Overview of the Endangered Species Program

Glen Smart

In the late 1950s and early 1960s, we became increasingly aware, as a Nation, of declining populations of birds and mammals. Rates of extinction appeared to be skyrocketing and the situation was becoming critical. The country needed to take action to reverse this trend.

The Federal government began to show interest in the problem and acknowledged that it needed to intervene on a hands-on basis. The Washington, D.C., office of the U.S. Fish and Wildlife Service (USFWS) began to promote a program, championed by Dr. Ray Erickson, senior scientist at headquarters, to initiate captive research and propagation of birds and mammals. Research was needed to stabilize and recover populations in the wild. In order to save endangered species, the need was not only to raise birds and mammals in captivity but also to release them into the wild to augment populations.

Dr. Erickson envisioned a three-pronged program: a section of laboratory investigations; a section of propagation, whereby Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, would maintain captive populations of animals; and the field stations where field biologists would study the populations in the wild to determine what actions needed to be taken to reverse the downward trends.

Gene Knoder, a biologist with the USFWS stationed in Monte Vista Refuge in Colorado, began working with a captive population of sandhill cranes (*Grus canadensis*). Ray envisioned that they could be raised at Patuxent because we needed to work with a closely related or surrogate species whose population was much more abundant than that of the endangered whooping crane (*Grus americana*). Because most of these endangered species had rarely or never been bred in captivity, Patuxent researchers used the surrogates to develop techniques that were likely to be successful in the wild rather than to risk working directly with the endangered species.

The whooping crane was a rare species at that time in the mid-1960s, and, to the best of our knowledge, its population had been reduced to about 14 or 15 birds, although the exact number was disputed. Most of these birds wintered along the Gulf Coast of Texas and migrated to an unknown part of northern Alberta, Canada. In the early 1950s, a biologist returning from a forest fire saw a whooping crane with one offspring on the ground in Wood Buffalo National Park, which extends from northern Alberta into the Northwest Territories.

Through a cooperative effort with the Canadian Wildlife Service, the USFWS developed a program whereby we would remove one egg from each two-egg clutch and bring it into captivity, where the chicks could be hatched and reared; in this way, we could develop a captive breeding population.

The Endangered Species research team at its peak in early 1980s, at Snowden Hall, Patuxent Wildlife Research Center, Laurel, MD, 1980 (left to right, 1st row: Ray Erickson, Randy Perry, Paul Sykes, Mike Scott, John Serafin; 2nd row: Glen Smart, John Sincock, Noel Snyder, Sandy Wilbur; 3rd row: Jim Jacobi, Dave Mech, Dave Ellis, Scott Derrickson; 4th row: Barbara Nichols, Jim Carpenter, Cam Kepler; 5th row: Sharon Fox, Jim Wiley, Conrad Hillman; not present: George Gee, Gene Cowan). Photo by Paul Sykes, U.S. Fish and Wildlife Service.

Cranes commonly lay two eggs but, because of sibling rivalry and food availability, typically only a single chick is reared. Therefore, we were salvaging the egg that would theoretically be lost to sibling aggression or starvation.

Beginning in 1967, Ray and I traveled to Wood Buffalo National Park, near Fort Chipewyan, Alberta, to meet with Canadian Wildlife Service biologist Ernie Kuyt. He was a

Glen Smart (U.S. Fish and Wildlife Service), Ernie Kuyt (Canadian Wildlife Service), and Ray Erickson (U.S. Fish and Wildlife Service) with eggs, 1967. Photo by U.S. Fish and Wildlife Service.

delight to be around, and his knowledge of the area and his cooperative nature made him a valuable partner. Because only Ernie was authorized to leave the helicopter once we landed at a nest, it was his responsibility to collect the egg.

Before we could enter the park, of course, we had to have permits. Ray and I were issued permits to enter Wood Buffalo National Park, retrieve the eggs, and bring them out. The nesting area is about 80 percent water, consisting mostly of small, very shallow ponds. Most of them did not contain fish, as the ponds froze solid every winter. Many invertebrates did inhabit the ponds, however, and in this general area the cranes would nest and raise their young. The birds were typically very reluctant to leave the nest as Ernie neared them. On occasion, they even challenged the helicopter, which in itself was quite exciting.

We had developed a 1-cubic-foot case made of Styrofoam with a cavity in the middle into which an egg could be placed. The plan was for Ernie to put the egg in this Styrofoam case and carry it out of the park. If he dropped the case, then, optimistically, the egg would not break or be damaged. Ernie looked at the case and said, "There's no way that I'm going to carry that thing back and forth." From then on, every egg that was collected from a nest at Wood Buffalo National Park was carried out in Ernie's old woolen sock! As far as I know, every egg that ever came out of Wood Buffalo National Park got a ride in Ernie's woolen sock, and, to my knowledge, he never dropped an egg. He would go out, examine the nest, photograph the nest, select the egg that he felt was less liable to hatch, collect the egg, and make his way back to the helicopter, where he would relinquish the egg to us. Ray and I maintained them in a portable incubator that we had brought with us.

Glen Smart and Ray Erickson (U.S. Fish and Wildlife Service) monitoring crane eggs, 1967. Photo by U.S. Fish and Wildlife Service.

In the first year (1967), we were going to be flown back to Maryland in an executive jet by the Canadian Wildlife Service, or by the Canadian Air Force. However, that was the year of the Six-Day War in the Middle East. U Thant, the Secretary General of the United Nations, took our plane that year, and we had to come back on a commercial flight. Thereafter, we returned in first-class accommodations with an executive jet each year.

The feather development of each chick was closely monitored at Patuxent. By November or December, a chick has molted its feathers from the mid-neck down through most of the body, but it still has a brown neck and brown wings, which are indicative of that time of the year. The birds have a continuous molt, so they continue to molt throughout the winter. By the time they fly north in the spring, the birds are completely white except for the brown head.

Another species we worked with in the 1960s was a small race of Canada goose (*Branta canadensis*) that breeds only in the Aleutian Islands off the coast of Alaska. At that time, they were called the Aleutian goose (*Branta hutchinsii leucopareia*). Their population had declined to such an extreme point that we thought they were extinct. This belief changed, however, when a refuge manager, Bob Jones (USFWS), made one of his lengthy trips into the outer Aleutians in an open dory. He was on Buldir Island, which is a relatively small pinnacle of rock about 5 × 8 miles in size, with very precipitous cliffs. He found a population of about 100 to 150 Aleutian geese breeding there.

The Aleutian geese originally were quite common throughout the Aleutians. With the interest in fur coats and other fur clothing, the arctic fox (*Alopex lagopus*) furs were very valuable and desirable. The Russians fur trappers brought foxes to many of these islands, and subsequently the foxes reproduced. The trappers would come back at the appropriate times and harvest the foxes for furs—it was almost a captive fur-animal population. This population of foxes was extremely detrimental to the ground-nesting species of birds and other animals there. The Aleutian Canada goose was one of the most obvious of the birds and it was one of the first to disappear because of predation by the foxes. Fortunately for the birds, no foxes were brought to Buldir Island because of its precipitous cliffs; fortunately for us, one small area on the northern side of Buldir Island is relatively flat, allowing us access to the island. We traveled to the island and went ashore in late spring. We collected approximately 22 goslings that were newly hatched and brought them back to Patuxent to be part of our breeding population.

Aleutian Canada geese nest similarly to the other Canada geese. We raised many of these birds, but the problem then was how to release them back into the wild. In the 1960s, the Aleutian Islands National Wildlife Refuge staff was actively destroying the foxes on various islands. As an island would be cleared of foxes, we would transport some of these captive-reared geese to the island and release them, hoping that they would disperse and repopulate the island. Unfortunately, although the foxes were gone, there were still many bald eagles (*Haliaeetus leucocephalus*) remaining. Because eagles are fond of geese as a dinner item, that plan was less than successful.

We tried several alternatives. One solution that worked well, once the islands were cleared of foxes, was to go out to Buldir Island, capture an adult and the goslings that were with that adult, transport them to another island, and release them as a family unit. They would then mature, reproduce,

Ray Erickson (U.S. Fish and Wildlife Service) and chick. Photo from the newspaper "Laurel Leader." Reprinted with permission from The Baltimore Sun. All rights reserved.

Crane flock manager Bruce Williams, U.S. Fish and Wildife Service, with young whooping crane, 1986. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

and eventually repopulate the island. Although this population was only about 100 to 150 geese when discovered by USFWS biologist Bob Jones, it now has skyrocketed to the more than 200,000 Aleutian Canada geese that are alive today (2016).

The Laboratory Investigations Program at Patuxent consisted of professionals in selected areas of expertise. These included many of the first people Ray hired, including a nutritionist, a physiologist, and a veterinarian to care for the birds in captivity and to cater to their every need. The field portion of the program was staffed originally with six biologists. Patuxent biologist Roy Tomlinson went to Arizona to study the masked bobwhite quail (*Colinus virginianus ridgwayi*), which is a desert form of bobwhite (*Colinus virginianus*) that was nearly destroyed. The remaining population was found mostly in Sonora, Mexico, with additional birds occupying a few valleys that extend into southern Arizona.

When cattle herds from Mexico were driven north to Tucson to the railheads, they destroyed most of the fragile grasslands, which are slow to recover. As a result, over time the habitats of the masked bobwhite quail in the United States were destroyed.

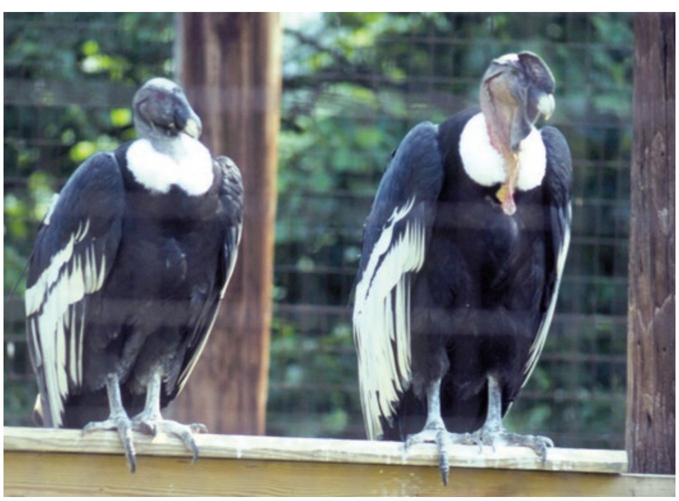
Roy conducted most of his work in Sonora. He developed a technique by which he would go into the desert and find a cactus wren (*Campylorhynchus brunneicapillus*) nest that he knew would be lined with feathers that the wrens obtain from the desert floor. Roy would examine the nest and identify bird species from the feathers that he found. If he found bobwhite quail feathers, of course, he would assume they were indicative of the presence of bobwhites in the area.

I went with him when we received the first bobwhites from two brothers in Tucson, Jim and Seymour Levy. They had been studying the birds on their own, and had a few birds in captivity. They let us have three or four pairs. We brought them to Patuxent and attempted to breed them. We were successful and got a number of eggs. The birds' fertility was quite low, however; the chicks were weak and so inbred that production was practically nil. Therefore, we needed to obtain some new birds to bolster that breeding population.

I went to northern Mexico with Roy; we trapped about 20 birds and brought them back to Patuxent. They proved easy to breed; we could literally breed them by the hundreds. We had no idea how to release them, however, so we began by simply placing them in a pen. We allowed them to remain there for a few days, where we fed and cared for them, and then we opened the door and let them walk out. This plan, unfortunately, was not successful because of the many hawks and other predators in the area. The bobwhites were quite uneducated in the ways of the wild, and, as a result, suffered substantial mortality.

Next, we paired neutering females from a captive Texas bobwhite quail population with male masked bobwhites so they would not hybridize. As chicks hatched in the incubator, we would put 12 to 15 with one of these pairs, take them to the desert, and release them. Again, results were similar to those of the earlier releases, but with one exception: the mesh on the pens was large enough that the babies could get out and begin to forage a little on their own, but the parents would always call them back. We would keep them there for a week or so, until they became familiar with the area, and then release them. We did build a stable population for a while but, because of the inadequate habitat, I do not think that population has been very successful. I believe there are still a few quail in Arizona and a few in Sonora.

The California condor (*Gymnogyps californianus*) population was 12 or 13 birds, and the appropriate course of action regarding the species was a very controversial subject in the area of their native habitat. One faction of biologists felt very strongly that we should leave the birds alone to die in dignity,



Andean condor pair in captive breeding pen at Patuxent Wildlife Research Center, Laurel, MD. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Andean condors with backpack transmitters, Patuxent Wildlife Research Center, Laurel, MD. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

and not bring them into captivity, where they would be no longer condors at all, but similar to captive chickens. The other faction felt that, in order to save them, we needed to bring all condors into captivity, breed them, and eventually release them back into the wild.

When the population began to decline precipitously, the State of California indicated that Patuxent could catch all of the birds and bring them into captivity. However, no California condors were allowed to leave the State of California. Unfortunately, then, we were not able to bring them back to Patuxent.

However, we were able to reach a compromise with the San Diego Zoo and the Los Angeles Zoo. The zoos built facilities that were off exhibit to the public and began to raise California condors. At Patuxent, we were studying the closely related Andean condor (*Vultur gryphus*). We found that by removing eggs as they were laid, we could obtain multiple clutches in a given year (a clutch being one egg in condors). Typically, we would get three or four eggs from a female, but I believe we once got as many as nine. By removing eggs, we could greatly increase the productivity of a given condor pair. Snyder (2016) discusses the details of this negotiation on the fate of the condors in depth.

The black-footed ferret (*Mustela nigripes*) was another animal we studied at Patuxent, but we had little success with it. Because of other priorities, we reduced the effort we were investing in this program, and it was eventually taken over by a consortium of State wildlife agencies and zoos with the guidance of the USFWS. Thousands of captive-raised black-footed ferrets have been released in eight western states, and also in parts of Canada and Mexico (National Black-Footed Ferret Conservation Center, n.d.; U.S. Fish and Wildlife Service, 2015).

Hawaii was home to a multitude of endangered species. Many of them were forest birds, including the Hawaiian crow (*Corvus hawaiiensis*), which was rare. John Sincock was the first biologist hired by Patuxent for that program. He began studying this and a variety of other species. The Hawaiian research program was difficult to conduct because of the terrain, but the researchers involved made great progress in the conservation of endangered species on the islands (Scott and Kepler, 2016).

Noel Snyder was the first Patuxent biologist to work on the Puerto Rican parrot (*Amazona vittata*) in Puerto Rico. This bird's population was very low—fewer than 20. We worked with this species briefly at Patuxent, after which Region 4 of the U.S. Fish and Wildlife Service and the Commonwealth of Puerto Rico became involved and set up a captive breeding population and facilities in Puerto Rico. They are doing well with them and in 2011 had about 500 birds, either in captivity or in one of two wild populations.

One of the first things that we found to be a limiting factor for the parrot was the curved-bill thrasher (*Margarops fuscatus*). The thrashers would go into the parrot nesting cavities, pierce the eggs, throw them out, and then use the nest site themselves. Dr. James Wiley, Patuxent (Wiley, 2016), presents a more detailed discussion of the Puerto Rican parrot research project.

Patuxent researcher Paul Sykes worked on snail kites (*Rostrhamus sociabilis*) and dusky seaside sparrows (*Ammodramus maritimus nigrescens*) in Florida. Snail kites feed almost exclusively on the apple snail. The kite population is currently (2016) doing well. Unfortunately, the dusky seaside sparrows did not fare as well, and actually became extinct during the period when Paul was working on them.

Paul Sykes is also well known for his studies with other endangered species, including the Kirtland's warbler (*Setophaga kirtlandii*) and the ivory-billed woodpecker (*Campephilus principalis*). A study of the Kirtland's warbler was initiated in 1985 on the bird's wintering grounds in the Bahamas, West Indies, as part of Patuxent's Endangered Wildlife Research Program. On the morning of February 26, Sykes and Paul Sievert captured an adult male Kirtland's warbler in a mist net

Paul Sykes, U.S. Fish and Wildlife Service, with a recently banded Kirtland's warbler, Eleuthera, Bahamas, West Indies, 1985. Photo by Paul Sievert, U.S. Fish and Wildlife Service.

Wolf with collar-mounted transmitter being tracked by David Mech, U.S. Fish and Wildlife Service, in Minnesota. Photo by U.S. Fish and Wildlife Service.

in a patch of low, dense shrub/scrub dominated by buttonsage (*Lantana involucrata*). The site was 1.3 miles north of the town of Governor’s Harbour in the middle of the island of Eleuthera. The warbler was uniquely color banded and various morphological data were recorded, but in the excitement it managed to get free before it was photographed. Sykes named the bird “The Governor” for the proximity of its winter territory to Governor’s Harbour. The warbler was recaptured at the same locality on February 28 and photographs were taken, including the one shown here, with the warbler being firmly held by Sykes. To the best of our knowledge, this was the first time a live Kirtland’s warbler was photographed in the Bahamas, and at that time it was only the second banding of the species in the islands.

Dr. David Mech studied gray wolves (*Canis lupus*) in northern Minnesota and Michigan. Dave was a student at Purdue University when he studied wolves on Isle Royale in Michigan. He became very well known because of his studies, and subsequently was hired by the USFWS as the field biologist to study this population. Dave has been working with these animals since the early 1960s, and continues to work on wolves in that area. He presents major aspects of his studies together with supporting data in the chapter titled “Patuxent’s Long-Term Research on Wolves,” farther on in this report (Mech, 2016).

References Cited

Mech, L.D., 2016, Patuxent’s long-term research on wolves, *in* Perry, M.C., ed., The history of Patuxent—America’s wildlife research story: U.S. Geological Survey Circular 1422, p. 197–212. [Also available at https://doi.org/10.3133/cir1422.]

National Black-Footed Ferret Conservation Center, n.d., Black-footed ferret connections at blackfootedferret.org—Captive breeding, accessed June 3, 2016, at http://blackfootedferret.org/captive-breeding/.

Scott, J.M., and Kepler, C.B., 2016, Endangered species research in Hawaii—The early years (1965–87), *in* Perry, M.C., ed., The history of Patuxent—America’s wildlife research story: U.S. Geological Survey Circular 1422, p. 183–196. [Also available at https://doi.org/10.3133/cir1422.]

Snyder, N.F.R., 2016, Conserving California condors in the 1980s, *in* Perry, M.C., ed., The history of Patuxent—America’s wildlife research story: U.S. Geological Survey Circular 1422, p. 147–156. [Also available at https://doi.org/10.3133/cir1422.]

U.S. Fish and Wildlife Service, 2015, Black-footed ferret—*Mustela nigripes*: U.S. Fish and Wildlife Service fact sheet, Region 6 (Mountain-Prairie Region), accessed June 3, 2016, at https://www.fws.gov/mountain-prairie/factsheets/Black-Footed-Ferret.pdf.

Wiley, J.W., 2016, Endangered species research in the Caribbean, *in* Perry, M.C., ed., The history of Patuxent—America’s wildlife research story: U.S. Geological Survey Circular 1422, p. 157–170. [Also available at https://doi.org/10.3133/cir1422.]

Conserving California Condors in the 1980s

Noel F.R. Snyder

By the late 1970s, the California condor (*Gymnogyps californianus*) was in serious trouble, with probably no more than about 30 birds left in existence, all in a mountainous region just north of Los Angeles that is vegetated mainly in chaparral and grasslands. All estimates of population size and trends offered since the early condor studies by Carl Koford in the 1930s and 1940s indicated a continuing decline toward extinction, and it appeared that few years were left before the species would be gone (see Koford, 1953; Wilbur, 1978). Evidently, the conservation steps that had been taken, including the creation of a number of important condor reserves, were not resulting in recovery of the species.

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, had been involved in studies of the species since the mid-1960s, beginning with the efforts of Fred Sibley from 1966 to 1969 and continuing with the work of Sanford Wilbur through the 1970s (Sibley, 1968; Wilbur, 1978). The causes of the decline remained controversial and difficult to resolve, however, because of the enormous practical difficulties involved in studying such a rare and highly mobile species in exceedingly rugged terrain, especially when research was limited by political constraints to passive, nonintensive techniques and funding for research was minimal.

By 1980, no functioning captive population of California condors was yet in existence, largely because of the consistent opposition of biologist Carl Koford and other early researchers of the species, who believed a captive flock would represent an abandonment of efforts to conserve the wild population. Nevertheless, Patuxent had established a surrogate captive population of Andean condors (*Vultur gryphus*) in anticipation of a need for captive breeding of the California species and had been successful in demonstrating routine capacities of the Andean birds to lay replacement eggs—thus greatly increasing their reproductive potential under intensive management (see Erickson and Carpenter, 1983).

California condor, Ventura County, CA, 1980s. Photo by David Clendenen, U.S. Fish and Wildlife Service.

Fortunately, two outside evaluations of the recovery program were conducted in 1978—one by Jared Verner of the U.S. Forest Service and one by a combined Audubon-American Ornithologists' Union panel chaired by Robert Ricklefs of the University of Pennsylvania (Verner, 1978; Ricklefs, 1978). Both evaluations strongly recommended the initiation of intensive research and management techniques such as radio-telemetry and captive breeding. These reports were crucial in mobilizing the National Audubon Society to mount a lobbying effort with Congress that resulted in the creation in 1979 of a well-funded, final intensive program on behalf of the condor.

On-the-ground operations of the new program were initiated in 1980 and were led by Patuxent in collaboration with the National Audubon Society, but there were many other cooperators, including the California Department of Fish and Game, the U.S. Forest Service, the Bureau of Land Management (BLM), the Los Angeles and San Diego Zoos, and several California universities and research institutions.

Sespe Condor Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

My personal involvement in condor research began at this point as field leader of Patuxent’s condor program; John Ogden became the principal leader of National Audubon’s field efforts. In this presentation, I briefly review the cooperative studies that were conducted in the 1980s to identify the primary causes of decline of the wild population and the cooperative efforts to create a viable captive population, as well as certain aspects of subsequent releases of captives to the wild—subjects covered in more detail in Snyder and Snyder (2000, 2005) and Snyder (2007).

Research on Causes of Decline in the 1980s

At the start of the new intensive program in 1980, there were three primary competing hypotheses under consideration regarding the main cause of the decline of the California condor. The first was the position of Miller and the McMillan brothers (1965), who had studied the species in the early 1960s and believed that the bird was breeding normally, but was suffering from overwhelming mortality stress from illegal shooting and from poisoning campaigns, especially ground squirrel poisoning using Compound 1080 (an organofluorine pesticide). The second hypothesis was the proposal of Wilbur (1978) that the species was suffering from declining carrion food supplies and had largely stopped breeding, with only two pairs still known to be actively reproducing in the late 1970s. The third hypothesis was that of Kiff and others (1979) that the condor was suffering major stress from dichlorodiphenyldichloroethylene (DDE) contamination of its food supplies, which apparently had caused a more than 30-percent decline in eggshell thickness in the 1960s and could still be causing reproductive effects such as frequent egg breakage and lowered reproductive output.

All three of these hypotheses were plausible, but all suffered from only fragmentary supporting evidence and none was fully persuasive, though there was special concern about the potential effects of DDE, as the extent of eggshell thinning apparently had been severe in the 1960s. To resolve which factors were truly responsible for the condor’s continuing decline, so that conservation could proceed intelligently, comprehensive studies of contaminant levels, breeding productivity, mortality rates, and causes of mortality in the wild population were needed. In pursuit of these goals, diverse research activities were planned, many of them aided by radiotelemetry.

Intensive basic biological studies were especially crucial at this stage because it was not clear that all potentially important causes of the decline had been identified. One source of mortality that was not recognized by Koford, Miller, and the McMillans, or by any other historical condor researcher, was lead poisoning resulting from the birds’ ingestion of ammunition fragments in hunter-shot carcasses. Locke and others (1969) at Patuxent had published a paper on a captive Andean condor dying from feeding on an ammunition-contaminated carcass, and there was every reason to suspect frequent exposure of California condors to lead-contaminated carcasses because of the large amount of hunting going on in the State. Unless a substantial number of condors could be radiotagged so that dead birds could be found promptly and comprehensively necropsied, it could be difficult to determine the severity of the threat of lead poisoning.

Crucial to evaluating all hypotheses was the development of improved methods of censusing the wild population. From 1965 until 1980, estimates of the size of the condor population were based largely on the annual simultaneous October Survey during which people were stationed at overlooks of known condor concentration areas throughout the range (see Mallette and Borneman, 1966). This methodology was relatively crude because of difficulties involved in recognizing and eliminating duplicate sightings of birds that moved from one observation point to another and because only a modest fraction of the range of the species was covered by accessible observation points. Program cooperators initially anticipated that if many of the birds in the wild population could be radio-tagged, the uncertainties in future October Surveys could be substantially reduced. Instead, a more reliable and informative method of censusing evolved through the extensive use of a less advanced technology—photography of flying birds (see Snyder and Johnson, 1985). Early success with this new photographic method led to abandonment of the October Survey after 1981.

Each individual condor was discovered to be unique in its flight feather pattern as a result of unique feather damage events and highly variable molt of feathers (Snyder and others, 1987). Because feather patterns changed only slowly through time, when a sufficient number of photos of flying condors had been taken throughout the condor range, all individuals could be continuously recognized and counted. The photos were sorted chronologically into files representing the histories of individual birds—histories that revealed not only the movements of the birds but also how many birds were present on specific dates. Much of the credit for this effort goes to Eric

California condor with distinctive feather damage and molt, southwestern California, 1980s. Photo by Jesse Grantham, U.S. Fish and Wildlife Service.

Noel F.R. Snyder (left), U.S. Fish and Wildlife Service, and Eric Johnson, California Polytechnic State University, San Luis Obispo, CA, sorting condor photos. 1982. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

Johnson and his students at California Polytechnic State University in San Luis Obispo, but essentially everyone involved in studying condors contributed to its success. By 1982, it was possible for the first time to census the wild population accurately and continuously.

The photographic censusing revealed a very rapid decline in the remnant population associated with very high mortality rates. From late 1982 to mid-1985, the population decreased in annual decrements from 21 to 19 to 15 to 9 known individuals, and the average annual mortality rate for the population was more than 25 percent per year, a rate far greater than any that could allow population stability or growth under known or potential reproductive rates (see Meretsky and others, 2000). Such figures clearly indicated a grave crisis in survival of the wild population irrespective of any potential reproductive problems. Unexpectedly, the mortality rate was slightly higher in full adults (26.8 percent) than in immatures (22.2 percent), a finding that was important in identifying potential causes of decline, as discussed below.

While photographic censusing was underway, a major effort also was made to find all nests in the wild population and to directly track their rates of success and causes of failure. To this end, a staff of nest observers was assembled that grew to 12 individuals by the time the program was several years old. All nesting pairs were eventually located and studied on a continuing basis despite major logistical difficulties.

Most condor nests were caves in cliffs, but one active study site was discovered in a burned-out hollow of a giant sequoia. Nests were generally hard to find because the breeding pairs were dispersed over an extensive and rugged terrain and visited their nests infrequently. To find active nests of pairs that were not radiotagged, we employed multiday vigils at strategic lookout points within potential nesting areas, following the movements of prospective nesting birds through telescopes, looking for aerial signs of nesting behavior, and then gradually homing in on the locations of nests. Once active nests had been located, they were given steady daylight coverage from distant observation points until the young fledged or the nests failed. Twenty-three of the 25 active nests found during studies in the 1980s were sites that had not been previously documented as condor nests by earlier researchers, but most of these nests were internally plastered with excrement layers, indicating repeated use in earlier years rather than new nests.

As summarized in Snyder and Snyder (2000, 2005), the studies of breeding biology in the 1980s resulted in the following major conclusions:

1. Most adults were paired and were breeders, although two of the pairs found were likely pairs of homosexual males that had nest sites but laid no eggs. These pairs likely resulted from the existence of a slightly skewed sex ratio among adults. Other than these two pairs, there were no generic signs of a failure of adults to breed, and all clearly heterosexual adult pairs were breeding consistently except when burdened with dependent fledglings. Even when the total population of condors in the wild, including immatures, had declined to just 15 individuals in 1984, five

Condor nest in giant sequoia, Ventura County, CA, 1984. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

Observation point for locating condor nests in Sespe Condor Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Pair flight display of California condors, southwestern California, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

pairs of condors—two-thirds of the population—were still actively breeding.

2. Nesting efforts were reasonably successful, resulting in fledglings in nearly half the nesting attempts, a rate similar to those documented for other solitary nesting vultures. Nestlings were consistently well fed, and the survival rate of nestlings to fledging was high. Most nest failures occurred at the egg stage.

3. Clutch size was invariably a single egg, and nesting pairs readily laid replacement eggs when early-laid eggs failed as a result of predation or were taken into captivity.

4. Pairs that produced a fledgling in one year were capable of breeding late in the next spring, but then typically skipped breeding in the third year while they still were tending a dependent fledgling from late in the second year. Thus, successful pairs were evidently capable of producing two young in 3 years.

5. The primary cause of the moderate number of nesting failures was predation by common ravens (*Corvus corax*) on eggs. There were no persuasive signs of reproductive failure to DDE contamination, such as chronic egg breakage unrelated to raven predation. Neither was there any evidence of chronic failure of eggs to hatch after full-term incubation. As documented in Snyder and Meretsky (2003), the correlation between eggshell thickness and DDE levels in eggshell membranes was weak; instead, eggshell thickness was highly correlated with egg size, indicating that the thin eggshell fragments collected in the 1960s could have come from relatively small eggs rather than from structurally weak eggs. One female in the 1980s was laying eggs whose shell thickness was nearly 25 percent less than the historical mean, but her eggs were also very small and she was the most successful female of her period in producing fledglings. Her eggshells were of an appropriate thickness for the size of her eggs, and there is no good evidence that she suffered from structurally weak eggs. The apparently severe shell thinning of the 1960s could have been largely an artifact of small egg size in the few females sampled, which may well have included the small-egged female studied in the 1980s. Unfortunately, egg size was not documented for any of the eggs in the 1960s but, consistent with egg size being the primary determinant of shell thickness, nesting success in the 1960s, as documented by Fred Sibley (1968) and in a later analysis by Snyder (1983), was not distinguishable from nesting success in the 1980s, and was reasonably strong.

Therefore, the intensive studies of the 1980s yielded no clear evidence of major breeding problems due to food stress, DDE contamination, nest predation, or any other factors, but instead indicated that excessive mortality of free-flying adults and immatures was the primary cause of population decline. Moreover, judging from the eight dark-headed immatures (about one-third of the population) whose existence we were fortuitously able to document at the start of the intensive program, there had been no major problems with reproduction at least as far back as the late 1970s.

The intensive studies of the 1980s, therefore, were most supportive of the hypothesis of Miller and others (1965) that the primary problems of the species were mortality factors, not reproductive factors (Wilbur, 2004). However, accumulating evidence (Snyder, 2007) indicated that the single most important mortality factor was not shooting or the sorts of poisoning described by these researchers, but was instead the kind of poisoning we had feared might be of primary importance as described by Locke and his collaborators in 1969—lead poisoning (Locke and others, 1969; Snyder and Snyder, 2000, 2005; Snyder, 2007).

Probably just as a result of chance, the condors we were able to radiotag in the 1980s had much better survival rates than the condors that were not radiotagged, so that relatively few dead condors were recovered for necropsy, and information on specific mortality factors was accumulated only slowly. Nevertheless, of the four free-flying condors that were recovered dead or dying in the 1980s, three were found to be victims of lead poisoning. The fourth was a victim of cyanide poisoning, presumably from a coyote trap. Poisoning from contaminated food is one of the few causes of mortality that can be expected to affect adults as severely as immatures and, therefore, it provides a plausible explanation for the nearly identical mortality rates found for these age classes in the 1980s. In contrast, if the population had been suffering mainly from shooting or collision mortality, one would have expected the mortality rate of relatively unwary and clumsy immatures to greatly exceed that of adults–a situation found in populations of many large raptorial birds.

When the first well-documented case of lead poisoning occurred in 1984, there was not yet nearly enough evidence to conclude that lead might be the most important cause of

John Schmitt, U.S. Fish and Wildlife Service, with lead-poisoned condor, 1980s. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

the species' decline. However, when two more condors were diagnosed as victims of lead poisoning in the next 1-1/2 years and a full 40 percent of the wild population was lost over the winter of 1984–85, a belief that the species might be in deep trouble from this source became tenable, first for the California Fish and Game Commission and ultimately for the U.S. Fish and Wildlife Service (USFWS). This belief was the major force that led both agencies to decide that the last remaining wild condors should be brought into captivity—an action that was accomplished by early 1987.

The problem of lead poisoning from ammunition fragments remains unsolved today (2016) despite the accumulation of supporting data indicating that lead poisoning from ammunitions has been a major problem for the condor, as well as for other wildlife species such as swans and eagles (see discussion in Snyder [2007]).

The supporting data for condor lead poisonings have come from ongoing releases of captive condors to the wild that have been conducted since the early 1990s (Jane Hendron, U.S. Fish and Wildlife Service, unpub. report, 1998; Snyder and Snyder, 1989, 2000). These releases have been followed by many lead-poisoning mortalities plus many more near-mortalities from lead poisoning that have been countered by returning birds to captivity for emergency chelation treatment. One can question why releases have been attempted in the absence of mitigation or removal of the main cause of extirpation, but in any event they have confirmed beyond reasonable doubt that lead poisoning continues to be the major threat to wild populations. The release program in Arizona alone has performed considerably more than 150 emergency chelations of lead-poisoned birds since releases began in 1996 (see Walters and others [2010]). In spite of such rescue efforts, however, lead poisoning remains the principal source of mortality in the release programs (see Finkelstein and others [2012], Rideout and others [2012]).

Formation of a Captive Flock

Formation of a captive flock of condors involved capturing wild condors from the egg stage to the adult stage. This process faced opposition from individuals and some conservation organizations, as described in detail by Wilbur (2004) and Syder and Snyder (2000, 2005). The process could have been completed with only minimal effects on the wild population if it had been started early enough and had been limited to collecting eggs early in the breeding season, leaving time for pairs to recycle with replacement eggs (Snyder and Snyder, 2000, 2005). A captive flock was established at the Los Angeles Zoo in 1982, and only about half the captive flock was taken as eggs. The remainder consisted of nestlings and free-flying birds trapped from the wild, after it became clear that the wild population was inviable and about to disappear completely.

At the start of the intensive program, the California condor had never been bred in captivity and no members of the species were in confinement except Topatopa, a wild male fledgling that had come into the Los Angeles Zoo with an injured foot in 1967. Unfortunately, taking eggs from the wild population was politically impossible until 1983. Replacement egg-laying was well known for captive Andean condors by the start of the intensive program, but, because at that time such layings had not been clearly documented in the California condor permit, clearance to use this approach could not be secured from State and Federal authorities, although it seemed likely that California condors would have the same capacities.

Instead, the captive acquisition program was initially limited by permit restrictions to obtaining an unpaired female bird to pair with Topatopa, the only California condor already in captivity. This was a dubious strategy at best because a captive population consisting of one pair was far from adequate to sustain or significantly bolster the species and because Topatopa was known to be a behaviorally compromised bird. Topatopa had been held in isolation from his species since the late 1960s, and his potential for breeding was highly questionable because of his strong orientation to humans. Further, identifying an unpaired female in the wild population and capturing her posed some strong practical difficulties at that time, as condors cannot be sexed externally and were not yet individually identifiable. Efforts to obtain a potential mate for Topatopa were fruitless during the first 3 years of the intensive program.

Fortunately, the intensive observations of nesting pairs in 1982 allowed conclusive documentation of a case of natural replacement clutching in the wild, eliminating the roadblock to forming a captive flock from eggs. Proof of natural replacement clutching was arguably the most important and beneficial result of the intensive nesting studies of the 1980s. It now became possible to take eggs from all breeding pairs in the wild and to artificially incubate them at the San Diego Zoo, while the pairs recycled with replacement eggs in the wild. In the first year of operations—1983—four eggs were taken from three pairs and all hatched successfully, producing four surviving young. Together with two chicks produced in the wild, six young were produced that year, in contrast to the typical average of two young produced in previous years. Results were even better in 1984, when five pairs produced seven surviving young. Thus, the removal of eggs for artificial incubation demonstrably increased overall reproduction of the remaining wild birds largely through replacement layings. Indeed, all pairs but one ultimately demonstrated a potential for double clutching within a single breeding season; three pairs even demonstrated a capacity for triple clutching (see Snyder and Hamber [1985]).

