material isolated from filtrates. Further studies showed that each fraction was composed of a carbohydrate core, which was apparently responsible for elicitor activity, combined with other material from the cell wall.

Digestion of the isolated materials with appropriate enzymes revealed that the smallest fragment with full elicitor activity was a β-glucan fragment with a mass of about 10,000 daltons. The β-glucan is a highly branched polymer of glucose connected through the 3- and 6-positions. The molecule also contains about 4 percent mannose, another sugar. Albersheim has subsequently isolated a nearly identical β-glucan from the cell walls of brewers' yeast, which is not a plant pathogen, but which could be a large source of the material.

Albersheim argues that this is the first time that a material isolated from the cell wall of a pathogen has been shown to be involved in the defensive response of a plant. And that response appears to be very specific. Less than 0.01 nanomole (10^{-11} mole) of elicitor applied to a single soybean hypocotyl results in the accumulation of 150 nanomoles of glyceollin, a 15,000-fold amplification. This is apparently accomplished, he has further shown, by stimulation of the activity of phenylalanine ammonia-lyase, one of the first enzymes involved in the synthesis of phytoalexins. This effect is not obtained, Albersheim adds, with compounds that are highly similar in structure to the β-glucan, even when they are applied in quantities that are as much as 1000 times larger.

Albersheim isolated what is apparently the same elicitor from three different races of PMS, one of which would grow on the particular type of soybeans he was using and two of which would not. He found that each of the elicitors stimulated the accumulation of approximately the same quantities of glyceollin in the soybean. This suggests to him that production of the phytoalexin is not a specific determinant of a plant's resistance to infection. Such a possibility seems to receive confirmation from his observation that simultaneous exposure of the plants to the elicitor and the PMS race that normally grows on the plant does not impede that growth. Growth is halted, however, if the elicitor is applied 10 hours before the fungus. Albersheim thus suggests that resistance—at least in the PMS-soybean system—might be the result of the growth rate of the attacking pathogen. If the growth rate is slow, phytoalexins can accumulate in toxic concentrations before the pathogen can spread; if it is fast, the pathogen's spread can outdistance the phytoalexins.

These results are in direct contradiction to those that have been achieved by Keen, whose elicitor has also been derived from PMS. Keen finds that the elicitor from the PMS race to which the plant is resistant produces much less accumulation of glyceollin than does the elicitor from the race that grows on soybeans. Albersheim attributes Keen's results to impurities in the elicitor preparation. But Keen argues that Albersheim has isolated only a general elicitor whereas he, Keen, has isolated a specific elicitor that is actually involved in the disease process and that is responsible for species resistance to pathogens. These differences will probably not be resolved until Keen has more fully characterized his elicitor.

Albersheim's results, like those of Bowers, show potential for the development of new types of pesticides. Unfortunately, the β-glucan is such a large molecule that it may not enter plants readily. If that should be the case, Albersheim speculates, it might be possible to prepare derivatives of the elicitor that could readily be taken up by the plant, as has already been accomplished with drugs for animals. Application might also be easier if simpler chemicals such as that Keen thinks he has isolated, are also found to have elicitor activity. The elicitors would also be expected not to persist in the environment and to be so specific in their activity that, again, no harm to other biota would be expected.

—THOMAS H. MAUGH II

Endangered Bird Species: Habitat Manipulation Methods

The endangerment and extinction of avian species, subspecies, and local populations due to environmental poisoning, hunting, and habitat destruction have prompted a new conservation endeavor: crisis management to bolster failing populations until they, and the ecosystems on which they depend, recover so that they can again be self-sustaining.

Unlike classic conservation techniques—education, legal protection, and habitat preservation and management—these new methods are highly manipulative. Biologists intercede directly in the afflicted birds' life cycles, either by moving or manipulating the birds themselves, or by manipulating their immediate breeding or feeding habitat.

Because threatened birds are perceived by both scientists and the public as an extremely valuable resource, there is strong pressure to interfere with them only on the basis of carefully defined, testable hypotheses, whose confirmation provides justification for disturbing the birds. Thus far in most cases it has not been possible to wait for this kind of proof. But as the discipline develops, its practitioners hope, it will become increasingly possible to intervene with one species using a technique already tested in another.

A case in point is the osprey (*Pandion haliaetus*). Demographic studies in the 1960's by Charles J. Henny, Jr., of the U.S. Fish and Wildlife Service (USFWS) indicated that local populations of ospreys in North America must produce between 0.95 and 1.30 young per breeding pair annually to maintain their numbers. In the mid-1960's, productivity fell below 0.50 among ospreys in coastal New Jersey and southern New England, due in large part to DDT, dieldrin, and possibly polychlorobiphenyls.

Egg Transfer and Double-Clutching

A manipulative method to halt this decline was proposed by a biology student at Wesleyan University, Connecticut, Paul Spitzer. He conceived of the idea of tiding the Connecticut ospreys over their crisis by replacing their pesticide-laden, infertile eggs with "cleaner" eggs taken from reproductively healthy ospreys breeding in less contaminated areas. He called this technique "egg transfer."

