Chapter 11
Evolution of a Short-Term Study of Lodgepole Pine Dwarf Mistletoe Vectors that Turned Into a Long-Term Study of the Remarkable Gray Jay on the Fraser Experimental Forest, Colorado, 1982–2009

Thomas H. Nicholls

Abstract This is a summary of a 5-year short-term study that evolved into 28 years of long-term research on the US Department of Agriculture, Forest Service's Fraser Experimental Forest in Colorado. The study was begun in 1982 by Forest Service Research Scientists Thomas H. Nicholls and Frank G. Hawksworth to determine the importance of mammal and bird vectors in the long-distance dissemination of lodgepole pine (*Pinus contorta*) dwarf mistletoe (*Arceuthobium americanum*), an economically devastating forest disease of western forests. The original vector study evolved into a study of a plant growth regulator using ethephon for controlling small pockets of lodgepole pine dwarf mistletoe initiated by vector-disseminated seed. An in-depth study of the ecology of the most common vector of dwarf mistletoe, the gray jay (*Persisoreus canadensis*), followed. The gray jay study evolved into sub-studies on: radio-tracking gray jays between infected and healthy stands in 1983, the exotic West Nile virus in 2003, the development of a method to predict populations and habitat carrying capacities for gray jays by using modeling and geographic information systems techniques in 2005, the use of the polymerase chain reaction technique to sex gray jays for the first time in 2005, and determining the impact of the native mountain pine beetle (*Dendroctonus ponderosae*) outbreak on gray jay habitat and population in 2009.

Keywords Gray jay · Fraser experimental forest · Lodgepole pine · Dwarf mistletoe · Ethephon · Frank G. Hawksworth · Mountain pine beetle · Polymerase chain reaction · West Nile virus

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11.1 Introduction

11.1.1 The Fraser Experimental Forest Study Area

The 9,300-ha Fraser Experimental Forest (EF), in the Arapaho-Roosevelt National Forest, is located 9.6 km southwest of Fraser, in Grand County, CO. It is administered by the Rocky Mountain Research Station headquartered in Fort Collins, CO. The elevation of the Forest ranges from 2,682 to 3,903 m.

The USDA Forest Service dedicated the Fraser EF in 1937 as an outdoor laboratory to research subalpine forests representative of much of the central and southern Rocky Mountains. The Fraser EF is particularly noted for its long-term climate and hydrological research. In 1978, the United Nations designated the Fraser EF a World Biosphere Reserve, one of many worldwide dedicated to the study and conservation of the diversity and integrity of plant and animal communities within natural ecosystems. Forest Service EFs and Biosphere Reserves by their very nature are strategic places for carrying out long-term ecological and environmental studies with minimal human disturbance.

11.1.2 Research with Frank Hawksworth

An animal vector study on lodgepole pine (*Pinus contorta*) dwarf mistletoe (*Arceuthobium americanum*) was initiated in 1982 on the Fraser EF by this author (Fig. 11.1) and Frank Hawksworth (Fig. 11.2). At the time, I was a Forest Service Research plant pathologist and project leader of the Forest Disease Research Project at the US Department of Agriculture, Forest Service's North Central Forest Experiment Station (NCFES), now the Northern Research Station, St. Paul, MN. Hawksworth held similar positions at the Rocky Mountain Forest and Range Experiment Station, now the Rocky Mountain Research Station.

In the western USA, dwarf mistletoe species have a greater impact on forests than any other pathogen, decreasing growth rates, distorting tree form, reducing wood quality, and killing trees. It has been estimated that more than 11 million ha are infested in western forests and Alaska with 4.64 million m^3 of wood lost annually (Hawksworth and Shaw 1984). Lodgepole pine dwarf mistletoe affects about 40 % of the lodgepole pine type, causing major economic timber production losses through tree deformity and mortality (Drummond 1982). Assessments of the effects of lodgepole pine dwarf mistletoe in Montana, Colorado, and Wyoming indicated the annual loss exceeds 1.1 million m^3/year (Hawksworth and Dooling 1984).

The major economic impact of lodgepole pine dwarf mistletoe inspired scientists to learn more about its biology and management. Their studies are summarized in Hawksworth and Johnson (1989). Some of these studies were initiated on the Fraser EF as follows.

Fig. 11.1 Project Leader, Research Plant Pathologist, and Wildlife Biologist Thomas H. Nicholls from the North Central Forest Experiment Station, St. Paul, MN holding a banded 11-year-old gray jay in 1993 (**a**, *left*) and four gray jays in 2009 (**b**, *right*), Fraser Experimental Forest, CO

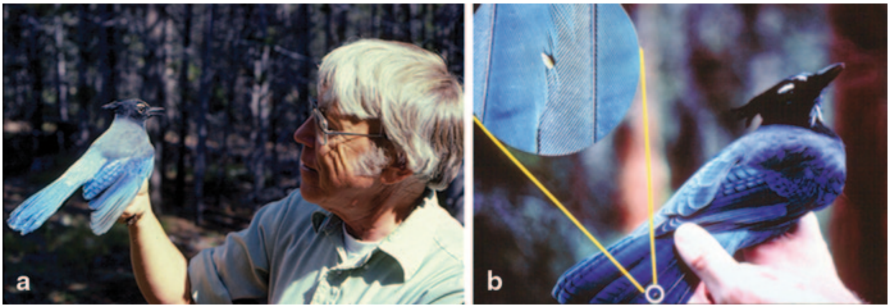

Fig. 11.2 Project Leader and Research Plant Pathologist Frank G. Hawksworth from the Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, holding a Steller's jay in 1982 (**a**, *left*) with a dwarf mistletoe seed on its tail feather (**b**, *right*), Fraser Experimental Forest, CO