Thus, by late 1984, a captive flock was being rapidly assembled, and a consensus developed that in the following year the taking of eggs should continue, but that it might be possible to channel some of the production possible with replacement clutching into sustaining the wild population with an early release program. This hope was based on an assumption of reasonably good survival of the existing wild breeding pairs. The recovery team developed a plan approved by all cooperators in the program by which a pair would begin to contribute to a release program once five progeny had been obtained from the pair for permanent holding in the captive flock. By late 1984, two pairs were each represented by five progeny in captivity, so it appeared that both these pairs could produce young for a release program starting in 1985 if they survived to the 1985 breeding season. At that point, causes and rates of decline for the wild population were still not well established, and there was every reason to continue to attempt to maintain the wild population. Most program participants were looking forward to splitting the benefits of replacement clutching between the wild and captive populations in 1985.

Unfortunately, mortality of breeding pairs proved catastrophic over the winter of 1984–85, and only one of the five pairs active in 1984 survived to lay eggs in 1985. This was not one of the pairs with five progeny in captivity. Moreover, of the 15 birds in the wild population in late 1984, only 9 were still alive by mid-1985—a 40-percent decline in the wild population in just a few months. This extremely high mortality was observed mostly in birds that were never recovered, so causes of mortality were for the most part unknown, although one of the lost birds was recovered moribund and was determined to be another victim of lead poisoning. The failure of the assumptions underlying an early release program to hold true during the winter of l984–85 led to one of the most contentious periods of debate over strategies in the history of the condor program.

On one side of the debate were those who, like me, believed that it was wisest and most conservative to conclude from recent events that the wild population was truly inviable and that release of captives into such a population would actually decrease the chances of ultimate recovery of the species by compromising the viability of the captive population. It appeared that lead poisoning could, in fact, be the major problem and that any hope that this problem could be reversed before the species became extinct in the wild was unrealistic. Meanwhile, the captive flock was neither large enough nor genetically diverse enough to ensure viability—at that time it was made up almost entirely of the progeny of a few pairs. Capturing the last free-flying birds might at least achieve a viable captive population and allow time to correct the lead problem, whereas leaving them in the wild would almost certainly be to watch them, and possibly the species, perish quickly with no long-term benefit. The California Fish and Game Commission opposed both releases and leaving birds in the wild (see discussion in Snyder and Snyder [2005]).

On the other side of the debate were people and organizations that argued that the recent high mortality was likely atypical and that it was crucial to maintain the wild population as long as possible by proceeding with releases even though the minimal conditions established by the recovery team for releases could not be met. Without birds in the wild, it was argued, it would not be possible to maintain existing and prospective condor reserves or funding for a continuing condor program (Wilbur, 2004).

The opposing points of view resulted in a stalemate through much of 1985. No releases were conducted because they required approval at both the Federal and State levels, which was not obtainable. The only action agreed upon through extensive negotiation was that three of the remaining nine birds in the wild could be brought into captivity. These three birds were trapped into captivity in the summer of 1985.

The position of the recovery team on capture of the last wild birds was initially ambivalent, although in early 1985 the team quickly reached a consensus that releases should not be initiated. However, by the summer of 1985, the team recommended that at least three of the remaining six wild birds should be taken captive, and by the fall of 1985, the team was in full agreement with the State of California's preferred position that all wild birds should be taken captive. This agreement developed in part because of a vigorous debate on the issue held at the International Vulture Symposium in Sacramento in November of that year.

Then, in early December 1985, the USFWS reversed its position and the long debate was finally resolved with a consensus of the USFWS with the State of California and the recovery team that all wild birds should be taken captive and that no near-term releases should be conducted (Snyder and Snyder, 2000, 2005). This agreement clearly came about because another condor still in the wild contracted terminal lead poisoning at this point, making it increasingly plausible that the major problem in the wild was indeed lead poisoning, a very difficult problem to solve quickly.

However, agreement that the last birds should come into captivity still had to clear two more hurdles: (1) a lawsuit filed by the National Audubon Society to prevent trapping of the last wild birds, and (2) objections to trapping the last wild birds from a group of Native Americans. The lawsuit and Native American objections were successfully resolved by mid-1986, and the last birds were trapped into captivity by early 1987, yielding an initial captive flock of 27 birds, consisting of 13 males and 14 females (Snyder and Snyder, 2000, 2005).

As hoped, the California condor proved adaptable to captive conditions and has bred readily in confinement, with all birds initially taken captive eventually becoming captive breeders—even Topatopa, although he was one of the very last to begin reproduction. The number of condors currently in existence now totals near 400, about half of them in the wild and half in captivity. This total is far greater than the low point of 22 individuals reached in 1982 before a captive program was launched (Snyder and Snyder, 2005).

Releases and Prospects for Viable Wild Populations

Following the rapid success in captive breeding, releases to the wild were begun in the early 1990s, first in southern California, then later in Arizona, other locations in California, and Baja California. Unfortunately, like the historical wild population in the 20th century, none of these populations has yet achieved viability, even with intensive management. Problems have been diverse but, as discussed above and in Snyder (2007), Walters and others (2010), Rideout and others (2012), and Finkelstein and others (2012), lead poisoning soon emerged again to dominate the list of negative factors. These authors agree that viable, self-sustaining wild populations likely will never be achieved unless the lead poisoning threat is fully addressed.

Other than a long-standing ban on lead shot in waterfowl hunting, lead ammunitions have not been banned anywhere in the United States except in the condor range in California, where a ban was instituted in 2007 and expanded in 2013. Elsewhere, prospective bans face continuing political opposition from interest groups fearful of potential consequences (see discussion in Snyder [2007]).

As was widely anticipated, the California ban on lead ammunitions, though an important step symbolically, has not ended condor lead poisonings in the State, perhaps because lead ammunitions are still readily obtainable in other parts of the country. Lead poisoning may continue if the supply of lead ammunitions is not fully removed

In favoring a ban on the use of lead ammunitions, most condor conservationists have not sought the end of hunting activities, but only the end of hunting activities using toxic ammunitions. In fact, hunting activities, so long as they are conducted with nontoxic ammunitions, may prove to be crucially beneficial for condor conservation in many regions by providing an adequate long-term carrion food supply (Snyder and Snyder, 2000, 2005).

Final Remarks

Although a major threat, lead poisoning is not the only source of the excessive mortality of wild California condors, and excessive mortality is not the only problem associated with releases. Discussions of other threats to the species are found in Mee and Hall (2007) and Walters and others (2010). The release population along the central California coast, for

Condor release site, Sespe Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

example, has recently been experiencing reproductive problems that are reflected in low hatchability of eggs (Burnett and others, 2013). Causes of the low hatchability have not been identified conclusively, although there are concerns that it may stem from these birds feeding heavily on carcasses of marine mammals, which are known to carry high levels of many contaminants (Marine Mammal Commission, 1999). Which contaminant might be involved is as yet unclear.

Another problem that is currently being vigorously debated is the need to ensure the future existence of optimal foraging regions for the species (Snyder and Snyder, 2005). Nesting habitats of the condor are mostly well-protected National Forest lands, but foraging habitats are largely private ranchlands that are being progressively lost to development. Arguably, the most important foraging region for the historical wild population and for the release population in southern California lies on the Tejon Ranch in Kern County, CA, parts of which were designated Critical Habitat for the species by the USFWS in 1976. The Tejon Ranch owners are now (2016) proposing major housing developments that would directly compromise a substantial portion of this Critical Habitat (Snyder and Snyder, 2005, p. 175). These development plans, if implemented, could have major adverse effects on the species.

Altogether, the condor program was one of the longest and most arduous efforts in Patuxent's Endangered Wildlife Research Program. That the condor is still with us is a great credit to the USFWS, and although wild populations of the species are not yet self-sustaining, there is reason to hope that this goal can be reached if the commitment shown by involved agencies in the past can be sustained, and the remaining obstacles to full recovery can be successfully addressed.

References Cited

Burnett, L.J., Sorenson, K.J., Brandt, Joseph, Sandhaus, E.A., Ciani, Deborah, Clark, Michael, David, Chandra, Theule, Jenny, Kasielke, Susie, and Risebrough, R.W., 2013, Eggshell thinning and depressed hatching success of California condors reintroduced to central California: Condor, v. 115, no. 3, p. 477–491. [Also available at http://dx.doi.org/10.1525/cond.2013.110150.]

Erickson, R.C., and Carpenter, J.W., 1983, Captive condor propagation and recommended release procedures, *in* Wilbur, S.R., and Jackson, J.A., eds., Vulture biology and management: Berkeley, CA, University of California Press, p. 385–399.

Finkelstein, M.E., Doak, D.F., George, Daniel, Burnett, Joe, Brandt, Joseph, Church, Molly, Grantham, Jesse, and Smith, D.R., 2012, Lead poisoning and the deceptive recovery of the critically endangered California condor: Proceedings of the National Academy of Sciences of the United States of America, v. 109, no. 28, p. 11449–11454. [Also available at http://dx.doi.org/10.1073/pnas.1203141109.]

Kiff, L.F., Peakall, D.B., and Wilbur, S.R., 1979, Recent changes in California condor eggshells: Condor, v. 81, no. 2, p. 166–172. [Also available at https://sora.unm.edu/node/102945.

Koford, C.B., 1953, The California condor: National Audubon Society Research Report, no. 4, New York, National Audubon Society, 154 p.

Condor foraging area, Tejon Ranch, Kern County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Locke, L.N., Bagley, G.E., Fricke, D.N., and Young, L.T., 1969, Lead poisoning and aspergillosis in an Andean condor: Journal of the American Veterinary Medical Association, v. 155, no. 7, p. 1052–1056. [Also available at http://www.cabdirect.org/abstracts/19721300469.html;jsessionid=4C0E8F4F6FE033F53E11C80F2BAE0E35.]

Mallette, R.D., and Borneman, J.C., 1966, First cooperative survey of the California condor: California Fish and Game, v. 52, no. 3, p. 185–203.

O'Shea, T.J., Reeves, R.R., and Long, A.K., eds., 1999, Marine mammals and persistent ocean contaminants: Bethesda, MD, Marine Mammal Commission, Proceedings of the Marine Mammal Commission Workshop, Keystone, CO, October 12–15, 1998, 150 p. [Also available at http://www.mmc.gov/wp-content/uploads/contaminantsreport.pdf.]

Mee, Allan, and Hall, L.S., eds., 2007, California condors in the 21st century: Series in Ornithology no. 2, Cambridge, MA, and Washington, D.C., Nuttall Ornithological Club and American Ornithologists' Union, 279 p.

Meretsky, V.J., Snyder, N.F.R., Beissinger, S.R., Clendenen, D.A., and Wiley, J.W., 2000, Demography of the California condor—Implications for reestablishment: Conservation Biology, v. 14, p. 957–967. [Also available at http://dx.doi.org/10.1046/j.1523-1739.2000.99113.x.]

Miller, A.H., McMillan, I., and McMillan, E., 1965, The current status and welfare of the California condor: National Audubon Society Research Report, no. 6, 61 p.

Ricklefs, R.E., ed., 1978, Report of the advisory panel on the California condor: National Audubon Society Conservation Report, no. 6, 27 p.

Rideout, B.A., Stalis, Ilse, Papendick, Rebecca, Pessier, Allan, Puschner, Birgit, Finkelstein, M.E., Smith, D.R., Johnson, Matthew, Mace, Michael, Stroud, Richard, Brandt, Joseph, Burnett, Joe, Parish, Chris, Petterson, Jim, Witte, Carmel, Stringfield, Cynthia, Orr, Kathy, Zuba, Jeff, Wallace, Mike, and Grantham, Jesse, 2012, Patterns of mortality in free-ranging California condors (*Gymnogyps californianus*): Journal of Wildlife Diseases, v. 48, no. 1, p. 95–112. [Also available at http://dx.doi.org/10.7589/0090-3558-48.1.95.]

Sibley, F.C., 1968, The life history, ecology and management of the California condor (*Gymnogyps californianus*): Laurel, MD, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Annual Progress Report, Project no. B–22, 34 p.

Snyder, N.F.R., 1983, California condor reproduction, past and present, *in* Temple, S.A., ed., Bird Conservation 1: Madison, WI, University of Wisconsin Press, p. 67–86.

Snyder, N.F.R., 2007, Limiting factors for wild California condors, *in* Mee, Allan, and Hall, L.S., eds., California condors in the 21st century: Series in Ornithology no. 2, Cambridge, MA, and Washington, D.C., Nuttall Ornithological Club and American Ornithologists' Union, p. 9–33.

Snyder, N.F.R., and Hamber, J.A., 1985. Replacement-clutching and annual nesting of California condors: Condor, v. 87, no. 3, p. 374–378. [Also available at https://sora.unm.edu/node/103587.]

Snyder, N.F.R., and Johnson, E.V., 1985, Photographic censusing of the 1982–1983 California condor population: Condor, v. 87, no. 1, p. 1–13.

Snyder, N.F.R., Johnson, E.V., and Clendenen, D.A., 1987, Primary molt of California condors: Condor, v. 89, no. 3, p. 468–485. [Also available at https://sora.unm.edu/node/103834.]

Snyder, N.F.R., and Meretsky, V.J., 2003, California condors and DDE—A re-evaluation: Ibis, v. 145, no. 1, p. 136–151. [Also available at http://dx.doi.org/10.1046/j.1474-919X.2003.00132.x.]

Snyder, N.F.R., and Snyder, H.A., 1989, Biology and conservation of the California condor, *in* Power, D.M., ed., Currrent Ornithology, v. 6: New York, Plenum Press, p. 175–267.

Snyder, Noel, and Snyder, Helen, 2000, The California condor, a saga of natural history and conservation: London, Academic Press, 410 p.

Snyder, N.F.R., and Snyder, H.A., 2005, Introduction to the California condor: Berkeley, CA, University of California Press, 271 p.

Verner, J., 1978, California condors—Status of the recovery effort: Washington, D.C., U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station: Berkeley, CA, General Technical Report PSW–28, 30 p. [Also available at http://www.fs.fed.us/psw/publications/documents/psw_gtr028/psw_gtr028.pdf.]

Walters, J.R., Derrickson, S.R., Fry, D.M., Haig, S.M., Marzluff, J.M., and Wunderle, J.M., Jr., 2010, Status of the California condor (*Gymnogyps californianus*) and efforts to achieve its recovery: Auk, v. 127, no. 4, p. 969–1001. [Also available at http://dx.doi.org/10.1525/auk.2010.127.4.969.]

Wilbur, S.R., 1978, The California condor, 1966–1976—A look at its past and future: North American Fauna, v. 72, p. 1–136. [Also available at http://dx.doi.org/10.3996/nafa.72.0001.]

Wilbur, S.R., 2004, Condor tales—What I learned in twelve years with the big birds: Gresham, OR, Symbios, 400 p.

Endangered Species Research in the Caribbean

James W. Wiley

Although indigenous Amerindian populations adversely affected the biota of their island environments, it was not until the arrival of Europeans that populations of many plant and animal species in the Caribbean Islands declined dramatically (Snyder and others, 1987). Island species are particularly vulnerable to changes in the environment, which, in the extreme, can lead to their extinction. The small populations of many species that occupy islands have limited gene pools and typically show extremes of specialization, characteristics that place those species at high risk for decline and extinction with rapid environmental change. The most important factor in the decline of most Caribbean Island species has been the rapid increase in human population and the environmental changes related to that growth (Snyder and others, 1987).

Among the islands in the Caribbean, Puerto Rico has experienced arguably the most radical transformation of any pre-Columbian habitat. Puerto Rico formerly was covered in natural vegetation, but by 1912 fewer than 1 percent of the original forests were still virgin; all other areas were cut, plowed, grazed, burned, or otherwise degraded (Snyder and others, 1987). The extensive agriculture supported by Puerto Rico's fertile soils allowed the human population on this small (11,489 square kilometers [km^2] [4,436 square miles (mi^2)]—204 kilometers [km] [127 miles (mi)] east to west and 76 km [47 mi] north to south at the widest points) island to increase rapidly, to the point that in 2015, with 4 million residents (about 350/km^2 [900/mi^2]), it was one of the most densely populated islands in the world. Although agriculture is no longer of major importance in Puerto Rico, the human population has continued to grow, causing many plant and animal species to decline or disappear from the island (Snyder and others, 1987).

The endemic Puerto Rican parrot (*Amazona vittata*) is perhaps the most charismatic and emblematic of the species affected by the many environmental problems that have faced Puerto Rican wildlife in the past 500 years. Early accounts reported the parrot's presence throughout the island and on at least three of Puerto Rico's four major satellite islands. All indications are that the parrot was once abundant on the island, perhaps numbering more than 1 million individuals. As Europeans settled the land, parrot populations declined rapidly and disappeared from one after another part of the island (Snyder and others, 1987).

Development of an Endangered Species Research Program in Puerto Rico

In 1946, Ventura Barnés, a biologist with the Commonwealth of Puerto Rico Department of Agriculture and Commerce, expressed concern over the parrot's decline (Rodríguez-Vidal, 1959). From 1953 through 1956, José Rodríguez-Vidal, another Commonwealth biologist, supported by the Pittman-Robertson Program of the U.S. Fish and Wildlife Service (USFWS), conducted the first detailed study of the parrot. Rodríguez-Vidal found that the parrot population in the mid-1950s consisted of only about 200 individuals, and those birds were localized in one small area in eastern Puerto Rico—the Luquillo Forest (Rodríguez-Vidal, 1959). The evidence of the parrot's precariously low numbers and restricted range prompted further apprehension on the part of Commonwealth Department of Agriculture and Commerce biologists,

Puerto Rican parrot ready to fledge, 1975. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

who attempted to reintroduce the parrot in western Puerto Rico, outside its remnant range. Unfortunately, those efforts failed. Early studies by Rodríguez-Vidal and others indicated that a broad array of environmental problems could have been responsible for the parrot's decline (Snyder and others, 1987).

At the urging of Frank Wadsworth, Director of the International Institute of Tropical Forestry (IITF), Río Piedras, Puerto Rico, and with similar efforts by Ray Erickson, assistant director in charge of endangered species research at Patuxent Wildlife Research Center in Laurel, MD (Patuxent), a cooperative program to rescue the parrot was begun in late 1968. The program was developed as a collaboration of the USFWS, U.S. Department of Agriculture, U.S. Forest Service (Forest Service), and the government of the Commonwealth of Puerto Rico, with support from the World Wildlife Fund. The initiation of the Puerto Rican parrot program closely followed passage of the Federal Endangered Species Preservation Act (1966) and inclusion of the parrot on the Federal Endangered Species List in 1967.

At the onset of the Patuxent program in Puerto Rico, all participants recognized that the parrot was in steep decline and extreme measures would probably be needed to save the species. To maximize the likelihood of determining the important factors affecting the parrot population, studies were not restricted to the parrot, but included efforts to understand the biological characteristics of important natural enemies of this species and the biology of other, closely related parrot species (Snyder and others, 1987).

History of Patuxent Biologists at the Puerto Rico Field Station

Cameron Kepler was the first biologist to lead the Caribbean research program. The Forest Service provided Cam and his wife, Angela ("Kay"), with a live-in field station in the heart of the parrot's remnant range in the protected Luquillo Forest, to allow them direct, daily access to the remaining population. The Keplers conducted research on the parrot and other species of conservation concern from 1968 to 1971. Cam Kepler's parrot work focused on determining population size and distribution within the Luquillo Forest, where he developed reliable censusing methods (Kepler, 1972b). Unfortunately, the accuracy of the counts did not show a hoped-for larger population of parrots than had previously been reported. Kepler gave special attention to parrots in the eastern half of the Luquillo Forest, where he documented daily and seasonal foraging behavior and sought to obtain information on recruitment and mortality. Cam left Puerto Rico in late 1971 to become Visiting Researcher at the Edward Grey Institute of Field Ornithology, Oxford University, after which he returned to Patuxent in 1973 to head the whooping crane (*Grus americana*) captive breeding program. He moved on to Hawaii to establish the Maui field station in 1977, but returned to Patuxent (Southeast Research Station, Athens, GA) in 1986 to conduct research on Kirtland's warbler (*Seteophaga kirtlandii*) and other species.

Pico el Yunque, El Yunque National Forest (formerly Luquillo Forest), Puerto Rico, mid-1970s. Photo by Helen Snyder, U.S. Fish and Wildlife Service.

Cam and Kay Kepler, U.S. Fish and Wildlife Service, at field station, Luquillo Forest, Puerto Rico, 1970. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Noel Snyder (left) and John Taapken, U.S. Fish and Wildlife Service, prepare for a day in the field, Puerto Rico, mid-1970s. Photo by Helen Snyder, U.S. Fish and Wildlife Service.

Noel Snyder was the second scientist to head the Puerto Rico field station. Noel and his wife, Helen, conducted detailed studies of parrot biology from 1972 through 1976, concentrating on the population's breeding biology. Constant daylight observations of all known nests (2–5) were conducted from blinds throughout breeding seasons. The Snyders made critical advances in the understanding of the parrot's challenges and, as each bit of knowledge was obtained, immediate efforts were made to correct identified problems. For the first time, the decline of the parrot population was reversed, and the wild population began to increase slowly in number. Further, a captive parrot program was established in Puerto Rico under the watch of the Snyders, who developed fundamental husbandry techniques for captives (Snyder and others, 1987).

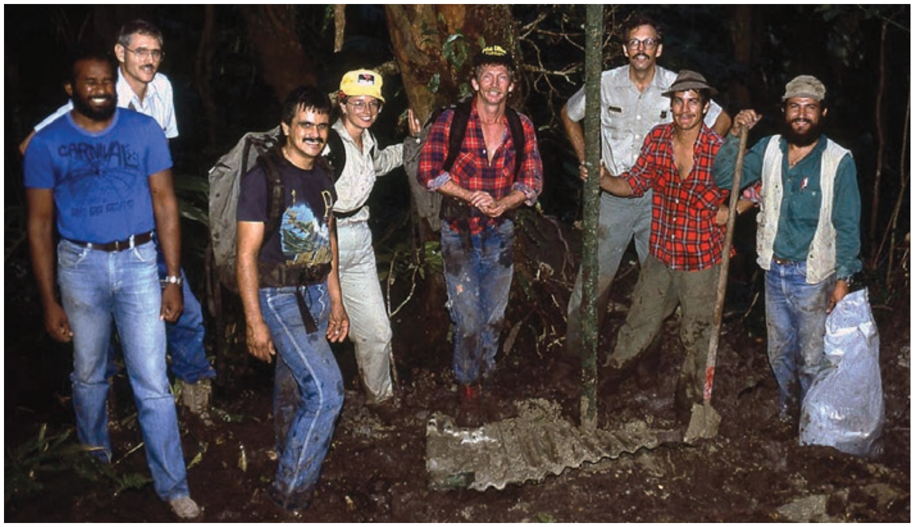
Jim and Beth Wiley's work overlapped with that of the Snyders; they came to the program as Forest Service employees in 1975, replacing Noel when he transferred to Patuxent in 1976. After a writing stint at Patuxent, Noel headed back to the field to study snail kites (*Rostrhamus sociabilis*) in 1978, before leading the California condor (*Gymnogyps californianus*) research program beginning in 1980. Noel left the Patuxent program in 1987, when he retired, but continued writing scientific papers as a private researcher. The Wileys continued the work initiated by the Keplers and Snyders, with emphasis on improving reproductive success in the wild population and developing techniques for releasing captive-produced birds into the wild. The aviary flock increased in number, produced the first captive-bred Puerto Rican parrots, and provided a vital resource for managing the wild flock. During this period, the first releases of captive-produced parrots were made in the Luquillo Forest, and radiotelemetry was used to track post-fledging parrots (Lindsey and Arendt, 1991). The Wileys left Puerto Rico in late 1986, following Noel Snyder to California, where Jim studied the California condor through 1991, when he entered the U.S. Geological Survey (USGS) Cooperative Research Units program.

Gerald Lindsey joined the Puerto Rico program in 1985. After the Wileys' departure, he led the program, conducting additional work on parrot movements by using telemetry. Gerald overlapped with Marcia Wilson, who assumed leadership of the program in 1989, after which time Gerald followed Wiley out to California, where the two worked together again—this time on the condor project—before Gerald transferred to Hawaii in 1991.

Marcia Wilson (1989–91) continued to oversee nesting investigations, the captive program, and tracking of free-flying parrots. In her first year at the station, Marcia was faced with a major hurricane, which damaged much of the Luquillo Forest. Under the challenging post-hurricane conditions, her team documented the greatly reduced population size and distribution of the parrot (Wilson and others, 1994). Marcia left the Puerto Rico field station in 1991 to assume an administrative post at Patuxent in Maryland.

Wylie Barrow (1990–92) and J. Michael ("Joe") Meyers (1990–95) joined Marcia in Puerto Rico as Patuxent staff members before she went to Laurel. Barrow and Meyers continued the telemetry work and developed refined parrot-marking techniques. Meyers was the last of the Patuxent scientists to lead the parrot project, which was abandoned in 1995. Barrow and Meyers continued as USGS wildlife research biologists—Wylie at the National Wetlands Research Center and Joe at Patuxent, stationed at the University of Georgia in Athens.

Even before Marcia Wilson left the Puerto Rico field station, a transition of agency roles had begun. In 1990, the USFWS (Region 4) assumed the lead in management aspects of the parrot conservation program, including operation of the aviary, in cooperation with the Puerto Rico Department of Natural Resources (PRDNR) and the Forest Service. Patuxent



Puerto Rican field crew at East Fork, Puerto Rico, 1989. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

closed the Puerto Rico field station in 1995. Francisco ("Tito") and Ana Vilella, the first biologists involved in the USFWS program (1989–95), were followed by Augustín Valido (1991–2001), Fernando Nuñez (2000–06), and Tom White (1999–present [2016]), among others.

Pearly-eyed thrasher—a parrot predator, 1970s. Photo by John Taapken, U.S. Fish and Wildlife Service.

Challenges and Accomplishments of Patuxent's Program for Conservation of the Puerto Rican Parrot

At the outset, Patuxent biologists were faced with a staggering, diverse array of environmental problems affecting the parrot (Snyder and others, 1987). Foremost among these was the near-complete, island-wide habitat destruction and alteration. Although parrots formerly were found through all of the island's habitats ranging from woodland to forest, the species requires habitat that includes trees large enough to harbor cavities for nesting. By the mid-1950s, the Luquillo Forest was the only location in Puerto Rico that supported a parrot population, mainly because it was the only sizable habitat that provided nesting cavities. Early studies by Barnés, Rodríguez-Vidal, and others had provided few clues about the parrot's problems (Rodríguez-Vidal, 1959). Rodríguez-Vidal and others suggested that poor nest success, apparently due mainly to rat (*Rattus rattus*) and pearly-eyed thrasher (*Margarops fuscatus*) predation, was responsible, but a comprehensive appreciation of nesting and other difficulties was still lacking.

Kepler studied three nests from blinds and determined that many of the birds in the population were not breeding. He also found that the population had declined precipitously since the mid-1950s and, with only about 24 wild birds in existence in 1968, the species was perilously close to extinction in the wild.

Noel Snyder intensified observations at nests, and initiated comprehensive studies of the ecology of the parrot. Through extensive searches and tree climbing, it was determined that although many large trees and cavities existed within the protection of the Luquillo Forest, only a few existing cavities were actually suitable for parrot nesting. Many of the most amenable cavity-bearing trees had been removed through historic logging and timber-stand improvement practices in the forest. Further, a tradition of felling nest trees or hacking into cavities to harvest chicks for pets selectively destroyed the most suitable (that is, parrot-occupied) nesting habitat. Snyder's finding that few good cavities were available for nesting parrots led to an effort to improve existing suboptimal cavities as well as provide suitable artificial cavities for parrots.

Detailed studies of parrot breeding biology were initiated in 1973 with constant daylight observations from blinds of as many nests as possible given constraints of personnel and their energy limitations. Those were days of pressing urgency, as the wild population continued its decline toward extinction and the time remaining to find solutions to slow and reverse the rapid loss of birds grew increasingly limited. In fact, when the low point of only 13 birds known in the wild was reached in mid-1975, the goal had to be nothing less than a rapid turnaround in the plummeting population to prevent genetic collapse of the species. This pressure led scientists to conduct intensive trials of innovative methods to protect the parrot and reverse the decline in reproductive output.

Intensive observations revealed the relative unimportance of some natural and exotic predators, including Puerto Rican boa (*Epicrates inornatus*) and introduced Javan mongoose (*Herpestes javanicus*). Although both are known predators of parrots, their role in the decline of the species was evaluated to be less significant than that of other threats. Exotic rats and pearly-eyed thrashers were determined to be important predators and competitors of the parrot. The now-ubiquitous thrasher is evidently a recent invader of the forest and may not have threatened historical populations of parrots. Both thrashers and rats use tree cavities for nesting, with thrashers being particularly aggressive cavity competitors with parrots. Rats were found to be more important as scavengers of abandoned parrot eggs or chicks, but nevertheless remained a threat to nest contents and were controlled within key nesting areas. The thrasher menace was addressed first through direct elimination of birds that demonstrated a threat at parrot nests. That labor-intensive strategy was not sustainable, however, and other control mechanisms were explored. Experimental trials using various alternatives of cavity size and dimension revealed that thrashers and parrots differed with respect to preferred nest-cavity characteristics, thereby indicating a potential option for thrasher management (Snyder and others, 1987). Nest boxes of various configurations and sizes were placed in the forest and their acceptance by thrashers was monitored to determine that species' preferences. Comparing those data with data collected from successful parrot nests revealed that parrots preferred deeper cavities than thrashers. A program of deepening existing parrot nesting cavities was begun, along with provisioning thrashers occupying the parrots' nesting areas with one or more optimal thrasher-sized nest boxes. That strategy greatly reduced thrasher-parrot competition and resulted in improved parrot nest success.

European honeybee (*Apis mellifera*), another exotic species, also proved to be an important cavity competitor with parrots. Honeybees seek cavities with characteristics attractive to parrots. Once established in a parrot nest cavity, honeybees may occupy that site for years, excluding the parrot and further diminishing the overall availability of parrot nest sites. Provisioning of additional nearby artificial boxes was not feasible in controlling honeybee invasions of parrot nests. Fortunately, honeybees typically do not swarm and seek new cavities until after the parrot nesting season. A practice of physically removing honeybee colonies that invaded parrot nests was used successfully for bee control.

Most natural cavities in the Luquillo Forest, where annual rainfall averages 500 centimeters (nearly 200 inches), were found to have wet bottoms, a characteristic that was determined to lower the chances of parrot egg and chick survival. Therefore, in addition to fortifying natural cavities against predators and competitors, all existing cavities were modified to eliminate problems caused by entry of water.

Although capture of parrots, especially taking young from nests, was an important historical factor in the decline of the parrot, that practice had declined by the 1960s, in part because of greater legal protection of the species and its habitat, but also because the pet trade had changed. People who wanted pet parrots were more likely to purchase an exotic parrot from a pet store than to encounter an individual selling Puerto Rican parrots. Unfortunately, this shift from native to exotic birds being sought as pets introduced other threats to the Puerto Rican parrot. Exotic parrots that escaped or were intentionally released from captivity established populations in Puerto Rico, and those species threatened the native species as competitors for habitat. Even though most alien parrots characteristically remained near populated areas, these established exotics posed a far more insidious threat: imported birds might carry exotic diseases against which the native parrot likely would have no defense.

Harvesting of wild parrots was also deterred by program personnel who guarded all active nests throughout the day, while watching for signs of other problems that would affect nest success and productivity. Although manpower constraints did not allow for constant vigil at all nests every day, the number of nests monitored was maximized through the dedication of technicians and volunteers. A tabulation of Patuxent parrot program activities from 1973 to 1979 showed that scientists and assistants had logged more than 20,000 hours of observations from blinds and lookouts.

Radiotelemetry techniques for tracking parrots were developed and have proven invaluable in advancing the conservation of the species. In 1985, studies of parrot movements using telemetry were brought to the forefront of the research program in an effort to determine areas of vulnerability of parrots to predation. Telemetry of marked birds confirmed the conclusions reached from observations and tallies of parrots: post-fledging mortality in the wild flock was high. Known and suspected predators included resident red-tailed hawks (*Buteo jamaicensis*), which are found in extraordinarily high densities in the Luquillo Forest, and wintering peregrine falcons (*Falco peregrinus*) (Lindsey and others, 1994).

As Patuxent scientists tallied the many environmental problems faced by the parrot in the Luquillo Forest, they also examined the possibility of establishing flocks in other parts of Puerto Rico that might exhibit less challenging environmental conditions than those in the extremely wet rain forest at Luquillo and, therefore, might prove to be better suited for

Gerald Lindsey, U.S. Fish and Wildlife Service, tracking parrots with telemetry, Luquillo Forest, Puerto Rico, 1986. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

Helen Snyder, U.S. Fish and Wildlife Service, with Hispaniolan parrots, Sierra de Baharuco, Dominican Republic, 1982. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Beth Wiley, U.S. Fish and Wildlife Service, feeding young parrots, Puerto Rican parrot aviary, Luquillo Forest, Puerto Rico, 1980s. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

self-sustaining populations of the parrot. It became obvious that by using current (1985) techniques the parrot population at Luquillo could be sustained only through rigorous and extensive management. Although the Luquillo Forest offered substantial protection against poaching and habitat alteration, the parrot population there was facing more risk factors (especially the wetter environment and denser populations of predators and competitors) than existed in other areas in Puerto Rico. Several areas that might have been appropriate for potential reintroduction areas of the parrot were protected as Commonwealth forests and, with a shift of the island's human population away from an agrarian-based society, natural cover, albeit second growth, had increased dramatically to about 40 percent of land cover. Patuxent scientists believed it would be advantageous to maintain the Luquillo Forest population, which was an important source of behavioral memory, while establishing a second free-flying flock distant from the Luquillo population and supported by an on-site aviary at a second release area. Río Abajo Commonwealth Forest was judged to be a suitable site for this next phase of the recovery effort on the basis of its recent (1940s) history of parrot presence, habitat recovery, security, and lower densities of predators and competitors.

With intensive and extensive efforts by many dedicated people, the Luquillo Forest wild population began a slow recovery from the low of 13 individuals and only 2 breeding pairs in 1975 (Snyder and others, 1987). By 1989, the wild population had reached 47 individuals and as many as 5 (1975, 1984) breeding pairs in a year. In September 1989, however, the first major hurricane in 57 years devastated the Luquillo Forest. Despite an apparent loss of more than half the parrots in the wild, biologists subsequently located a new nesting area that may have been established as a consequence of the storm. In fact, an until-then program-high number of breeding pairs (six) nested in 1991. By 1995, when Patuxent discontinued the parrot program, the wild population had increased to 44 individuals (Snyder and others, 1987).

Captive Puerto Rican parrots were established at Patuxent in 1970, with two birds donated by the Mayagüez Zoo in western Puerto Rico. In early 1972, Paul Sykes (USFWS) and Mike Lennartz (Forest Service) were detailed temporarily to Puerto Rico, where they captured two wild birds despite tremendous odds and physical challenges. One parrot survived and was added to the Patuxent flock. At that time, however, an outbreak of Asiatic Newcastle disease in Puerto Rico led to rigorous quarantine for any birds entering the United States, making it impractical to continue developing the captive flock at Patuxent. The quarantine problem and the need to move parrot eggs and chicks to and from wild nests for protection and treatment led to the establishment of an aviary in the Luquillo Forest in 1973, at which time activities shifted from capture of wild, free-flying birds to harvesting eggs and chicks from the wild to build the captive flock. In fact, most new members of the captive flock were added when eggs or chicks could not be maintained safely in the wild because of potentially lethal threats to their health and safety. At the onset of developing an on-site captive flock, a primary goal was to obtain genetic representation of as many of the existing wild parrots as possible.

With the establishment of the aviary in Puerto Rico, first in the Snyders' living room and later at a dedicated aviary field station building, salvaging and manipulation of wild nest contents became practical. Eggs and chicks threatened by problems such as predation, parasitism by warble (*Philornis pici*) and black soldier (*Hermetia illucens*) flies, or wet cavity floors could be removed temporarily to the aviary, treated or guarded in a safe environment until the threat at the wild nest had been addressed, then returned in time to fledge in the wild (Snyder and others, 1987). The ability to salvage endangered eggs and chicks was further improved through the establishment of an on-site captive flock of the closely related Hispaniolan parrot (*Amazona ventralis*). Captive Hispaniolan parrots served as surrogates for the endangered species in many ways. During periods of high risk at wild Puerto Rican parrot nests, captive-produced Hispaniolan parrot eggs and chicks were fostered into wild nests to replace Puerto Rican parrot eggs and chicks until the danger had passed. Hispaniolan parrots were used as “guinea pigs” to test for suitability of various procedures before they were used on Puerto Rican parrots (Snyder and others, 1987). Furthermore, captive Hispaniolan parrots proved extremely useful and reliable in incubating eggs and brooding of captive- and wild-produced Puerto Rican parrot eggs and chicks. In fact, Hispaniolan parrots were far better at incubating eggs and brooding chicks than were mechanized incubators and brooders, and required far less intense interaction with humans—an important concern for avoiding parrot imprinting on humans and reliance on people as sources of food.

