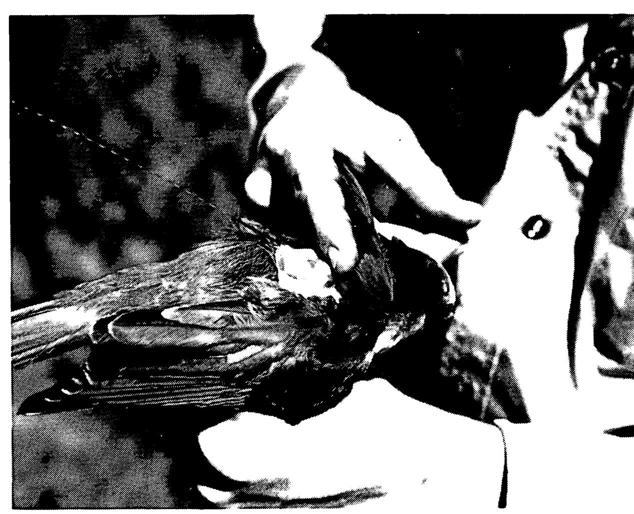

Figure 21.—*Position of radio transmitter on back of gray jay.*

Figure 22.—*Gray jay with radio transmitter in place before release.*

Directional radio fixes obtained in 1973 with hand-held antennas provided information on the general location of home ranges of three gray jays. The jays used the main mistletoe infection center near Spirit Lake but each used a slightly different part of the remaining spruce stand.

The approximate 1974 home ranges of individual gray jays ranged from 8 to 21 ha as exemplified in figure 23. Home range, defined by Burt (1940), is that area used regularly by a bird during activities such as food gathering, seeking shelter, and rearing young. Because in this study gray jays were not monitored throughout the year, home range was described in terms of an activity radius as explained by Odum *et al.* (1955). It was evident that gray jays used all parts of their home range, spending much of their time in mistletoe infection centers. For example, two radio-tagged gray jays were trapped seven times with one or more mistletoe seeds on their bodies (fig. 24). There was only a small overlap in the home ranges of individual gray jay family groups. Thus, each family group had a high degree of exclusive use of their home range, which could be classified as a territory as defined by Pitelka (1959). Gray jays were most active during morning hours, the hours when most mistletoe seeds are dispersed (Hudler and French 1976).

Infection patterns in the study area and the movements of gray jays, as determined by radio telemetry,

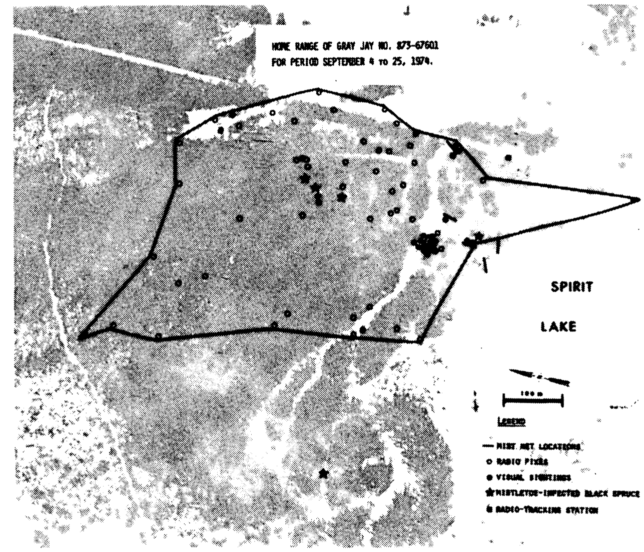

Figure 23.—*Home range of gray jay No. 873-67601 for the period of September 4 to 25, 1974, was 21 ha based on 50 radio fixes and 23 visual sightings.*

were similar in many instances. Isolated mistletoe-infected trees were present along a drainage ditch east of the main infection center. Many radio fixes as well as visual observations indicated that gray jays frequently used this area presumably to search for insects that were common near the open water. Gray jays were observed preening while perched on trees along the ditch.

Animal Behavior

Field Observations

Mistletoe seeds were dispersed in the area when resident birds and squirrels gathered and stored food.