In 1982–1983, Frank Hawksworth and I decided to work together because we were both interested in studying how dwarf mistletoes spread long distances and how isolated pockets of infection become established in otherwise healthy forest stands. My experience and academic training were in both plant pathology and wildlife ecology and I held a Federal Bird Banding Permit needed to capture, band, and release birds after examining them for various pathogens. I was interested in how plant and animal pathogens were picked up and disseminated by vectors and Frank was a world authority on dwarf mistletoes. Frank was also incredibly productive as a scientist—writing more than 275 papers—while having significant administrative duties as well. He had initiated several long-term dwarf mistletoe studies and had several of them ongoing in various western states when we worked together. Frank was also an avid birder, keeping life lists even of birds seen in his own backyard. His expertise and mine made a good match to conduct a study of vectors of lodgepole pine dwarf mistletoe on the Fraser EF, where long-term studies were encouraged.

Frank turned out to be an important mentor for me. I found him to be an amazing friend, teacher, scientist, forest pathologist, administrator, and always a pleasure to work with and be with. He had supreme attention to scientific detail, a necessary scientific skill I wanted to learn. He taught me that skill through his patient guidance and his subdued, good-natured humor, often displayed when least expected. He also taught me to be curious about almost everything biological and to see how everything is tied together in the web of life.

I also learned why Frank was such a productive scientist. In those days, Forest Service project leaders were supposed to spend about 30 % of their time on administrative and leadership duties and 70 % on scientific research. I was spending too much time on administrative duties and not enough time on scientific research and leadership where my real interests were. In Frank's office, I noticed a big pile of papers in his in-box. I asked him about it one time. He claimed that he let all administrative requests for what he thought was "nonessential" information generated by others to pile up in his in-box until someone asked for the information a second—or sometimes a third—time, after which he promptly responded. More often than not, however, no one ever asked him again for that information, giving him more time for his research. Another reason Frank was so productive was that he worked long hours, often on weekends. He was efficient and he hired good people who were willing to work as hard as he did.

11.2 Lodgepole Pine Dwarf Mistletoe Studies on the Fraser Experimental Forest

11.2.1 Background

Early studies revealed that dwarf mistletoe spreads short distances by sticky seed shot up to 15 m from ripening explosive fruits. The seeds stick to anything they hit, including birds and mammals.

It was not known how long-distance spread occurred in lodgepole pine until our vector study. However, bird and mammal vectors were suspected as a result of previous studies by former students and technicians who worked on black spruce (*Picea mariana*) eastern dwarf mistletoe (*Arceuthobium pusillum*) in Minnesota (Hudler et al. 1974, Ostry et al. 1983). Hudler et al. (1979) went on to discover birds also disseminated seeds of ponderosa pine (*Pinus ponderosa)* dwarf mistletoe (*Arceuthobium vaginatum*).

The objective of our original 1982 study was to identify animal vectors of dwarf mistletoe on lodgepole pine and to determine their importance in the establishment of new infection centers that could not be explained by normal short-distance spread of sticky mistletoe seeds. The term vector as used here is defined as any animal able to transmit a pathogen. Cell traps, mammal ear tags, mist nets, bird bands, and radio telemetry were used to trap mammals and birds and to mark them individually to document their movements and to learn how mistletoe seeds were carried beyond the normal seed dispersal range of infected trees.

11.2.2 Bird and Mammal Vectors

The study identified the following ten bird and four mammal vectors of lodgepole pine dwarf mistletoe seed: the gray jay (Fig. 11.1), Steller's jay (*Cyanocitta stelleri*; Fig. 11.2), mountain chickadee (*Parus gambeli*), dark-eyed junco (*Junco hyemalis*), hermit thrush (*Catharus guttatus*), American robin (*Turdus migratorius*), yellow-rumped warbler (*Dendroica coronata*), northern saw-whet owl (*Aegolius acadicus*), Townsend's solitaire (*Myadestes townsendi*), three-toed woodpecker (*Picoides tridactylus*), least chipmunk (*Eutamius minimus*), golden-mantled ground squirrel (*Spermophilus lateralis*), red squirrel (*Tamiasciurus hudsonicus*), and pine marten (*Martes americana*). The study found that birds and mammals foraging in infected lodgepole pine become inadvertent targets of explosive, sticky mistletoe seeds that stick to feathers or fur. Although such events are rare, a sufficient proportion of birds (27 %) carried dwarf mistletoe seeds to make some dispersal probable. As animals move about the forest, or clean their bodies, mistletoe seeds can be deposited on healthy lodgepole pine where they sometimes stick, germinate, and cause new infections.

Previous studies on the Fraser EF had found 59 species of birds using the Forest. During this study, we added 14 species to the Forest bird list that we either banded or observed. Detailed results are reported in Hawksworth and Weins (1996), Hawksworth et al. (1987), Nicholls and Hawksworth (1983), and Nicholls et al. (1984a, b, 1987c, 1989).

11.2.3 Control of Dwarf Mistletoes

11.2.3.1 Chemical Control

A chemical control method was tested on the Fraser EF in the 1980s in cooperation with Forest Pathologists David Johnson, USDA Forest Service, Forest Pest Management, Lakewood, CO, and Kathy Robbins of NCFES, both now retired. This work was inspired by William Livingston et al. (1985), who showed that ethylene-releasing agents could help prevent the spread of black spruce eastern dwarf mistletoe in Minnesota.