Although the wild population began to recover from its 1975 low, by mid-1979 only 25 or 26 birds were known to exist in the wild. The slow recovery made efforts to use the captive flock to augment the wild population even more important to the parrot’s survival. Efforts to achieve captive reproduction involved developing techniques for sexing the captives and methods of artificial insemination. Experiments in the aviary revealed that replacement clutching was a valuable procedure to increase egg production of parrots; therefore, this practice was incorporated into the captive program to boost production. The first captive-bred Puerto Rican parrot chick was produced in 1979 and was fostered into an active nest, from which it successfully fledged. Thereafter, all fit chicks produced through 1986 were fostered into wild nests.

As part of the preparation for releases of free-flying, captive-produced Puerto Rican parrots, experimental releases of captive-produced Hispaniolan parrots were conducted in the Dominican Republic in 1982. Those releases of 36 birds resulted in an encouraging survival rate of 33 percent, which is approximately the rate the program had been able to achieve through efforts to manage the wild Puerto Rican parrot flock.

Mike Lennartz, U.S. Forest Service, carrying Puerto Rican parrots, Luquillo Forest, Puerto Rico, 1980s. Photo by Paul Sykes, U.S. Fish and Wildlife Service.

Half-grown captive Puerto Rican parrot. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

Additional advancements with radiotelemetry and other marking techniques gave biologists the confidence to release three free-flying, captive-produced Puerto Rican parrots into the Luquillo Forest in 1986. That release was preceded by aversion conditioning of release candidate parrots by using a trained red-tailed hawk. Again, the survival rate was one out of three, and, importantly, the surviving individual reached sexual maturity and bred in the wild.

After Ray Erickson retired from Patuxent in 1980, the program for the conservation of the Puerto Rican parrot was managed differently. Field work was delegated primarily to technicians and junior scientists, and active nests were monitored remotely. Senior scientists devoted more time to communicating with their superiors and writing scientifically defensible research proposals and manuscripts rather than making field observations and guarding nests, a function that had proven critical to the recovery effort (Lindsey, 1992). Therefore, although the junior scientists and technicians were very capable and dedicated to the success of the project, the knowledge, experience, and judgment of the senior scientists were no longer being applied directly to decision-making in the field.

Patuxent administrators continued to work on parrot recovery progress after the USFWS and the PRDNR assumed expanded roles in the parrot program. The second wild population in Río Abajo, Puerto Rico, was not established in spite of strong evidence that the Luquillo Forest environment was not optimal for the survival of a viable, self-sustaining wild population (Snyder and others, 1987, p. 270). Over time, the USFWS strengthened its relations with PRDNR and the program's leadership shifted away from Patuxent. In 1990, the Puerto Rican government established and administered a second captive breeding site at the Río Abajo aviary in western Puerto Rico. Patuxent's parrot program ended in 1995.

Present Status of the Puerto Rican Parrot

The establishment of a disjunct western population of Puerto Rican parrots has been of pivotal importance in the recovery of the parrot. By 2012, the wild population at Río Abajo totaled 40 to 50 birds, after only 6 years of releases. Even more encouraging, 10 pairs in the western area were productive in the wild in 2012. The collective captive populations in the Luquillo Forest and Río Abajo aviaries, which support both of the wild populations, currently (2016) number more than 400 birds. A third wild population was established at a second western site (Maricao) in Puerto Rico in 2015 (U.S. Fish and Wildlife Service, 2016).

Unfortunately, however, after more than 40 years of intense efforts to establish a self-sustaining population of parrots in the Luquillo Forest, the flock still struggles to survive, with a 2016 wild population of only about 12 birds. If other areas of Puerto Rico are included, however, the wild population of the parrot is more than 100 birds (Breining, 2015).

Research on Other Parrot Species and Training of Caribbean Conservationists and Biologists

Comparative studies of the Puerto Rican parrot and parrot species on other islands were an important component of the research conducted by Patuxent biologists. Such studies provided insights into some of the ecological and behavioral aspects of Puerto Rican parrot biology, particularly when "healthy" populations were compared with the small remnant population surviving in Puerto Rico. In such comparisons, wild populations of Hispaniolan parrots were studied where they occurred in large numbers in unaltered ecosystems in the Dominican Republic. Among other species studied, to varying extents, were Bahama parrot (*Amazona leucocephala bahamensis*) in Great Abaco and Great Inagua Islands (Kepler, 1982); Grand Cayman (*A. l. caymanensis*) and Cayman Brac (*A. l. hesterna*) parrots in the Cayman Islands (Wiley, 1991); Cuban parrot (*A. l. leucocephala*) in Cuba and Isla de Pinos (now Isla de la Juventud) (Aguilera and others, 1999); black-billed (*A. agilis*) and yellow-billed (*A. collaria*) parrots in Jamaica; and St. Vincent parrot (*A. guildingii*), St. Lucia parrot (*A. versicolor*), and imperial (*A. imperialis*) and red-necked (*A. arausiaca*) parrots in Dominica (Beissinger and Snyder, 1992; Snyder and others, 1987). In addition to conducting studies of other parrot species and their ecosystems, Patuxent scientists trained many resident conservation officers and biologists on site or during their extended stays at the Puerto Rico field station. Parrot research and management techniques—for example, development of reliable censusing methodology and using artificial and improved natural nest structures to augment natural habitat—were transferred to other islands and incorporated into those countries' parrot conservation efforts.

Other Endangered Species Research by Patuxent Scientists in the Caribbean

Because of the urgency of reversing the population decline of the Puerto Rican parrot, Patuxent biologists focused their research on that species; however, many other Caribbean wildlife species were in need of conservation efforts. For several species, that need could only be speculated upon, because no reliable population numbers or trends were available. Island agencies often asked Patuxent scientists to participate in studies of species in addition to the parrot. Therefore, Patuxent biologists considered it important to explore the biology of other species identified as possibly threatened to provide baseline data on those populations as well as a biologically sound foundation upon which to base local and international conservation efforts.

Seabirds on several of Puerto Rico's offshore islands and cays were the focus of Kepler's extra-parrot research (Kepler, 1978). Cam also conducted the first study of Puerto Rican nightjar (*Caprimulgus noctitherus*), a species that was thought to have become extinct until its rediscovery in 1961. His work and subsequent surveys by other Patuxent biologists produced a basic understanding of the distribution of, status of, and threats to the nightjar. In addition, Cam and Kay Kepler surprised the ornithological world with their discovery of a new species of warbler (the elfin-woods warbler, *Setophaga angelae*) in Puerto Rico in 1970 (Kepler and Parkes, 1972).

Two pigeon species of international concern—plain pigeon (*Patagioenas inornata*) (Wiley and others, 1982) and white-crowned pigeon (*P. leucocephala*) (Wiley and Wiley, 1979)—were studied by Patuxent personnel. Both suffered from the extreme habitat modification seen in Puerto Rico and other Caribbean islands. Results of the studies were used by the PRDNR to manage the pigeon populations. The formerly endangered Puerto Rican plain pigeon (*P. i. wetmorei*) has

Male white-crowned pigeon brooding, Puerto Rico, early 1980s. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

shown remarkable recovery since the 1970s, when only about 120 birds survived, to the several thousand pigeons that are currently (2016) spread over a large portion of Puerto Rico.

The endangered yellow-shouldered blackbird (*Agelaius xanthomus*) and several other native host species of a recently arrived brood parasite, shiny cowbird (*Molothrus bonariensis*), were the subject of extensive research that improved understanding of the ecological relations between the parasite and its hosts (Cruz and others, 1985, 1988; Wiley, 1985, 1988). Patuxent scientists and technicians developed techniques for controlling the effects of brood parasitism on host species, which resulted in improved reproductive success and productivity of hosts, including the yellow-shouldered blackbird (Post and Wiley, 1976, 1977; Wiley and others, 1991).

Several endangered or threatened species of raptors were the subject of in-depth research by Patuxent biologists. The threatened status of endemic races of sharp-shinned (*Accipiter striatus venator*) and broad-winged (*Buteo platypterus brunnescens*) hawks was determined, and Patuxent scientists initiated research on the ecology and behavior of these species. The restricted range of the endemic race of short-eared owl (*Asio flammeus portoricensis*) was determined and its status was identified as being of national concern.

White-necked crow (*Corvus leucognaphalus*), endemic to Hispaniola and Puerto Rico, was extirpated from Puerto Rico in the early 1960s. Patuxent scientists conducted a detailed study to determine the possible cause of that extirpation by studying populations of the crow in the Dominican Republic (Wiley, 2006). That study resulted in a recommendation to reintroduce the crow to Puerto Rico as part of a restoration of the island's original ecosystems and a hedge against extirpation in Hispaniola and, thereby, extinction. The data collected on the crow in the Dominican Republic serve as a baseline for reintroduction into Puerto Rico, although no action to do so has been undertaken.

A detailed study of the critically endangered St. Croix ground lizard (*Ameiva polops*) was conducted by Beth and Jim Wiley at Green and Protestant Cays at the request of the government of the U.S. Virgin Islands. That study provided baseline information on the population size, habitat requirements, and management needs of the lizard. The formerly endangered Puerto Rican boa (*Epicrates inornatus*) was the subject of a diet study by Jim Wiley (2006).

In addition to studies of threatened wildlife species, Patuxent biologists led or were involved in research on several nonthreatened species that were important to the understanding of the ecology of the parrot and other species—for example, investigations of rat populations in the Luquillo Forest, pearly-eyed thrasher ecology and behavior (Snyder and Taapken, 1978), and warble and soldier fly biology.

Patuxent scientists served as members or consultants on Federal recovery teams for the Puerto Rican parrot, Puerto Rican plain pigeon, Puerto Rican nightjar, yellow-shouldered blackbird, and several other species in Puerto Rico and the U.S. Virgin Islands. The Patuxent scientists' research results provided baseline data critical to the development of recovery plans.

Contributions of Patuxent Wildlife Research Center to Caribbean Conservation Efforts

It may never be known whether the efforts of Patuxent scientists and the many other employees and volunteers to save the Puerto Rican parrot actually prevented the species' extinction. Certainly their efforts shifted the parrot's trajectory from a precipitous decline headed for extinction toward population growth, albeit slow growth beset by many setbacks over the years. Although confidence is not yet warranted, the parrot appears to have beaten the odds and recovered from an extremely small population consisting of few individuals and, consequently, a dangerously small gene pool. Of course, whether genetic problems will appear in the future is unknown.

Similarly, it is difficult to evaluate the importance of Patuxent's efforts to save other species from extinction. Certainly Patuxent scientists helped to recognize the problems faced by several species and to provide population estimates upon which the results of future recovery efforts could be assayed. Regardless of the effect of Patuxent on the recovery of individual species, the program had wide and lasting effects on conservation in the region. Importantly, the parrot program was one of the first conservation issues to attract the attention of the Puerto Rican public and helped to establish a foundation for the elevated conservation ethic seen on the island today.

Another of the most important byproducts of the Patuxent research program in the region has been the training of several conservationists and biologists from other islands while the Patuxent scientists were on site or during their extended stays in Puerto Rico. Patuxent scientists visited all islands having parrot populations and involved local conservationists in research and management efforts. Effective and experimental technologies were thereby transferred to other islands and incorporated into those countries' parrot conservation efforts.

The many other people who sacrificed and worked under extremely difficult conditions as they participated in parrot recovery efforts also merit acknowledgment. Most were employed by the Forest Service, USFWS, and PRDNR, but many others generously donated their time as volunteers. Advances made through Patuxent and its collaborating agencies would not have been possible without their valuable contributions. Equally important as the conservation of individual species and their ecosystems are the effects of Patuxent's Caribbean program on the professional development of the many technicians, assistants, graduate students, and volunteers who went on to become influential contributors to conservation efforts in Puerto Rico and elsewhere (table 1). In fact, several of those program associates have become important decision makers in the parrot's recovery.

Table 1. Representative technicians, students, and volunteers who participated in Patuxent Wildlife Research Center's Endangered Species Program in the Caribbean, and highlights of their subsequent careers.

[AM, aviary manager; AT, aviary technician; F&AT, field and aviary technician; FT, field technician; GS, graduate student; T, trainee; US, undergraduate student; V, volunteer; BBS, North American Breeding Bird Survey; EYNF, El Yunque National Forest; GIS, Geographic Information Specialist; IITF, International Institute of Tropical Forestry; NGO, Nongovernment organization; NMEMNRD, New Mexico Energy, Minerals and Natural Resources Department; PRDNR, Puerto Rico Department of Natural Resources; PRP, Puerto Rican parrot; Patuxent, Patuxent Wildlife Research Center; TNWRA, Tennessee Wildlife Resources Agency; UPR, University of Puerto Rico; USDA-APHIS, U.S. Department of Agriculture-Animal and Plant Health Inspection Service; USFS, U.S. Department of Agriculture-Forest Service; USFWS, U.S. Fish and Wildlife Service; USGS, U.S. Geological Survey; USNPS, U.S. National Park Service]

Program participant	Status in program	Post-program contributions
Hernán Abreu	F&AT	Environmental Scientist, USNPS
Wayne Arendt	F&AT/GS	Wildlife Biologist, IITF
Bonnie Bell	F&AT	Enforcement Officer, USFWS
Kelly Brock	AM/GS	Endangered Species Specialist, U.S. Navy
Julio Cardona	V	Scientist and Director, Puerto Rican conservation NGO
Orlando Carrasquillo	F&AT	Supervisory Biological Technican, Ecosystem Team, EYNF, USFS
José Colón	F&AT	Sociedad Ornitología Puertorriqueña, environmental consultant, photographer
Victor Cuevas	F&AT	Visitor Information Service Leader, EYNF, USFS
Carlos Delannoy	F&AT	Professor and Department Chair of Biology, UPR-Mayagüez
Linda DeLay	V	GIS, NMEMNRD
Oscar Díaz-Marrero	F&AT	Refuge Manager, USFWS
Joe diTomaso	F&AT	Department Plant Science Chair and Professor, University of California at Davis
Sharon Dougherty	V/GS	Endangered Species Biologist and cofounder, Circle Mountain Biological Consultants, Inc.
Rosemarie Gnam	V/GS	Chief, Division Science Authority International Affairs Program, USFWS
Nelson Green	T/V	Manager, captive parrot program in Dominica
Quammie Greenaway	T/V	Conservation Officer, Dominica Forestry Department
Robin Knopp	F&AT	Veterinarian
Ed LaRue	F&AT/GS	Endangered Species Biologist and Chief Executive Officer, Circle Mountain Biological Consultants, Inc.
Benjamin ("Benji") Layton	F&AT/GS	Regional Big Game/Waterfowl Coordinator, TNWRA
Sebastian Lousada	V/US	Private aviculturalist
Aurea ("Puchi") Moragón	AT	Website Manager, EYNF, USFS
Fernando Nuñez	F&AT/GS	Leader of PRP Recovery Program, USFWS Region 4
Keith Pardieck	FT	Patuxent BBS Program Coordinator
José Rodríguez	AT	First comanager. of captive program at Río Abajo aviary, PRDNR
Ann Smith	AT	First comanager. of captive program at Río Abajo aviary, PRDNR
Dwight Smith	F&AT	Businessman
John Taapken	F&AT	Businessman and politician
Monica Tomosy	V/GS	Chief, U.S. Bird Banding Laboratory; USFS liaison to USGS
Edgar Vazquez Cabrera	F&AT	Biologist, PRDNR and USDA-APHIS
Michael Zamore	T/V	Wildlife Research officer, Dominica Forestry Department

Selected References

Aguilera, X.G., Alvarez, V.B., Wiley, J.W., and Rosales, J.R., 1999, Population size of Cuban parrots *Amazona leucocephala* and sandhill cranes *Grus canadensis* and community involvement in their conservation in northern Isla de la Juventud, Cuba: Bird Conservation International, v. 9, no. 2, p. 97–112. [Also available at https://doi.org/10.1017/S0959270900002227.]

Beissinger, S.R., and Snyder, N.F.R., 1992, New world parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, 288 p.

Breining, Greg, 2015, Puerto Rican parrot comeback: National Wildlife, accessed June 3, 2016, at https://www.nwf.org/News-and-Magazines/National-Wildlife/Birds/Archives/2015/Puerto-Rican-Parrot-Comeback.aspx.

Brock, M.K., and White, B.N., 1991, Multifragment alleles in DNA fingerprints of the parrot, *Amazona ventralis*: Journal of Heredity, v. 82, no. 3, p. 209–212. [Also available at http://jhered.oxfordjournals.org/cgi/content/abstract/82/3/209.]

Cruz, Alexander, Manolis, T., and Wiley, J.W., 1985, The shiny cowbird in the Caribbean: Ecology of an avian brood parasite undergoing range expansion, *in* Buckley, P.A., Foster, M.S., Morton, E.S., Ridgely, R.S., and Buckley, F.G., eds., Neotropical ornithology: Ornithological Monographs no. 36, p. 607–620. [Also available at http://www.jstor.org/stable/40168308.]

Cruz, Alexander, and Wiley, J.W., 1989, The decline of an adaptation in the absence of a presumed selection pressure: Evolution, v. 43, no. 1, p. 55–62. [Also available at http://dx.doi.org/10.2307/2409163.]

Cruz, Alexander, Wiley, J.W., Nakamura, T.K., and Post, W., 1988, The shiny cowbird, *Molothrus bonariensis,* in the West Indian region—Biogeographical and ecological implications, *in* Woods, C.A., ed., Biogeography of the West Indies—Past, present, and future: Gainesville, FL, Sandhill Crane Press, Inc., p. 519–540.

Derrickson, S.R., and Snyder, N.F.R., 1992, Potentials and limits of captive breeding in parrot conservation, *in* Beissinger, S.R., and Snyder, N.F.R., eds., New World parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, p. 133–163.

Enkerlin-Hoeflich, E.C., Snyder, N.F.R., and Wiley, J.W., 2006, Behavior of wild *Amazona* and *Rhynchopsitta* parrots, with comparative insights from other psittacines, *in* Luescher, A.U., ed., Manual of parrot behavior: Ames, IA, Blackwell Publishing, p. 13–25.

Kepler, A.K., 1977, Comparative study of todies (Todidae)—With emphasis on the Puerto Rican tody, *Todus mexicanus*: Publications of the Nuttall Ornithological Club, no. 16, 190 p.

Kepler, C.B., 1972a, Notes on the ecology of Puerto Rican swifts, including the first record of the white-collared swift *Streptoprocne zonaris*: Ibis, v. 114, no. 4, p. 541–543. [Also available at http://dx.doi.org/10.1111/j.1474-919X.1972.tb00856.x.]

Kepler, C.B., 1972b, The ecology of the Puerto Rican parrot, an endangered species: Ibis, v. 114, no. 3, p. 442–443. [Also available at http://dx.doi.org/10.1111/j.1474-919X.1972.tb00846.x.]

Kepler, C.B., 1978, The breeding ecology of sea birds on Monito Island, Puerto Rico: Condor, v. 80, no. 1, p. 72–87. [Also available at http://sora.unm.edu/node/102818.]

Kepler, C.B., and Kepler, A.K., 1973, The distribution and ecology of the Puerto Rican whip-poor-will, an endangered species: Living Bird, v. 11, p. 207–239.

Kepler, C.B., and Kepler, A.K., 1978, The sea-birds of Culebra and its adjacent islands, Puerto Rico: Living Bird, v. 16, p. 21–50.

Kepler, C.B., and Parkes, K.C., 1972, A new species of warbler (Parulidae) from Puerto Rico: Auk, v. 89, no. 1, p. 1–18. [Also available at http://sora.unm.edu/node/22201.]

Lindsey, G.D., 1992, Nest guarding from observation blinds: Strategy for improving Puerto Rican parrot nest success: Journal of Field Ornithology, v. 63, no. 4, p. 466–472. [Also available at http://www.jstor.org/stable/4513745.]

Lindsey, G.D., and Arendt, W.J., 1991, Radio tracking Puerto Rican parrots—Assessing triangulation accuracy in an insular rain forest: Caribbean Journal of Science, v. 27, nos. 1–2, p. 46–53.

Lindsey, G.D., Arendt, W.J., and Kalina, Jan, 1994, Survival and causes of mortality in juvenile Puerto Rican parrots: Journal of Field Ornithology, v. 65, no. 1, p. 76–82. [Also available at https://sora.unm.edu/node/51865.]

Lindsey, G.D., Arendt, W.J., Kalina, Jan, and Pendleton, G.W., 1991, Home range and movements of juvenile Puerto Rican parrots: Journal of Wildlife Management, v. 55, no. 2, p. 318–322. [Also available at http://dx.doi.org/10.2307/3809157.]

Meyers, J.M., 1994, Leg bands cause injuries to parakeets and parrots: North American Bird Bander, v. 19, no. 4, p. 133–136. [Also available at https://sora.unm.edu/node/93291.]

Meyers, J.M., 1995, A colored leg banding technique for *Amazona* parrots: Journal of Field Ornithology, v. 66, no. 4, p. 582–589. [Also available at https://sora.unm.edu/node/52018.]

Meyers, J.M., 1995, Puerto Rican parrots, *in* LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., and Mac, M.J., eds., Our living resources—A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems: Washington, D.C., U.S. Department of the Interior, National Biological Service, p. 83–85. [Also available at https://pubs.er.usgs.gov/publication/70148108.]

Meyers, J.M., 1996, Evaluation of 3 radio transmitters and collar designs for *Amazona*: Wildlife Society Bulletin, v. 24, no. 1, p. 15–20. [Also available at http://www.jstor.org/stable/3782826.]

Meyers, J.M., 1996, New nesting area of Puerto Rican parrots: Wilson Bulletin, v. 108, no. 1, p. 164–166. [Also available at http://sora.unm.edu/node/131371.]

Meyers, J.M., Arendt, W.J., and Lindsey, G.D., 1996, Survival of radio-collared nestling Puerto Rican parrots: Wilson Bulletin, v. 108, no. 1, p. 159–163. [Also available at http://sora.unm.edu/node/131370.]

Post, William, and Wiley, J.W., 1976, The yellow-shouldered blackbird—Present and future: American Birds, v. 30, no. 1, p. 13–20. [Also available at https://sora.unm.edu/node/112547.]

Post, William, and Wiley, J.W., 1977, Reproductive interactions of the shiny cowbird and the yellow-shouldered blackbird: Condor, v. 79, p. 176–184. [Also available at https://sora.unm.edu/node/102731.]

Post, William, and Wiley, J.W., 1977, The shiny cowbird in the West Indies: Condor, v. 79, p. 119–121. [Also available at https://sora.unm.edu/node/102712.]

Rodríguez-Vidal, J.A., 1959, Puerto Rican parrot study: San Juan, Puerto Rico, Department of Agriculture of the Commonwealth of Puerto Rico, Monograph no. 1, 15 p.

Snyder, N.F.R., 1977, Puerto Rican parrots and nest-site scarcity, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 47–53.

Snyder, N.F.R., 1978, Increasing reproductive effort and success by reducing nest-site limitations—A review, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 27–33.

Snyder, N.F.R., Derrickson, S.R., Beissinger, S.R., Wiley, J.W., Smith, T.B., Toone, W.D., and Miller, B., 1996, Limitations of captive breeding in endangered species recovery: Conservation Biology, v. 10, no. 2, p. 338–348. [Also available at http://www.jstor.org/stable/2386850.]

Snyder, N.F.R., King, W.B., and Kepler, C.B., 1982, Biology and conservation of the Bahama parrot: Living Bird, v. 19, p. 91–114.

Snyder, N.F.R., and Taapken, J.D., 1978, Puerto Rican parrots and nest predation by pearly-eyed thrashers, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 113–120.

Snyder, N.F.R., and Wiley, J.W., 1994, Puerto Rican parrot conservation—A retrospective evaluation by two former leaders of the program (1972–1986): PsittaScene, v. 6, no. 1, p. 6–7. [Also available at https://www.parrots.org/files/psitta/442/ps_6_1_feb_94.pdf.]

Snyder, N.F.R., Wiley, J.W., and Kepler, C.B., 1987, The parrots of Luquillo—Natural history and conservation of the Puerto Rican parrot: Los Angeles, CA, Western Foundation of Vertebrate Zoology, 384 p.

U.S. Fish and Wildlife Service, 2016, Conserving the nature of America--Significant achievement in the transfer of Puerto Rican parrots to the Maricao Commonwealth Forest: accessed November 10, 2016, at https://www.fws.gov/news/ShowNews.cfm?ID=26D2B5A7-5056-AF00-5BA3BAAD09E24C98.

Wiley, J.W., 1979, The white-crowned pigeon in Puerto Rico: Status, distribution, and movements: Journal of Wildlife Management, v. 43, no. 2, p. 402–413. [Also available at http://dx.doi.org/10.2307/3800349.]

Wiley, J.W., 1980, The Puerto Rican parrot (*Amazona vittata*)—Its decline and the program for its conservation, *in* Pasquier, R.F., ed., Conservation of New World parrots: Washington, D.C., Smithsonian Institution Press for the International Council for Bird Preservation, Technical Publication no. 1, p. 133–159.

Wiley, J.W., 1983, The role of captive propagation in Puerto Rican parrot conservation, *in* Risser, A., and Todd, F., eds., Jean Delacour/International Federation for the Conservation of Birds—Symposium on breeding birds in captivity: Los Angeles, CA, International Federation for the Conservation of Birds, p. 441–453.

Wiley, J.W., 1985a, Bird conservation in the United States Caribbean, *in* Temple, S.A., ed., Bird conservation 2: Madison, WI, University of Wisconsin Press for International Council for Bird Preservation, p. 107–159.

Wiley, J.W., 1985b, Shiny cowbird parasitism in two avian communities in Puerto Rico: Condor, v. 87, no. 2, p. 165–176. [Also available at http://sora.unm.edu/node/103553.]

Wiley, J.W., 1985c, Status and conservation of forest raptors in the West Indies, *in* Newon, I., and Chancellor, R., eds., Raptor conservation: International Council for Bird Preservation, Technical Publication no. 5, p. 199–204.

Wiley, J.W., 1985d, The captive programme for the endangered Puerto Rican parrot *Amazona vittata*: Aviculture Magazine, v. 91, no. 2, p. 110–116.

Wiley, J.W., 1985e, The Puerto Rican parrot and competition for its nest sites, *in* Moors, P.J., ed., Conservation of island birds—Case studies for the management of threatened island species: Cambridge, England, International Council for Bird Preservation, Technical Publication no. 3, p. 213–223.

Wiley, J.W., 1986a, Habitat change and its effects on Puerto Rican raptors: International Council for Bird Preservation Birds of Prey Bulletin no. 3, p. 51–56. [Also available at http://www.raptors-international.org/book/birds_of_prey_1986/Wiley_1986_51-56.pdf.]

Wiley, J.W., 1986b, Status and conservation of raptors in the West Indies: International Council for Bird Preservation Birds of Prey Bulletin no. 3, p. 57–70. [Also available at http://www.raptors-international.org/book/birds_of_prey_1986/Wiley_1986_57-70.pdf.]

Wiley, J.W., 1988, Host selection by the shiny cowbird: Condor, v. 90, no. 2, p. 289–303. [Also available at http://sora.unm.edu/node/103956.]

Wiley, J.W., 1991, Status and conservation of parrots and parakeets in the Greater Antilles, Bahama Islands, and Cayman Islands: Bird Conservation International, v. 1, p. 187–214. [Also available at https://doi.org/10.1017/S0959270900000599.]

Wiley, J.W., 1996, Ornithology in Puerto Rico and the Virgin Islands, *in* Figueroa Colón, J.C., ed., The scientific survey of Puerto Rico and the Virgin Islands—An eighty-year reassessment of the islands' natural history: New York, Annals of the New York Academy of Sciences, v. 776, p. 149–179. [Also available at http://dx.doi.org/10.1111/j.1749-6632.1996.tb17419.x.]

Wiley, J.W., 2003, Habitat association, size, stomach contents, and reproductive condition of Puerto Rican boa (*Epicrates inornatus*): Caribbean Journal of Science, v. 39, no. 1, p. 189–194.

Wiley, J.W., 2006, The ecology, behavior, and conservation of a West Indian corvid, the white-necked crow (*Corvus leucognaphalus*): Ornithología Neotropical, v. 17, no. 2, p. 105–146. [Also available at https://sora.unm.edu/node/119745.]

Wiley, J.W., Cotte, R., Parker, W.T., Raffaele, H.A., Vivaldi, J.L., and Snyder, N.F.R., 1982, Puerto Rican plain pigeon recovery plan: Atlanta, GA, U.S. Fish and Wildlife Service, 52 p. [Also available at https://www.fws.gov/caribbean/PDF/Recovery_Plans/Columba_inornata_wetmorei.pdf.]

Wiley, J.W., and Gee, G., 1981, Using captive propagation to help save the Puerto Rican parrot: AFA Watchbird, v. 8, no. 5, p. 4–11. [Also available at https://journals.tdl.org/watchbird/index.php/watchbird/article/view/2037/0.]

Wiley, J.W., Gnam, R.S., Koenig, S.E., Dornelly, A., Gálvez, X., Bradley, P.E., White, T., Zamore, M., Reillo, P.R., and Anthony, D., 2004, Status and conservation of the family *Psittacidae* in the West Indies: Caribbean Journal of Ornithology, v. 17, p. 94–154.

Wiley, J.W., and Perry, H.R., Jr., 1985, El programa de investigaciones ornitológicas de Patuxent, *in* Stiles, F.G., and Aguilar, P.G., eds., Proceedings I Symposio de Ornitologia Neotropical, IX Congreso LatinAmericano de Zoologico, 14–15 Octobre 1983: Arequipa, Peru, Asociación Peruana para Conservación de la Naturaleza, World Wildlife Fund–U.S. and U.S. Fish and Wildlife Service, 126 p.

Wiley, J.W., Post, William, and Cruz, Alexander, 1991, Conservation of the yellow-shouldered blackbird *Agelaius xanthomus*, an endangered West Indian species: Biological Conservation, v. 55, no. 2, p. 119–138. [Also available at http://dx.doi.org/10.1016/0006-3207(91)90052-B.]

Wiley, J.W., Snyder, N.F.R., and Gnam, R.S., 1992, Reintroduction as a conservation strategy for parrots, *in* Beissinger, S.R., and Snyder, N.F.R., eds., New World parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, p. 165–200.

Wiley, J.W., and Wiley, B.N., 1979, The biology of the white-crowned pigeon: Wildlife Monograph no. 64, 54 p.

Wiley, J.W., and Wunderle, J.M., Jr., 1993, The effects of hurricanes on birds, with special reference to Caribbean islands: Bird Conservation International, v. 3, no. 4, p. 319–349. [Also available at http://dx.doi.org/10.1017/S0959270900002598.]

Wilson, K.A., Field, R., and Wilson, M.H., 1995, Successful nesting behavior of Puerto Rican parrots: Wilson Bulletin, v. 107, no. 3, p. 518–529. [Also available at http://sora.unm.edu/node/131313.]

Wilson, K.A., Wilson, M.H., and Field, Rebecca, 1997, Behavior of Puerto Rican parrots during failed nesting attempts: Wilson Bulletin, v. 109, no. 3, p. 490–503. [Also available at http://sora.unm.edu/node/131502.]

Wilson, M.H., Kepler, C.B., Snyder, N.F.R., Derrickson, S.R., Dein, F.J., Wiley, J.W., Wunderle, J.M., Jr., Lugo, A.E., Graham, D.L., and Toone, W.D., 1994, Puerto Rican parrots and potential limitations of the metapopulation approach to species conservation: Conservation Biology, v. 8, no. 1, p. 114–123. [Also available at http://dx.doi.org/10.1046/j.1523-1739.1994.08010114.x.]

Wunderle, J.M., Jr., Snyder, N.F.R., Muiznieks, Britta, Wiley, J.W., and Meyers, J.M., 2003, Histories of Puerto Rican parrot nests in the Caribbean National Forest/Luquillo Experimental Forest, 1973–2000: Portland, OR, U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, General Technical Report IITF–GTR–21, 28 p. [Also available at http://www.fs.fed.us/pnw/pubs/iitf/gtr21.pdf.]

A Personal Perspective on Searching for the Ivory-Billed Woodpecker: A 41-Year Quest

Paul W. Sykes, Jr.

Introduction

I first learned about the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, while attending high school in the mid-1950s. Patuxent wildlife biologists Brooke Meanley, Chandler (Chan) S. Robbins, and Robert (Bob) E. Stewart, Sr., visited me at my parents' home in Norfolk, VA. I was the compiler of the Norfolk County Christmas Bird Count (which included the eastern portion of the Virginia sector of the Dismal Swamp). As part of that count, we had for several years been estimating populations of red-winged blackbirds (*Agelaius phoeniceus*) and common grackles (*Quiscalus quiscula*) in the millions. Patuxent was beginning studies of blackbird depredations on agricultural crops.

Approximately 10 years later, while I was attending graduate school at North Carolina State University at Raleigh, the chairman of my graduate committee, Thomas L. Quay, professor of zoology, suggested that I visit Patuxent to meet some of the staff and investigate job opportunities with the Bureau of Sport Fisheries and Wildlife (which became the U.S. Fish and Wildlife Service) within the U.S. Department of the Interior. I made two such trips, and was greatly impressed by the caliber of the research being conducted at Patuxent.

Toward the end of my graduate studies during the first half of 1967, I applied for a position as a wildlife biologist (research) at Patuxent, and, much to my delight, I got the job. I was hired on July 7, 1967, by Ray C. Erickson, Assistant Director of Patuxent; he was also in charge of the Endangered Wildlife Research Program housed at Snowden Hall on the Patuxent campus. At that time, Eugene (Dusty) H. Dustman was the center director, Pearle Sisler was head of the personnel office, and Bertha Preston was the program's secretary, with Barbara Nichols coming on board several years later. Others in the program at the time included Glen Smart, Gene Cowan, Bruce Williams, James Stephenson, and Wayne Shifflett. Wildlife biologists at the field stations included John L. Sincock at Kauai, Winston (Win) E. Banko on the "Big Island" of Hawaii, Fred C. Sibley in California, Roy E. Tomlinson in Arizona, and Donald Fortenbery in South Dakota. Bill and Lucille Stickel and Brooke Meanley and family lived nearby at Patuxent in a two-story duplex. (In the late 1960s, fellow employees were addressed by their first names, from the Bureau director down. The agency was like extended family.)

After the departure of Norman Holgerson, my duty station was a one-man office in Delray Beach, Palm Beach County, FL. This was my first permanent job, and resulted in a career that lasted just short of 40 years; I retired on April 3, 2007. My primary duties were to investigate the distribution, population dynamics, and biology of the snail kite (*Rostrhamus sociabilis plumbeus*) (at that time the common name was Everglade kite or Florida Everglade kite), the ivory-billed woodpecker (*Campephilus principalis principalis*), the dusky seaside sparrow (*Ammodramus maritimus nigrescens*) (formerly considered a full species, unfortunately now extinct), and other endangered species in the southeastern United States.

The Bureau of Sport Fisheries and Wildlife Research project work unit on the ivory-billed woodpecker (IBWO), "Status and distribution of the American ivory-billed

Nestling ivory-billed woodpecker and J.J. Kuhn, local guide, in the Singer Tract, LA, March 6, 1938. Photo by James T. Tanner, graduate student, Cornell University. Photo coutesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

woodpecker," authorized me to work with the species in the southeastern United States from October 1, 1967, to October 1, 1970. Given the circumstances, this project became open-ended, or, as fellow researcher J. Michael Scott (at the Hawaii field station on the "Big Island") told Ray Erickson at one of our Endangered Species Research Program meetings at Patuxent, "Thanks for the long leash."

The information presented here is derived from my weekly and monthly activity reports (1967–92), memoranda and other correspondence, office files, my field notes, the literature, and consultations and work with others. My efforts to find the IBWO are described here for the first time, and are presented in chronological order. The names of those who contributed to my field work are included for the historical record. Without the help of these persons and many others, my searches would not have been possible.

J.J. Kuhn, a local guide, and Peter Paul Kellogg, Cornell University, making sound recording of ivory-billed woodpecker in the Singer Tract, LA, April 1935. Photo by James T. Tanner, Cornell University graduate student. Photo courtesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

Searches

On my first attempt to locate an IBWO, I traveled alone to the Green Swamp in northern Polk County, FL, on October 14, 1967. On October 16, I accompanied Richard A. Long (wildlife officer, Florida Game and Fresh Water Fish Commission—now the Florida Fish and Wildlife Commission), in an open 4x4 Jeep into the Green Swamp along the Withlacoochee River in Polk and Sumter Counties. It was on this trip that I heard what sounded like a loud white-breasted nuthatch (*Sitta carolinensis*)—like the "kent" calls of an IBWO. I had on tape a copy of IBWO vocalizations from the Cornell Lab of Ornithology (Ithaca, NY) that Professors Arthur A. Allen and Peter Paul Kellogg and doctoral student James T. Tanner had recorded at the Singer Tract (an 81,000-acre property named after the sewing machine company that owned the land) in northeastern Louisiana in the mid-1930s. I had studied this tape prior to beginning my search so I could readily recognize the vocalizations if I encountered any IBWOs.