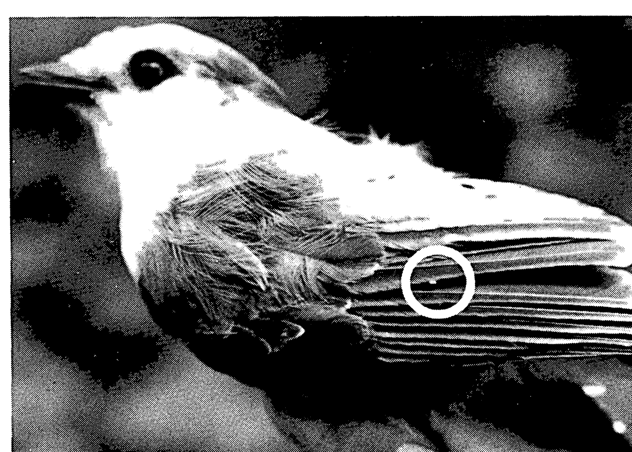

Figure 24.—*Radio-tagged gray jay recaptured with a seed adhering to a primary wing feather.*

At no time were birds or other animals seen searching for or eating mistletoe seeds or shoots.

Seed dispersal coincided with the southern migration of many bird species through the area in 1974. Warblers were predominantly active in infection centers and could be observed foraging for insects within dead and dying mistletoe-infected trees. At times as many as 50 to 100 warblers could be seen searching for food within seed-bearing brooms of infected trees.

Red squirrels were observed gathering and storing spruce cones during this time, jumping from broom to broom and from tree to tree during their foraging, often triggering seed discharge. Six red squirrel nests and a robin's nest were found in brooms.

All birds were observed preening and bill-wiping during and after feeding. Gray jays spent much time preening their feathers and bill- wiping, usually while in the tops of spruce.

Birds and squirrels used all parts of trees from low lateral branches to terminal leaders when foraging and perching. Boreal chickadees (*P. hudsonicus)* foraged directly in mistletoe brooms more frequently than other species. Chickadees hopping around within infected trees discharged many seeds. Food gathering and storage by gray jays brought them into contact with infected and healthy trees. Visual observations indicated that areas used for storing food were free from mistletoe infection. Less bird activity was observed in dense, healthy portions of the stand. However, in large and small mistletoe infection centers, warblers, chickadees, and gray jays were common, probably because more insects were available in the infected and dead trees.

Food Preference Study

Juncos and chickadees did not eat mistletoe seeds. When given mistletoe seeds, berries, and mistletoe shoots only, both bird species picked up seeds but never swallowed them. At the end of the trials, 81 percent of the mistletoe seeds put in the feeding trays were accounted for. This indicates that the birds ate mistletoe seeds only occasionally and then only if no other source of food was readily available.

Force-feeding birds provided evidence that mistletoe seeds may not be palatable to them. When mistletoe seeds were placed at the back of the mouth, the bird would use its tongue to work it forward and then would spit it out. In all instances, seeds were not readily accepted and were either immediately spit out whole or smashed with the bill. Birds readily ate cracked corn after being offered mistletoe seeds.

Seed Movement Study

Of the 660 mistletoe seeds placed on branches of spruce trees, 177 of them were removed. Of these, 96 (12 percent) were unaccounted for. Most likely, the seeds were smashed in such a way as to render them unidentifiable. As was observed in the field, the chickadees in the enclosure spent much of their time searching branches and needles of trees for food. They often pecked at the seeds and removed many of them. At times as many as six or more seeds were picked off branches, smashed, and then spit out. Only rarely did it appear that these smashed seeds were swallowed.

Birds on several occasions removed seeds from one tree, flew to another, and either smashed or dropped them intact while perched in that tree. Seeds were found at the base of trees that had no seeds placed on their branches, but, none were found adhering to branches. On trees that had mistletoe seeds placed on them, some branches had more seeds adhering to them than were originally placed there.