The objective of this work was to determine whether small pockets of infected trees originating from vector-disseminated seed could be saved and adjacent

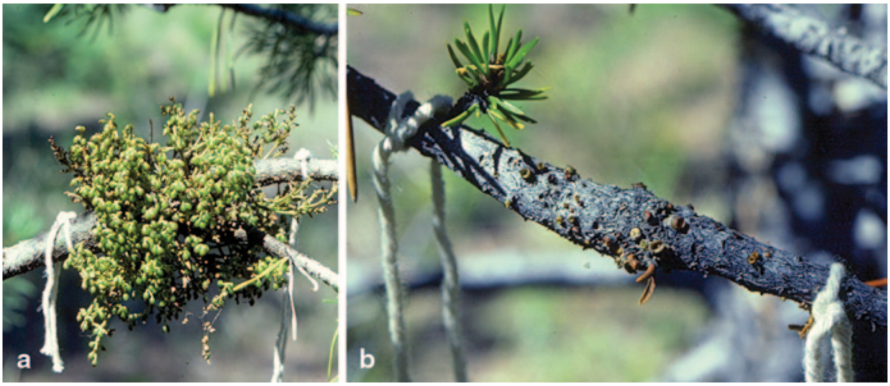

Fig. 11.3 Lodgepole pine dwarf mistletoe before (**a**, *left*) and several days after (**b**, *right*) being sprayed with an ethephon growth regulator, Fraser Experimental Forest, CO

healthy trees protected by treating infected trees with ethephon, a growth regulator. It acts by releasing ethylene, a plant hormone, which when absorbed by the plant interferes with the growth process. Ethephon is found in nature and, among other things, causes tree leaves to abscise at the end of a growing season. We found that it did the same to mistletoe shoots (Nicholls 1989; Nicholls et al. 1987a, b).

Ethephon at 2,500 ppm in water with a spreader applied by ground sprayers was effective in causing mistletoe shoots, flowers, and fruits to drop off trees (Fig. 11.3), thereby significantly reducing seed dispersal for up to 4 years after treatment. However, it did not kill the parasite's endophytic system in the host tissue, so shoots often resprouted in 3–5 years. Many of the sprouts eventually produced seeds. As a result, frequent ethephon treatments would be required to effectively manage this disease, making it economically unfeasible for use under forest conditions.

Ethephon treatments using ground sprayers can be used to slow the development and spread of dwarf mistletoe in high-value trees located in campgrounds, small parks and golf courses, and around buildings. Control of dwarf mistletoe shoots presumably can also reduce the drain of nutrients from the host tree to the parasite. Because of these benefits, ethephon was registered for these uses with the US Environmental Protection Agency. Aerial applications of ethephon by helicopter, however, were not effective in controlling lodgepole pine dwarf mistletoe under forest conditions (Robbins et al. 1989). These research results spawned additional studies of ethephon control of other western dwarf mistletoe species, which achieved similar results.

11.2.3.2 Silvicultural Control

Vector study results explained how new satellite infection centers become established in healthy stands far removed from main infection centers. Dwarf mistletoe plants are dioecious, so a female and male plant would have to become established within pollination range to develop a satellite infection. Although satellite infection centers are relatively scarce, the explosive mechanism of seed dispersal utilized by dwarf mistletoes enables them to intensify and spread rapidly once a new infection center is established.

The most practical management plan recommended for controlling small infection centers in otherwise healthy stands is to find them through periodic, systematic land or aerial surveys and remove them. Removal can be done by cutting infected trees and a 40-m-wide buffer strip of adjacent trees that may be harboring latent infections yet not showing signs and symptoms. Dwarf mistletoe is an obligate parasite; once the host is killed, so is the parasite. Follow-up surveys 5–10 years after eradication efforts will determine whether all infected trees were removed, or whether more eradication of infected trees is needed. This management action is recommended only in stands being managed for forest products. When used with other dwarf mistletoe management strategies, this approach effectively prevents, or slows, the spread of dwarf mistletoe (Hawksworth and Johnson 1989).

11.2.3.3 Benefits of Dwarf Mistletoes to Wildlife

In the previous study, I had been looking through the eyes of a forest pathologist. Later, having switched disciplines by becoming a wildlife project leader and scientist in 1986, I found that control of dwarf mistletoe may not be the best management action to take in all situations, especially in terms of overall ecosystem health and diversity of wildlife.

Dwarf mistletoes are a major cause of tree deformity and mortality in affected coniferous stands throughout the Northern Hemisphere and lead to significant economic damage. However, the resulting dead and declining trees have a positive effect on many wildlife species that use infected trees for nesting, shelter, and food (Hawksworth and Weins 1996; Nicholls et al. 1984a; Ostry and Nicholls 1991). Mistletoes create canopy openings providing conditions suitable for plant species not ordinarily found in dense, healthy stands, which in turn attract a variety of animal species. Mistletoe shoots are eaten by some mammal and bird species. Insects are abundant in affected trees and thus attract a wide variety of insect-eating birds such as woodpeckers, nuthatches, and warblers, as observed in the Fraser EF. In addition, several species of raptors and songbirds nest and forage in the witches' brooms produced by various dwarf mistletoe species.

The Fraser EF study and related studies have shown that mistletoes play a positive role in creating more compositional (both plant and animal), structural, and functional diversity in forests. Whether this result is good or bad depends upon management objectives. For example, if timber management for tree health and forest products is the primary objective, dwarf mistletoe control is essential when economically feasible. If forest health, wildlife management, species diversity, and wildlife viewing are the primary stand objectives, mistletoe control is not essential and may even be detrimental to some wildlife species, especially in marginal and noncommercial stands.