When I heard the nuthatch-like vocalizations, the hair on the back of my neck stood up and I experienced an intense adrenaline rush. Richard quickly stopped the vehicle on the bank of the river. I stepped out of the vehicle and looked around. The sound originated at the top of a water oak (*Quercus nigra*)—it was a blue jay (*Cyanocitta cristata*)! I was both surprised and disappointed—but I learned that blue jays can produce a very good imitation of an IBWO call and, therefore, hearing the bird without seeing it can lead to false reports of this woodpecker. From that time to the present (2016), I have heard from observers who witnessed blue jays making such calls; one report was from New Jersey, far from the IBWO's historic range. Other species, particularly northern flickers (*Colaptes auratus*), also may on occasion mimic an IBWO call. Henry M. Stevenson (professor of zoology, Florida State University, oral commun., about 1969) told me he had witnessed a flicker giving a call that sounded like that of an IBWO in either Alabama or northern Florida (I cannot recall which). In Louisiana, graduate student Laurence (Laurie) C. Binford (Louisiana State University, oral commun., about 1969) heard a flicker giving a call that sounded like an IBWO. In both cases, the source of the calls was found and the birds' true identities were determined. At the time, neither of these gentlemen knew of the other's observation.

H.V. (Tommy) Hines (pilot and game management agent, Bureau of Sport Fisheries and Wildlife) flew me over the Green Swamp and along the course of the Withlacoochee River on October 17, 1967. No IBWOs were found in the swamp on October 14, 16, or 17.

I conducted a search in southwestern Florida on October 31, 1967, with James (Jimmy) Poncier (wildlife officer, Florida Game and Fresh Water Fish Commission). We worked Bright Hour Ranch, Sour Orange Hammock, Myrtle Slough, and Prairie Creek in DeSoto County, and the Sparkman area and Babcock Ranch in Charlotte County. In the late afternoon, I flew with John R. Dowd (pilot, Florida Game and Fresh Water Fish Commission) for 1.5 hours at low altitude (300–400 feet [ft]), making a big loop over the State psychiatric hospital on Florida State Road 70, Sour Orange Hammock, Tipper Bay Slough, Telegraph Swamp, Babcock Ranch, Prairie Creek, and Tiger Bay Slough. No IBWOs were detected and no sign of their presence was noted.

On November 10, 1967, Henry Stevenson (Florida State University) and I searched for IBWOs on the Chipola River and at Dead Lake in Gulf and Calhoun Counties in the Florida Panhandle. We lost our way on the river for a short time, as we returned to the boat landing after dark with no flashlight or other light source. We did not observe any IBWOs or see any sign of their presence. In 1950, IBWOs were reported in this area by ornithologists Whitney Eastman and Muriel Kelso, and also by Davis Crompton, a birder from Massachusetts, but in that same year James T. Tanner (then professor of zoology, University of Tennessee) and Herbert L. Stoddard, Sr. (director and president of Tall Timbers Research Station, Tallahassee, FL), searching separately, did not locate the species. However, naturalist John V. Dennis reported hearing an IBWO call five times in the Chipola River Swamp on April 5, 1951. This appears to be the last report of the IBWO in the area (Jackson, 2004).

On November 12, 1967, Wayne Shifflett (then a refuge management trainee at St. Marks National Wildlife Refuge, formerly at Patuxent) and I looked for IBWOs along the east side of the Apalachicola River, in Tates Hell Swamp, and in part of the Apalachicola National Forest in Franklin County, FL, with negative results. I spent much of November 13 on the east side of the Apalachicola River in Liberty County, also with negative results.

I visited Tall Timbers Research Station just north of Tallahassee on November 14, 1967, where W. Wilson Baker (biologist at the station) introduced me to Herbert Stoddard. Stoddard stated that he had seen IBWOs several times, but did not divulge dates, locations, or other details of his sightings (Herbert Stoddard, Tall Timbers Research Station, oral commun., 1967). I learned later that most of Stoddard's sightings had occurred years earlier when he was much younger. Presumably such sightings were in the Panhandle of Florida. I never discovered the exact locations of most of them.

James Tanner near large sweet gum tree in optimum ivory-billed woodpecker habitat, Singer Tract, LA, May 1937. Photo by James T. Tanner, Cornell University graduate student. Photo courtesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

My first special assignment away from Patuxent's Florida field station was to verify reports by John Dennis of IBWO sightings in what is now the Big Thicket National Preserve of eastern Texas. I had first met John in the late 1950s on Martha's Vineyard, MA, when I was an undergraduate student. At that time he was mist-netting (capturing birds with Japanese mist nets) and banding landbird migrants as part of "Operation Recovery," a cooperative study of fall bird migration in the eastern United States, mainly along the Atlantic Coast. On April 17, 1948, John Dennis and Davis Crompton had rediscovered and photographed IBWOs in eastern Cuba after the species had not been seen for several years (Dennis, 1948; Jackson, 2004). In 1966–68, John was under contract with the Bureau of Sport Fisheries and Wildlife to locate IBWOs that were being reported by local residents in eastern Texas.

I met Harry Goodwin (Endangered Species Manager, U.S. Fish and Wildlife Service [USFWS]) at his office in the Main Interior Building in Washington, D.C., on August 9, 1967. Harry briefed me on the reports that John Dennis had been sending him of IBWO sightings, vocalizations, feeding signs, etc., in East Texas. Harry needed to know for certain if these reports were accurate (at one point Dennis estimated 5 to 10 pairs). The information Harry presented to me was very encouraging.

On the afternoon of August 25, 1967, I was at an IBWO meeting at Patuxent that was attended by John Dennis, Ray Erickson, and Harry Goodwin, and also Patuxent research managers Ralph Andrews and Gene Knoder. At this gathering, I obtained more information on contacts and places to search in East Texas, coastal South Carolina, Georgia, and Florida. In the course of our discussions, Dennis mentioned that because beetle infestations in large timber stands might tend to attract any IBWO present in an area, it might be worthwhile to contact foresters in the southeastern United States for possible leads to the locations of such infestations (John Dennis, contractor, U.S. Fish and Wildlife Service, oral commun., 1967). At the close of the meeting, he gave me several suggestions based on his long experience searching for IBWOs that I found helpful during field work in Texas starting in early January 1968.

With the information I had been given at this meeting and the earlier meeting with Harry Goodwin, I fully expected to find an IBWO in the southeastern United States in the coming year. In preparation for the trip to Texas, I invited James Tanner to join me in searching for IBWO in Texas, and he accepted. Jim (who died in January 1991) was the world's foremost authority on the IBWO and is the only person ever to have conducted a formal study of the species in the wild in the United States (Tanner, 1942), as part of his doctoral program at Cornell University under the direction of Arthur Allen. All other investigators, from Mark Catesby in 1731 to recent times (Catesby, 1731; Jackson, 2002), have had only brief encounters with IBWOs.

Male ivory-billed woodpecker at nest in red maple tree, Singer Tract, LA, April 1935. Photo by James T. Tanner, Cornell University graduate student. Photo coutesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

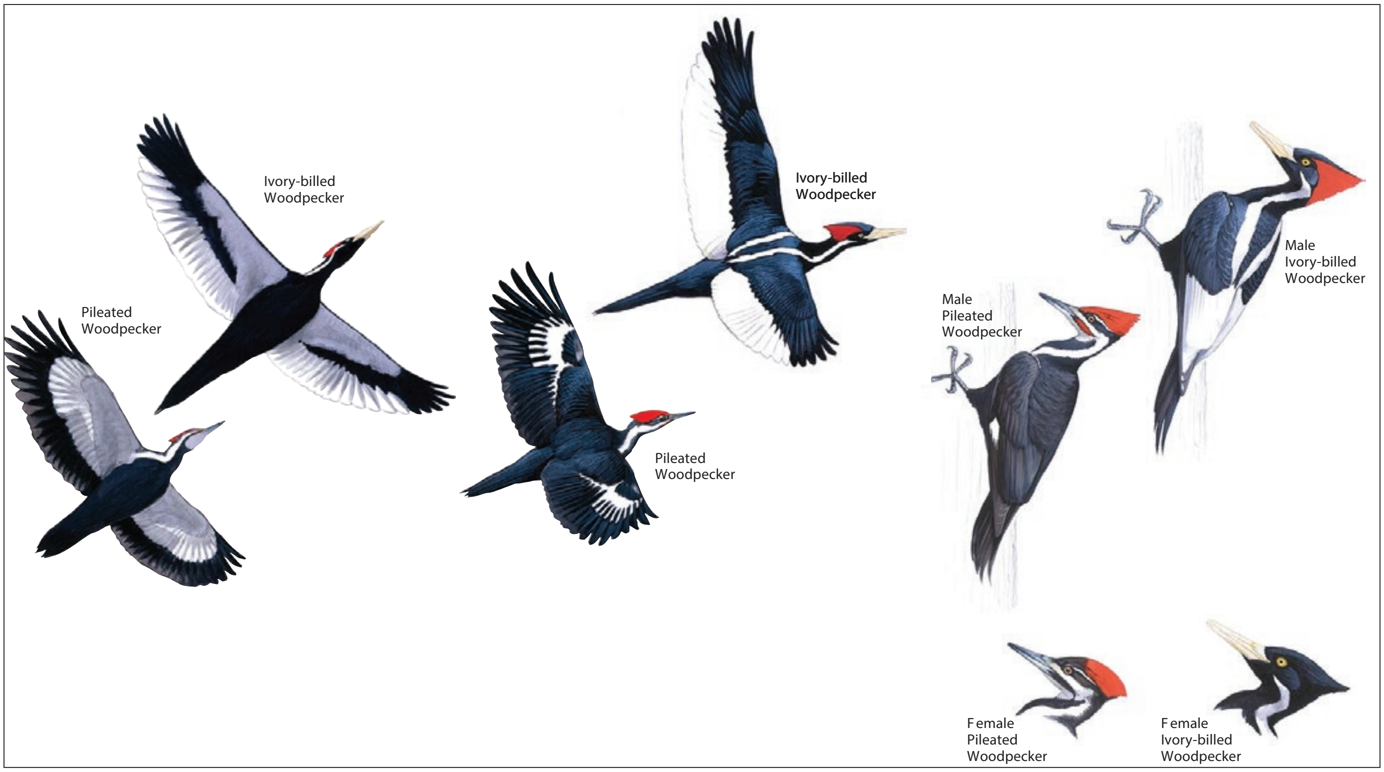
While en route to East Texas in early January 1968, I visited Henry Stevenson at Florida State University; George H. Lowery, Jr., and Robert J. Newman (professors of zoology, Museum of Zoology, Louisiana State University, Baton Rouge); and Jacob (Jake) M. Valentine (Gulf Coast Wildlife Management Biologist, Bureau of Sport Fisheries and Wildlife, Lafayette, LA) to discuss IBWOs and Mississippi sandhill cranes (*Grus canadensis pulla*). Upon reaching Texas, I talked with Bureau and State personnel about the IBWO and made arrangements to obtain access to boats and to fly over the Neches River flood plain. I began field work on January 10 and continued through January 31, 1968, in the Neches and Angelina River bottoms and a section along the Trinity River to the west, spending a total of 118 hours in the field. During the search, I covered 64 mi on foot, 372 mi by boat, 380 mi by airplane, and 2,600 mi in vehicles. Jim Tanner and I searched in the field together from January 19 to 27, and the two of us spent January 23 in the field with John Dennis. During January 21–27, Jim Tanner and I were joined in the field by Ernest McDaniel. Ernest was a teacher living in Kountze, TX, and a past president of the Texas Ornithological Society. He is an accomplished birder and woodsman, and knows East Texas well, particularly the area north of Dam B Reservoir on the Neches River bottoms, where most reported sightings have occurred. Ernest had been searching in the Big Thicket region for the past 6 years, but had not seen or heard an IBWO. During 1966 and 1967, he increased his efforts to find the bird. He had been checking woodpecker cavities, finding only evidence of the common species of woodpeckers and small mammals. (It should be noted that he could free-climb a tree like a squirrel.)

The Neches River bottoms are used heavily for outdoor recreation and commercial purposes. We interviewed several people who had reported seeing an IBWO. We searched carefully (two or more times) on foot in localities where the birds had been reported, as well as at other areas that appeared promising. Stopping and listening for a period of several minutes at intervals was standard procedure in all field work. The search protocol also included looking for feeding signs (bark scaling, pits, etc.) and possible nesting/roosting cavities. Tanner (1942) used this technique for locating IBWOs and found it to be highly successful.

I did not see or hear any IBWOs or find any tangible evidence to confirm their presence in eastern Texas. Reliable observers have not seen IBWOs despite being alert and searching for them in the Neches River Basin. We found during searching that feeding sign and several roost holes believed to be made by IBWOs were actually those of the pileated woodpecker (*Dryocopus pileatus*), a very common species in the Big Thicket region.

With most IBWO reports, a bird had either been seen but not heard, or heard but not seen. Many reports of IBWOs had been accepted without question, leading to the dissemination of much erroneous information. Although it cannot be proven that IBWOs are not present, it is remotely possible that the birds that were reported were merely passing through the area where they were seen. The reported sightings of the IBWO in eastern Texas appear to be misidentifications, probably of pileated woodpeckers. I submitted a 31-page in-house report (P.W. Sykes, Jr., U.S. Fish and Wildlife Service, unpub. report, 1968), which included an appendix of 14 maps (portions of U.S. Geological Survey [USGS] topographic quadrangles showing the areas visited), documenting my findings to Ray Erickson, Harry Goodwin, and John Aldrich (zoologist, National Museum of Natural History, Washington, D.C.). On my return trip to the field station at Delray Beach, I stopped at Louisiana State University and briefly discussed my findings in East Texas with George Lowery and several of his graduate students.

George M. Heinzman and H. Norton Agey (Heinzmann [sic] and Agey, 1971; Heinzman's name is misspelled throughout the article), working on surveys for the Florida Audubon Society's Bald Eagle Conservation Project, covered more than 1 million acres in central Florida, mostly large cattle ranches. They had access to most of the private properties, and visited them as many as three or four times per year to document the status of activity at eagle nests. They reported sightings or vocalizations of IBWOs on 11 occasions from 1967 to 1969, with no reports in 1965 and 1966. They spent 41 days in the area where they reported the presence of IBWOs. I was invited to join them in 1968 and was asked not to divulge the search location. I honored that request for 43 years but, because no IBWOs have been reported from this particular location since 1969 and all principal parties are deceased, I believe it is now time to make the location known. The Heinzman and Agey



Comparison of pileated and ivory-billed woodpeckers showing ventral and dorsal views in flight and perched. From paintings by David Allen Sibley, well-known author and bird artist; used with permission.

IBWO reports were at a large cattle ranch with locked gates west of U.S. Route 27 in Hardee and Highlands Counties, north of Highlands Hammock State Park.

I visited the site with George and Norton on May 18 and 19, 1968. We did not see or hear any IBWOs. Prior to my visit, on January 21, 1968, the duo found a dead sweetgum (*Liquidambar styraciflua*) that exhibited a freshly excavated cavity whose entrance hole was 44 ft above ground. On April 21 they found the tree had fallen and its trunk had broken into pieces at the entrance hole. Measurements of the entrance hole and cavity were more characteristic of IBWO than of pileated woodpecker. Two down feathers were found in the cavity, and a white feather was found on the ground beside the entrance hole. The feathers were sent to the U.S. National Museum of Natural History (a part of the Smithsonian Institution), and the white feather was identified by Alexander Wetmore, former Secretary of the Smithsonian Institution and world-renowned ornithologist, as the innermost secondary feather of an IBWO. Dr. Wetmore commented that he could not positively identify the down feathers because no IBWO nestling specimens (this was prior to widespread use of deoxyribonucleic acid [DNA] analysis) were available for comparison (Heinzmann [sic] and Agey, 1971). Some years later, Jerome Jackson (Whiteker Eminent Scholar in Science at Florida Gulf Coast University, Naples, FL, oral commun., 1994) examined the white feather and agreed it was the innermost secondary feather of an IBWO. After George Heinzman died, Norton Agey kept the tree stub with the cavity for a while, then gave it to Byrum (Buck) W. Cooper (a birder and friend of Norton, living in Haines City, FL). Buck donated the tree stub to the Florida Museum of Natural History. The stub with the cavity (now reassembled) and the three feathers are still at the Florida Museum of Natural History on the campus of the University of Florida in Gainesville, where I have examined them several times.

In an interesting twist to this story, Jerome Jackson, while examining IBWO specimens at the Florida Museum of Natural History, found the innermost secondary feather missing from a female IBWO specimen collected in Florida in 1929. Is this an amazing coincidence or was fraudulent activity involved? We will probably never know with certainty. I can only say that George Heinzman and Norton Agey were friends of mine, and I do not believe they would commit such an act.

Heinzman and Agey recorded what they thought were vocalizations of an IBWO, but subsequent analysis at the Cornell Lab of Ornithology revealed them to be those of a pileated woodpecker. Samples from the base of the quill of the white secondary feather were sent to two laboratories for genetic analysis in 2005 to verify the identification as material from an IBWO. The results from the two labs were inconclusive (Andrew [Andy] W. Kratter, Florida Museum of Natural History, oral commun., about 2005). In addition to his position as Curator of Birds at the Florida Museum of Natural History, Andy served on the American Ornithologists' Union (AOU) Committee on Classification and Nomenclature, and formerly served on the American Birding Association's Checklist Committee. But, to my knowledge, the feathers have not been tested for arsenic or other preservatives that would have been used in preparation of a museum specimen to protect it in a collection.

I revisited the Green Swamp of Florida on October 1, 1969, with Gary Hickman (biologist, Bureau River Basins Office, Vero Beach, FL; later in his career he was USFWS regional director for Alaska, Anchorage). We covered areas in the Withlacoochee State Forest from the North, Center, and South Grade Roads, and a road extension off the Center Grade. On October 2, Gary and I covered areas on the north and south sides of the Withlacoochee River in the Green Swamp and some private lands along the river. Both days produced negative results.

During 1970, reports of IBWO came from South Carolina. From September 12 to 20, 1970, I searched in Scape Oer and Black Water Swamps and along the Congaree River with Bob and Liz Teulings, Evelyn Dabbs, Eli Parker, and Peggy Kilby. Bob Teulings is a coauthor of "Birds of the Carolinas" (Potter and others, 1980, 2006); Evelyn Dabbs at the time was the President of the Carolina Bird Club; Eli Parker was a local birder who claimed to have seen IBWOs in the Scape Oer Swamp (Sumter County) in all seasons pre-1970; and Peggy Kilby was a local birder. I soon discovered that Eli knew the pileated woodpecker quite well. The Teulings and I canoed 45 mi down the Congaree River starting just south of Columbia on September 15. On September 18, from Santee, the Teulings and I canoed 2 mi on the Congaree and 23 mi on the Wateree River. Evelyn Dabbs, the Teulings, and I searched a swamp area in the central part of the Francis Marion National Forest on September 19. The Scape Oer Swamp was searched on September 12, 13, 14, 17, and 20. In the course of searching I played a tape of the IBWO vocalizations, but we did not see or hear any IBWOs.

At the 1971 AOU meeting in Seattle, WA, Professor George Lowery of LSU had two color, slightly out-of-focus photographs, apparently taken with an inexpensive camera by someone he knew (see Jackson [2004] for details). The photos were believed to have been taken within a year or so of the meeting. I, along with several others, including Laurence (Laurie) C. Binford (California Academy of Science) and Burt L. Monroe, Jr. (professor of biology, University of Louisville, later to become chairman of the AOU's Committee on Classification and Nomenclature) were invited to view the photos. We went to Dennis R. Paulson's lab at the University of Washington to examine the photos more carefully. The images were small, but showed the correct color and markings of the IBWO. The bill and eyes were not visible, and we could not determine whether, in fact, the image was of a live bird. Nearly all those present were skeptical of the authenticity of the photos and the photographer. At that time Professor Lowery would not reveal the location where the photos were taken or the name of the person who took them. It was surmised by those present in Paulson's lab at the time that the location was somewhere in the Atchafalaya River Basin of southern Louisiana. Therefore, during the early 1970s, I acquired a set of USGS 7.5-minute quadrangles covering the entire Atchafalaya River Basin. I planned to fly over the region, identify the most promising areas on the quads, and check them by boat and on foot to determine whether IBWOs might still be present. Funding for this proposed project was not forthcoming, however, and the plan was abandoned.

From 1973 through 1984, I looked for IBWOs in peninsular Florida, including the Big Cypress area (now Big Cypress National Preserve); Fakahatchee Strand (now Fakahatchee Strand Preserve State Park); Ocala National Forest; Loxahatchee River; and Highlands Hammock, Myakka River, and Tomoka State Parks. I visited some of these areas several times without finding any sign of IBWO. From 1985 through 1999, I did not search for IBWOs, as I had transferred to Patuxent's Athens, GA, field station and was involved with other research projects. During this latter period I did not hear of any IBWO reports that sounded plausible.

On April 1, 1999 (April Fool's Day!), while hunting turkeys, David Kulivan, a graduate student at LSU, observed at close range what he thought was a pair of IBWOs in the Pearl River Wildlife Management Area (WMA). This area is on the Mississippi–Louisiana border, on the east side of Interstate 59 and just north of Slidell, LA. His description of the birds was excellent. This sighting was not made public for several weeks. Shortly after the news broke, I was contacted by Robert (Bob) P. Russell (biologist, USFWS, Minneapolis–St. Paul, MN) about a trip he was planning to search for IBWOs in the Pearl River WMA early in 2000, prior to leaf-out. In early February 2000, 10 people including Bob and I met at a motel in Slidell. For the next 10 days we (I was afield February 5–9) systematically searched for IBWOs in teams of two or three, with negative results except for Juliana Simpson (a birding friend of Bob Russell), who claimed to have heard and glimpsed an IBWO. This report was investigated immediately, but no IBWO was found. We concentrated our efforts in and around the site where Kulivan reported his sighting. The entire WMA is heavily hunted (only squirrel hunting was in season during our visit). A team search by the Cornell Lab of Ornithology in early 2002 did not find any IBWOs or any sign that they were present.

Several weeks prior to the dramatic public announcement of the rediscovery of IBWO by John (Fitz) W. Fitzpatrick (Director, Cornell Lab of Ornithology), Scott Simon (Director, Arkansas Chapter of The Nature Conservancy), Gale Norton (Secretary of the Interior), and others at Main Interior Building, Washington, D.C., on April 28, 2005, I received a telephone call from longtime birding friend Carl Perry in Pennsylvania that an IBWO had been observed in the Big Woods of eastern Arkansas. As all searching in 2004 and early 2005 had been kept secret, I was awestruck by this news. Carl had been tracking reports of IBWO sightings for several years and had developed an e-mail and telephone "grapevine" with many people throughout the southeastern United States. For details of the event, see Fitzpatrick (2005), Fitzpatrick and others (2005), Milius (2005), and Stokstad (2007).

I traveled to eastern Arkansas six times in search of the IBWO and looked for possible signs that it might be present. The earlier trips were on my own time and at my own expense, as as there was no funded project in place to support this work. The first trip was May 5–7, 2005, in the company of Steve Holzman (USFWS, Ecological Services, Athens, GA), Carl Perry, and Pierre D. Howard (birding friend, attorney, and former Lieutenant Governor of Georgia). We searched the Bayou de View sector of the Cache River National Wildlife Refuge (NWR) and environs, Brinkley, and Prairie Lake of the southeastern White River NWR and environs, Dagmar WMA, and Rex Hancock Black Swamp WMA. On this trip I became interested in woodpecker bill marks that were evident from bark scaling, and excavation of pits and furrows. On all subsequent trips I measured such bill marks.

On the second trip (June 30–July 2) I was accompanied by my wife, Joan. We visited Prairie Lake and Prairie Bayou, as well as other sites in the White River NWR. We were assisted by Richard E. Hines (refuge biologist), Jamie Kellum (refuge forester), and graduate students T.J. Benson and Nick Anich (Arkansas State University). We began to examine and measure the bill marks of pileated woodpeckers on trees where bark scaling and furrow excavations were present. We did this outside Arkansas to compare our observations with the features we had found at White River NWR.

On August 11–14, 2005, I visited Arkansas again. I traveled by canoe with M. David Luneau, Jr. (professor of electronics, University of Arkansas at Little Rock), on the Bayou de View north of State Route 17 on August 12. On April 25, 2004, David and his brother-in-law had inadvertently captured on video a distant, out-of-focus image of a large black and white woodpecker flying from behind the base of a tree. The camera was set on automatic and therefore was focused on the nearest object(s), which happened to be the handle of a canoe paddle and his brother-in-law's knee; consequently, the background with the bird was out of focus. This is the 4 seconds of video analyzed by the Cornell Lab, which concluded that the

Paul Sykes, U.S. Geological Survey, searching for the ivory-billed woodpecker in Bayou de View, AR, in 2005. Photo by Oron L. (Sonny) Bass, Jr., Everglades National Park.

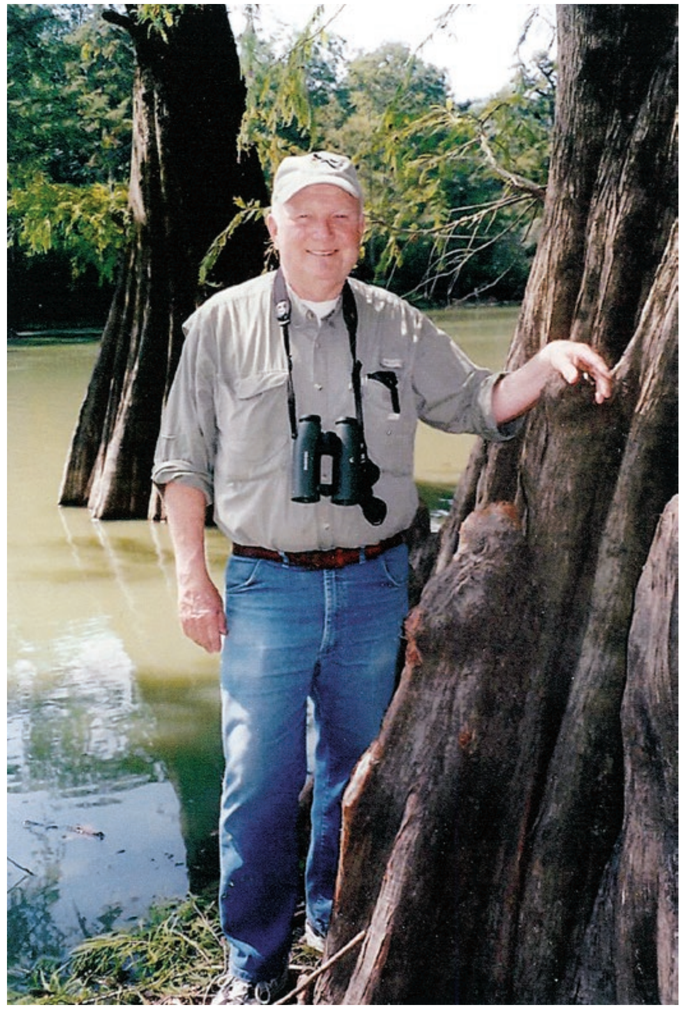
bird was an IBWO. Other locations visited on this trip were in the southern part of White River NWR.

Joan and I made a trip to Arkansas during September 28–31, and were assisted at the Cache River NWR by Ryan Mollnow, refuge biologist. We visited the George Tract, Biscoe Bottoms Unit, and east side of Bayou de View between State Route 17 and Interstate 40. Jacks Bay and Big Island in the White River NWR were searched September 30–31.

Carl Perry and I visited eastern Arkansas during January 11–15, 2006. We were joined on this trip by birding friends from Macon, GA, Tyrus (Ty) Ivey and Jerry and Marie Amerson. During the course of the trip, we visited points along Bayou de View, Areas A and B, Stabb Lake in the Cache River NWR, the Vera Denning property (we had permission to visit this private site), and The Nature Conservancy property at an area known as Boom Access. On January 14, I met Martjan Lammertink (woodpecker researcher from the Netherlands) and his wife Utami (both part of the Cornell search team), and we searched in the Boom Access area and examined bill marks on many trees, some of which I made impressions of using quick-setting mold putty. At this point, not having seen or heard an IBWO, I and others began to doubt the reliability of the reported sightings on the Bayou de View and in the surrounding areas.

A search was made at the Congaree National Park, SC, just south of Columbia, by Steve Holzman and me, together with Craig Watson (USFWS, Charleston, SC), Bill Hulslander (Park Resources Manager), Laurel Moore Barnhill (biologist, South Carolina Department of Natural Resources [now with the USFWS at Atlanta, GA]), Stuart Greeter (Realty Division, South Carolina Department of Natural Resources [DNR]), and birders Sherr Scott and Fran Rametta (South Carolina). We covered the elevated loop boardwalk area and the trail from Cedar Creek south to the Kingsnake Trail. Steve and I measured several large woodpecker bill marks on dead trees during the course of the day. No IBWOs were found, but a lot of fresh woodpecker feeding sign was noted. Joan and I visited the Congaree National Park again in April 2006. We covered the area of the boardwalk, but found no sign of the IBWO.

The sixth and final trip to eastern Arkansas was made by Steve Holzman and me on February 6–18, 2005, as part of the volunteer search team of Cornell Lab of Ornithology at White River NWR, with Tom Snetzinger (formerly with USFWS in Hawaii), as team leader. Other members of our crew were Kenneth (Ken) P. Able (California; retired professor of biology, State University of New York at Albany), Oron (Sonny) L. Bass (biologist, Everglades National Park), Keith Brady (a birder from Washington State), Walt D. Koenig (researcher, Hastings Natural History Reservation, CA, and former editor of "The Condor"), Melinda Welton (birder, Franklin, TN), and Larry White (birder, Evergreen, CO). Working in pairs, we searched the Prairie Lake area, Scrub Grass Bayou, Alligator Lake, Horseshoe Lake, the powerline right-of-way, Round Island, Prairie Lake Campground, the Lightbulb area, Jacks Bay, the levee south to the confluence of the White and Arkansas Rivers, and Dana Rockin. On February 12, Sonny, Keith, Walt, Steve, and I, in two borrowed canoes, searched the Bayou de View from State Route 17 south to the powerline and east to the Vera Denning property, but found no sign of IBWOs.



Paul Sykes, U.S. Geological Survey, during ivory-billed woodpecker surveys in the Congaree Swamp, SC, 2006. Photo by Joan Sykes, Watkinsville, GA.

Of interest, during the course of our 2 weeks at White River NWR, Sonny Bass discovered an albinistic pileated woodpecker that was seen for a period of 3 to 4 days. Several others of our group saw it, and the bird was photographed. Snyder and others (2009) stated that pileateds occasionally exhibit abberant extensive white wing patches closely resembling those of perched ivory-bills. Sometime in the late 1970s, Noel Snyder told me of seeing a pileated in south-central Florida with many of the secondary feathers being white. Therefore, some of the reports of ivory-bills in the southeastern United States could well have been part-albino pileateds.

When it was learned that IBWOs had reportedly been seen in the Choctawhatchee River Basin in northwestern

Florida in the winters of 2005 and 2006, Sonny Bass, Carl Perry, and I visited that area during July 23–28, 2006. Because the water level in the swamp was low at the time, we were able to cover areas on foot that are flooded in winter. Much to our surprise, people were riding jet skis and wave riders up and down the river. We searched Bruce Landing and Creek, Roaring Cutoff, the McCaskill Landing area, and boat landings on both sides of the river from U.S. Route 90 south to Florida State Highway 20 in a canoe borrowed from Steve Holzman. The three of us floated 40 mi on the Choctawhatchee River from Morrison Springs County Park south to Florida State Highway 20, including Dead River Landing, the powerline crossing of the river (both sides), Seven Runs Creek, Lost Lake, Little Lost Lake, and Tilley Landing. Most of our effort during this trip was concentrated around the powerline crossing, Bruce Creek, and Roaring Cutoff. No sign of IBWOs was found, but we did see many pileated woodpeckers, as well as their foraging marks on dead trees.

I visited the Choctawhatchee River on October 27–28, 2006, with Bob Russell and Gloria Rios (LaFalda, Argentina). We met Bobby W. Harrison (assistant professor of communications and arts, Oakwood University, Huntsville, AL) on October 26 at Ponce de Leon, FL, where we discussed IBWOs (Bobby and Tim W. Gallager, editor of the Cornell Lab's "Living Bird," and kayaker Gene M. Sparling, local guide, had reported seeing an IBWO on the Bayou de View on February 27, 2004). Bob, Gloria, and I watched under the powerline on the west bank of the Choctawhatchee River and searched the Morrison Springs area, Fox Hollow Drive off Route 284, Holmes Landing, and Dead River Landing, with negative results.

On my third trip to the Choctawhatchee River, Sonny Bass and I spent November 7–12, 2006, in the field. The deer hunting (gun) season opened during this visit, and the river bottom sounded like a shooting gallery. The entire river bottom is heavily hunted for game species; we found expended shell casings, camp sites, and trash throughout. We searched the west bank of the river at the powerline from U.S. Highway 90 downstream to Morrison Springs in Sonny's motorized canoe-boat. On foot, we checked the peninsula east of Morrison Springs downstream to Old Creek, covering more of the bottomland on foot because the water level was low. We took the canoe-boat from Dead River Landing through a series of small lakes to the main river course and from McCaskill Landing downstream to just north of Roaring Cutoff Island. We also hiked around Horseshoe Lake and followed the creek northeast to Carlisle Lake, took the canoe-boat from Florida State Highway 20 to the river, and traveled downstream to East River (which makes a loop off the east side of the Choctawhatchee River) and up East River, and checked Tilley and Bruce Creek Landings. At 10:05 a.m., we stopped for a break on the east side of the Choctawhatchee River about 1 mi upstream from the south end of East River. At 10:15 a.m., we heard three very loud sounds like an ax hitting a tree with great force at an estimated distance of 1,000 ft. We never saw what made the sounds, and we are certain no other people were in the area. The area is low and not suitable for camping. No IBWOs were detected on this trip.

My last trip looking for IBWOs in the western Florida Panhandle was from February 20 to March 2, 2007. The river level was very high at that time. I searched with Peter Range (refuge ranger, USFWS, Savannah River NWR Complex, GA) and Steve Calver (biologist, U.S. Army Corps of Engineers, Savannah, GA) on the powerline right-of-way on the west side of the river, the Bruce Creek area, and Grassey and McCaskill Landings; took Peter's boat upriver from McCaskill Landing to the Interstate 10 bridge; and searched Gum Creek Landing, the slough in the Oak Creek area, lower Carlisle Creek, Horseshoe Lake, and Cougar Island at Roaring Cutoff. Ken Able joined us in the search on February 22. We checked out Cow and Cedar Log Landings north of Morrison Springs along County Route 181C. We put in at Cedar Log Landing, paddled upstream about 1.5 mi, and stopped on the east bank to listen. At about 5:00 p.m., Peter reported he heard what sounded like kent calls in a series, but what actually made the calls was not seen. Steve and I heard nothing. Ken had gone by kayak to Lost Lakes. On February 25, birding friends Harry Armistead (Philadelphia, PA), Bob Ake (professor of chemistry, Old Dominion University, Norfolk, VA), and four others arrived to search for the woodpecker. On February 26, Peter, Steve, and I put the boat in at Cedar Log Landing and checked areas along the east side of the river opposite Old Creek, as well as the powerline right-of-way on the west side of the river. The next day we observed and listened at Horseshoe Lake; while we were there, John Puschock (professional bird guide, and owner and operator of Zugunruhe Birding Tours in Seattle, WA) came by in his kayak and stopped to discuss the IBWO situation. John had not seen or heard an IBWO since he started searching the Choctawhatchee River in early January 2007. John later told me he did not believe there were any IWBOs in the region.

During the last 5 days of this trip we spent a lot of time looking and listening on the west bank of the river at the powerline. This site is at a bend of the river. It provides a 0.5-mi view up and down the river and more than a 1-mi view across the swamp forest to the east, all the way to the upland. On February 28, in addition to the powerline area, Ken and I checked Tilley and Dead Lake Landings. At the latter, we spoke with Bobby Harrison and others. On March 1, Carl Perry joined Ken Able and me at the powerline on the east side of the river on the edge of the upland. We had permission to cross private land to reach this site. Many pileated woodpeckers are found in this area, as well as other places throughout the Choctawhatchee River bottoms. Also on March 1, Ken and I checked the boat landings south of Florida State Highway 20, including Bozman, Simpler's, and Rooks fish camps, Smoke House Lake, and Magnolia Landing. On March 2, my final day, Carl, Ken, and I watched and listened at the powerline. On this trip, no one in our group or whom we met in the area had ever observed an IBWO on the Choctawhatchee River.