Bird Preening Study

Birds released into the enclosure without seeds on their bodies periodically preened and groomed their feathers and consistently bill-wiped after feeding and drinking. However, birds released into the enclosure with seeds on their bodies preened and bill-wiped much more often and longer. Seeds on the bill and head were removed immediately by bill-wiping and rubbing the head against a branch. The last seeds to be removed were either inaccessible or not bothersome such as those on the upper or lower tail coverts or under the wings. Several times seeds were found on birds 48 hours after they had been put on. A total of nine seeds, seven from juncos and two from black-capped chickadees, were found tightly attached to spruce needles and branches as a direct result of preening and bill-wiping. These seeds were on susceptible portions of the trees and positioned so that they could have caused infections if they would have been allowed to germinate (fig. 25).

DISCUSSION

All of the satellite infection centers examined were too far from the main infection center and from each other to have originated from the explosive discharge of mistletoe seed. This indicates that some other agent was involved in seed dispersal.

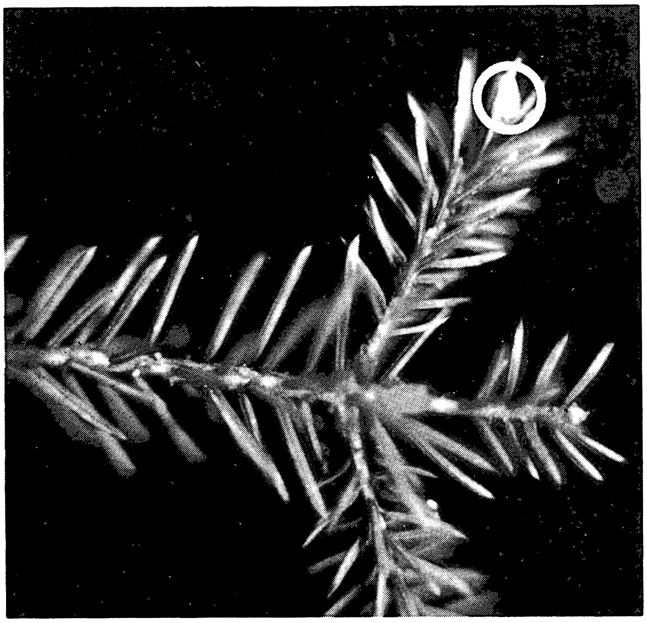

Figure 25.—*Twig taken from potted tree used as a perch in enclosure in the captive bird studies. Black light was used to locate fluorescent-dyed mistletoe seed wiped onto branch during preening.*

Wind may influence local spread of dwarf mistletoe within a center (Parmeter and Scharpf 1972) but is not thought to be responsible for establishing isolated satellite infection centers (Hudler and French 1976). The random location of satellite centers in the Spirit Lake area and distances from other infection centers support this theory (Ostry 1978). Birds and squirrels active within areas of mistletoe infection were identified as important agents responsible for the type of infection pattern present. Bird activity, particularly that of the gray jay, was high in all areas where satellite infections were found.

Many factors, both biological and physical, limit the number of satellite infection centers that arise from vector-borne seeds. These factors may explain why relatively few satellite centers are present even though many animals come into contact with mistletoe seeds.

In the Spirit Lake area most of the satellite infection centers were fairly large and easily located with large-scale aerial photography. However, when only a few infected trees were present, it was extremely easy to miss seeing them on the ground and often impossible to detect them on aerial photographs.

A single, vector-borne staminate infection could remain undetected throughout the rotation of a stand, as could scattered pistillate-infected trees. Only when several infected trees die, opening the crown canopy, does mistletoe infection become evident in a stand. Depending upon the vigor and age of the hosts, it may take many years for mistletoe to develop, spread, and eventually kill a tree. As a result, many vector-borne infections may go unnoticed.

If no vector were involved, dwarf mistletoe infection would slowly radiate out from the initial point of infection. This is not the pattern seen. Instead, dwarf mistletoe infection resembles the pattern of infection seen in the true mistletoes. This pattern consists of many secondary infections resulting from animal activity that develop away from the initial infections. Considering the distances and locations of satellite infection centers in the Spirit Lake area and elsewhere, there is little doubt that vector-borne seed and subsequent infection augment the spread of dwarf mistletoe seed.

Birds and squirrels are important in spreading dwarf mistletoe seed to new areas, but they are even more so in intensifying infection within trees and a local area. Birds and squirrels in infection centers come into contact with seeds when they forage for food, build nests, or perch in infected trees. They often trigger seed discharge as they jump or hop in brooms.