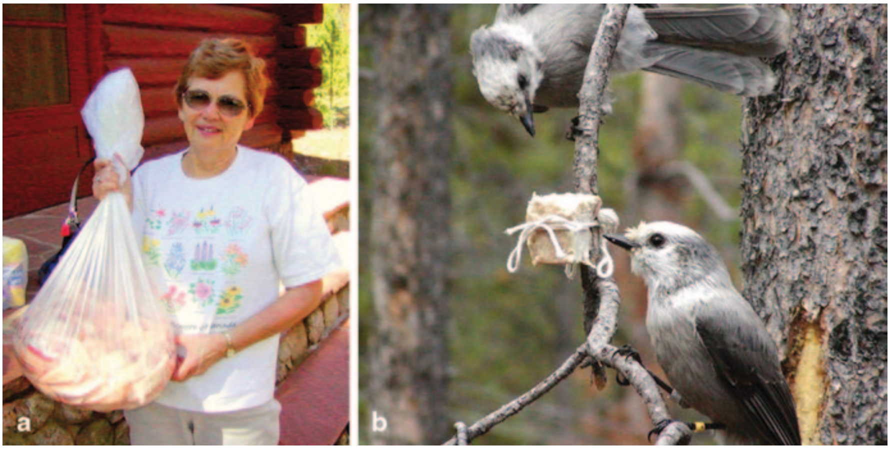

Fig. 11.4 Forest Service Volunteer Mary Lou Nicholls preparing suet bait in 2007 for trapping gray jays in mist nets, Fraser Experimental Forest, CO (**a**), and gray jays responding to the bait (**b**)

11.3 Gray Jay Studies on the Fraser Experimental Forest

11.3.1 Background

I found the ecology of the gray jay so interesting in its own right that I continued research on this species after my retirement in 1994. My wife, Mary Lou, and I continued to work on the project as Forest Service volunteers (Fig. 11.4). Mary Lou's assistance was essential to the research effort as she took on duties such as making suet bait balls and preparing meals for all the researchers, working dawn to dusk along with the rest of us.

11.3.1.1 Natural History of the Gray Jay

Although the gray jay is a vector of lodgepole pine dwarf mistletoe, it became clear in our subsequent studies that the gray jay is an integral part of a healthy ecosystem and an important indicator of forest health where it lives. We found the gray jay to be a remarkable, highly intelligent, long-lived, territorial bird with an amazing memory and skills in survival, foraging, and communication, as detailed in the following summary of its natural history gathered from our research, general sources, and material in *The Birds of North America* (Strickland and Ouellet 1993).

The gray jay is in the order of perching birds (Passeriformes) and belongs to the family Corvidae, which includes crows, ravens, magpies, and jays, all highly intelligent birds. Some of its common names are camp robber, Canada jay, meatbird, and whiskey-jack. The species is found only in North American boreal and subalpine forests. Preferred habitats include black spruce, tamarack (*Larix laricina*), white spruce (*Picea glauca*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine.

The gray jay is well known for its bold, almost tame, behavior around humans. A frequent visitor at backwoods cabins, campsites, logging camps, or isolated resorts, it will often raid human food caches, or even take food from human hands. Despite its association with humans, this jay does not live in towns or civilized developments. It is exclusively a bird of remote forests and thus a good indicator species of healthy, pristine forests. In fact, gray jays disappear as soon as an area becomes overly developed, or its habitat destroyed.

Male and female gray jays have similar plumage, making it difficult to sex in the field. Their average weight is 73 g. Adults generally pair for life, but will take a new mate upon the loss of one. They are nonmigratory, long-lived birds (up to 17 years) with an adult annual mortality rate of about 20 %, as compared to about 50 % mortality in migratory birds. Being nonmigratory, it avoids many migration perils, which helps to explain its higher survival rate. Adult gray jays maintain and defend a permanent year-round territory ranging from about 25 to 150 ha based on various studies.

Gray jays have an omnivorous diet that includes insects, berries, mushrooms, carrion, and nestling birds. During non-winter months, especially in late summer and fall, the jay shapes some of its food into oval pellets, or boli, with its tongue. It permeates the bolus with saliva produced by two large mandibular salivary glands located on each side of the head just behind the beak. The sticky saliva is used to glue boli to vegetation or within bark crevices, where they dry to form a hard protective covering around the food. With its remarkable memory, the gray jay finds most of its hidden food, allowing this species to survive often harsh, winter weather conditions. This food-stashing behavior eliminates the need to migrate south for winter to find food, as many bird species do. Stored food caches also allow gray jays to nest earlier than most birds as some of the food is used to feed nestlings before spring food supplies become plentiful.

Gray jays build a new nest every year in late February or early March on a branch or in an upright crotch of a conifer, commonly 2 m off the ground. It is a bulky, compact structure often containing strips of bark, twigs, grasses, mosses, spider webbing, cocoons, and catkins. It is heavily lined with fine grasses, feathers, fur, and hair, providing thick insulating walls that help to keep eggs warm during freezing temperatures. The male chooses the nest site, initiates the nest building, and is joined later by the female. The nest takes about 3 weeks to build. Only one brood is produced annually. The female lays two to five greenish, speckled eggs, which she incubates. The male will feed the female on the nest. Eggs hatch in 18–20 days and young fledge in 20–23 days, well before migrant birds return. Fledging birds are sooty gray all over and look completely different from their parents. They achieve their adult plumage by late fall after molting juvenile feathers.