Discussion

During the span of our searches for the IBWO in eastern Arkansas and northwestern Florida, the widths of bill marks made by foraging large woodpeckers on dead or dying trees were measured in these two states as well as Georgia, Maryland, Mississippi, North and South Carolina, Tennessee, and Virginia. These marks were measured on 19 species of hardwoods. The bill tips of 182 pileated and 178 ivory-billed woodpeckers were measured and the shape of bill tips noted at 15 museum collections. Posters illustrating measurements of the bill marks and bill tips of the two species have been presented at meetings at Patuxent (2005), AOU (University of California, Santa Barbara, 2005), Georgia Ornithological Society (Jekyll Island, GA, 2005), and at a Special Symposium—The Ecology of Large Woodpeckers: History, Status, and Conservation (Brinkley, AR, 2005).

Four cavities reported to be those of the IBWO are known to be extant in curated collections that my wife, Joan, and I examined. There is one such cavity at each of the following institutions: Museum of Comparative Zoology, Harvard University, Cambridge, MA; Cornell Lab of Ornithology, Ithaca, NY; Florida Museum of Natural History, University of Florida, Gainesville; and Anniston Museum of Natural History, Anniston, AL. The cavity at Cornell is the nest that Arthur A. Allen, Peter Paul Kellogg, and James T. Tanner studied in the Singer Tract in Louisiana in the mid-1930s. Their photographs of this nest, including the one on page 174 showing a male IBWO, were widely published.

After conducting several double-blind tests measuring the widths of bill marks made by large woodpeckers in bark scaling, excavation of nesting/roosting cavities, pits, and furrows on trees and examining the data, Steve Holzman and I found that the idea one might be able to determine whether such marks were made by either a pileated or an ivory-billed woodpecker was not possible as originally had been thought. There was too much variability in taking repeated measurements of the same bill mark by the same person or between different persons to be able to distinguish between the two species. There was also too much variability within marks made between individuals of the same species to be useful. Bill-mark widths also varied between tree species and state of tree decay, and there was a lot of variation in the shape and depth of the bill tips of specimens in museum collections both within and between the two species. So much for "pipe dreaming"—we had no smoking gun.

Through Judd A. Howell (director of Patuxent at the time), funding during the latter part of this project was made possible from the center's discretionary fund. Post-early 1970s and prior to funding, all searching was on my own time and at my own expense.

The history of the IBWO is well summarized by Jerry Jackson (2004) and Noel Snyder and others (2009). The David Luneau video, presented as proof of the existence of the IBWO in eastern Arkansas by John Fitzpatrick and associates in "Science" (Fitzpatrick and others, 2005, 2006), has been questioned by other investigators (Jackson, 2006; Jones and others, 2007; Sibley and others, 2006). I viewed David Luneau's 4-second clip three or four times. In my opinion, because the image is out of focus (when the original, small image was enlarged, it became pixelated), too little of the bird is visible, and the lighting is insufficient, the bird cannot be identified with any confidence.

My searches for the IBWO began in 1967 and continued intermittently through 2007. This effort has taken me to Florida, South Carolina, Louisiana, Texas, and Arkansas. Given the information contained in several reports from Florida, Texas, and Arkansas, I was certain I would see a living IBWO on at least four or five occasions, but it did not happen—I have never seen or heard the species in the wild, but have examined many study skins and mounts, and have listened to recordings of its vocalizations and double knocks made by Arthur A. Allen, Peter Paul Kellogg, and James T. Tanner.

It is impossible to say when the last living IBWO was seen in the United States. Although there are many reports of sightings over the past 70 years, there is no undisputed, verifiable proof of the bird's existence since the early 1940s. Invariably, whenever an IBWO sighting is in the news, there is a sharp spike in the number of sightings reported; the reports usually cease after a year or two. It is most unfortunate that so little effort to save the species was undertaken from the mid-1930s through at least the 1970s. Although it is obvious that the IBWO lost most of its habitat in the southeastern United States, I came to the conclusion many years ago that shooting of the birds for any number of reasons may have been the cause of its final demise. Noel Snyder (formerly with Patuxent conducting research on the California condor [*Gymnogyps californianus*] and snail kite) and associates came to a similar conclusion (Snyder and others, 2009), and they discuss the matter in detail.

James T. Tanner (1942; University of Tennessee, oral commun., 1968) and others that preceded him typically located IBWOs first by their calls or double knocks or raps, then followed the sounds to see the bird(s). In most of the reports made in the last several decades, the bird was either heard but not seen, or seen but not heard. These reports are contrary to accepted knowledge about how to locate the species. Furthermore, most observers saw only a fleeting glimpse of a large black and white bird flying away, did not have time to use binoculars or take a picture, typically observed under poor lighting conditions, had a view obstructed by vegetation or other objects, were searching alone, and so on.

Although several plausible sightings of IBWOs have been reported, it is puzzling to me why, if the bird still exists, no good-quality photos (film or digital) or video has been forthcoming. Likewise, all audio recordings of calls and double knocks have been of only common species or sounds resulting from nonliving events (gunshots), or were inconclusive with respect to the origin of the sound. I am unaware of any animal on the planet as large as the IBWO, living and flying about in habitat surrounded by a sea of humanity, that can escape detection, especially given the great effort expended in eastern Arkansas and northwestern Florida during 2004–06. It is also troubling to me that the bird repeatedly "is seen" and then cannot be refound. My long field experience over much of North America during the past 66 years tells me that something is amiss.

After the April 28, 2005, announcement about the rediscovery of the IBWO in the Big Woods of eastern Arkansas, and given the prestige of the agencies, institutions, organizations, and esteemed individuals involved, it is my opinion that most (perhaps as many as 95 to 99 percent) of the people who started searching for the bird believed that it was still alive and present in the area. I was in this camp for a while. Therefore, many searchers may have been subconsciously biased and, as a result, not sufficiently cautious in their identifications under field conditions. In other words, their perception was in error—and they did not actually see what they believed they saw. Field experience and skill levels with respect to bird identification also affect the accuracy of the identifications, particularly when species that are rare in a given area or species believed to be extinct or near extinct in a given area are found. Those who have extensive field experience with birds know that bird identification requires checking as many field marks as possible and repeating this process several times while viewing the bird. A brief glimpse or an otherwise poor view can result in misidentification. All birders make identification mistakes sooner or later; the point is to be as careful as possible in all identifications. In the words of English poet Alexander Pope, "To err is human…" On any bird search, enthusiasm and expectation can rule the day. The high degree of anticipation and excitement inherent in this modern-day hunt can sometimes override caution, which may be problematic in the search of the elusive ivory-billed woodpecker.

Acknowledgments

This project could not have been carried out without the splendid assistance, cooperation, understanding, and support of friends, associates, and colleagues. I thank you all. In particular, I wish to thank Ken Able (State University of New York at Albany, retired); Sonny Bass (Everglades National Park, FL, retired); Steve Calver (U.S. Army Corps of Engineers, Savannah, GA, retired); Ray Erickson (U.S. Geological Survey [USGS] Patuxent Wildlife Research Center [Patuxent], Laurel, MD, retired; Andy Kratter (Florida Museum of Natural History, Gainesville, FL); Richard Hines (White River National Wildlife Refuge, AR); Steve Holzman (U.S. Fish and Wildlife Service [USFWS], Atlanta, GA); Judd A. Howell (USGS Patuxent, Laurel, MD, retired); Bonnie Kepler (USGS Patuxent, Athens, GA); Cameron Kepler (USGS Patuxent, Athens, GA, retired); Brooke Meanley (USGS Patuxent, Laurel, MD); Carl Perry (Armstrong World Industries, Lancaster, PA); Matthew Perry (USGS Patuxent, Laurel, MD, retired); Tom Quay (North Carolina State University, Raleigh); Peter Range (USFWS, Savannah River National Wildlife Refuge complex, GA-SC, retired); Bob Russell (USFWS, Minneapolis-St. Paul, WI); Henry Stevenson (Florida State University, Tallahassee); my wife, Joan Sykes; and Jim Tanner (University of Tennessee, Knoxville). I thank David Allen Sibley (author and bird artist, Concord, MA) for permission to use his very fine images of pileated and ivory-billed woodpeckers in this chapter.

References Cited

Catesby, Mark, 1731, Natural history of Carolina, Florida and the Bahama Islands: London, Benjamin White, v. 1, p. 16.

Dennis, J.V., 1948, A last remnant of ivory-billed woodpecker in Cuba: Auk, v. 65, no. 4, p. 497–507. [Also available at https://sora.unm.edu/node/19571.]

Fitzpatrick, J.W., 2005, The ivory-billed woodpecker still lives: Living Bird, v. 24, no. 3, p. 4–5.

Fitzpatrick, J.W., Lammertink, Martjan, Luneau, M.D., Jr., Gallagher, T.W., Harrison, B.R., Sparling, G.M., Rosenberg, K.V., Rohrbaugh, R.W., Swarthout, E.C.H., Wrege, P.H., Swarthout, S.B., Dantzker, M.S., Charif, R.A., Barksdale, T.R., Remsen, J.V., Jr., Simon, S.D., and Zollner, Douglas, 2005, Ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America: Science, v. 308, no. 5727, p. 1460–1462. [Also available at http://dx.doi.org/10.1126/science.1114103.]

Fitzpatrick, J.W., Lammertink, Martjan, Luneau, M.D., Jr., Gallagher, T.W., and Rosenberg, K.V., 2006, Response to comment on "ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America": Science, v. 311, no. 5767, p. 1555. [Also available at http://dx.doi.org/10.1126/science.1123581.]

Heinzmann, G.M., and Agey, H.N., 1971, The ivory-billed woodpecker found in central Florida: Florida Naturalist, v. 44, p. 46–47, 64.

Jackson, J.A., 2002, Ivory-billed woodpecker (*Campephilus principalis*), *in* Poole, A., and Gill, F., eds., The birds of North America: Philadelphia, PA, The Birds of North America, Inc., no. 711, 27 p. [Also available at https://birdsna.org/Species-Account/bna/species.ivbwoo.]

Jackson, J.A., 2004, In search of the ivory-billed woodpecker: Washington, D.C., Smithsonian Books, 295 p.

Jackson, J.A., 2006, Ivory-billed woodpecker (*Campephilus principalis*)—Hope, and the interfaces of science, conservation, and politics: Auk, v. 123, no. 1, p. 1–15. [Also available at http://dx.doi.org/10.1642/0004-8038(2006)123[0001:IWCPHA]2.0.CO;2.]

Jones, C.D., Troy, J.R., and Pomara, L.Y., 2007, Similarities between *Campephilus* woodpeckers double raps and mechanical sounds produced by duck flocks: Wilson Journal of Ornithology, v. 119, no. 2, p. 259–262. [Also available at http://dx.doi.org/10.1676/07-014.1.]

Milius, Susan, 2005, Comeback bird: Science News, v. 167, no. 24, p. 376–378. [Also available at https://www.sciencenews.org/article/comeback-bird.]

Potter, E.F., Parnell, J.F., and Teulings, R.P., 1980, Birds of the Carolinas (1st ed.): Chapel Hill, NC, University of North Carolina Press, 408 p.

Potter, E.F., Parnell, J.F., Teulings, R.P., and Davis, Ricky, 2006, Birds of the Carolinas (2d ed.): Chapel Hill, NC, University of North Carolina Press, 399 p.

Sibley, D.A., Bevier, L.R., Patten, M.A., and Elphick, C.S., 2006, Comment on "Ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America": Science, v. 311, no. 5767, p. 1555. [Also available at http://dx.doi.org/10.1126/science.1122778.]

Stokstad, Erik, 2007, Gambling on the ghost bird: Science, v. 317, no. 5840, p. 888–892.

Snyder, N.F.R., Brown, D.E., and Clark, K.B., 2009, The travails of two woodpeckers—Ivory-bills and imperials: Albuquerque, NM, University of New Mexico Press, 170 p.

Tanner, J.T., 1942, The ivory-billed woodpecker: New York, National Audubon Society Report no. 1, 111 p.

Endangered Species Research in Hawaii: The Early Years (1965–87)

J. Michael Scott and Cameron B. Kepler

Hawaii is an ecologically isolated archipelago 2,500 miles from the nearest continent. Its isolation resulted in a taxonomically unbalanced flora and fauna with remarkable examples of adaptive radiation among those groups of organisms that won the dispersal sweepstakes. It was one of the last oceanic island groups to be populated by humans, about 900 A.D. by Polynesian travelers and in 1778 by Europeans. Relatively recent colonization by humans did not save it, however, from the biodiversity losses suffered by other isolated archipelagos—it only delayed them (Scott and others, 1988; Pratt and others, 2009a).

The size of those losses and the severity of the threats were formally recognized by the United States in 1964 with the publication of "Rare and Endangered Fish and Wildlife of the United States" by the U.S. Department of the Interior (DOI) Committee on Rare and Endangered Wildlife Species (U.S. Department of the Interior, 1964). Sixteen of the 62 species in that book, vertebrates all, were Hawaiian. That "red book" provided information that was used to compile the first formal list of endangered species under the 1966 Endangered Species Preservation Act, commonly referred to as "the Class of 67" (Wilcove and McMillan, 2006). That first list reinforced the findings of the Committee on Rare and Endangered Wildlife Species that Hawaii was home to some of the most highly endangered species in the United States. Twenty of the first 78 species listed under the Preservation Act (25.6 percent) were from Hawaii.

Dr. Ray Erickson was well aware of the challenges the country faced in recovering endangered species. A biologist in the Division of Research of the Bureau of Sport Fisheries and Wildlife in Washington, D.C., Dr. Erikson was a member of the Committee on Rare and Endangered Wildlife Species. Beginning in 1956, he had been advocating for funding to rear one of America's rarest birds, the whooping crane (*Grus americana*), in captivity and to conduct research on the sandhill crane (*Grus canadensis*) as its surrogate species. In early 1961, responding to a White House call for new ideas from Federal employees, Ray offered a proposal for a captive propagation and research program on rare and endangered species. Although small amounts of funding were received as early as that year to construct pens for sandhill cranes and support studies of their behavior in Colorado, funds sufficient to initiate a multispecies field and laboratory program to study rare and endangered species were not available until March 1966, when the Bureau signed off on $350,000 to support endangered wildlife research. With those funds, the research and captive propagation effort was moved to Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, from Monte Vista National Wildlife Refuge, Alamosa, CO, and Ray was placed in charge of what came to be known as the Endangered Wildlife Research Program. The original focus on captive rearing of whooping cranes and their surrogate the sandhill crane continued, but these efforts were quickly expanded to include other imperiled species and their surrogates, including black-footed ferret (*Mustela nigripes*), California condor (*Gymnogyps californianus*), Puerto Rican parrot (*Amazona vittata*), masked bobwhite quail (*Colinus virginianus ridgwayi*), and Aleutian Canada goose (*Branta canadensis leucopareia*) (U.S. Fish and Wildlife Service, 1976a, b; 1977). Ray Erickson originally envisioned an Endangered Wildlife Research Program that would include a field research component involving 10 field biologists that would complement the laboratory studies and captive propagation efforts at Patuxent. Four field biologists were eventually assigned to Hawaii. The first of these was Winston (Win) Banko. His task, as it was for all of us, was broad—work on the endangered birds of Hawaii. He arrived on Oahu in 1966, but later moved to the "Big Island" of Hawaii. John Sincock, who was assigned to Kauai, joined him in the islands in 1967. In 1974, Mike Scott joined Win Banko on the island of Hawaii, and, in 1977, Cam Kepler was assigned to Maui.

That first cohort of Patuxent's endangered species biologists in Hawaii, Banko, Kepler, Scott, and Sincock, conducted extensive studies on the endangered flora and fauna of the islands (see Selected References). Their studies involved reviews of the literature and museum collections to determine the extent of studies conducted and the historical distribution of each species, their status and distribution in the field (Scott and others, 1977), their natural history and ecology threats, and recovery planning. Simultaneously, they were developing the methods needed to accurately identify and rigorously assess the distribution and abundance of Hawaii's threatened and endangered species under the difficult conditions of complex terrain, adverse weather, and extremely low bird densities.

John Sincock, U.S. Fish and Wildlife Service, after surveying a Kau transect on Hawaii, summer 1976. Photo by U.S. Fish and Wildlife Service.

Jim Jacobi and Mike Scott, U.S. Fish and Wildlife Service, in Hawaii on the Kona side transect, summer 1978. Photo by U.S. Fish and Wildlife Service.

John Sincock, U.S. Fish and Wildlife Service, waiting for helicopter in Alaka'i Swamp, Kauai, 1983. Photo by Paul W. Sykes, Jr., U.S. Fish and Wildlife Service.

Several books that provide a synthesis of these and other efforts to save Hawaii's endangered avifauna and document the methods developed to survey and analyze the information from field studies emerged from the work of Patuxent's biologists and others in the islands. These included Ralph and Scott (1981), Scott and others (1986), Scott and others (1993), Scott and others (2002), Stone and Scott (1985), and Stone and Stone (1989). The importance of collaborations with other researchers from Federal and State agencies, nongovernmental organizations, and academia as well as the private landowners of Hawaii to the success of these efforts cannot be overstated. The list of those who worked with us in the field, helped with funding, and collaborated on almost every one of the publications that resulted from the U.S. Fish and Wildlife Service (USFWS) effort in the islands is long. One need only consider the institutional affiliations of the authors of the reports, journal articles, and books we wrote or edited and the individuals we recognized in the acknowledgments sections of each publication to gain an appreciation of the truly interdisciplinary and interinstitutional nature of our work in the islands.

The arrival of the first Patuxent researchers followed shortly after the arrival of Gene Kridler on Oahu in 1965. As the first DOI biologist and manager assigned to Hawaii, Gene played a key role in identifying research needs and obtaining funds to conduct the needed research. The late 1960s and early 1970s saw a great increase in research on the Hawaiian biota. Andrew Berger (ornithologist, American Museum of Natural History, New York) and his students at the University of Hawaii, other academic researchers, and folks at the Hawaii Department of Forestry and Wildlife (HDFW) were conducting life-history studies on many of the endemic birds (Berger and others, 1969; Engilis and Pratt, 1993; Frings, 1969; Shallenberger, 1977; Shallenberger and Vaughn, 1978; Swedberg, 1967). In 1970, the International Biological Program (Mueller-Dombois and others, 1981) initiated studies on island ecosystems and their biological organization. Finally, the U.S. Forest Service initiated studies on feather molting and behavior of Hawaiian birds (Ralph and Fancy, 1994) and the influence of nonnative species on native ecosystems (Scowcroft and Giffin, 1983). The role of Patuxent's four research biologists, working along with others, in that resurgence of interest in Hawaii's endangered biota is documented in the narrative that follows.

Win Banko came to the islands in 1966 and spent his first year on Oahu. He relocated to the island of Hawaii, where he established the Kilauea field station, a year later. Upon finding that little field work had been conducted on birds in Hawaii since the early 1900s (for example, Baldwin, 1945, 1947, 1953; Warner, 1960, 1967, 1968), Banko determined that his contribution to understanding the endangered species of Hawaii would be in examining the literature, long-forgotten field notes, and museum specimens to determine what information was already known and where the gaps in our knowledge lay. Early on, however, Win went into the field to survey the birds of Kipahulu Valley, Maui, where, as a member of The Nature Conservancy's Kipahulu expedition led by Rick Warner, he rediscovered the Maui nukupuu (*Hemignathus lucidus affinis*) (Warner, 1967; Banko, 1968). Banko also detected populations of several endangered forest bird species near Hawaii Volcanoes National Park. This discovery led to the selection of this area for intensive ecological studies by scientists associated with the International Biological Program and the U.S. Forest Service (Mueller-Dombois and others, 1981; Ralph and Fancy, 1994).

The bibliography on Hawaiian birds and the documentation and Banko's summaries of 20,700 status and distribution records were published by the Hawaii Cooperative Ecosystems Study Unit as part of its special reports series from 1980 to 1990. In addition to his library work, Win conducted field studies of Hawaiian crows (*Corvus hawaiiensis*) on the leeward side of Hawaii and searched for the endangered Hawaiian dark-rumped petrel (*Pterodroma sandwichensis*) and other seabirds high on the desolate volcanic slopes of Mauna Kea and Mauna Loa (Banko, 1980). His studies of the crow documented its precarious status and prompted the decision to bring the first Hawaiian crows into captivity for propagation. Those birds were housed in flight cages at Hawaii Volcanoes National Park for a short period, then transferred to State managers and used to form the nucleus of the Hawaiian crow captive propagation effort (National Research Council, 1992). Win retired from the USFWS in 1977.

Soon after his arrival in the islands in 1967, John Sincock conducted wetland surveys to identify possible sites for new wildlife refuges. John also initiated the first statistically rigorous inventories of endangered birds in the forested areas of Kauai (Sincock and others, 1984; Scott and others, 1986) and of the endangered birds of the Leeward Islands (Laysan, Midway, and Nihoa): Laysan finch (*Telospiza cantans*), Nihoa millerbird (*Acrocephalus familiaris kingi*), Nihoa finch (*Telospiza ultima*), and Laysan duck (*Anas laysanensis*). The Leeward Islands transects he established for the land bird inventories have been surveyed for more than 40 years (Conant and Morin, 2002; Morin and Conant, 1997). The wetland surveys of Kauai, conducted collaboratively by John with refuge manager Gene Kridler, provided the information needed to establish Hanalei, Huleia, and Kilauea Point National Wildlife Refuges and complemented the statewide waterfowl surveys by the HDFW (Engilis and Pratt, 1993). John expanded his research efforts to include natural history studies and threats to survival of three seabirds: Newell's shearwater (*Puffinus newelli*), band-rumped storm petrels (*Oceanodroma castro*), and Hawaiian dark-rumped petrels. After documenting the rediscovery of nesting areas for Newell's shearwaters (Sincock and Swedberg, 1969), he translocated eggs of this species under nesting wedge-tailed shearwaters (*Puffinus pacificus*) to secure low-elevation nesting areas at the then Kilauea Point National Administrative site (Byrd and others, 1984). Presumed offspring resulting from those efforts or their young still continue to nest on what is now Kilauea National Wildlife Refuge (http://www.fws.gov/endangered/news/bulletin-spring2009/shearwaters-of-kilauea-point.html).

Recognizing the heavy mortality suffered by Newell's shearwaters and Hawaiian dark-rumped and band-rumped storm petrels from crashing into the ground and other obstacles as a consequence of light pollution, John worked with Tom Telfer (HDFW) and researchers at the University of Wisconsin to develop methods to reduce light pollution by switching and shielding light sources (Reed and others, 1985; Telfer and others, 1987).

Left to right: Dave Marshall, Gene Kridler, and Win Banko, U.S. Fish and Wildlife Service, in Alaka'i Swamp, Kauai, HI, 1966. Photo by U.S. Fish and Wildlife Service.

Sincock and Tom Telfer established the Save Our Shearwaters (SOS) program in the 1970s. This project involved informing the island community of the consequences of the annual "raining of shearwaters" and its causes, and rescuing and then releasing stranded birds. Like almost every one of the Patuxent research studies, it quickly became a family affair when John's wife, Renate, took on many of the day-to-day activities of this effort—helping to enlist volunteers in the rescue effort, picking up birds, coordinating volunteers, and housing and releasing birds. The SOS program continues to this day (2016) under the auspices of the Kauai Humane Society (http://kauaihumane.org/services/saveourshearwaters).

John was the first to propose and then conduct an assisted colonization for the Northwest Islands passerines. Working with folks in the HDFW and with Gene Kridler of the USFWS, he successfully translocated Laysan finches to Pearl and Hermes Reefs. However, their efforts to translocate Nihoa finches to French Frigate Shoals were unsuccessful (Conant and Morin, 2002). One product of John's efforts in the Leeward Islands was a conservation plan for the future protection of the islands' endemic avifauna (Sincock and Kridler, 1977). John was the last of the original cohort of Patuxent research biologists to leave Hawaii. He left the islands and the USFWS in 1988.

Mike Scott arrived fresh from graduate school in the fall of 1974 to work with the endangered birds of Hawaii. Working with John Sincock, USFWS refuge manager Gene Kridler, and State wildlife biologists Ernie Kosaka, David Woodside, and Ronald Walker, he identified the information needs that were most important to recovering the endangered species of Hawaii. It was not the "niche differentiation studies of endemic Hawaiian birds" (MacArthur and Levin, 1961) that Mike had envisioned when he accepted the position of endangered species biologist with the USFWS. The questions to which managers needed answers were far more policy- and management-relevant. The decision-making process for recovery planning and implementation required answers to questions such as: Which species are extant? Where can they be found? How many are there? How do their distribution and density vary geographically? Who owns/manages the land, and what is its conservation status? The information gained from answering these questions could be used by managers to take the first two steps toward conserving Hawaii's endangered forest birds—identifying and securing essential imperiled species habitat. It became clear to Mike and his colleagues that to answer those questions an extensive survey of all remaining forest bird habitat in the islands was needed. The result of their planning was the Hawaiian Forest Bird Survey (HFBS), a program to survey all remaining forest bird habitat in the islands, from the tree line down to the cane fields or the coast, on all the main islands in Hawaii with the exception of Oahu. The forest birds of Oahu were surveyed separately by others (Shallenberger and Vaughn, 1978).

Prior to launching the HFBS in 1976, a population survey was conducted to determine the distribution and abundance of the palila (*Loxioides bailleui*). That effort was led by University of Hawaii graduate student Charles Van Riper, whereas Mike Scott and David Woodside of the HDFW took the lead on the multiagency effort. They laid transects throughout the dry mamane (*Sophora chrysophylla*) and naio (*Myoporum sandwicense*) forests of the upper elevations of Mauna Kea, where the last remaining palila resided (Van Riper and others, 1978). These surveys, covering the entire geographical, geophysical, and ecological range of the palila, were repeated in 1980, and have been repeated every year since then (Jacobi and others, 1996; Banko and others, 2009). That standard—the surveying of the entire range of a species—was used for the larger HFBS (described below) that followed.

With funding and administrative support from the management side of the USFWS, logistical support from Ernie Koska and others from the HDFW, and leadership from John Sincock and Mike Scott, this historic undertaking (Pratt and others, 2009a) was launched in the Kau Forest on the island of Hawaii in the spring of 1976 (U.S. Fish and Wildlife Service, 1976a, b; 1977) and concluded on the island of Kauai in the summer of 1981 (Scott and others, 1986). Observers were selected from applicants who were screened for birding experience, physical fitness, hearing acuity, birding ability, familiarity with Hawaiian birds, and ability to spend extended periods in remote locations to conduct field studies. All field folks were trained in distance estimation and the audio, behavioral, and visual characteristics of the forest birds of Hawaii, as well as safety and sampling protocols (Kepler and Scott, 1981; Ramsey and Scott, 1981; Scott and others, 1986). Members of that first year's survey team, particularly Jim Jacobi, provided input to the study design that resulted in adding surveys for mapping rare and endangered plants and increased documentation of feral animal presence to the survey protocols. To supplement the quantitative capabilities of the group, Scott asked Fred Ramsey, longtime friend, lifelong birder, and professor in the statistics department at Oregon State University, to join the team to provide the statistical and analytical rigor needed to fully analyze the survey findings (Ramsey and others, 1979, 1987; Ramsey and Scott, 1978, 1979, 1981).

By the time the last sampling station was surveyed, members of the HFBS had recorded 30 native species and 33 nonnative species; counted hundreds of thousands of birds; characterized vegetation (Jacobi, 1983, 1989; Jacobi and Scott, 1985); and documented the occurrence of nonnative plant species (Warshauer and others, 1983), damage from feral animals, the presence of rare plants, and the discovery of new ones (Warshauer and Jacobi, 1982) at 9,940 survey stations during 20,789 count periods along 876 miles of transects (Scott and others, 1986). A dozen or so new species of plants were described and much new information was gained on the distribution and abundance of rare plants from the botanical collections created by James Jacobi, Rick Warshauer, Holly McEldowney, and others. Throughout Mike's tenure in Hawaii, his wife, Sharon, played a key role in his research, making radio checks with field crews; picking up team members at the end of a transect; and serving as professional sounding board, editor, and all-around advisor for Mike.

The results of the HFBS were published in "Forest Bird Communities of the Hawaiian Islands" (Scott and others, 1986) and many other peer-reviewed publications that are described elsewhere. The 1986 synthesis received The Wildlife Society's Best Monograph Award. A review of the book characterized the HFBS as "a biological exploration of a high order and an excellent demonstration of applied statistics and despite my gloomy prediction, ecology of a high order…a model for other federal agencies charged with conservation programs" (Pimm, 1988). The complete electronic records of bird observation and transect locations of the HFBS are archived at the U.S. Geological Survey (USGS) Kilauea field station on the island of Hawaii (R.J. Camp, U.S. Geological Survey, written commun., 2010). The results of the HFBS complemented earlier statewide surveys of waterbirds (Engilis and Pratt, 1993; Reed and others, 2007; Swedberg, 1967) and game birds (Schwartz and Schwartz, 1949). Mike left Hawaii in 1984 to supervise the condor research effort in California.

Cam Kepler arrived in Maui in 1977 and joined the HFBS then underway on the Hamakua coast. Kepler participated in the surveys of Kona, Kohala, and Mauna Kea, including the extensive training sessions each spring (Kepler and Scott, 1981) in the years that followed. In 1980–81, he was coleader of the surveys of Maui, Molokai, Lanai, and Kauai.

During the HFBS, variable circle point counts for birds were conducted only in the first 4 hours of the day, weather permitting. This schedule provided time in the afternoons, after camp was set up, to make incidental observations in the study area. On May 12, 1981, during an incidental bird survey, Cam Kepler discovered the first nest of the small Kauai thrush (*Myadestes palmeri*) in a streamside cliff in one of the many embedded streams in the Alaka'i Swamp, on Kauai (Kepler and Kepler, 1983). All 13 small Kauai thrushes observed in the HFBS counts were also in deep gorges with flowing water, a finding consistent with observations made over 700 days in the Alaka'i by John Sincock (Scott and others, 1986). Knowledge of the microhabitats and nest-site locations of this endangered species allowed for more robust population estimates and management of the small Kauai thrush in subsequent years (Woodworth and others, 2009).

From 1977 to 1981, Cam and his wife, Kay Kepler, initiated surveys of several offshore islands to assess their seabird populations and plant communities (Kepler and Kepler, 1980; Kepler and others, 1984, 1990; Simons and others, 1985). All four islands hold breeding colonies of wedge-tailed shearwaters and Bulwer's petrels (*Bulweria bulwerii*). The information from the surveys was made available to the Hawaii Department of Land and Natural Resources (DLNR) to inform their management activities on the seabird islands.

In 1978 and 1979, Cam studied the water birds of Kealia and Kanaha Ponds on Maui. Kanaha Pond was protected as a State bird sanctuary, but the much larger Kealia Pond was privately owned. He found that most of the endangered Hawaiian stilts (*Himantopus mexicanus knudseni*) frequently left Kanaha to feed at Kealia, and that the two wetlands were strongly linked, both being essential to the survival of the stilt and Hawaiian coot (*Fulica alai*). In 1984, Cam was asked to provide biological information about Kealia to the Maui County Council, which was considering changing the wetland to a development district (harbor development was a possible use). Because of information provided by Cam and others (Shallenberger, 1977), Kealia was retained in conservation district zoning. Cam also provided his results to Federal and State agencies as well as nongovernmental organizations. After years of deliberation, the USFWS made plans to acquire Kealia Pond (http://www.fws.gov/kealiapond/) as a wildlife refuge.

In 1984, following completion of the HFBS, Cam initiated an expanded research program on the ecology of Hanawi's forest birds, including biological stresses affecting them. In 1986, Cam found the first nest of the po'o-uli (*Melamprosops phaeosoma*), and he, with Andy Engilis and Marie Ecton (USFWS), monitored this and a second (renesting) nest (Kepler and others, 1996; Engilis and others, 1996).

During their studies of the po'o-uli, the team noted a sobering increase in pig activity in the area (Mountainspring and others, 1990; Engilis, 1990). Habitat destruction by pigs resulted in soil loss of as much as 3 inches per year in Maui's primary watershed, far more than previously had been suspected. Cam's studies of the damage being caused by pigs to Hawaii's native ecosystems complemented those of others (Stone, 1985; Stone and Stone, 1989). This information and the briefings by Cam and others to media and public agencies alerted decision makers and the public to the threat pigs posed to endangered species and the public water supply.

During this same period, Haleakala National Park initiated a multimillion-dollar program to fence its entire holdings and expanded its ungulate control program (Pratt and others, 2009a). The Hawaii DLNR created the Hanawi Natural Area Reserve adjacent to The Nature Conservancy's Waikamoi Preserve, and both organizations initiated their own fencing and control programs (Price and others, 2009). Kepler traveled to Athens, GA, in 1987 to study Kirtland's warbler (*Setophaga kirtlandii*).

After Kepler left Hawaii, Patuxent maintained a research staff at the Kilauea field station that continued to study Hawaii's imperiled flora and fauna. That research is summarized in Scott and others (2002) and Pratt and others (2009a).

The Science Policy Discourse: Making a Difference in Policy and on the Ground

In addition to publishing their findings widely in scientific journals, Mike Scott and others made repeated presentations on the conservation implications of the HFBS and their other studies to the Hawaii Department of Forestry and

Wildlife and USFWS managers and biologists, as well as at many meetings of professional societies and conservation groups. By the late 1970s, word of the HFBS was spreading on the mainland and the conservation status of Hawaii's imperiled biota had attracted increased attention from The Nature Conservancy. The Nature Conservancy's Henry Little came to the islands in 1978. After becoming acquainted with the concept of the HFBS and its findings, he used the information from the HFBS to develop the Endangered Forest Bird Project. Working with Henry, Scott presented results of the HFBS and its implications for conservation of Hawaii's endangered biota to The Nature Conservancy's National Board of Directors in 1980. Funding for additional work by the Conservancy in Hawaii quickly became available. Henry used these funds to expand The Nature Conservancy's work in the islands.

In 1980, Henry hired Kelvin Taketa and Hardy Spoehr, and together they launched the Endangered Forest Bird Project (The Nature Conservancy, 1982). The objective of this project was to use the results of the HFBS and other research efforts in the islands to identify the areas critical to for the conservation of Hawaii's imperiled biota. The project's steering committee was composed of community leaders. Sincock, Scott, and Kepler served on the project's science advisory team along with National Park Service biologists and scientists from academia. In the fall of 1982, the Hawaii chapter of The Nature Conservancy was established. Henry Little quickly assembled a first-class board of trustees for the chapter, consisting of leaders in business, the nonprofit sector, and government. Realizing the importance of science-driven decision making, Henry Little tied the trustees to the science by using the Endangered Forest Bird Project's science advisory board and Cam Kepler's appointment to the Board of Trustees (1982–87) to bring science to the board's conservation actions decision-making process. This organizational structure ensured a powerful flow of ideas between formerly disparate parts of the Hawaiian conservation community and the scientific community. The science board identified and ranked important factors that were essential to the survival of Hawaii imperiled species (The Nature Conservancy, 1982, 1983, 1985), and gave that information to the Board of Trustees of the Hawaii chapter of The Nature Conservancy. The trustees quickly approved several areas for acquisition as nature reserves. The management challenges faced by the managers of those lands were identified in a "Save an Acre" commentary that was published in "Science" (Scott and Kepler, 1983). The response was phenomenal. By 1984, more than $4 million for conservation of endangered forest bird habitat had been brought into Hawaii, mostly in response to the information provided by the HFBS. Henry and Kelvin received the DOI Conservation Service Award in 1984 for their conservation efforts in Hawaii.

While The Nature Conservancy was conducting its conservation activities, Hawaii's Natural Area Reserve System was identifying possible areas for designation as Natural Areas and the USFWS was screening areas for possible new wildlife refuges. The conservation efforts of these three groups were not entirely independent of each other, and each used shared resources to inform its decisions regarding establishment and design of new ecological reserves. Those decisions, made with the benefit of information from the HFBS and other sources, led to the designation of 12 protected areas, including the USFWS Hakalau Forest National Wildlife Refuge (http://www.fws.gov/refuge/hakalau_forest) and an area in Kipahulu Valley on Maui that later became part of Haleakala National Park. Other Natural Area Reserves were established both independently and collaboratively by the Hawaii DLNR and The Nature Conservancy. These areas include Pu'u Maka'ala (http://dlnr.hawaii.gov/ecosystems/nars/hawaii-island/puu-makaala/) and Pu'u O Umi Natural Area Reserves (http://dlnr.hawaii.gov/ecosystems/nars/hawaii-island/puu-o-umi-3/) on the island of Hawaii (Scott and others, 1987b). The Nature Conservancy and the State established Waikamoi Preserve (http://www.nature.org/about-us/index.htm?intc=nature.tnav.about) and the 7,500-acre Hanawi Natural Area Reserve (http://dlnr.hawaii.gov/ecosystems/files/2013/07/Hanawi-Management-Plan.pdf) on Maui. The Nature Conservancy established Kamakou Preserve (http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/hawaii/placesweprotect/kamakou.xml) and Pelekunu (http://dlnr.hawaii.gov/ecosystems/files/2013/09/Pelekunu-LRP-DRAFT-FINAL.pdf), Olokui (http://dlnr.hawaii.gov/ecosystems/nars/reserves/molokai/olokui/), and the 1,330-acre Puu Ali'i Natural Area Reserves (http://dlnr.hawaii.gov/ecosystems/nars/reserves/molokai/puu-alii/) on Molokai.