Our study of animals trapped during the time of seed dispersal indicated that seeds can adhere to fur or feathers and be carried to and deposited on healthy trees. Results of the captive bird study supported this hypothesis.

Seeds on the head of a bird are removed quickly. Seeds on parts of the bird's body which are hard for it to reach or that have dried deep in the feathers are left on longer. These seeds are only removed after several thorough bathings. Some seeds were found on birds 2 days after placement. This indicates that seeds could be carried great distances by migratory birds before being removed. These birds, perched on portions of trees susceptible to mistletoe infection, could inoculate trees during bathing and preening activities.

Under humid conditions such as heavy dew, wet snow, or rain, seeds adhered to birds active in infected trees, and several seeds were found on birds after all brooms had stopped discharging seeds. This post dispersal period lengthens the period of time in which a bird or squirrel is likely to come into contact with seeds. All the seeds found on squirrels were on the surface of their fur. Seeds adhering lightly to their bodies could easily be transferred to healthy foliage during their foraging.

In 1975 mistletoe fruits matured early and the peak seed dispersal period began on September 8, 10 days earlier than in 1974. Migrating birds were just beginning to pass through the study area. Some of these species were not trapped in the area until long after the seeds had been discharged. Thus, resident birds such as gray jays were presumably more important as potential vectors. Species of birds acting as vectors may vary from year to year depending upon the timing of seed dispersal in relation to migration patterns of the various species. A possibility exists that migrating birds could spread *A. americanum*, found on jack pine in southern Ontario and Manitoba, to jack pine in the Lake States. Jack pine is a major species in the Lake States and the introduction of *A. americanum* by bird vectors could threaten this resource.

Involvement of vectors has management implications in controlling this parasite. Animal vectors can increase the rate of spread and intensification of dwarf mistletoe infection locally. Once established, each center of dwarf mistletoe infection will remain an inoculum reservoir for future infections. It may be necessary to control these small centers within a stand to prevent additional centers from developing as a result of vector-borne seed (Ostry and Nicholls 1979a). To protect commercially valuable stands from vector-borne infections, control measures may also be warranted in black spruce sites of marginal value that serve as reservoirs for the parasite. This would be especially important if the commercial stand was early in its rotation (Johnston 1977).

Gray jays use infection centers as small as 20 m^2. From a management standpoint this means a small center overlooked in a control program may provide inoculum that could be spread by birds to other parts of the stand. Birds are attracted to stand edges, especially to mistletoe-infected trees that support large numbers of insects. For this reason, it is important to eliminate all infected trees and trees that may have latent infections.

CONCLUSIONS

1. Birds and squirrels use mistletoe-infected trees for nesting and food-gathering. They probably do not eat mistletoe seeds.
2. Mistletoe seed dispersal often coincides with the period of peak animal activity.
3. Openings in spruce stands resulting from mistletoe-killed trees are used more than healthy portions of a stand by many bird species.
4. Mistletoe seeds discharged from their berries can stick to the fur or feathers of animals.
5. Previously discharged seeds adhering to branches can be inadvertently picked up on the bodies of foraging animals under conditions of high humidity.
6. Preening and hygienic habits of birds are responsible for seeds being deposited onto healthy trees.
7. Birds and squirrels are important in intensifying mistletoe infections in localized areas due to their activities during seed dispersal. Gray jays may be one of the most important species responsible for initiating new satellite infection centers.
8. Migrating birds may disseminate mistletoe seed over long distances.
9. The pattern and distribution of some satellite infection centers result from the activities of animal vectors.
10. In some management situations, small centers of mistletoe infection should be controlled to minimize vector-borne infections.
11. Radio telemetry techniques and equipment can be effectively used to study small avian vectors of pathogens.

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Animal vectors of eastern dwarf mistletoe of black spruce. Res. Pap. NC-232. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 16 p.

Describes a study to determine the importance of animals in the spread of eastern dwarf mistletoe of black spruce. Radio telemetry, banding, and color-marking techniques were used to study vectors of this forest pathogen.

KEY WORDS: radio telemetry, disease, parasite, *Perisoreus canadensis,* forest management.