Juvenile gray jays start a remarkable deadly struggle for dominance in June. The winning dominant juvenile bird expels its rival siblings from its parents' territory (Strickland 1991). About 80 % of expelled siblings die by fall. The other 20 % move into a failed nesting territory occupied by two adults. This behavior explains the trios of gray jays commonly seen in fall and winter. The winner has the advantage of learning the locations of its parents' food caches; using this food source allows it to overwinter successfully. This nonbreeding bird does not help parents with nest building or feeding of young in the nest. Nest activity, like nest predation, are thus reduced. However, it will help feed the young after they fledge. The dominant offspring will often stay with its parents for 2–3 years, or until a nearby territory becomes available, which it then occupies.

Gray jays have a complex communication system that uses many different vocalizations to keep in touch with each other or to defend their territories. They can also easily imitate other birds such as ravens and Steller's jays.

According to Breeding Bird Survey and Christmas Bird Count long-term data, the gray jay overall is doing well. However, there are concerns of possible declining local populations, especially in Alberta, Manitoba, southern Ontario, northeastern Minnesota, and northern Wisconsin. Although the International Union for the Conservation of Nature classifies the conservation status of the gray jay as a species of least concern, there are threats to the species on the horizon. These threats are loss of habitat due to extensive forest fires; insect outbreaks; logging of the boreal forest and oil, gas, and mining exploration and development; West Nile virus (WNV); and global climate change.

Waite and Strickland (2006) recently reported that climate change has contributed to a rapidly declining gray jay population, studied for about 50 years, at the southern edge of its range in Ontario. Recent warmer autumns apparently rot stored perishable food caches the bird depends upon to survive the winter. Reduced food supplies lead to delayed breeding, reduced reproductive success, and sometimes abandonment of territories. As global warming heats up their natural "refrigerator," allowing food caches to rot before they can be used, a range contraction to cooler climates is expected. This remarkable species requires more research into its natural history as it faces new environmental threats to its survival.

11.3.1.2 The Gray Jay as an Indicator Species

Our early study results found that not only is the gray jay one of the most common vectors of lodgepole pine dwarf mistletoe, but it is also an important indicator of forest health. As a result, our later research objectives began to focus on gray jay movements, longevity, health, site fidelity, and ecology so that we could better understand this species. The baseline information obtained proved valuable to our future work on the Fraser EF.

Leanne Egeland (Fig. 11.5), NCFES biological technician and the USDA Forest Service, Forest Health Management Unit, Gunnison, CO, now retired, helped on all aspects of the dwarf mistletoe and gray jay work for most of the 28 years of research on the Fraser EF. We believe this to be the longest continuous study of gray jays in the USA. It was started at a time when the study of nongame species like the gray jay was moving more to the forefront of wildlife conservation research efforts.

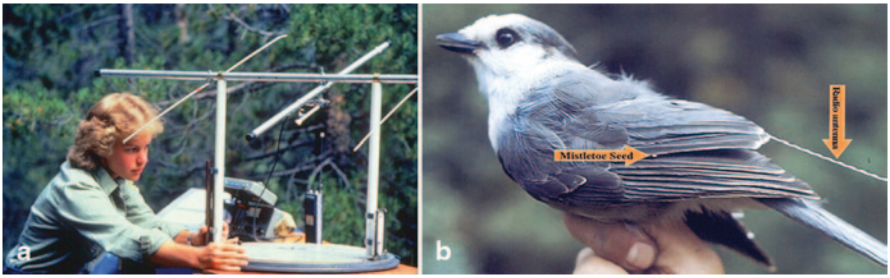

Fig. 11.5 Biological Technician Leanne Egeland using an Osborne Fire Finder to radio-track a gray jay (**a**). The tracked gray jay showing a dwarf mistletoe seed on its wing feather in 1983 (**b**). The bird is wearing a radio transmitter used to track its movements between infected and healthy stands of lodgepole pine on the Fraser Experimental Forest, CO

11.3.2 Gray Jay-Dwarf Mistletoe Seed Study

The objective of this study was to find out if gray jays moved back and forth between dwarf mistletoe-infected and healthy stands of lodgepole pine while carrying dwarf mistletoe seeds. Five gray jays were fitted with 3.7-g transmitters and radio-tracked from three fixed radio-tracking receiving stations located 800–1,000 m apart in the Fraser EF (Fig. 11.5). By obtaining degree bearings and triangulating, bird locations could be determined similar to the way forest fires are found.

A 58.7-ha stand of 70-year-old lodgepole pines within the radio-tracking study area was examined for satellite infections centers (Hawksworth et al. 1987). Radio tracking showed that gray jays frequently flew between dwarf mistletoe-infected and healthy parts of the stand. Some birds were known to have mistletoe seed on their feathers when retrapped and released during that study (Fig. 11.5).

Locations from five radio-tracked birds over a period of 4–12 days showed a home range average of 85 ha (200 ac) based upon 50 data days. The home range of one pair of jays overlapped, but the other birds maintained distinct boundaries between each other. The pair of jays exhibited territorial behavior similar to what we found in banding studies.

11.3.3 Gray Jay Life Span and Habitat Study

Since 1982, we banded and released 704 individual gray jays in the Fraser EF. To capture birds, we annually used up to 50 fixed mist-net trapping locations about 800 m apart by road centered in the Fraser EF headquarters. The average weight of these birds was 73 g. We handled 1,968 new and retrapped gray jays over the course of our study. Many were retrapped and released numerous times, often at or near the very location where they were originally banded—showing an extremely high site fidelity.