On the island of Kauai, the 213-acre Kaluahonu Preserve easement to protect nesting sites of Newell's shearwater (http://www.abcbirds.org/conservationissues/habitats/BCR/hawaii.html) and the 3,579-acre Hono O Na Pali Natural Area Reserve (http://hawaii.gov/dlnr/dofaw/nars/reserves/kauai/honoonapali) to conserve forest birds and rare plants were established. These and several other previously mentioned nature reserves on Kauai were established, in part, because of information provided by the work of Patuxent's research biologists and their conservation partners.

The key to the quick application of information from the survey to the establishment of new protected areas for forest birds was the collaborative development of management- and policy-relevant research questions with managers and the continued involvement of the managers in conducting the survey, making the information available to decision makers in a user-friendly way (The Nature Conservancy, 1982, 1983, 1985; Scott and others, 1986). The use of graphics showing the lack of overlap in the areas established and managed for their conservation value and the distribution of the birds of conservation interest was a particularly powerful tool (Scott and others, 1987b, 1993).

Many of the tools used in the HFBS have been used by others. The gap analysis process, first used as a means to identify gaps in the protected areas network for endangered

Hawaiian birds (Scott and others, 1987a; Scott and others, 1993), is used worldwide to assess the conservation status of species and ecosystems (Rodrigues and others, 2004a, b; see also http://gapanalysis.usgs.gov/about-gap/our-history/). Every signatory to the Convention on Biological Diversity Treaty (http://en.wikipedia.org/wiki/Convention_on_Biological_Diversity) uses gap analysis to identify gaps in protection of their biological resources (http://www.cbd.int/doc/publications/cbd-ts-24.pdf), and GAP is an established program in the USGS (http://gapanalysis.usgs.gov/). Variable circular plots are widely used to estimate bird numbers (Estades and Temple, 1999). The 1980s rare bird surveys of the Micronesian Islands by John Engbring (USFWS), Fred Ramsey, and others used the methods and protocols of the HFBS to census the imperiled birds of Rota, Tinian, Aguijan, and Saipan (Engbring and others, 1986).

The translocation of Nihoa finches to new locations in the Leeward Islands by John Sincock and others was unsuccessful, but a population of Laysan finches persists today (2016) on Pearl and Hermes Atoll because of a 1967 introduction by John and Gene Kridler (Morin and Conant, 1997; Conant and Morin, 2002). Newell's shearwater can be found today at Kilauea Point National Wildlife Refuge on Kauai (http://www.fws.gov/endangered/news/bulletin-spring2009/shearwaters-of-kilauea-point.html) because of the translocation efforts of John and others. Those early translocation efforts in the Leeward Islands and Kauai demonstrated the results that could be achieved, and provided a model for the recent translocation efforts to decrease the risk of extinction for Laysan ducks (*Anas laysanensis*) and Nihoa millerbirds (*Acrocephalus familiaris kingi*) (Reynolds and others, 2008; U.S. Fish and Wildlife Service, 2014).

Finally, the Hawaiian crow is known to occur only in captivity (Banko, 2009; Lieberman and Kuehler, 2009). Its future as a wild bird lies with the captive flock made possible through the early efforts of Ernie Kosaka, Ah Fat Lee, Fern Duvall, and others in the HDFW and Win Banko to ensure that there would be options for the Hawaiian crow's survival (http://blogs.sandiegozoo.org/2009/04/21/hawaii-bird-program-open-house).

Our work in Hawaii differed in several ways from that done elsewhere in Patuxent's Endangered Species Program. First, we were tasked with studying an entire avifauna, whose life histories, distribution and ecology, and indeed very existence were undocumented, whereas other programs focused only on a single species. In response to this challenge, we pioneered the development of ecosystem recovery plans for Hawaii's birds (Kepler and others, 1984; Scott and others, 1984; Sincock and others, 1984) rather than the single-species plans that were the standard in the 1970s and 1980s. We also developed new approaches for detecting and monitoring rare birds (Reynolds and others, 1980; Ramsey and others, 1979); however, the clinical interventions and captive propagation of individual animals that were a major component of many of Patuxent's other endangered species field research efforts were only a minor part of ours.

Where Do We Go From Here?

Nearly 50 years after the first endangered species research biologists arrived in the islands, what have we learned? As a result of the work of Patuxent's biologists and other researchers from State and Federal agencies, nongovernmental organizations, and academia in the islands, we learned a lot about the rare things. We learned where they are and where they are not; new sampling methods for rare species; distribution, abundance, habitat associations, and biology of rare species; the nature of threats to survival of Hawaii's endangered birds and plants; and the management actions needed to mitigate those threats. The take-away lessons from those early research efforts are sobering: recovery is slow and asking conservation-relevant research questions is a difficult process, but using the results of that research in a timely manner in the field to implement management actions at scales that increase the survival chances of a species is much more so. Our most important lesson may have been that the consequences of delaying or not implementing management actions are often irreversible.

The birds of Hawaii are still highly endangered (Gorresen and others, 2009; Pratt and others, 2009b). None of the birds unrecorded or insufficiently documented during the HFBS was reliably reported after the survey (Gorresen and others, 2009). The chances that the unreported birds—for example, Kauai nukupuu (*Hemignathus lucidus hanapepe*) and Kauai akialoa (*Hemignathus ellisianus stejengeri*)—escaped detection are vanishingly small (Elphick and others, 2010; Gorressen and others, 2009; Reynolds and others, 2002; Scott and others, 1986, 2008; Sykes and others, 2000). Several birds observed during the HFBS—for example,'o'u (*Psittirostra psittacea*) (Kauai and Hawaii), Kauai 'o'o (*Moho braccatus*), large Kauai thrush (*Myadestes myadestinus*), Molokai thrush (*Myadestes lanaiensis rutha*), Maui akepa (*Loxops coccineus ochraceus*), Maui nukupuu, and po'o-uli—as well as the Oahu creeper (*Paroreomyza maculata*) observed on Oahu during surveys by Shallenberger and Vaughn (1978) have not been seen for 10 or more years. As mentioned above, one species, the Hawaiian crow, is known to occur only in captivity.

Why are these birds still endangered? For many of the species we were tasked with saving, we failed to eliminate or mitigate threats and restore habitat at temporal and spatial scales consistent with achieving recovery goals. The consequence of our failure to act at the necessary scales and speed to reduce threats was often extinction. None of the putatively "extinct" species, save possibly the po'o-uli (Groombridge, 2009; Woodworth and others, 2009), benefited from the well-funded and intensive rescue efforts mounted for species like the California condor or peregrine falcon (*Falco peregrinus*). The work forces involved in several of those mainland conservation efforts commonly were larger than the population of the endangered species they were attempting to save. Unfortunately, for many other endangered Hawaiian birds, the resources to implement needed conservation efforts were not available and many of the management actions identified in the first recovery plans were not implemented or were implemented at scales that were not conservation-relevant.

For example, the first Kauai Forest Bird Recovery Plan (Sincock and others, 1984) called for removal of feral ungulates from the Alaka'i Swamp, the heart of the last remaining habitat for Kauai's endangered forest birds, but the first ungulate fences were not built until 27 years later (http://dlnr.hawaii.gov/ecosystems/files/2013/08/Proposal-Extension-of-Hono-o-Na-Pali-NAR.pdf). In the intervening three decades, three species on Kauai—Kauai 'o'o, the 'o'u, and the large Kauai thrush—have become extinct and two new species have been listed.

Similarly, the 1986 recovery plan for the palila called for removal of feral ungulates from critical habitat of the palila, a recommendation that was supported by two court decisions (Juvik and Juvik, 1984; Meltz, 1994). Twenty-six years later, although our knowledge of the ecology and biology of the palila has increased substantially (Banko and others, 2009), mouflon (*Ovis gmelini musimon*) are still found in critical habitat of the palila in large numbers and are being managed as a recreationally sustainable population for hunters, in part with Federal funds provided under the Pittman-Robertson Act (https://www.fws.gov/laws/lawsdigest/FAWILD.HTML).

Why was there a failure to implement management actions that were known to prevent extinction and promote recovery (Kepler and others, 1983; Scott and others, 1984; Sincock and others, 1984)? Current recovery efforts in Hawaii, the state with the highest density of endangered species per acre in the country, lag far behind those in other states in terms of conservation funds received. Hawaiian terrestrial vertebrates, 30 species, received $1.7 million, with 5 species (the Hawaiian crow, Hawaiian common moorhen [*Gallinula chloropus sandvicensis*], Newell's shearwater, po'o-uli, and Hawaiian stilt) receiving 78 percent of those funds spent on Hawaii's terrestrial vertebrates (U.S. Fish and Wildlife Service, 1996).

The situation is more complex than a lack of funds, however. In a thoughtful treatment of this question, David Leonard and others have suggested that lack of funding (Leonard, 2008; Restani and Marzluff, 2002), lack of understanding of the plight of endangered birds in the islands, and failure to convince folks of the plight have contributed to an urgent need for conservation action. Additionally, there are substantial sociopolitical barriers to implementing conservation actions to benefit endangered forest birds related to conflicting management objectives for areas where endangered species occur (for example, sustaining a recreationally viable population of mouflon for hunters as opposed to maintaining the integrity, diversity, and health of palila habitat [Banko and others, 2009]).

Where do we go from here? We have the advantage of nearly 50 years of research and the wisdom and insights gained from four decades of management actions, successful and unsuccessful; revised recovery plans for all but the northwestern passerine species; and a larger and more diverse conservation constituency with thousands of interested citizens and new citizen conservation groups (the Hawaii Conservation Alliance [http://hawaiiconservation.org/], Hawaii Association of Watershed Partnerships [http://hawp.org/], and Hawaiian Wetland Joint Venture [http://pcjv.org/hawaii/]) with which to work. These new institutional structures focused on maintaining the integrity of native ecosystems and their ecological processes will provide new perspectives on what actions are needed to save the remainder of Hawaii's endangered ecosystems and species (Pratt and others, 2009b). Fortunately, working with the broader conservation perspectives offers new hope for the future of Hawaii's endemic flora and fauna.

The ability of these conservation efforts to prevent extinction of additional species has been made more difficult, however, because of climate change, the increase in human population, and the need to act at landscape scales (Price and others, 2009). Finally, success will require more bridge building and collaboration among different constituencies, and major new commitments of collaboration and financial resources.

Acknowledgments

The authors are grateful to Gene Kridler (U.S. Fish and Wildlife Service [USFWS]); Ernie Kosaka (Hawaii Department of Forestry and Wildlife [HDFW] and later USFWS); Henry Little and Kelvin Taketa (The Nature Conservancy); and Ron Walker and David Woodside (HDFW), our management advisory council during our research in the islands. We also thank all those who participated in the surveys, and Paul Banko (University of Washington student, and later USFWS); Sheila Conant (University of Hawaii); Ray Erickson, John

Aloha from Hawaii—John Sincock and his assistant, Mike Scott, U.S. Fish and Wildlife Service, in their truck at the end of several days' work, summer 1976. Photo by U.S. Fish and Wildlife Service.

Fay, Jim Jacobi, and Loyal Mehrhoff (USFWS); Thane Pratt (HDFW, and later USFWS); Fred Ramsey (USFWS summer employee from Oregon State University); Sharon Scott (Mike Scott's wife); Rob Shallenberger (USFWS); Charles Van Riper (USFWS summer employee from the University of Hawaii); and Ron Walker (HDFW) for insights and comments on earlier versions of this manuscript. Our work in the islands benefited greatly from the administrative support provided by Ray Erickson and others at the Patuxent Wildlife Research Center. Finally, this research would not have been possible without Ray's vision for an endangered species research program and his supervisory philosophy of "a big umbrella and long leash."

Selected References

Baldwin, P.H., 1945, The Hawaiian Goose, its distribution and reduction in numbers: Condor, v. 47, no. 1, p. 27–37. [Also available at https://sora.unm.edu/node/99579.]

Baldwin, P.H., 1947, The life history of the Laysan Rail: Condor, v. 49, no. 1, p. 14–21. [Also available at https://sora.unm.edu/node/99790.]

Baldwin, P.H., 1953, Annual cycle, environment and evolution in the Hawaiian honeycreepers (Aves: Drepaniidae): University of California Publications in Zoology, v. 52, no. 4, p. 285–398.

Banko, P.C., 2009, 'Alalā, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 473–486.

Banko, P.C., Brinck, K.W., Farmer, Chris, and Hess, S.C., 2009, Palila, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 513–522.

Banko, W.E., 1968, Rediscovery of the Maui nukupuu, *Hemignathus lucidus affinis*, and sighting of Maui parrotbill, *Pseudonestor xanthophrys*, Kipahulu Valley, Maui, Hawaii: Condor, v. 70, no. 3, p. 265–266. [Also available at https://sora.unm.edu/node/101761.]

Banko, W.E., 1972, Bibliography of Hawaiian birds exclusive of the 'Elepaio, Mauna Loa Field Station: U.S. Fish and Wildlife Service, Hawaii Volcanoes National Park, HI, 87 p.

Banko, W.E., 1979a, History of endemic Hawaiian birds—Introduction: CPSU/UH Avian History Report 1, Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, 14 p. [Also available at http://hdl.handle.net/10125/329.]

Banko, W.E., 1979b, History of endemic Hawaiian birds—Specimens in museum collections: CPSU/UH Avian History Report 2, Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, 80 p. [Also available at http://hdl.handle.net/10125/333.]

Byrd, G.V., Sincock, J.L., Telfer, T.C., and Moriarity, D.I., 1984, Cross-fostering experiment with Newell's race of Manx shearwater: Journal of Wildlife Management, v. 48, no. 1, p. 163–168. [Also available at http://www.jstor.org/stable/3808464.]

Berger, A.J., Eddinger, C.R., and Frings, S.C., 1969, The nest and eggs of the anianiau: Auk, v. 86, no. 2, p. 183–187. [Also available at https://sora.unm.edu/node/21847.]

Clapp, R.B., Kridler, Eugene, and Fleet, R.R., 1977, The natural history of Nihoa Island, Northwestern Hawaiian Islands: Atoll Research Bulletin, no. 207, 147 p. [Also available at http://www.sil.si.edu/DigitalCollections/atollresearchbulletin/ARB_RecordSingle.cfm?issue=207.]

Conant, Sheila, and Morin, M.P., 2002, Laysan finch and Nihoa finch, *in* Poole, A., and Gill, F., eds, The birds of North America, no. 639: Philadelphia, PA, The birds of North America, Inc., 32 p. [Also available at http://bna.birds.cornell.edu/bna/species/639a/articles/introduction and http://bna.birds.cornell.edu/bna/species/639b/articles/introduction.]

Conant, Sheila, Pratt, H.D., and Shallenberger, R.J., 1998, Reflections on a 1975 expedition to the lost world of the alaka'i and other notes on the natural history, systematics, and conservation of Kauai birds: Wilson Bulletin, v. 110, no. 1, p. 1–22. [Also available at https://sora.unm.edu/node/131535.]

Elphick, C.S., Roberts, D.L., and Reed, J.M., 2010, Estimated dates of recent extinctions for North American and Hawaiian birds: Biological Conservation, v. 143, no. 3, p. 617–627. [Also available at http://www.sciencedirect.com/science/article/pii/S0006320709004911.]

Engbring, John, Ramsey, F.L., and Wildman, V.J., 1986, Micronesian forest bird survey, 1982—Saipan, Tinian, Aguiguan, and Rota: U.S. Fish and Wildlife Service Report, 143 p.

Engilis, Andrew, Jr., 1990, Field notes on native forest birds in the Hanawi Natural Area Reserve, Maui: 'Elepaio, v. 50, no. 8, p. 67–72.

Engilis, Andrew, Jr., and Pratt, T.K., 1993, Status and population trends of Hawaii's native water-birds, 1977–1987: Wilson Bulletin, v. 105, no. 1, p. 142–158. [Also available at https://sora.unm.edu/node/131082.]

Engilis, Andrew, Jr., Pratt, T.K., Kepler, C.B., Ecton, A.M., and Fluetsch, K.M., 1996, Description of adults, eggshells, nestling, fledgling, and nest of the po'o-uli: Wilson Bulletin, v. 108, no. 4, p. 607–619. [Also available at https://sora.unm.edu/node/131423.]

Estades, C.F., and Temple, S.A., 1999, Deciduous-forest bird communities in a fragmented landscape dominated by exotic pine plantations: Ecological Applications, v. 9, no. 2, p. 575–585. [Also available at http://www.jstor.org/stable/2641145.]

Frings, S.C., 1967, The natural history of the Hawaiian 'Elepaio—A review of the literature: 'Elepaio, v. 27, no. 12, p. 108–111.

Giffin, J.G., Scott, J.M., and Mountainspring, Stephen, 1987, Habitat selection and management of the Hawaiian crow: Journal of Wildlife Management, v. 51, no. 2, p. 485–494. [Also available at http://www.jstor.org/stable/3801038.]

Gorresen, P.M., Camp, R.J., Reynolds, M.H., Woodworth, B.L., and Pratt, T.K, 2009, Status and trends of native Hawaiian songbirds, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 108–136.

Groombridge, 2009, Po'o-uli, *in* Pratt, T.K., Atkinson, C., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 487–498.

Jacobi, J.D., 1978, Vegetation map of the Kau Forest Reserve and adjacent lands of Hawaii: U.S. Forest Service Resource Bulletin PSW 16, 3 p. booklet and plate. [Also available at https://archive.org/details/IND79069444.]

Jacobi, J.D., 1989, Technical report 68—Vegetation maps of the upland plant communities on the islands of Hawaii, Maui, Molokai, and Lanai: Honolulu, HI, University of Hawaii at Manoa, 25 p. [Also available at http://manoa.hawaii.edu/hpicesu/techr/068.pdf.]

Jacobi, J.D., and Scott, J.M., 1985, An assessment of the current status of native upland habitats and associated endangered species on the island of Hawai'i, *in* Stone, C.P., and Scott, J.M., eds., Hawai'i's terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, p. 3–22. [Also available at http://www.hear.org/books/hte1985/pdfs/hte1985.pdf.]

Jacobi, J.D., Fancy, S.G., Giffin, J.G., and Scott, J.M., 1996, Long-term population variability in the palila, an endangered Hawaiian honeycreeper: Pacific Science, v. 50, no. 4, p. 363–370. [Also available at http://hdl.handle.net/10125/2910.]

Juvik, J.O., and Juvik, S.P., 1984, Mauna Kea and the myth of multiple use—Endangered species and mountain management in Hawaii: Mountain Research and Development, v. 4, no. 3, p.191–202. [Also available at http://www.jstor.org/stable/3673140.]

Kepler, C.B., Burr, Tim, Cooper, C.B., Dunatchik, Dave, Medeiros, Joseph, Scott, J.M., Ueoka, Meyer, and Wong, Wesley, 1984, Maui-Molokai Forest Birds Recovery Plan, May 1984: Portland, OR, U.S. Fish and Wildlife Service, 110 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015024958426.]

Kepler, C.B., and Kepler, A.K., 1980, The birds of Molokini Island, Maui: 'Elepaio, v. 40, no. 11, p. 147–151.

Kepler, C.B., and Kepler, A.K., 1983, A first record of the nest and chicks of the small Kauai thrush: Condor, v. 85, no. 4, p. 497–499. [Also available at http://sora.unm.edu/node/103397.]

Kepler, C.B., Kepler, A.K., and Simons, T.R., 1984, Hawaii's seabird islands, No. 1—Moke'ehia: 'Elepaio, v. 44, no. 7, p. 71–74.

Kepler, C.B., Kepler, A.K., Simons, T.R., Hobdy, B., and Simons, P.M., 1990, Hawaii's seabird islands, No. 3—Moku-Ho'Oniki and Kanaha Rock, Molokai: 'Elepaio, v. 50, no. 9, p. 75–81.

Kepler, C.B., Pratt, T.K., Ecton, A.M., Engilis, Andrew, Jr., and Fluetsch, K.M., 1996, Nesting behavior of the po'o-uli: Wilson Bulletin, v. 108, no. 4, p. 620–638. [Also available at http://sora.unm.edu/node/131424.]

Kepler, C.B., and Scott, J.M, 1981, Reducing bird count variability by training observers, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 366–371. [Also available at https://sora.unm.edu/node/49.]

Leonard, D.L., Jr., 2008, Recovery expenditures for birds listed under the U.S. Endangered Species Act—The disparity between mainland and Hawaiian taxa: Biological Conservation, v. 141, no. 8, p. 2054–2061. [Also available at http://www.sciencedirect.com/science/article/pii/S0006320708002085.]

MacArthur, Robert, and Levin, Richard, 1967, The limiting similarity, convergence and divergence of coexisting species: American Naturalist, v. 101, no. 921, p. 377–385. [Also available at http://www.jstor.org/stable/2459090.]

Meltz, Robert, 1994, Where the wild things are—The Endangered Species Act and private property: Environmental Law, v. 24, p. 369–417. [Also available at http://heinonline.org/HOL/Page?handle=hein.journals/envlnw24&g_sent=1&collection=journals&id=397.]

Morin, M.P., Conant, Sheila, and Conant, Patrick, 1997, Laysan and Nihoa millerbird, *in* Poole, A., and Gill, F., eds., The Birds of North America, no. 302: Philadelphia, PA, The Birds of North America, Inc., 29 p. [Also available at http://bna.birds.cornell.edu/bna/species/302/articles/introduction.]

Mountainspring, Stephen, Casey, T.L.C., Kepler, C.B., and Scott, J.M., 1990, Ecology, behavior and conservation of the poo-uli (*Melamprosops phaesoma*): Wilson Bulletin, v. 102, no. 1, p. 109–122. [Also available at https://sora.unm.edu/node/130788.]

Mountainspring, Stephen, and Scott, J.M., 1985, Interspecific competition among Hawaiian forest birds: Ecological Monographs, v., 55, no. 2, p. 219–239. [Also available at https://www.jstor.org/stable/1942558.]

Mueller-Dombois, Dieter, Bridges, K.W., and Carson, H.L., eds., 1981, Island ecosystems—Biological organization in selected Hawaiian communities: Stroudsberg, PA, Hutchinson–Ross Publishers, 583 p.

National Research Council, 1992, Scientific bases for the preservation of the Hawaiian crow: Washington, D.C., National Research Council, 148 p. [Also available at http://www.nap.edu/read/2023/.]

Pimm. S.L., 1988, Forest bird communities of the Hawaiian Islands—Their dynamics, ecology, and conservation, by J.M. Scott, Stephen Mountainspring, F.L. Ramsey, and Cameron Kepler (book review): Auk, v. 105, no. 2, p. 400-402. [Also available at http://www.jstor.org/stable/4087519.]

Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., 2009a, Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, 707 p.

Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., Woodworth, B.L., and Mehrhoff, L.A., 2009b, Can Hawaiian forest birds be saved?, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C, Jacobi, J.D., and Woodworth, B.L., eds. Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, p. 552–580.

Pratt, T.K., Kepler, C.B., and Casey, T.L.C., 1997, Poouli (*Melamprosops phaeosoma*), *in* Poole, A., and Gill, F., eds., the Birds of North America, no. 272: Philadelphia, PA, Academy of Natural Science, and the Washington, D.C., American Ornithologists' Union, 16 p. [Also available at http://bna.birds.cornell.edu/bna/species/272/articles/introduction.]

Price. J.P., Jacobi, J.D., Pratt, L.W., Warshauer, F.R., and Smith, C.W., 2009, Protecting forest bird populations across landscapes, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, p. 381–404.

Ralph, C.J., and Fancy, S.G., 1994, Timing of breeding and molting in six species of Hawaiian honeycreepers: Condor, v. 96, no. 1, p. 151–161. [Also available at http://sora.unm.edu/node/104830.]

Ralph, C.J., and Scott, J.M., 1981, Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, 630 p. [Also available at https://sora.unm.edu/node/49.]

Ramsey, F.L., and Scott, J.M., 1978, Use of circular plot surveys in estimating the density of a population with Poisson scattering: Corvallis, OR, Oregon State University, Department of Statistics, Technical Report 60, 34 p.

Ramsey, F.L., and Scott, J.M., 1979, Estimating population densities from variable circular plot surveys, *in* Cormack, R.M., Patil, G.P., and Robson, D.S., eds., Sampling biological populations: Fairland, MD, International Cooperative Publishing House, p. 155–181.

Ramsey, F.L., and Scott, J.M., 1981, Tests of hearing ability, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 341–345. [Also available at https://sora.unm.edu/node/49.]

Ramsey, F.L., Scott, J.M., and Clark, R.T., 1979, Statistical problems arising from surveys of rare and endangered forest birds, *in* Proceedings of the 42nd Session of the International Statistical Institute, v. 1: Manila, Republic of Philippines, p. 471-483.

Ramsey, F.L., Wildman, Valerie, and Engbring, John, 1987, Covariate adjustments in variable area wildlife surveys: Biometrics, v. 43, no. 1, p. 1–11. [Also available at http://www.jstor.org/stable/2531943.]

Reed, J.M., Elphick, C.S., Zuur, A.F., Ieno, E.N., and Smith, G.M., 2007, Time series analysis of Hawaiian waterbirds, *in* Zuur, A.F., Ineo, E.N., and Smith, G.M., eds., Analyzing ecological data: New York, Springer-Verlag, p. 615–632. [Also available at https://ase.tufts.edu/biology/labs/reed/documents/pub2007ReedAED.pdf.]

Reed, J.R., Sincock, J.L., and Hailman, J.P., 1985, Light attraction in endangered procellariiform birds—Reduction by shielding upward radiation: Auk, v. 102, no. 2, p. 377–383. [Also available at https://sora.unm.edu/node/24108.]

Restani, Marco, and Marzluff, J.M., 2002, Funding extinction? Biological needs and political realities in the allocation of resources to endangered species recovery—An existing priority system, which should guide the Fish and Wildlife Service in endangered species recovery, is ineffective, and current spending patterns decrease long-term viability of island species: BioScience, v. 52, no. 2, p. 169–177. [Also available at http://bioscience.oxfordjournals.org/content/52/2/169.full.pdf+html.]

Reynolds, M.H., and Snetsinger, T.J., 2002, The Hawai'i rare bird search 1994–1996, *in* Scott, J.M., Conant, Sheila, and Van Riper, Charles, III, eds., Evolution, ecology, conservation and management of Hawaiian birds—A vanishing avifauna: Studies in Avian Biology, no. 22, p. 133–143. [Also available at http://www.arlis.org/docs/vol1/46665903.pdf.]

Reynolds, M.H., Seavy, N.E., Vekasy, M.S., Klavitter, J.L., and Laniawe, L.P., 2008, Translocation and early post-release demography of endangered Laysan teal: Animal Conservation, v. 11, no. 2, p. 160–168. [Also available at http://dx.doi.org/10.1111/j.1469-1795.2008.00166.x.]

Reynolds, R.T., Scott, J.M., and Nussbaum, R.A., 1980, A variable circular plot method for estimating bird numbers: Condor, v. 82, no. 3, p. 309–313. [Also available at https://sora.unm.edu/node/103083.]

Rodrigues, A.S.L., Akçakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, Luigi, Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, Michael, Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, Jan, Sechrest, Wes, Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., and Yan, Xie, 2004a, Global gap analysis—Priority regions for expanding the global protected areas network: BioScience, v. 54, no. 12, p. 1092–1100. [Also available at http://www.jstor.org/stable/10.1641/0006-3568(2004)054[1092:ggaprf]2.0.co;2.]

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, Luigi, Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, Michael, Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, Jan, Sechrest, Wes, Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., and Yan, Xie, 2004b, Effectiveness of the global protected area network in representing species diversity: Nature, v. 428, p. 640–643. [Also available at http://dx.doi.org/10.1038/nature02422.]

Schwartz, C.W., and Schwartz, E.R., 1949, A reconnaissance of the game birds of Hawaii: Hilo, HI, Board of Commissioners of Agriculture and Forestry, 168 p.

Scott, J.M., Baker, J.K., Berger, A.J., Kosaka, E., Landgraf, L., Ralph, C.J., Woodside, D., Bachman, R., and Burr, T., 1984, Hawaii forest bird recovery plan: Portland, OR, U.S. Fish and Wildlife Service, 72 p.

Scott, J.M., Conant, Sheila, and Pratt, H.D., 1979, Field identification of the Hawaiian creeper on the island of Hawaii: Western Birds, v. 10, no. 2, p. 71–80. [Also available at https://sora.unm.edu/node/122081.]

Scott, J.M., Conant, Sheila, and Van Riper, Charles, III, eds., 2002, Evolution, ecology, conservation and management of Hawaiian birds—A vanishing avifauna: Studies in Avian Biology, no. 22, 428 p. [Also available at https://sora.unm.edu/node/87.]

Scott, J.M., Csuti, Blair, Jacobi, J.D., and Estes, J.E., 1987a, Species richness—A geographic approach to protecting future biological diversity: BioScience, v. 37, no. 11, p. 782–788. [Also available at https://www.jstor.org/stable/1310544.]

Scott, J.M., Davis, Frank, Csuti, Blair, Noss, Reed, Butterfield, Bart, Groves, Craig, Anderson, Hal, Caicco, Steve, D'Erchia, Frank, Edwards, T,C., Jr., Ulliman, Joe, and Wright, R.G., 1993, Gap analysis—A geographic approach to protection of biological diversity: Wildlife Monographs, no. 123, 41 p. [Also available at http://www.jstor.org/stable/3830788.]

Scott, J.M., Goble, D.D., Wiens, J.A., Wilcove, D.S., Bean, Michael, and Male, Timothy, 2005, Recovery of imperiled species under the Endangered Species Act—The need for a new approach: Frontiers in Ecology and the Environment, v. 3, no. 7, p. 383–389. [Also available at http://www.jstor.org/stable/3868588.]

Scott, J.M., Jacobi, J.D., and Ramsey, F.L., 1981a, Avian surveys of large geographical areas—A systematic approach: Wildlife Society Bulletin, v. 9, no. 3, p. 190–200. [Also available at http://www.jstor.org/stable/3781837.]

Scott, J.M., and Kepler, C.B., 1983, Hawaii's upland forests: Science, v. 220, no. 4601, p. 1002. [Also available at http://www.jstor.org/stable/1690794.]

Scott, J.M., Kepler, C.B., Stine, P., Little, H., and Taketa, K., 1987b, Protecting endangered forest birds in Hawaii—The development of a conservation strategy: Transactions of the North American Wildlife and Natural Resources Conference, v. 52, p. 348–363.

Scott, J.M., Kepler, C.B., Van Riper, Charles, III, and Fefer, S.I., 1988, Conservation of Hawaii's vanishing avifauna—Hawaiian birds provide one of the best, and most spectacular, showcases of divergent evolution: BioScience, v. 38, no. 4, p. 238–252. [Also available at http://www.jstor.org/stable/1310847.]

Scott, J.M., Kepler, C.B., Van Riper III, Charles, Stone, C.P., and Fefer, S.I., 1989, Integrated conservation strategy for Hawaiian forest birds—A reply: BioScience, v. 39, no. 7, p. 476-479. [Also available at http://www.jstor.org/stable/1311141.]

Scott, J.M., Mountainspring, Stephen, Ramsey, F.L., and Kepler, C.B., 1986, Forest bird communities of the Hawaiian Islands—Their dynamics, ecology and conservation: Studies in Avian Biology, no. 9, 431 p. [Also available at https://sora.unm.edu/node/56.]

Scott, J.M., Mountainspring, Stephen, Van Riper, Charles, III, Kepler, C.B., Jacobi, J.D., Burr, T.A., and Giffin, J.G., 1984, Annual variation in the distribution, abundance and habitat response of the palila (*Loxioides balleiui*): Auk, v. 101, no. 4, p. 647–664. [Also available at https://sora.unm.edu/node/24018.]

Scott, J.M., and Ramsey, F.L., 1981a, Effects of abundant species on the ability of observers to make accurate counts of birds: Auk, v. 98, no. 3, p. 610–613. [Also available at https://sora.unm.edu/node/23582.]

Scott, J.M., and Ramsey, F.L., 1981b, Length of count period as a possible source of bias in estimating bird numbers, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 409–413. [Also available at https://sora.unm.edu/node/49.]

Scott, J.M., Ramsey, F.L., and Kepler, C.B., 1981b. Distance estimation as a variable in estimating bird numbers from vocalizations, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 334–340. [Also available at https://sora.unm.edu/node/49.]

Scott, J.M., Ramsey, F.L., Lamertink, Martjan, Rosenberg, K.V., Rohrbaugh, Ron, Wiens, J.A., and Reed, J.M., 2008, When is an “extinct” species really extinct? Gauging the search efforts for Hawaiian forest birds and the ivory-billed woodpecker: Avian Conservation and Ecology, v. 3, no. 2, article 3 [n.p.], accessed September 9, 2016, at http://www.ace-eco.org/vol3/iss2/art3/.

Scott J.M., and Sincock, J.L., 1977, Recent observations on the birds of the Koolau Forest Reserve, Maui: Western Birds, v. 8, no. 3, p. 113–116. [Also available at https://sora.unm.edu/node/122019.]

Scott, J.M., Woodside, D.H., and Casey, T.L.C., 1977, Observations of birds in the Molokai Forest Reserve, July 1975: ‘Elepaio, v. 38, no. 3, p. 25–27.

Scowcroft, P.G., and Giffin, J.G., 1983, Feral herbivores suppress mamane and other browse species on Mauna Kea, Hawaii: Journal of Range Management, v. 36, no. 5, p. 638–645. [Also available at https://journals.uair.arizona.edu/index.php/jrm/issue/view/419.]

Shallenberger, R.J., 1977, An ornithological survey of Hawaiian wetlands: Honolulu, HI, Ahuimanu Productions, v. 1, 105 p.

Shallenberger, R.J., and Vaughn, G.K., 1978, Avifaunal survey in the central Koolau range, Oahu: Kailua, HI, Ahuimanu Productions, 51 p.

Simons, T.R., Kepler, C.B., Simons, P.M., and Kepler, A.K., 1985, Hawaii’s seabird islands, no. 2—Hulu Island and vicinity, Maui: ‘Elepaio, v. 45, no. 11, p. 111–113.

Sincock, J.L., Daehler, R.E., Telfer, T., and Woodside, D.H., 1984, Kauai Forest Bird Recovery Plan: Portland, OR, U.S. Fish and Wildlife Service, p. 1–69.

Sincock, J.L., and Scott, J.M., 1980, Cavity nesting of the akepa on the island of Hawaii: Wilson Bulletin, v. 92, no. 2, p. 261–263. [Also available at https://sora.unm.edu/node/129739.]

Sincock, J.L., and Swedberg, G.E., 1969, Rediscovery of the nesting grounds of Newell’s Manx shearwater (*Puffinus puffinus newelli*), with initial observations: Condor, v. 71, no. 1, p. 69–71. [Also available at https://sora.unm.edu/node/101817.]

Stone, C.P., 1985, Alien animals in Hawai’i’s native ecosystems—Toward controlling the adverse effects of introduced vertebrates, *in* Stone, C.P., and Scott, J.M., eds., Hawai’i’s terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, p. 251–297. [Also available at http://www.hear.org/books/hte1985/pdfs/hte1985.pdf.]

Stone, C.P., and Scott, J.M., eds., 1985, Hawai’i’s terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, 584 p.

Stone, C.P., and Stone, D.B., eds., 1988, Conservation biology in Hawaii: Honolulu, HI, University of Hawaii, 252 p. [Also available at http://manoa.hawaii.edu/hpicesu/book/1988_chap/.]

Sugihara, R.T., 1997, Abundance and diets of rats in two native Hawaiian forests: Pacific Science, v. 51, no. 2, p. 189–198. [Also available at https://scholarspace.manoa.hawaii.edu/bitstream/10125/3110/1/v51n2-189-198.pdf.]

Swedberg, G.E., 1967, The koloa—A preliminary report on the life history and status of the Hawaiian duck (*Anas wyvilliana*): Honolulu, HI, Hawaii Department of Land and Natural Resources, 56 p.

Sykes, P.W., Kepler, A.K., Kepler, C.B., and Scott, J.M., 2000, Kauai oo (*Moho bracattus*), Oahu oo (*Moho apicalis*), Bishop’s oo (*Moho bishop*), Hawaii oo (*Moho nobilis*), and kioea (*Chaetoptila angustipluma*), *in* Poole, A., and Gill, F., eds., The birds of North America, no 535: Philadelphia, PA, Birds of North America, Inc., 32 p. [Also available at http://bna.birds.cornell.edu/bna/species/535a/articles/introduction.]

Telfer, T.C., Sincock, J.L., Byrd, G.V., and. Reed, J.R., 1987, Attraction of Hawaiian seabirds to lights—Conservation efforts and effects of moon phase: Wildlife Society Bulletin, v. 15, no. 3, p. 406–413. [Also available at http://www.jstor.org/stable/3782548.]

The Nature Conservancy, 1982, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 21 p.

The Nature Conservancy, 1983, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 18 p.

The Nature Conservancy, 1985, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 12 p.

U.S. Department of Interior, 1964, Rare and endangered fish and wildlife of the United States: Washington D.C., U.S. Department of Interior, 62 p.

U.S. Fish and Wildlife Service, 1976a, Recovery effort intensifies to save Hawaii's endangered wildlife: Endangered Species Technical Bulletin, v. 1, no. 5, insert following p. 2.

U.S. Fish and Wildlife Service, 1976b, Hawaii bird survey yields mixed results: Endangered Species Technical Bulletin, v. 1, no. 5, p. 1–2.

U.S. Fish and Wildlife Service, 1977, Special report—Patuxent's endangered wildlife research program: Endangered Species Technical Bulletin, v. 2, no. 11, p. 6–9.

U.S. Fish and Wildlife Service, 1996, Endangered species expenditures—Fiscal year 1996: accessed December 2, 2014, at http://www.fws.gov/endangered/esa-library/pdf/FY_1996.pdf.

U.S. Fish and Wildlife Service, 2014, Nihoa Millerbird Translocation Project: accessed October 2, 2014, at http://www.fws.gov/pacificislands/nihoamillerbird.html.

Van Riper, Charles, III, and Scott, J.M., 1979, Observations on distribution, diet, and breeding of the Hawaiian thrush: Condor, v. 81, no. 1, p. 65–71. [Also available at https://sora.unm.edu/node/102920.]

Van Riper, Charles, III, Scott, J.M., and Woodside, D.M., 1978, Distribution and abundance patterns of the palila on Mauna Kea, Hawaii: Auk, v. 95, no. 3, p. 518–527. [Also available at https://sora.unm.edu/node/23172.]

Warner, R.E., 1960, A forest dies on Mauna Kea—How feral sheep are destroying an Hawaiian woodland: Pacific Discovery, v. 13, no. 2, p. 6–14.

Warner, R.E., ed., 1968, Scientific report of the Kipahulu Valley Expedition, Maui, Hawaii, 2 August–31 August, 1967: Honolulu, HI, The Nature Conservancy, 184 p. [Also available at http://manoa.hawaii.edu/hpicesu/speci/1967b.pdf.]

Warner, R.E., 1968, The role of introduced diseases in the extinction of the endemic Hawaiian avifauna: Condor, v. 70, no. 2, p. 101–120. [Also available at https://sora.unm.edu/node/101729.]

Warshauer, F.R., and Jacobi, J.D., 1982, Distribution and status of *Vicia menziesii* Spreng. (Leguminosae)—Hawai'i's first officially listed endangered plant species: Biological Conservation, v. 23, no. 2, p. 111–126. [Also available at http://dx.doi.org/10.1016/0006-3207(82)90034-9.]

Warshauer, F.R., Jacobi, J.D., LaRosa, A.M., Scott, J.M., and Smith, C.W., 1983, Technical report 48—The distribution, impact and potential management of the introduced vine *Passiflora mollisima* (Passifloraceae) in Hawai'i: Honolulu, HI, University of Hawaii, 39 p. [Also available at https://scholarspace.manoa.hawaii.edu/handle/10125/4329.]

Wilcove, D.S., and McMillan, Margret, 2006, The class of 67, *in* Goble, D.D., Scott, J.M., and Davis, F.W., eds., The Endangered Species Act at thirty—Reviewing the conservation promise: Covelo, CA, Island Press, p. 45–50.

Woodworth, B.L., Lieberman, A.A., Nelson, J.T., and Fretz, J.S., 2009, Puai'ohi. *in* Pratt, T.K., Atkinson, C., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 499–512.

Patuxent's Long-Term Research on Wolves

L. David Mech

The gray wolf (*Canis lupus*) was one of the first species placed on the Endangered Species List in 1967. The Endangered Species Act of 1973 legally protected the wolf along with other listed species.

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, began its Endangered Wildlife Program in 1966, and U.S. Fish and Wildlife Service (USFWS) biologist Ray Erickson was assigned to lead it. In 1973, I was transferred to the program from Region 3 of the USFWS, having been employed there since 1969 to study wolves in Minnesota.

Endangered Species Act protection of the wolf fostered its quick population response, and wolf numbers began to increase in their reservoir in northeastern Minnesota and adjacent Canada and expand throughout northern Minnesota and eventually into Wisconsin and Michigan. In 2009, the number of wolves in Minnesota was approximately 3,000, and there were at least 1,500 in Wisconsin and Michigan.

This chapter describes Patuxent's wolf research, which continued into 1993 when Congress incorporated the USFWS's Endangered Wildlife Research Program into the National Biological Survey (NBS). Eventually the NBS merged with the U.S. Geological Survey, and the long-term wolf research program was transferred to the Northern Prairie Wildlife Research Center. Through all the administrative changes, Patuxent's wolf research project continued through the various agencies into the present (2016).

The text that follows is modified from Mech (2009).

The seeds for the blossoming of the wolf (*Canis lupus*) population throughout the upper Midwest were embodied in a long line of wolves that had persisted in the central part of the Superior National Forest (SNF) of northeastern Minnesota, probably since the retreat of the last glaciers more than 10,000 years ago. This line of wolves had withstood not only the various natural environmental factors that had shaped them through their evolution, but also logging, fires, market hunting of prey animals, bounties, aerial hunting, and poisoning. These factors had exterminated their ancestors and dispersed their offspring to only a few wolf pack territories in the more accessible areas. The dense and extensive stretch of wild land that is now known as the Boundary Waters Canoe Area Wilderness had proven too formidable a barrier even for the foes of the wolf, which had striven to eliminate the animal and had succeeded everywhere else in the contiguous United States. The wolves of the SNF became the reservoir for the recolonization of wolves throughout Minnesota and into neighboring Wisconsin and the Upper Peninsula of Michigan.

The only other part of the 48 contiguous United States where wolves still survived in the late 1960s was Isle Royale in Lake Superior, just 32 kilometers (km) (20 miles [mi]) from Minnesota's coast (Vucetich and Peterson, 2009). Those wolves had crossed Lake Superior's rare ice bridge to the 540-square-kilometer (km^2) (208-square-mile [mi^2]) island from Ontario (or possibly Minnesota) in 1949. At that time, Isle Royale was a national park, and the wolves that reached the island were fully protected there from bounties, poisons, and aerial hunting.

Dave Mech, U.S. Fish and Wildlife Service, drugging wild wolf in Minnesota to radiocollar it, early 1970s. Photo by Don Elsing, U.S. Forest Service.

U.S. Fish and Wildlife Service wildlife technicians radiocollaring a wolf in Minnesota, mid-1980s. Photo by U.S. Fish and Wildlife Service.

The wolves of the central SNF also were those that wildlife biologist, wilderness enthusiast, and writer Sigurd Olson (1938) had trailed in the snow in the late 1930s and that Milt Stenlund (1955) had studied later. Although neither worker realized it, molecular geneticists would eventually debate whether the wolves they studied were a blend of animals descended from the most recent colonization of North America across the Bering land bridge (*Canis lupus*), such as those in northwestern Canada and Alaska, and wolves that putatively evolved in North America (*Canis lycaon*), such as those that inhabit southeastern Ontario (Wilson and others, 2000). Wolves with both types of genetic markers sometimes live in the same pack, and apparently many wolves in Minnesota are hybrids between the two types (Mech and Federoff, 2002; Wilson and others, 2009).

When the last remaining 700 or so wolves inhabiting Minnesota, most of them in the SNF, were placed on the Federal Endangered Species List in 1967, it was only logical to begin studying them. A few groundbreaking studies had provided some insights into the biology of wolves (for example, Olson, 1938; Murie, 1944; Cowan, 1947; Stenlund, 1955; Mech, 1966; Pimlott and others, 1969); however, because wolves were so scarce in the contiguous United States and lived in low densities and inaccessible areas where they did survive, much basic information about wolves was unknown. Fortunately, when wolves were declared endangered, wildlife researchers were beginning to apply the revolutionary technology of radiotracking (Cochran and Lord, 1963). Kolenosky and Johnston (1967) had proved in Ontario that radiotracking wolves was practical. This technique promised to greatly enhance the ability of researchers to discover many new things about the behavior and ecology of wolves.

In 1968, I began a pilot project in the central SNF using radiotracking to determine whether wolf packs were territorial (Mech and Frenzel, 1971). My preliminary aerial observations during 1966–67 and 1967–68 had shown that several packs of different sizes and color combinations were present in the area. Without reliable identifiers for each pack, however, and without being able to find packs systematically, I had only a subjective notion that they were territorial. Therefore, radiotracking wolves from aircraft, which allowed both identifying individuals and systematically locating them, was the ideal method to answer this question.

Study Area

My study area encompassed about 2,060 km^2 (795 mi^2) immediately east of Ely in the east-central SNF (48° N.

Aerial radiotracking of wolves in Minnesota by U.S. Fish and Wildlife staff, mid-1980s. Photo by U.S. Fish and Wildlife Service.

Aerial observation of radiocollared wolves in Minnesota as part of the ongoing U.S. Fish and Wildlife Service wolf census, mid-1980s. Photo by U.S. Fish and Wildlife Service.

92° W.). Although somewhat smaller than the areas I have reported on earlier, this area encompassed the core of that region in which I have been able to monitor the wolf population during the entire 40-year study (1966–2006) (fig. 1). The area represents only a small percentage of the total range of wolves in Minnesota.

Topography in the study area varies from large stretches of swamps and uneven upland to rocky ridges, with altitudes ranging from about 325 to 700 meters (m) (1,066–2,297 feet [ft]) above the National Geodetic Vertical Datum of 1988. Winter temperatures below -35 degrees Celsius (°C) (-31 degrees Fahrenheit [°F]) are not unusual, and snow depths (from about mid-November through about mid-April) generally range from 50 to 75 centimeters (cm) (20–30 inches [in.]). Summer temperatures rarely exceed 35 °C (95 °F). Conifers, including jack pine (*Pinus banksiana*), white pine (*P. strobus*), red pine (*P. resinosa*), black spruce (*Picea mariana*), white spruce (*P. glauca*), balsam fir (*Abies balsamea*), white cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*), predominate in the forest overstory. As a result of extensive cutting and fires, however, much of the coniferous cover is interspersed with large stands of white birch (*Betula papyrifera*) and aspen (*Populus tremuloides*). Heinselman (1993) presents a detailed description of the forest vegetation.

In the northeastern half of this area, as well as immediately north and east of it, the overwintering population of white-tailed deer (*Odocoileus virginianus*) was extirpated by about 1975 by a combination of severe winters, maturing vegetation, and a large wolf population (Mech and Karns, 1977), and the area has remained devoid of wintering deer ever since (Nelson and Mech, 2006). Moose (*Alces alces*) inhabit the entire area but occur at a higher density in the northeastern half. In spring, about a third of the deer inhabiting the southwestern half of the study area migrate into the northeastern half or beyond and return in fall (Hoskinson and Mech, 1976; Nelson and Mech, 1981). American beavers (*Castor canadensis*) occur throughout the study area, but generally are available as prey only from about April through November. Although all three prey species are consumed by wolves in the region (van Ballenberghe and others, 1975), the primary prey of wolves inhabiting the northeastern part has been moose since about 1975, whereas wolves in the southwestern part have consumed primarily deer.

Year-round hunting and trapping of wolves were legal until October 1970, when wolves were fully protected on Federal land within the SNF by the U.S. Forest Service. In August 1974, wolves were protected under the Endangered Species Act of 1973. In 1978, wolves in Minnesota were reclassified as threatened, but remained legally protected except for depredation control outside the SNF (Fritts and others, 1992). Illegal taking of wolves continued, however—primarily in fall and winter (Mech, 1977b; Mech and Hertel, 1983). Wolves in the upper Midwest, including Minnesota, were removed from the Endangered Species List in March 2007.

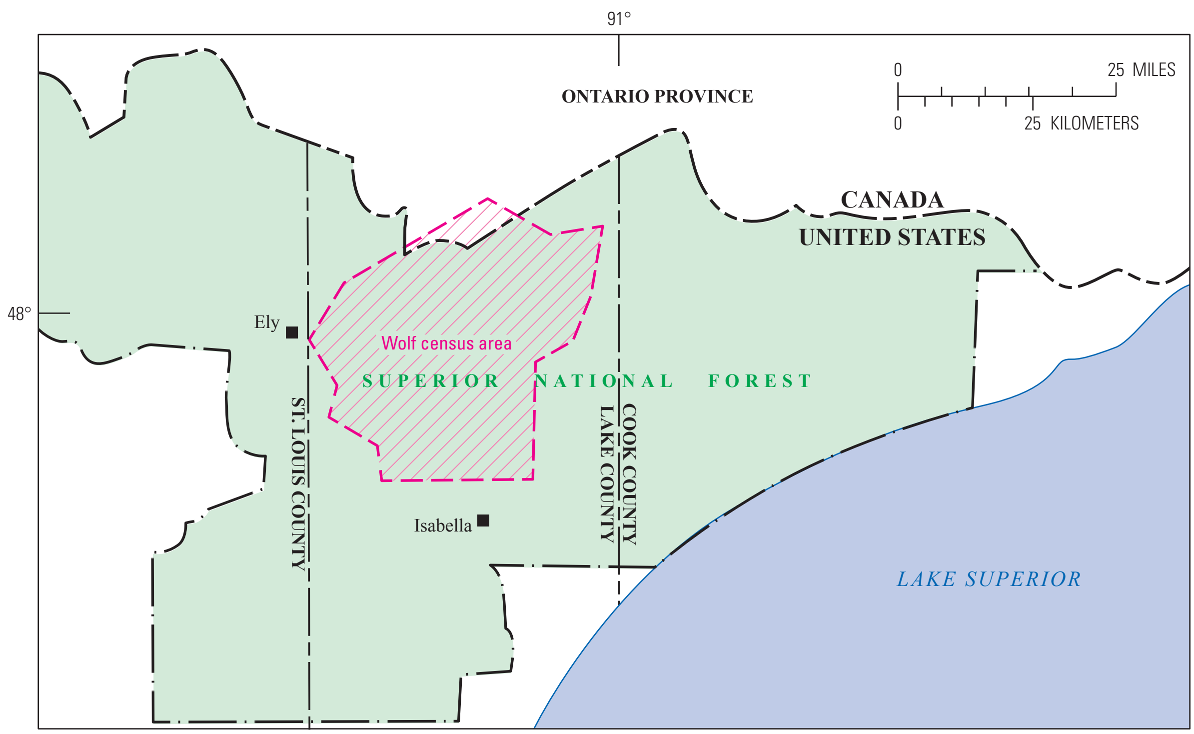


Figure 1. Location of the central Superior National Forest study area, Minnesota. (Modified from Mech, 2009)

Long-Term Research on Wolves, Wolf Packs, and Population Trends

My main objective at the beginning of the study was to determine spacing in the wolf population, but I also realized that by being able to find and identify each marked pack, I could obtain much additional information. For example, during winter I could count pack members, determine how consistently each pack maintained its size, track its movements, find and examine its kills, and locate marked wolves after death. In addition, if the packs were territorial, radiotagging a sufficient number of packs in the study area would allow me to determine the total number of wolves there by locating each pack and counting the pack members.

Over the long term, monitoring the population trajectory of wolves in the SNF became my primary objective. The longer this study continued, the more valuable the data on changes in population size became. The only other data available on wolf population trends were those from the Isle Royale study, which began in 1959 (Mech, 1966) and was continued by other researchers (Vucetich and Peterson, 2009). Although those data are of great interest, they characterize an island with no emigration or immigration and therefore cannot fully represent most populations of wolves. The opportunity to gather long-term data on a population of mainland wolves and determine the factors that drove the changes in that population was highly attractive.

The primary technique used has been live-trapping wolves in modified steel foot-traps, anesthetizing each animal (except most pups), weighing them, sampling their blood, and outfitting them with a radiocollar (Mech, 1974). Since 2000, my assistants, students, associates, and I also have estimated the age of each wolf on the basis of tooth wear (Gipson and others, 2000). We aerially radiotracked the wolves at least weekly during most years, and observed and counted them as often as possible, primarily from December through March (Mech, 1973, 1986). The largest number of wolves we saw during winter in each pack was considered to be the pack size. If the territory of a radiocollared pack fell partly outside the census area, the number of wolves assigned to the census area was multiplied by the percentage of the territory that fell in the area.

U.S. Fish and Wildlife Service staff examining wolf-killed deer, Minnesota, mid-1980s. Photo by U.S. Fish and Wildlife Service.

Territoriality of Wolf Packs

Each time we located a wolf, we recorded its location. We plotted these locations from October 1 through March 30 and from April 1 through September 30 each year, and used minimum convex polygons (MCPs) (Mohr, 1947) to represent territories (Mech, 1973, 1977b, 1986).

Pack territories based on radio locations were delineated for each radiocollared pack in the study area each year; however, some packs died out, new ones formed, and not all packs were radiocollared each year. The existence of nonradiocollared packs in the study area in any year was inferred from voids in the maps of the territorial mosaic. Incidental observations of nonradiocollared packs and (or) their tracks in these voids indicated the sizes of these packs. (Some data pertaining to individual packs in some years in this chapter may differ from data presented previously [Mech, 1973, 1977c, 1986] as a result of a reinterpretation of the data on the basis of additional experience with these packs.) If data on individual packs were unavailable for any year, pack-size estimates were made on the basis of the previous and subsequent years' data for packs occupying those territories. Because an unknown portion of the territories of some of these packs may have fallen outside the census area, these data are not precise. Data collected in 1966–67 and 1967–68 were based solely on observations of nonradiocollared packs during intensive aerial observations. In the estimates of population trajectory for wolves presented here, I considered the number of lone wolves to be inconsequential because they represented only a small proportion of the population, and most of these individuals were dispersers accounted for by using the maximum numbers in each pack. During the earlier part of the study, lone wolves were estimated to constitute 7 to 14 percent of the population (Mech, 1973).

Because monitoring the population density of wolves in the study area required the maintenance of radiocollars on several adjacent packs, the project became a data-gathering system that allowed several parallel studies. Knowing where wolf packs lived regularly and how many members each contained allowed Fred Harrington and me to approach on foot and howl to them under various conditions to determine their responses (Harrington and Mech, 1979). By tracking known packs in the snow and examining their scent marks, Roger Peters and I could describe and quantify scent-marking behaviors (Peters and Mech, 1975). Russell Rothman and I conducted a similar study on newly formed pairs of wolves (Rothman and Mech, 1979).

From 1968 through 2006, we live-trapped 712 wolves (119 female pups, 141 male pups, 239 females ≥1 year old, and 213 males ≥1 year old) in the study area, for a total of 1,044 captures of wolves from 15 or more packs. The number of packs radiocollared each year varied, and over the 38 years of radiotracking, some packs disappeared and many new ones formed. Weights of both males and females peaked at 5 or 6 years of age, with mean peak weights of 40.8 kg (89.9 pounds [lbs]) ± a standard error (SE) of 1.5 kg (3.3 lbs) and 31.2 kg (68.8 lbs) ± a SE of 2.4 kg (5.3 lbs), respectively (Mech, 2006a). From 2000 to 2004, the age structure of the population was relatively young, with only 12 percent of animals more than 1 year old being more than 5 years old (Mech, 2006b). Some wolves, however, lived to be 13 years old (Mech, 1988). Most females 4 to 9 years of age had bred, as determined by assessing nipple sizes; those that had not bred had lower average weights than those that had.

The study clearly established for the first time that each radiocollared pack inhabited a separate territory (Mech, 1973). Pimlott and others (1969, p. 78) had concluded that "the results are far from conclusive on the question of whether or not pack territoriality is involved," and Mech (1970, p. 105) had speculated that wolf packs might even have "spatio-temporal" territories. Radiotracking wolves in the SNF showed that they are territorial and that their territories are spatial (Mech, 1973). The wolves advertised and defended their territories by howling (Harrington and Mech, 1979), scent-marking (Peters and Mech, 1975), and direct aggression (Mech, 1994).

Analysis of wolf-pack territory size was not in the scope of this study. On the basis of MCPs of radiocollared wolf packs, territory sizes varied from 125 to 310 km^2 (48–120 mi^2) through winter 1973 (Mech, 1974). During 1997–99, however, the Farm Lake pack inhabited only 23 to 33 km^2 (9–13 mi^2), a density of 182 to 308 wolves per 1,000 km^2 (472–798 per 1,000 mi^2), the highest density ever reported (Mech and Tracy, 2004). The overall territorial structure gradually shifted over the years, although some semblance of the early structure was still apparent in 2006–07 (fig. 2).

Maximum winter pack sizes during 233 radiocollared pack-years (1 pack radiotracked for 1 year = 1 pack-year) varied from 2 to 15 and averaged 5.6 ± 0.20 (SE). Maximum winter pack sizes for 11 packs with at least 11 years of data varied from 2 to 8 to 2 to 15 per year, with means of 3.7 ± 0.5 (SE) to 7.9 ± 1.1 (SE); the small standard errors around these means show that individual packs in the study area tended to retain their basic sizes. Approximately 67 percent of the packs included a maximum of two to six members during winter, and 90 percent included two to nine (fig. 3).

One of the more novel findings of our long-term study was the concept of the buffer zone between wolf-pack territories (Mech, 1977c). There appears to be an area of 1 to 2 km (0.6–1.3 mi) around the edge of a wolf-pack territory where neighboring packs travel but spend little time (Mech and Harper, 2002), and wolves fight there, commonly to the death, if an encounter between packs occurs (Mech, 1994). Therefore, prey seem to survive longer in these zones. When the deer population declined early in the study, most of those

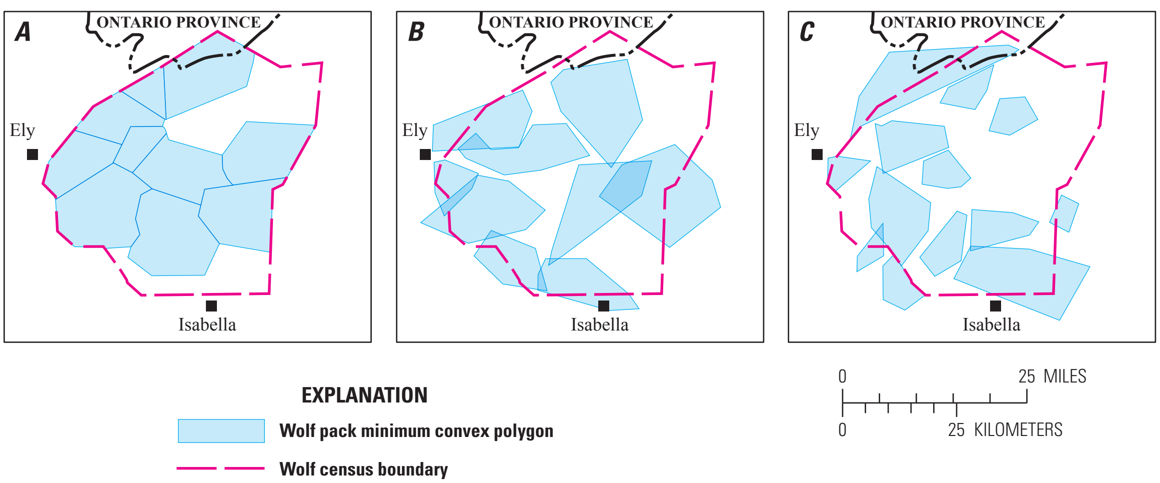


Figure 2. Territorial structure of wolf packs in the central Superior National Forest study area, Minnesota. *A*, represents the territorial structure from 1971 to 1973, but arbitrarily extends each pack's minimum convex polygon (MCP) to the boundaries of its neighbors (Mech, 1973). *B*, represents the actual MCPs for radiocollared packs during winter 1984–85 (Mech, 1986). *C*, represents the same for 2006–07. In 1984–85, a nonradiocollared wolf pack consisting of an estimated six wolves occupied an unknown part of the northeastern area, and in 2006–07, a nonradiocollared pack of eight wolves occupied the northeastern area. Several aerial surveys over the east-central area indicated that no wolves were present during winter 2006–07. (Modified from Mech, 2009)

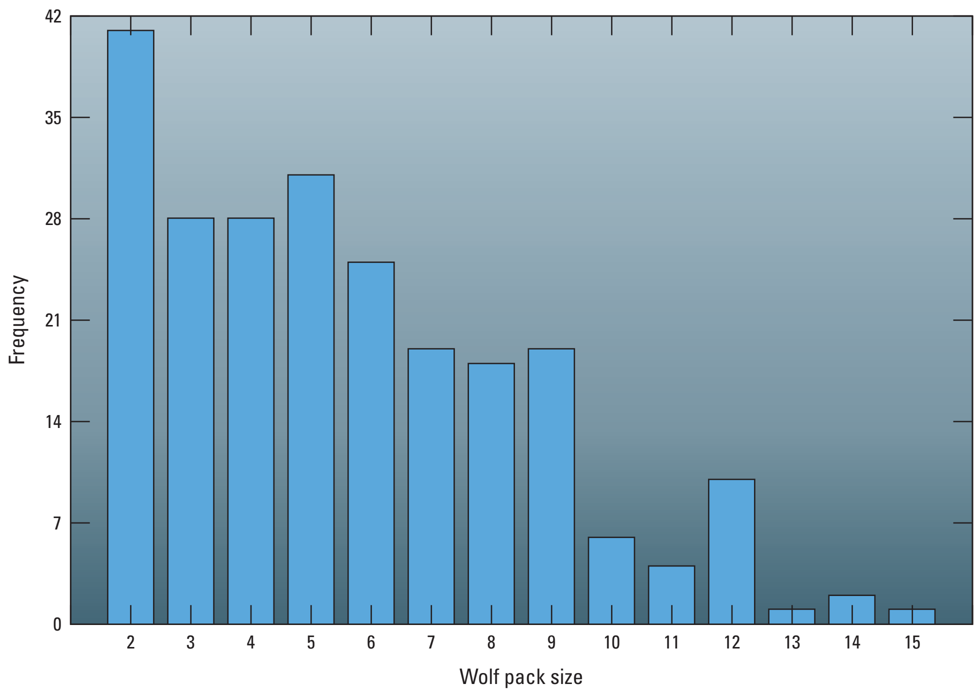


Figure 3. Distribution of maximum winter pack sizes in the central Superior National Forest study area, Minnesota, winter 1966–67 through winter 2006–07. (Modified from Mech, 2009)

remaining inhabited these zones (Hoskinson and Mech, 1976; Mech, 1977a, c; Nelson and Mech, 1981). Even after the deer population increased, we continued to find evidence of this relation (Kunkel and Mech, 1994).

Buffer zones between territories of wolf packs are important to territorial maintenance. In addition to fighting, adjacent packs scent-mark disproportionately there (Peters and Mech, 1975). Howling in and near the buffer zone undoubtedly also is important. Harrington and Mech (1979, p. 243) estimated that each pack on average is within howling range of at least one neighboring pack about 78 percent of the time, and "the probability of one pack hearing another, and the probability of encounters both increase when packs approach one another at a common border."

Population Trends

In our 2,060-km^2 (795-mi^2) study area, numbers of wolves ranged from 35 to 87 with a mean of 59 and a median of 55, and a density of 17 to 42 wolves per 1,000 km^2 (44–109 per 1,000 mi^2) with a mean of 28 per 1,000 km^2 (73 per 1,000 mi^2) and median of 27 per 1,000 km^2 (70 per 1,000 mi^2). The population decreased between the winters of 1968–69 and 1973–74 and subsequently increased ($r^2 = 0.33$; $P < 0.001$) (fig. 4). Mean pack size also increased after winter 1973–74 ($r^2 = 0.21$; $P < 0.01$). In winter 2006–07, the population was estimated to be 81 wolves, or 39 wolves per 1,000 km^2 (101 per 1,000 mi^2). Both the population and average-pack-size trends increased after 1973–74 at a mean annual rate of 0.01. Annual changes in the estimated size of the wolf population were related to annual changes in mean sizes of radiocollared packs ($r^2 = 0.35$; $P < 0.001$). Estimates of pack-size and population change were accurate because radiocollared packs were easily located and counted several times each winter.

From the beginning of the study through about the late 1980s, the proportion of wolves on a deer economy in our area decreased, and more wolves had to rely on moose. The decline in wolves through 1982 coincided with the decline in deer (fig. 5), which in turn coincided with maximum cumulative 3-year snow depth (Mech and others, 1987a). When the snowfall moderated in 1982–83, the number of deer began increasing again (Fuller and others, 2003). The trend for the wolf population that depended on deer declined curvilinearly, reaching a minimum about 1991 and gradually increasing through 2007 ($r^2 = 0.86$; $P < 0.00001$). The wolf population in the northern, northeastern, and eastern parts of the area that preyed increasingly on moose showed a reverse-sigmoid increase ($r^2 = 0.80$) from about 1978 through 2007, related ($r^2 = 0.12$; $P = 0.06$) to an increase in abundance of moose from 3,900 individuals in 1978 to 6,460 in 2007 (Mark Lennarz, Minnesota Department of Natural Resources, written commun., 2006).

Canine parvovirus (CPV) began affecting the SNF wolf population in the early 1980s and had its greatest effect

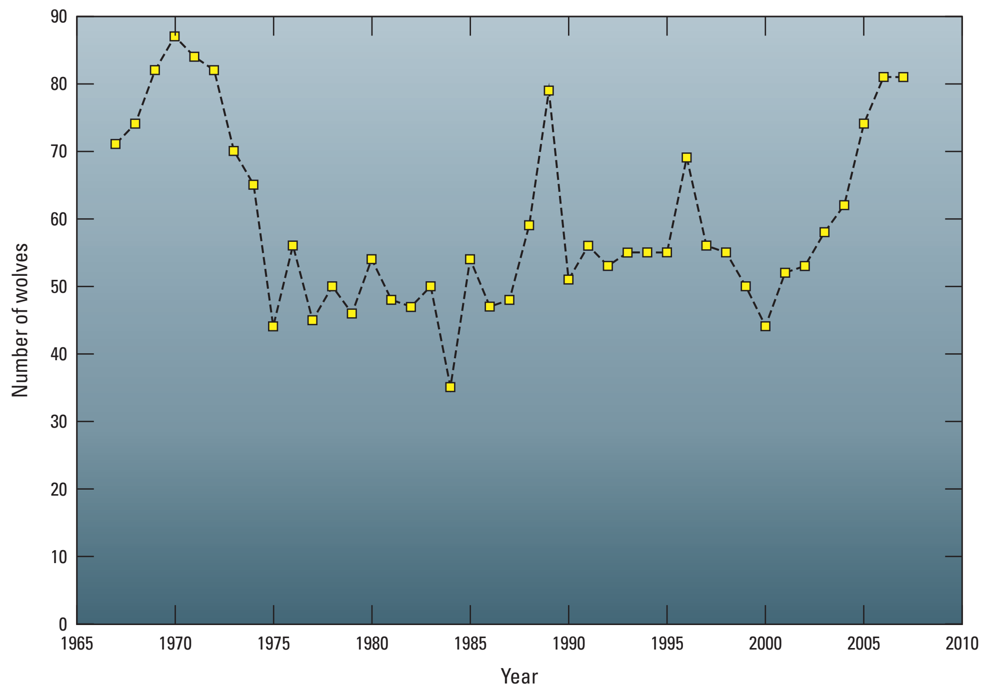


Figure 4. Size of the wolf population in the central Superior National Forest, MN, 1967–2007. (Modified from Mech, 2009)

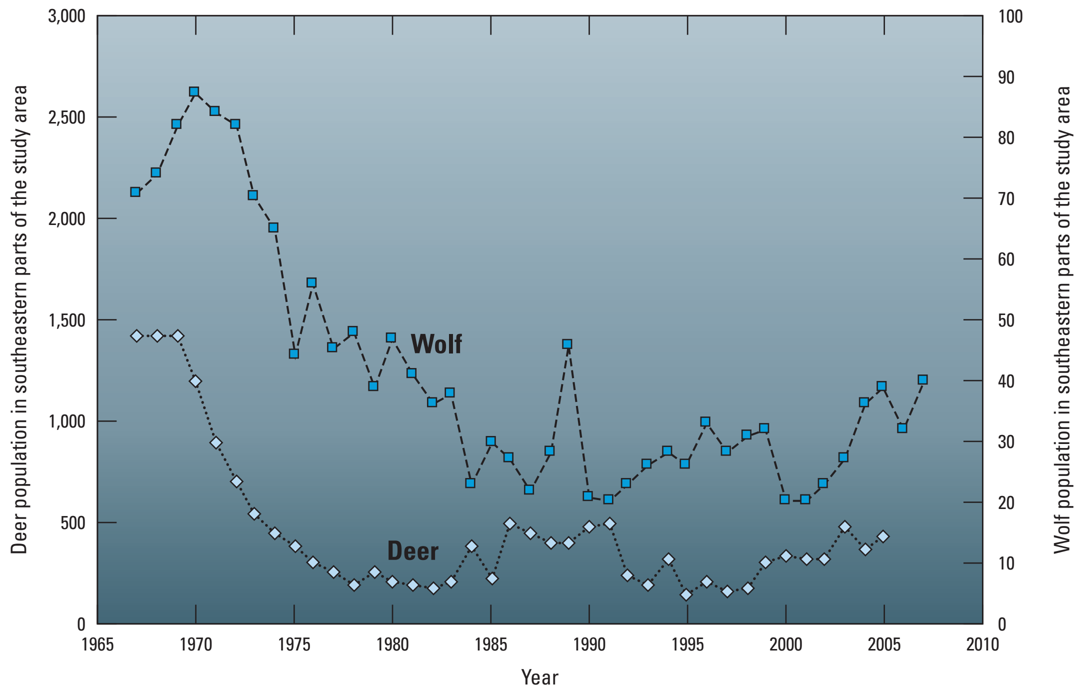


Figure 5. Size of the deer (1967–2005) and wolf (1967–2007) populations in southeastern parts of the central Superior National Forest study area, Minnesota. (Modified from Fuller and others, 2003, fig. 6.6)

from 1987 to 1993, after which the wolf population gained resistance (Mech and Goyal, 2011). From 1987 to 1993, the annual change in the wolf population was negatively related to seroprevalence of CPV (r = -0.92; P = < 0.01). The relation between CPV seroprevalence and an index of survival of wolf pups was r =- 0.73 (P = 0.06) (Mech and Goyal, 2011).

Dispersal

The wolf population occurred at a high density, and packs occupied most of the available space. Any excess production of pups therefore resulted in their dispersal as 1- to 3-year-olds (Mech, 1987; Gese and Mech, 1991). Some dispersers became nomadic in the general vicinity of their natal population, covering as much as 4,100 km^2 (1,577 mi^2) (Mech and Frenzel, 1971; Mech, 1987). Others, however, dispersed farther and helped recolonize other parts of Minnesota, as well as Wisconsin and Michigan (Mech and others, 1995; Merrill and Mech, 2000).

Studies of Deer Ecology

As I radiotracked wolves, it became clear that a thorough study of wolf ecology would require examination of the natural history and ecology of their main prey, white-tailed deer. In 1973, I began radiotagging deer in the same area and traced their movements, survival, and mortality along with those of the radiocollared wolves. Reed Hoskinson, University of Minnesota (Hoskinson and Mech, 1976), and then Mike Nelson, U.S. Fish and Wildlife Service (Nelson and Mech, 1981; Nelson, 1993), conducted the initial studies of deer. Mike remained with the project as a collaborator in charge of deer research (DelGiudice and others, 2009). Ted Floyd joined us as a graduate student and used our radiotagged deer to pioneer the technique of evaluating observability biases in aerial ungulate censuses, applying an adjustment for observability to our data (Floyd and others, 1979). We used this technique to count deer in winter through 1992 (Nelson and Mech, 1986a), until funding constraints forced us to discontinue it. Since 1992, we have used buck harvest in part of our area to index deer population trend. The number of deer in our area decreased from the late 1960s and 1970s, reached a minimum about 1981, and has slowly and intermittently increased since then (fig. 5).