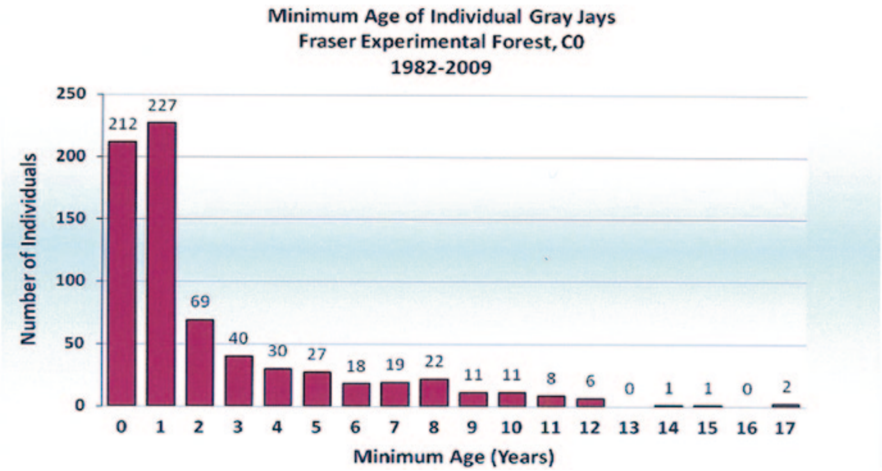

Fig. 11.6 Minimum age of 704 individual gray jays trapped, banded, and released from 1982 to 2009, Fraser Experimental Forest, CO. Zero birds are hatch year birds less than 1 year old

Study results revealed a relatively long life span for resident adult gray jays, which live in permanent, year-round, all-purpose territories in the subalpine forests in the Fraser EF. They often live under extreme winter weather conditions at high elevations.

Of the 704 gray jays we banded, 29 lived 10 or more years and 2 as long as 17 years (Fig. 11.6). Our first 17-year-old gray jay was first banded August 16, 1985, as a young hatch-year bird. It was last captured and released on Aug. 30, 2002. This bird holds the US record for gray jay longevity as confirmed by the US Geological Survey Bird Banding Laboratory (Fig. 11.7). This bird dispersed about 3.2 km away from its original banding location at Fraser EF headquarters. As an adult, it subsequently maintained a territory near the headquarters, where it was retrapped and released four times over the years (1998, 1999, 2000, and 2002). The bird's weight remained normal over the years, ranging between 69 and 73 g. Our second 17-year-old bird was last captured at the King/Elk Junction on September 6, 2009. It was first trapped and banded at that same location as an adult bird on August 25, 1993. It was caught and released nine times (1993, 1994, 1995, 1996, 1997, 1999, 2005, 2007, 2009) on its territory over the 17 years.

11.3.4 Study of the Threat of West Nile Virus to Gray Jays

WNV is an emerging, infectious, exotic disease that was first discovered in the African country of Uganda in 1937. In recent years, it has spread beyond its traditional boundaries, causing illness in birds, horses, and humans in Europe and now the USA. It was first discovered in the USA in 1999 in New York City. Since that time, WNV has been detected in humans, animals, and mosquitoes across the USA as it spread like a wave from east to west over a period of 5–6 years.

Fig. 11.7 Fraser Forest Technician Manuel Martinez holding a banded 17-year-old gray jay in 2002 at the Fraser Experimental Forest, CO. This bird was the oldest gray jay recorded in the wild in the USA according to the US Geological Survey Bird Banding Laboratory

Fig. 11.8 Zoonotic Pathologist and Microbiologist Kurt Reed, M.D., preparing gray jay blood samples in 2003 for analysis of WNV and other blood parasites in the Fraser Experimental Forest field laboratory in Colorado

WNV is spread by the bite of an infected mosquito. Mosquitoes become infected when they feed on infected birds. Infected mosquitoes can then spread WNV to humans and other susceptible animals when they bite them. Animals and people die when they cannot produce enough antibodies to fight off the disease, especially if they have a compromised or underdeveloped immune system. A particularly serious outbreak of WNV occurred in Colorado in 2003. It posed a serious threat to the susceptible gray jay population in the Fraser EF as well as other susceptible bird populations and humans throughout Colorado. In 2003, more humans (2,947) were infected in Colorado than in any other state, and 63 people died.

Zoonotic Pathologist Kurt Reed, M.D. (Fig. 11.8), previously with the Marshfield Clinic Research Foundation and now Professor, Department of Pathology and

Laboratory Medicine, University of Wisconsin-Madison, joined our research team in 2003 to study the impact of WNV on gray jays. He took blood samples from 296 gray jays from 2003 to 2007. Of 236 blood samples tested to date, all were negative for WNV antibodies except for two gray jays (bird band nos. 9822-51941 and 9822-52036) in 2003 that tested positive, with high WNV antibody titers of $\cong$1:20 and $\cong$1:40, respectively.

Jays are highly susceptible to the virus and many individuals may have died before they could develop protective antibodies and before we could find them in the field, where they can quickly be scavenged. However, circumstantial evidence as follows showed a major decline in the Fraser EF jay population that we hypothesized was caused by WNV.

The population of gray jays in the Fraser EF had been healthy for at least 21 years, but something was different about the birds in 2003. They were more difficult to trap and far fewer birds were trapped than in the previous 4 years despite similar trapping efforts. Their social structure seemed to be affected as some family groups appeared to be disorganized. There was a 37 % decrease in the number of birds netted in 2003 ($N=74$) compared to 2002 ($N=117$). The 2003 capture rate declined 33 % compared to the average capture rate of 110 birds for the previous 4 years, 1999–2002. We are not sure whether WNV mortality was the entire cause of this decline, but our WNV blood test results and field observations strongly hinted that WNV might have been the cause.