From 1973 to 2007, we radiocollared 347 deer, mostly females. In addition to learning much basic natural history about these deer (for example, Hoskinson and Mech, 1976; Nelson and Mech, 1981, 1987, 1990; Nelson, 1993; Mech and McRoberts, 1990), we found that wolves rarely killed adult females during summer (Nelson and Mech, 1986c), that wolf predation was greatest when snow was deepest (Nelson and Mech, 1986b), that daily predation rates during fall migration were 16 to 107 times those of deer in wintering areas or yards (Nelson and Mech, 1991), that survival of adult females was related to the nutritional condition of their mothers, and that survival of yearlings to 2-year-olds was related to the nutritional condition of their grandmothers (Mech and others, 1991).

We learned that condition was an important factor predisposing deer to predation by wolves, and various measures of condition provided evidence. Wolves tended to kill old deer (Mech and Frenzel, 1971; Mech and Karns, 1977; Nelson and Mech, 1986a); deer with abnormalities (Mech and others, 1970; Mech and others, 1971; Mech and Karns, 1977); deer with low blood fat (Seal and others, 1978); deer with low marrow fat (Mech and Frenzel, 1971; Mech, 2007); and newborn fawns of below-average weight and (or) with low serum urea nitrogen (Kunkel and Mech, 1994).

Deer condition in winter depends on snow depth because the deeper the snow, the more difficult it is to find food (Verme, 1968). Therefore, we were not surprised to find that the size of, and trend in, deer populations were related to snow conditions (Mech and others, 1971; Mech and Karns, 1977; Mech and others, 1991; Mech and others, 1987a; McRoberts and others, 1995; but see Messier, 1995).

Follow-Up Studies from, and Adjuncts to, the Superior National Forest Wolf Research

While trapping wolves in the SNF, I quickly realized that if we could capture them more easily, we could examine them more often and better monitor their weight, blood values, and condition. Furthermore, the early collars we used commonly did not last even 1 year, so replacing them was important. The longer data were collected, the more complete a picture we could gain of the natural history of packs and the spatial organization of the population.

To determine whether radio signals could be used to remotely dart and recapture a radiocollared wolf, I consulted my former coworker, Bill Cochran (University of Minnesota), who had pioneered radiotracking (Cochran and Lord, 1963). Cochran suggested using a squib—an electrically detonated matchhead, like a tiny flashbulb. When a signal sends current through the squib, it flashes. Gunpowder in front of the squib detonates, drives a dart, and injects a drug. This technique, however, requires a radio receiver attached to the dart to pick up the signal, and an electrically detonated dart small enough to be attached to a wolf collar. The dart also has to be wolf- and waterproof, and in a position to inject a drug into a wolf. We designed the mechanism, but needed a talented machinist to produce the experimental prototypes. Lee Simmons, Director of the Henry Doorly Zoo in Topeka, KS, came to the rescue. Ulysses (Ulie) Seal of the U.S. Veterans Administration Hospital, Minneapolis, MN, and an expert on drugs suitable for use in such a collar (Seal and others, 1970), completed the development team.

The time between conception and availability of a working dart collar was about 10 years. Sometime during the final development, Rick Chapman, a graduate student on the project, was hired by 3M Company, which had sufficient interest in the concept of the collar to invest considerable time and funding to perfect it (Mech and others, 1984).

We also tested the capture collar on several deer (Mech and others, 1990) and used it to conduct studies of year-round nutritional condition in deer (DelGiudice and others, 1992) and of capture stress (DelGiudice and others, 1990). We then tested the collar successfully on wild wolves (Mech and Gese, 1992) and used it to obtain such elusive types of data as serial weights and blood values on the same wolf over long periods, as well as field metabolic rates (Nagy, 1994). The most important contribution of the capture collars, however, was unexpected. To facilitate recovery of the collar in case it failed, Chapman invented a remote-release mechanism. When that mechanism was applied to global positioning system (GPS) collars, then being developed, biologists could retrieve the GPS collars to download the data (Merrill and others, 1998). Unfortunately, because commercial companies found it much more lucrative to produce GPS collars than capture collars, the latter soon became unavailable.

Blood Sampling

During the 1970s, Ulie Seal began studying aspects of blood that had direct application to our studies. I then began a productive collaboration with him, collecting blood from both wolves and deer. Although my main objective was to determine the nutritional condition of my study animals (Seal and others, 1975; Seal and others, 1978), the samples gained more significance for their usefulness in determining seroprevalence of CPV in our wolves (Mech and Goyal, 2011).

Studies of Captive Wolves

As these projects produced new information, they also spawned many questions. Some could be answered with additional field studies, but others required a different approach. Therefore, Jane Packard (Texas A&M University), Ulie Seal, and I set up a colony of captive wolves that could be observed closely and examined frequently, blood-sampled, and otherwise studied intensively (Seal and others, 1987; Seal and Mech, 1983; Packard and others, 1983, 1985). As that project grew, Cheri Asa, St. Louis Zoo (Asa and others, 1985; 1990), James Raymer, University of Indiana (Raymer and others, 1985, 1986); and Terry Kreeger, University of Minnesota (Kreeger and others, 1990, 1997) became additional collaborators. Glenn DelGiudice (University of Minnesota Ph.D. student) made use of both the captive wolf colony (Mech and others, 1987b) and the field studies in the SNF (DelGiudice and others, 1988, 1989) to begin investigations of the nutritional condition of various animals by using analyses of urine in the snow.

Beyond the Superior National Forest

Several other spin-offs of research in the SNF increased our knowledge of wolves and wolf recovery in the Midwest and elsewhere. Because radiotracking was so productive in the SNF where the wolf population had been long established and occurred at high density, I wanted to use the same techniques to examine a recently colonized wolf population. For this I recruited Steve Fritts (USFWS) to study a recently established wolf population 290 km (181 mi) away in northwestern Minnesota (Fritts and Mech, 1981).

We also assisted the Minnesota Department of Natural Resources in starting a research project on wolves in north-central Minnesota similar to the SNF study. We taught colleagues, students, and technicians how to live-trap, anesthetize, radiotag, and radiotrack wolves. Many of them continued research on wolves in other areas (Berg and Kuehn, 1982; Fuller and others, 2003; Boyd and others, 1995; Meier and others, 1995; Burch and others, 2005; Ream and others, 1991). Furthermore, we conducted an experimental reintroduction of four wolves into northern Michigan that demonstrated that translocated wolves held for a week tended to return homeward (Weise and others, 1979).

Biologists in other areas became interested in doing similar studies, so I was invited to Italy; to Riding Mountain National Park, Canada; and to Alaska to help organize their first radiotracking studies of wolves (Boitani and Zimen, 1979; Carbyn, 1980; Peterson and others, 1984). Some of my technicians helped start projects in Portugal and Romania. Furthermore, the Patuxent wolf project hosted biologists from Sweden, Israel, Portugal, Poland, Spain, Croatia, India, Italy, Mexico, Norway, Turkey, and Austria to receive training in wolf research techniques in the SNF study area.

Wolf Depredation Control Program

Responses to complaints about livestock depredation had been managed by the Animal Damage Control Branch of the USFWS, but in 1978, when wolves in Minnesota were reclassified from endangered to threatened, I was asked to design a control program for wolves. This program had to stay within the directives of a court order while still attempting to reduce wolf depredations on livestock—that is, taking a minimal number of wolves, yet satisfying farmers and ranchers. I was appointed to direct the program, and I assigned Steve Fritts, with his newly minted Ph.D. degree, to run it. Bill Paul, a newly hired technician on the SNF project, was his main assistant. These two workers conducted a well-respected program that continues under the auspices of the U.S. Department of Agriculture Wildlife Services (Fritts and others, 1992).

We tried many alternative nonlethal methods to reduce losses of livestock, such as translocating depredating wolves (Fritts and others, 1985), and using "fladry" (flagging), blinking lights, guard dogs, and taste aversion (Fritts and others, 1992), and conceived several other methods such as radiocontrolled shock collars, radioactivated alarm systems, human-applied scent marking, and recorded howling. None proved to be very effective or practical because the law allowed lethal control and the population was not so low (1,250 in 1978) that every last member needed to be preserved at all costs. Some of these concepts have since proved useful where lethal control is allowed or where wolf numbers are so low that extraordinary means are justified (Shivik, 2006; Musiani and others, 2003; Schultz and others, 2005). Fritts eventually was promoted to assistant leader of the Endangered Species Wildlife Research Program at Patuxent under leader Randy Perry, who had assumed Erickson's position when he retired. Fritts later went on to head the USFWS's wolf reintroduction into Yellowstone National Park with Ed Bangs.

Future Directions

To understand the functioning of natural wolf populations, it is important to follow the long-term trend of at least one long-extant population. The value of the information that science has obtained from the Isle Royale wolf population over 50 years is immeasurable (Vucetich and Peterson, 2009); however, the fact that the population is restricted to an island with no regular immigration or emigration is problematic. Because the central SNF study is the longest running, non-island study of a wolf population, continuing this investigation as long as possible is critical. Patuxent deserves credit for supporting this important work during its first two and a half decades.

Acknowledgments

This study was supported during its entirety by the U.S. Department of the Interior through the U.S. Fish and Wildlife Service (USFWS), the National Biological Survey, and the U.S. Geological Survey (USGS) (Patuxent, Midcontinent, and Northern Prairie Wildlife Research Centers), as well as by the U.S. Forest Service through the North Central Forest Experiment Station (now the North Central Research Station) and the Superior National Forest. Private funding sources included the New York Zoological Society, the World Wildlife Fund, the Mardag Foundation, the Special Projects Foundation of the Big Game Club, Wallace Dayton (Big Game Club), and Valerie Gates (Gates Family Foundation). I especially thank M.E. Nelson, J.J. Renneberg, and Tim Wallace (USFWS) as well as the many volunteers and graduate students who assisted with the field work. Shannon Barber-Meyer (USGS) and D.J. Demma (Alaska Department of Fish and Game) critiqued an early version of the manuscript and offered helpful suggestions for improvement.

References Cited

Asa, C.S., Mech, L.D., Seal, U.S., and Plotka, E.D., 1990, The influence of social and endocrine factors on urine-marking by captive wolves (*Canis lupus*): Hormones and Behavior, v. 24, no. 4, p. 497–509. [Also available at http://dx.doi.org/10.1016/0018-506X(90)90038-Y.]

Asa, C.S., Peterson, E.K., Seal, U.S., and Mech, L.D., 1985, Deposition of anal sac secretions by captive wolves (*Canis lupus*): Journal of Mammalogy, v. 66, no. 1, p. 89–93. [Also available at http://dx.doi.org/10.2307/1380960.]

Berg, W.E., and Kuehn, D.W., 1982, Ecology of wolves in north-central Minnesota, *in* Harrington, F.H., and Paquet, P.C., eds., Wolves of the world—Perspectives of behavior, ecology, and conservation: Park Ridge, NJ, Noyes Publications, p. 4–11.

Boitani, Luigi, and Zimen, Erik, 1979, The role of public opinion in wolf management, *in* Klinghammer, Erich, ed., The behavior and ecology of wolves: New York, Garland STPM Press, p. 471–477.

Boyd, D.K., Paquet, P.C., Donelon, Steve, Ream, R.R., Pletsher, D.H., and White, C.C., 1995, Transboundary movements of a colonizing wolf population in the Rocky Mountains, *in* Carbyn, L.N., Fritts, S.H., and Seip, D.R., Ecology and conservation of wolves in a changing world: Edmonton, Alberta, Canada, Canadian Circumpolar Institute, Occasional Publication 35, p. 135–140.

Burch, J.W., Adams, L.G., Follmann, E.H., and Rexstad, E.A., 2005, Evaluation of wolf density estimation from radiotelemetry data: Wildlife Society Bulletin, v. 33, no. 4, p. 1225–1236. [Also available at http://dx.doi.org/10.2193/0091-7648(2005)33[1225:EOWDEF]2.0.CO;2.]

Carbyn, L.N., 1980, Ecology and management of wolves in Riding Mountain National Park, Manitoba: Edmonton, Alberta, Canadian Wildlife Service, Final Report, L.M.S. Study Report No. 10, 182 p.

Cochran, W.W., and Lord, R.D., Jr., 1963, A radio-tracking system for wild animals: Journal of Wildlife Management, v. 27, no. 1, p. 9–24. [Also available at http://dx.doi.org/10.2307/3797775.]

Cowan, I.M., 1947, The timber wolf in the Rocky Mountain national parks of Canada: Canadian Journal of Research, v. 25d, no. 5, p. 139–174. [Also available at http://dx.doi.org/10.1139/cjr47d-012.]

DelGiudice, G.D., McCaffery, K.R., Beyer, D.E., Jr., and Nelson, M.E., 2009, Prey of wolves in the Great Lakes region, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 155–173. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_10.]

DelGiudice, G.D., Mech, L.D., Kunkel, K.E., Gese, E.M., and Seal, U.S., 1992, Seasonal patterns of weight, hematology, and serum characteristics of free-ranging female white-tailed deer in Minnesota: Canadian Journal of Zoology, v. 70, no. 5, p. 974–983. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z92-139?journalCode=cjz#.WDjNuWe7qRs.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1988, Chemical analyses of deer bladder urine and urine collected from snow: Wildlife Society Bulletin, v. 16, no. 3, p. 324–326. [Also available at http://www.jstor.org/stable/3782111.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1989, Physiological assessment of deer populations by analysis of urine in the snow: Journal of Wildlife Management, v. 53, no. 2, p. 284–291. [Also available at http://dx.doi.org/10.2307/3801124.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1990, Effects of winter undernutrition on body composition and physiological profiles of white-tailed deer: Journal of Wildlife Management, v. 54, no. 4, p. 539–550. [Also available at http://dx.doi.org/10.2307/3809347.]

Floyd, T.J., Mech, L.D., and Nelson, M.E., 1979, An improved method of censusing deer in deciduous-coniferous forests: Journal of Wildlife Management, v. 43, no. 1, p. 258–261. [Also available at http://dx.doi.org/10.2307/3800668.]

Fritts, S.H., and Mech, L.D., 1981, Dynamics, movements, and feeding ecology of a newly protected wolf population in northwestern Minnesota: Wildlife Monographs No. 80, 79 p. [Also available at http://www.jstor.org/stable/3830611.]

Fritts, S.H., Paul, W.J., and Mech, L.D., 1985, Can relocated wolves survive?: Wildlife Society Bulletin, v. 13, no. 4, p. 459–463. [Also available at http://www.jstor.org/stable/3782671.]

Fritts, S.H., Paul, W.J., Mech, L.D, and Scott, D.P., 1992, Trends and management of wolf-livestock conflicts in Minnesota: U.S. Fish and Wildlife Service, Resource Publication 181, 27 p. [Abstract available at https://pubs.er.usgs.gov/publication/5230226.]

Fuller, T.K., Mech, L.D., and Fitts-Cochrane, Jean, 2003, Wolf population dynamics, *in* Mech, L.D., and Boitani, Luigi, eds., Wolves—Behavior, ecology, and conservation: Chicago, University of Chicago Press, p. 161–191.

Gese, E.M., and Mech, L.D., 1991, Dispersal of wolves (*Canis lupus*) in northeastern Minnesota, 1969–1989: Canadian Journal of Zoology, v. 69, no. 12, p. 2946–2955. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z91-415.]

Gipson, P.S., Ballard, W.B., Nowak, R.M., and Mech, L.D., 2000, Accuracy and precision of estimating age of gray wolves by tooth wear: Journal of Wildlife Management, v. 64, no. 3, p. 752–758. [Also available at http://dx.doi.org/10.2307/3802745.]

Harrington, F.H., and Mech, L.D., 1979, Wolf howling and its role in territory maintenance: Behaviour, v. 68, no. 3–4, p. 207–249. [Also available at http://www.jstor.org/stable/4533952.]

Heinselman, Miron, 1993, The Boundary Waters wilderness ecosystem: Minneapolis, MN, University of Minnesota Press, 336 p.

Hoskinson, R.L., and Mech, L.D., 1976, White-tailed deer migration and its role in wolf predation: Journal of Wildlife Management, v. 40, no. 3, p. 429–441. [Also available at http://dx.doi.org/10.2307/3799944.]

Kolenosky, G.B., and Johnston, D.H., 1967, Radio-tracking timber wolves in Ontario: American Zoologist, v. 7, no. 2, p. 289–303. [Also available at http://www.jstor.org/stable/3881433.]

Kreeger, T.J., DelGiudice, G.D., and Mech, L.D., 1997, Effects of fasting and refeeding on body composition of captive gray wolves (*Canis lupus*): Canadian Journal of Zoology, v. 75, no. 9, p. 1549–1552. [Also available at http://dx.doi.org/10.1139/z97-781.]

Kreeger, T.J., Kuechle, V.B., Mech, L.D., Tester, J.R., and Seal, U.S., 1990, Physiological monitoring of gray wolves (*Canis lupus*) by radiotelemetry: Journal of Mammalogy, v. 71, no. 2, p. 259–261. [Also available at http://dx.doi.org/10.2307/1382180.]

Kunkel, K.E., and Mech, L.D., 1994, Wolf and bear predation on white-tailed deer fawns in northeastern Minnesota: Canadian Journal of Zoology, v. 72, no. 9, p. 1557–1565. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z94-207.]

McRoberts, R.E., Mech, L.D., and Peterson, R.O., 1995, The cumulative effect of consecutive winters' snow depth on moose and deer populations—A defense: Journal of Animal Ecology, v. 64, no. 1, p. 131–135. [Also available at http://www.jstor.org/stable/5834.]

Mech, L.D., 1966, The wolves of Isle Royale: Washingon, D.C., Department of the Interior, National Park Service, Fauna of the National Parks of the United States, Fauna Series No. 7, 210 p. [Also available at https://archive.org/details/wolvesofisleroya00royal.]

Mech, L.D., 1970, The wolf—The ecology and behavior of an endangered species: Garden City, NY, Natural History Press (Doubleday Publishing Company), American Museum of Natural History, 384 p.

Mech, L.D., 1973, Wolf numbers in the Superior National Forest of Minnesota: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–97, 10 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10618.]

Mech, L.D., 1974, Current techniques in the study of elusive wilderness carnivores, *in* Kjemer, Ingbrit, and Bjurholm, Per, eds., Proceedings of the 11th International Congress of Game Biologists, Stockholm, September 3–7, 1973, p. 315–322.

Mech, L.D., 1977a, Population trend and winter deer consumption in a Minnesota wolf pack, *in* Phillips, R.L., and Jonkel, C., eds., Proceedings of the 1975 Predator Symposium: Missoula, MT, Montana Forest and Conservation Experiment Station, p. 55–83.

Mech, L.D., 1977b, Productivity, mortality and population trends of wolves in northeastern Minnesota: Journal of Mammalogy, v. 58, no. 4, p. 559–574. [Also available at http://dx.doi.org/10.2307/1380004.]

Mech, L.D., 1977c, Wolf pack buffer zones as prey reservoirs: Science, v. 198, no. 4314, p. 320–321. [Also available at http://dx.doi.org/10.1126/science.198.4314.320.]

Mech, L.D., 1986, Wolf numbers and population trend in the Superior National Forest, 1967–1985: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–270, 6 p. [Also available at http://www.nrs.fs.fed.us/pubs/rp_rp_nc270.pdf.]

Mech, L.D., 1987, Age, season, and social aspects of wolf dispersal from a Minnesota pack, *in* Chepko-Sade, B.D., and Halpin, Z.T., eds., Mammalian dispersal patterns: Chicago, University of Chicago Press, p. 55–74.

Mech, L.D., 1988, Longevity in wild wolves: Journal of Mammalogy, v. 69, no. 1, p. 197–198. [Also available at http://dx.doi.org/10.2307/1381776.]

Mech, L.D., 1994, Buffer zones of territories of gray wolves as regions of intraspecific strife: Journal of Mammalogy, v. 75, no. 1, p. 199–202. [Also available at http://dx.doi.org/10.2307/1382251.]

Mech, L.D., 2006a, Age-related body mass and reproductive measurements of gray wolves in Minnesota: Journal of Mammalogy, v. 87, no. 1, p. 80–84.

Mech, L.D., 2006b, Estimated age structure of wolves in northeastern Minnesota: Journal of Wildlife Management, v. 70, no. 5, p. 1481–1483. [Also available at http://www.jstor.org/stable/4128071.]

Mech, L.D., 2007, Femur-marrow fat of white-tailed deer fawns killed by wolves: Journal of Wildlife Management, v. 71, no. 3, p. 920–923. [Also available at http://dx.doi.org/10.2193/2006-153.]

Mech, L.D., 2009, Long-term research on wolves in the Superior National Forest, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes region of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 15–34. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_2.]

Mech, L.D., Chapman, R.C., Cochran, W.W., Simmons, Lee, and Seal, U.S., 1984, Radio-triggered anesthetic-dart collar for recapturing large mammals: Wildlife Society Bulletin, v. 12, no. 1, p. 69–74. [Also available at http://www.jstor.org/stable/3781508.]

Mech, L.D., and Federoff, N.E., 2002, α_1-Antitrypsin polymorphism and systematics of eastern North American wolves: Canadian Journal of Zoology, v. 80, no. 5, p. 961–963. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z02-066.]

Mech, L.D., and Frenzel, L.D., Jr., eds., 1971, Ecological studies of the timber wolf in northeastern Minnesota: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–52, 62 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10573.]

Mech, L.D., Frenzel, L.D., Jr., and Karns, P.D., 1971, The effect of snow conditions on the vulnerability of white-tailed deer in wolf predation, *in* Mech, L.D., and Frenzel, L.D., Jr., eds., Ecological studies of the timber wolf in northeastern Minnesota: St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Forest Service Research Paper NC–52, p. 51–59. [Also available at http://www.treesearch.fs.fed.us/pubs/10573.]

Mech, L.D., Frenzel, L.D., Jr., Karns, P.D., and Kuehn, D.W., 1970, Mandibular dental anomalies in white-tailed deer from Minnesota: Journal of Mammalogy, v. 51, no. 4, p. 804–806. [Also available at http://dx.doi.org/10.2307/1378309.]

Mech, L.D., Fritts, S.H., and Wagner, Douglas, 1995, Minnesota wolf dispersal to Wisconsin and Michigan: American Midland Naturalist, v. 133, no. 2, p. 368–370. [Also available at http://dx.doi.org/10.2307/2426402.]

Mech, L.D., and Gese, E.M., 1992, Field testing the Wildlink Capture Collar on wolves: Wildlife Society Bulletin, v. 20, no. 2, p. 249–256. [Also available at http://www.jstor.org/stable/3782899.]

Mech, L.D., and Goyal, S.M., 2011, Parsing demographic effects of canine parvovirus on a Minnesota wolf population: Journal of Veterinary Medicine and Animal Health, v. 3, no. 2, p. 27–30. [Also available at http://www.academicjournals.org/journal/JVMAH/article-full-text-pdf/BD0AF9E3485.]

Mech, L.D., and Harper, E.K., 2002, Differential use of a wolf, *Canis lupus*, pack territory edge and core: Canadian Field Naturalist, v. 116, no. 2, p. 315–316. [Also available at http://wolf.org/wp-content/uploads/2013/09/264differentialuse.pdf.]

Mech, L.D. and Hertel, H.H., 1983, An eight-year demography of a Minnesota wolf pack, *in* Pulliainen, Erkki, and Sulkava, Seppo, eds, Proceedings of the Third International Theriological Congress, Helsinki, August 15–20, 1982, VI. Symposia on lagomorphs, beaver, bear, wolf, and mustelids: Acta Zoologica Fennica, v. 174, p. 249–250.

Mech, L.D., and Karns, P.D., 1977, Role of the wolf in a deer decline in the Superior National Forest: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Report NC–148, 23 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10669.]

Mech, L.D., Kunkel, K.E., Chapman, R.C., and Kreeger, T.J., 1990. Field testing of commercially manufactured capture collars on wild deer: Journal of Wildlife Management, v. 54, no. 2, p. 297–299. [Also available at http://www.jstor.org/stable/3809045.]

Mech, L.D., and McRoberts, R.E., 1990, Survival of white-tailed deer fawns in relation to maternal age: Journal of Mammalogy, v. 71, no. 3, p. 465–467. [Also available at http://dx.doi.org/10.2307/1381963.]

Mech, L.D., McRoberts, R.E., Peterson, R.O., and Page, R.E., 1987a, Relationship of deer and moose populations to previous winters' snow: Journal of Animal Ecology, v. 56, no. 2, p. 615–627. [Also available at http://dx.doi.org/10.2307/5072.]

Mech, L.D., Nelson, M.E., and McRoberts, R.E., 1991, Maternal and grandmaternal nutrition effects on deer mass and vulnerability to wolf predation: Journal of Mammalogy, v. 72, no. 1, p. 146–151. [Also available at http://www.jstor.org/stable/1381989.]

Mech, L.D., Seal, U.S., and DelGiudice, G.D., 1987b, Use of urine in the snow to indicate condition of wolves: Journal of Wildlife Management, v. 51, no. 1, p. 10–13. [Also available at http://dx.doi.org/10.2307/3801620.]

Mech, L.D., and Tracy, Shaun, 2004, Record high wolf, *Canis lupus*, pack density: Canadian Field Naturalist, v. 118, no. 1, p. 127–129. [Also available at http://journals.sfu.ca/cfn/index.php/cfn/article/view/896.]

Meier, T.J., Burch, J.W., Mech, L.D., and Adams, L.G., 1995, Pack structure dynamics and genetic relatedness among wolf packs in a naturally-regulated population, *in* Carbyn, L.D., Fritts, S.H., and Seip, D.R., eds., Ecology and conservation of wolves in a changing world: Edmonton, Alberta, Canadian Circumpolar Institute, Occasional Publication 35, p. 293–302.

Merrill, S.B., Adams, L.G., Nelson, M.E., and Mech, L.D., 1998, Testing releasable GPS radiocollars on wolves and white-tailed deer: Wildlife Society Bulletin, v. 26, no. 4, p. 830–835. [Also available at http://www.jstor.org/stable/3783557.]

Merrill, S.B., and Mech, L.D., 2000, Details of extensive movements by Minnesota wolves (*Canis lupus*): American Midland Naturalist, v. 144, no. 2, p. 428–433. [Also available at http://www.jstor.org/stable/3082950.]

Messier, Francois, 1995, Is there evidence for a cumulative effect of snow on moose and deer populations?: Journal of Animal Ecology, v. 64, no. 1, p. 136–140. [Also available at http://dx.doi.org/10.2307/5835.]

Mohr, C.O., 1947, Table of equivalent populations of North American small mammals: American Midland Naturalist, v. 37, no. 1, p. 223–249. [Also available at http://dx.doi.org/10.2307/2421652.]

Murie, Adolph, 1944, The wolves of Mount McKinley: Washington, D.C., U.S. Department of the Interior, National Park Service, Fauna of the National Parks of the United States, Fauna Series No. 5, 238 p.

Musiani, Marco, Mamo, Charles, Boitani, Luigi, Callaghan, Carolyn, Gates, C.C., Mattei, Livia, Visalberghi, Elisabetta, Breck, Stewart, and Volpi, Giulia, 2003, Wolf depredation trends and the use of fladry barriers to protect livestock in western North America: Conservation Biology, v. 17, no. 6, p. 1538–1547. [Also available at http://www.jstor.org/stable/3588902.]

Nagy, K.A., 1994, Field bioenergetics of mammals—What determines field metabolic rates: Australian Journal of Zoology, v. 42, no. 1, p. 43–53. [Also available at http://www.publish.csiro.au/paper/ZO9940043.htm.]

Nelson, M.E., 1993, Natal dispersal and gene flow in white-tailed deer in northeastern Minnesota: Journal of Mammalogy, v. 74, no. 2, p. 316–322. [Also available at http://dx.doi.org/10.2307/1382386.]

Nelson, M.E., and Mech, L.D., 1981, Deer social organization and wolf predation in northeastern Minnesota: Wildlife Monographs No. 77, 53 p. [Also available at http://www.jstor.org/stable/i294121.]

Nelson, M.E., and Mech, L.D., 1986a, Deer population in the central Superior National Forest, 1967–1985: St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Forest Service Research Paper NC–271, 7 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10058.]

Nelson, M.E., and Mech, L.D., 1986b, Mortality of white-tailed deer in northeastern Minnesota: Journal of Wildlife Management, v. 50, no. 4, p. 691–698. [Also available at http://dx.doi.org/10.2307/3800983.]

Nelson, M.E., and Mech, L.D., 1986c, Relationship between snow depth and gray wolf predation on white-tailed deer: Journal of Wildlife Management, v. 50, no. 3, p. 471–474. [Also available at http://dx.doi.org/10.2307/3801108.]

Nelson, M.E., and Mech, L.D., 1987, Demes within a northeastern Minnesota deer population, *in* Chepko-Sade, B.D., and Halpin, Z.T., eds., Mammalian dispersal patterns—The effects of social structure on population genetics: Chicago, University of Chicago Press, p. 27–40.

Nelson, M.E., and Mech, L.D., 1990, Weights, productivity, and mortality of old white-tailed deer: Journal of Mammalogy, v. 71, no. 4, p. 689–691. [Also available at http://dx.doi.org/10.2307/1381809.]

Nelson, M.E., and Mech, L.D., 1991, Wolf predation risk associated with white-tailed deer movements: Canadian Journal of Zoology, v. 69, no. 10, p. 2696–2699.

Nelson, M.E., and Mech, L.D., 2006, A 3-decade dearth of deer (*Odocoileus virginianus*) in a wolf (*Canis lupus*)-dominated ecosystem: American Midland Naturalist, v. 155, no. 2, p. 373–382. [Also available at http://www.jstor.org/stable/4094652.]

Olson, S.F., 1938, Organization and range of the pack: Ecology, v. 19, no. 1, p. 168–170. [Also available at http://www.jstor.org/stable/1930384.]

Packard, J.M., Mech, L.D., and Seal, U.S., 1983, Social influences on reproduction in wolves *in* Carbyn, L.N., ed., Wolves in Canada and Alaska—Their status, biology, and management: Ottowa, Ontario, Canadian Wildlife Service, Proceedings of the Canadian Wolf Workshop, Edmonton, Alberta, May 12–14, 1981, Canadian Wildlife Service Report Series no. 45, p. 78–85.

Packard, J.M., Seal, U.S., Mech, L.D., and Plotka, E.D., 1985, Causes of reproductive failure in two family groups of wolves (*Canis lupus*): Zeitschrift für Tierpsychologie, v. 68, p. 24–40. [Also available at http://dx.doi.org/10.1111/j.1439-0310.1985.tb00112.x.]

Peters, R.P., and Mech, L.D., 1975, Scent-marking in wolves—Radio-tracking of wolf packs has provided definite evidence that olfactory sign is used for territory maintenance and may serve for other forms of communication within the pack as well: American Scientist, v. 63, no. 6, p. 628–637. [Also available at http://www.jstor.org/stable/27845779.]

Peterson, R.O., Woolington, J.D., and Bailey, T.N., 1984, Wolves of the Kenai Peninsula, Alaska: Wildlife Monographs No. 88, 52 p. [Also available at http://www.jstor.org/stable/3830728.]

Pimlott, D.H., Shannon, J.A., and Kolenosky, G.B., 1969, The ecology of the timber wolf in Algonquin Provincial Park, Ontario: Toronto, Ontario, Ontario Department of Lands and Forests Research Report (Wildlife) No. 87, 92 p.

Raymer, J.H., Wiesler, D.P., Novotny, M.V., Asa, C.S., Seal, U.S., and Mech, L.D., 1985, Chemical investigations of wolf (*Canis lupus*) anal sac secretions in relation to breeding season: Journal of Chemical Ecology, v. 11, no. 5, p. 593–608. [Also available at http://dx.doi.org/10.1007/BF00988570.]

Raymer, J.H., Wiesler, D.P., Novotny, M.V., Asa, C.S., Seal, U.S., and Mech, L.D., 1986, Chemical scent constituents in urine of wolf (*Canis lupus*) and their dependence on reproductive hormones: Journal of Chemical Ecology, v. 12, no. 1, p. 297–313. [Also available at http://dx.doi.org/10.1007/BF01045612.]

Ream, R.R., Fairchild, M.W., Boyd, D.K., and Pletscher, D.H., 1991, Population dynamics and home range changes in a colonizing wolf population, *in* Keiter, R.K., and Boyce, M.S., eds., The greater Yellowstone ecosystem—Redefining America's wilderness heritage: New Haven, CT, Yale University Press, p. 349–366.

Rothman, R.J., and Mech, L.D., 1979, Scent-marking in lone wolves and newly formed pairs: Animal Behaviour, v. 27, no. 3, p. 750–760. [Also available at http://dx.doi.org/10.1016/0003-3472(79)90010-1.]

Schultz, R.N., Jonas, K.W., Skuldt, L.H., and Wydeven, A.P., 2005, Experimental use of dog-training shock collars to deter depredation by gray wolves: Wildlife Society Bulletin, v. 33, no. 1, p. 142–148. [Also available at http://www.jstor.org/stable/3784849.]

Seal, U.S.,. Erickson, A.W., and Mayo, J.G., 1970, Drug immobilisation of the Carnivora: International Zoological Yearbook, v. 10, no. 1, p. 157–170. [Also available at http://www.dx.doi/10.1111/j.1748-1090.tb01324.x.]

Seal, U.S., and Mech, L.D., 1983, Blood indicators of seasonal metabolic patterns in captive adult gray wolves: Journal of Wildlife Management, v. 47, no. 3, p. 704–715. [Also available at http://dx.doi.org/10.2307/3808606.]

Seal, U.S., Mech, L.D., and Van Ballenberghe, Victor, 1975, Blood analyses of wolf pups and their ecological and metabolic interpretation: Journal of Mammalogy, v. 56, no. 1, p. 64–75. [Also available at http://dx.doi.org/10.2307/1379606.]

Seal, U.S., Nelson, M.E., Mech, L.D., and Hoskinson, R.L., 1978, Metabolic indicators of habitat differences in four Minnesota deer populations: Journal of Wildlife Management, v. 42, no. 4, p. 746–754. [Also available at http://dx.doi.org/10.2307/3800765.]

Seal, U.S., Plotka, E.D., Mech, L.D., and Packard, J.M., 1987, Seasonal metabolic and reproductive cycles in wolves, *in* Frank, H., ed., Man and wolf—Advances, issues, and problems in captive wolf research: Boston, Dr. W. Junk Publishers, p. 109–125.

Shivik, J.A., 2006, Tools for the edge—What's new for conserving carnivores: BioScience, v. 56, no. 3, p. 253–259. [Also available at http://bioscience.oxfordjournals.org/content/56/3/253.full.]

Stenlund, M.H., 1955, A field study of the timber wolf (*Canis lupus*) on the Superior National Forest: Minnesota Department of Conservation Technical Bulletin, v. 4, 55 p.

Van Ballenberghe, Victor, Erickson, A.W., and Byman, David, 1975, Ecology of the timber wolf in northeastern Minnesota: Wildlife Monographs No. 43, p. 3–43. [Also available at http://www.jstor.org/stable/3830388.]

Verme, L.J., 1968, An index of winter weather severity for northern deer: Journal of Wildlife Management, v. 32, no. 3, p. 566–574. [Also available at http://dx.doi.org/10.2307/3798937.]

Vucetich, J.A., and Peterson, R.O., 2009, Wolf and moose dynamics on Isle Royale, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes Region of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 35–48. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_3.]

Weise, T.F., Robinson, W.L., Hook, R.A., and Mech, L.D., 1979, An experimental translocation of the eastern timber wolf, *in* Klinghammer, Erich, ed., The behavior and ecology of wolves: New York, Garland STPM Press, p. 346–419.

Wilson, P.J., Grewal, Sonya, Lawford, I.D., Heal, J.N.M., Granacki, A.G., Pennock, David, Theberge, J.B., Theberge, M.T., Voigt, D.R., Waddell, Will, Chambers, R.E., Paquet, P.C., Goulet, Gloria, Cluff, Dean, and White, B.N., 2000, DNA profiles of the eastern Canadian wolf and the red wolf provide evidence for a common evolutionary history independent of the gray wolf: Canadian Journal of Zoology, v. 78, no. 12, p. 2156–2166. [Also available at http://dx.doi.org/10.1139/z00-158.]

Wilson, P.J., Grewal, S.K., Mallory, F.F., and White, B.N., 2009, Genetic characterization of hybrid wolves across Ontario: Journal of Heredity, v. 100, suppl. 1, p. S80–S89. [Also available at http://dx.doi.org/10.1093/jhered/esp034.]

Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., 2009, Recovery of gray wolves in the Great Lakes Region of the United States—An endangered species success story: New York, Springer Science+Business Media, 350 p. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1.]

Muskrat (*Ondatra zibethicus*) on water, Patuxent Research Refuge, Laurel, MD, 1980. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.