WNV waned in Colorado after 2003. By 2009, there were only 102 human WNV cases and three deaths, and only three WNV-infected birds were reported in the state. The gray jay population in the Fraser EF started to rebound in 2005 and 2006, but declined again by 2009, when an insect outbreak and salvage logging began to destroy gray jay habitat.

WNV outbreaks, like other arboviruses, are cyclical in nature. We might be able to further strengthen our hypothesis that WNV was the cause of the population decline in 2003 by making more observations during the next WNV outbreak in Colorado. If and when that will happen is an unknown. That uncertainty is why places for long-term studies are valuable for ecological and disease research.

11.3.5 Habitat Use Study

In 2005, 39 of our gray jays in the Fraser EF were color-banded to determine habitat use. The birds were studied by Jennifer Berg (now Jennifer Lansing), a master's student at the University of Colorado-Denver under the direction of Prof. Diana Tomback. The objective of this study was to create a method to predict carrying capacities for birds by using geographic information systems techniques with our long-term data on gray jay distribution, habitat use, and territorial sizes (Berg 2006). Based upon this work, Berg and Tomback estimated the population of gray jays in the Fraser EF to be 682. Their models and field observations showed that the jays primarily used the more extensive lodgepole pine habitat although the Engelmann spruce/alpine fir habitat was used as well.

Fig. 11.9 Effects of the mountain pine beetle infestation of 2005 through 2009 on the Fraser Experimental Forest, CO. The beetle infested much of the older lodgepole pine, killing thousands of trees in prime gray jay habitat. Byers Peak, the tallest mountain (3,903 m or 12,805 ft) in the Forest, is seen in the background

11.3.6 Use of Polymerase Chain Reaction Technique to Sex Gray Jays

The plumage of female and male gray jays is identical, so we were unable to sex the birds in the field. The objective of this study was to use for the first time in 2005, DNA in blood samples to identify the sex of gray jays using polymerase chain reaction (PCR). Avian-sexing PCR uses the fact that male and female birds have different genes or chromosomes, much like mammals. We were able to determine the sex of 74 gray jays in 2005, 38 males and 36 females. As a control, the PCR method was used to correctly sex four red-shafted flickers and one hairy woodpecker that can be sexed by plumage in the field. As this database develops, it can serve as another spin-off study of genetic parentage, relationships, and dispersal of related gray jays in the Fraser EF.

11.3.7 Threat of Native Mountain Pine Beetle to Gray Jay Habitat

Lodgepole pine is the predominant cover type in the Fraser EF covering about half of the Forest. According to Forest Service Forest Health Management aerial surveys, a few 3-ha pockets of the native mountain pine beetle (MPB) were detected in the Fraser EF in 2002. By 2003, three areas of 80 ha or more were detected in our gray jay study area, and by 2009 much of the older lodgepole pine in the Fraser EF had been hit hard by the beetle (Fig. 11.9).

In 2009, the gray jay in the Fraser EF faced destruction of much of its prime lodgepole pine habitat because of the unprecedented MPB outbreak. Thousands of older trees in the Forest, including many infected with dwarf mistletoe, were killed. Salvage clearcutting of some stands starting in 2008 added to the loss of

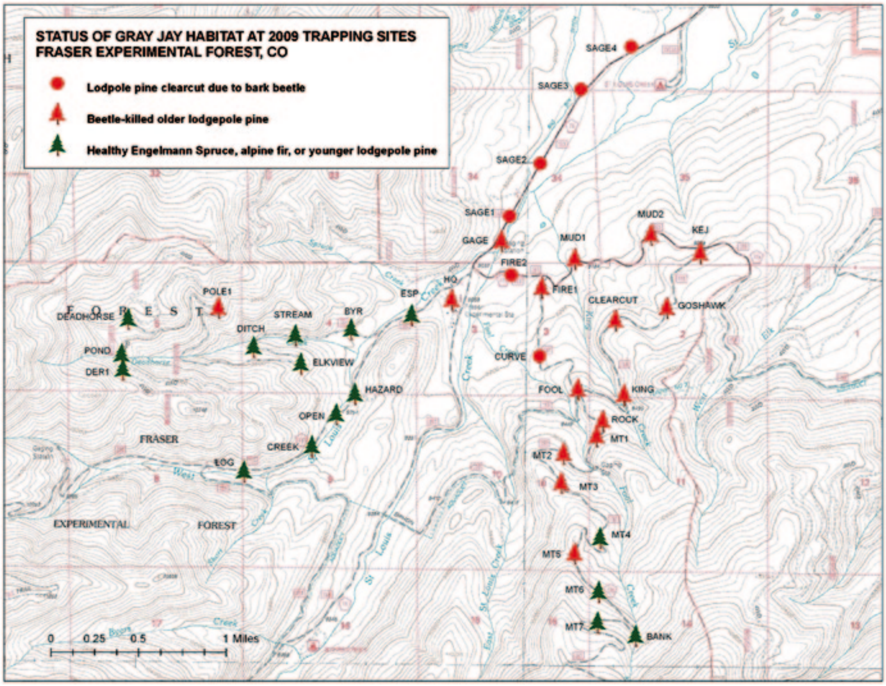

Fig. 11.10 The 22 (in *red*; out of 38) gray jay trapping sites and their associated lodgepole pine habitats that were seriously impacted by the mountain pine beetle in 2009, Fraser Experimental Forest, CO

the gray jay's habitat. Twenty two (58 %) of 38 gray jay trapping sites and adjacent gray jay habitat were seriously impacted by 2009 (Fig. 11.10). Only 67 gray jays were captured and released in 2009, a 39 % decrease in the average capture rate for 1999–2002 based upon a similar trapping effort. Providing nothing happens to the remaining Engelmann spruce/subalpine fir habitat in the meantime, it may be an important refuge for the gray jay as the lodgepole pine forest regenerates to once again provide suitable habitat.

The unprecedented MPB outbreak is thought to be caused by a combination of prolonged drought, warmer winters that allowed beetles to survive over winter, lack of timely forest thinning management in some areas, and fire control over past years that allowed development of large concentrations of fuel and overmature trees to develop. This combination of events apparently set the perfect stage for a massive MPB attack on stressed trees too weak to resist the beetle attack. The current situation is part of an unprecedented multispecies beetle outbreak and has caused significant and widespread tree mortality from Mexico to British Columbia (Rhoades et al. 2013). Millions of hectares of older lodgepole pine have been affected.

The gray jay is a forest bird that prefers to forage and nest in mature forests. It cannot successfully live outside a forested habitat that does not provide it with essential resources. These resources include food, water, shelter, and space required to successfully carry out its life cycle with a minimum of stress and loss of life. Losing millions of hectares of one of its preferred habitats to the bark beetle along with subsequent salvage logging could have a significant negative impact upon this species, according to our preliminary research results. Potential impacts of its habitat loss include lack of breeding, nesting failures, fewer fledglings, reduced life span, abandonment of territories, or even death.

11.4 Summary

11.4.1 A Lifetime of Collaboration with Frank Hawksworth

Decades ago, Frank Hawksworth started our collaboration on dwarf mistletoe research. I assisted Frank in resurveying some long-term dwarf mistletoe plots located along the rim of Grand Canyon National Park in Arizona and in the Mascelero Apache Indian Reservation in New Mexico. We were working 6 days a week to get the resurveying done. We also made trips to look for new species of dwarf mistletoe in such places as the San Juan Mountains in Colorado. On similar trips, Frank did discover new species of mistletoe and was honored for his efforts by having one named after him, *Arceuthobium hawksworthii.*

These field trips showed me that discovery was truly in Frank's nature. It was always an adventure traveling with him while discovering and learning new things about the biological world around us. Anything biological was "official business" and of interest to him. And he was always willing to share what he learned with others in a quiet, non-assuming way. He left a legacy of scientific accomplishment second to none, summarized in his most important publication coauthored with Delbert Weins entitled *Dwarf Mistletoes: Biology, Pathology and Systematics* (1996).

After Frank's retirement and up until a couple of years before his death in 1993, he remained as a Forest Service volunteer working on his beloved mistletoe research. As of 2009, the research continues partly in memory of Frank and partly because of new, important scientific research spin-offs resulting from the original lodgepole pine dwarf mistletoe vector study. Over time, these spin-offs evolved into a series of smaller studies as reported here as new knowledge was gained, new research questions emerged, and new technologies developed.

11.4.2 The Value of Long-term Research in Addressing New Questions

When we initiated our study in 1982, we were sure that dwarf mistletoe was the worst possible pest threat to lodgepole pine and that its major economic impact warranted significant research and management. Now, more than 28 years later, our research begs answers to many emerging questions not envisioned at the beginning of our study. For example, which pest, dwarf mistletoe, or MPB is more important in the long run to the health of the lodgepole pine ecosystem and those animals that depend upon it? Could timelier forest management have minimized economic and aesthetic losses caused by dwarf mistletoe and MPB? If our forests are not managed in a timely manner, will massive outbreaks of insects, diseases, and fires continue to inflict enormous economic losses, as seems to be happening in the western USA in recent years? How will habitat loss from such events affect gray jay populations? Are global climate changes predisposing forests to pest and fire outbreaks? Only long-term research can answer many of these and other emerging questions, questions that might never have been asked during a short-term study.

11.5 Conclusions

Forest Service EFs are essential for long-term ecological and pest research such as that reported here. Along with Natural Areas and National Parks, they are often the only places where such research can be done without undue artificial disturbance. This unique characteristic is a compelling reason for continued support and protection of our Forest Service EFs and other protected areas.

These areas will remain important as researchers continue to draw upon their long-term databases to answer emerging science questions. The following suggested future studies on the Fraser EF would build upon or complement the long-term research findings as reported in this paper:

- Determine survival, spread, distribution, and cumulative impact of lodgepole pine dwarf mistletoe as a new lodgepole pine forest regenerates after a MPB outbreak
- Document increased woodpecker and other cavity-nesting bird activity resulting from thousands of dead and dying trees killed by dwarf mistletoe and MPB
- Document what happens to other birds and animals dependent on lodgepole pine habitat during and after the MPB outbreak and salvage logging
- Determine impacts of MPB tree mortality and salvage logging on gray jay habitat and populations
- Determine whether the Engelmann spruce/alpine fir habitat will provide a refuge for gray jays and other forest birds, and whether it will provide a source of birds to repopulate a regenerating lodgepole pine forest
- Identify potential zoonotic (affecting both humans and animals) diseases and blood parasites affecting gray jays and other wildlife species stressed by the loss of their primary habitat
- Determine genetic parentage, gene dispersal, and movements of banded gray jays using DNA and PCR techniques
- Determine potential impact of global climate change on gray jay habitat, populations, reproduction, and perishable winter food caches

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