Eggs and also osprey hatchlings were obtained from Chesapeake Bay. They tolerated the move by boat, car, and plane. The adult Connecticut ospreys tolerated the disturbance of being frightened from their nests so the eggs could be switched. They returned to brood the transferred eggs, most of which hatched. The young developed and fledged uneventfully.

The key question was whether, in 3 or 4 years, they would return to breed on the Connecticut coast or would stop at Chesapeake Bay, where they had been conceived and where, it might be supposed, they were genetically programmed to go. In fact, of 45 transferred osprey eggs and chicks that fledged, 7 are known to have returned to the Connecticut–Long Island area when they reached breeding age, on the basis of markers affixed to their legs. Since some of the markers, which are made of colored plastic, are known to have been lost, Spitzer says that as many as 15 of the transferred ospreys may have returned. None has been reported breeding at Chesapeake Bay—an empirical datum that one day may contribute to the understanding of bird migration.

Egg transfer depends on the availability of other, healthier colonies of the birds as a source for the eggs, and it may help preserve a local population's existence and traditions, albeit not the purity of its gene pool. It could not help the very last population of a species.

Even when potential donor populations do exist, they too may be relatively stressed, so that biologists may be reluctant to compromise their productivity and recruitment by taking their eggs. This was the case with osprey populations in Maryland and Virginia in the early 1970's.

This predicament spurred one egg-supplier, Robert Kennedy of William and Mary College, Virginia, to recall from the ornithological literature that oologists once increased their osprey egg harvests by removing a breeding pair's entire clutch during a critically timed period early in incubation. This loss usually induced the ospreys to build a new nest and lay a second clutch, thereby doubling their production of eggs. Kennedy tried "double-clutching" as a conservation tool, and found he could double the hatch. The first-clutch eggs could be put under attentive but infertile females in nests nearby, or far away in Connecticut, or could be put in an incubator. Eggs or incubator-hatched chicks could also be used to supplement nests with smaller than usual clutches. The original pair could then be left to hatch and rear its own second clutch.

As it has turned out, the greatest value of egg transfer and double- or even triple-clutching may be with species other than ospreys, which, with the abatement in pesticide use, have recovered in most areas in the United States; only the New England and Great Lakes osprey populations are still far below pre-pesticide levels, according to demographer Henny. More important, raptor biologists say, these techniques and others elaborated from them have been shown to work with a number of wild and caged diurnal raptors, including the critically endangered American peregrine falcon (*Falco peregrinus anatum*). They are thus important bases for a wide variety of conservation measures—both in the field and through captive breeding projects—on behalf of raptorial birds.

Fig. 1. Young lesser spotted eagles that have been temporarily removed from their nests north of Kosice, Czechoslovakia, are fed pieces of freshly killed laboratory rats. If left together without any distraction (such as feeding) for more than a few minutes, they will attack each other savagely—a manifestation of the Cainistic sibling aggression that normally results in death of one of two hatchlings.

The failing bald eagle (*Haliaeetus leucocephalus*) population in coastal Maine has been assisted with clean eggs transferred from nests in the Middle West. However, the few attempts to double-clutch bald eagles and golden eagles (*Aquila chrysaetos*) thus far have failed.

Further evidence of the breeding raptors' tolerance of manipulation comes from experiments which demonstrate that eggs and young can be moved and will be nurtured and fledged by foster parents of a different species. This technique, "cross-fostering," has value in introducing or reintroducing a species into an area in which there is no extant breeding population.

In an early test of cross-fostering in the 1960's a West German raptor biologist, Bernd-Ulrich Meyburg, working in Czechoslovakia, showed that an egg or hatchling of the lesser spotted eagle (*Aquila pomarina*) would be accepted and could be reared by a pair of buzzards (*Buteo buteo*), much smaller raptors, if the buzzards' eggs were first removed from the nest. The value of this maneuver derives from the "Cainistic" behavior of young lesser spotted eagles: the typical clutch is two eggs, but the first born eaglet (Cain) virtually always drives the later-born—and so smaller—eaglet (Abel) from the center of the nest. Cain preempts food and maternal warmth to the point that the ill-starred Abel falls from the nest or perishes in it from hunger, neglect, and exposure.

Under natural circumstances the second egg may be expendable reproductive insurance against the first egg's failing to hatch. But the eagle's threatened status in Western Europe makes cross-fostering a possibly useful technique for enhancing—and perhaps even doubling—annual yields in local populations. Meyburg and a co-worker, Ján Švehlik, later obtained comparable salvage by climbing the aeries weekly and removing first Cain and then Abel for alternative week-long sojourns on Švehlik's back porch, where they were fed on a diet of laboratory rats and mice (see Fig. 1). After about 7 weeks, just before fledging, the sibling aggression diminishes sharply. The two nestlings can then be safely left together in the nest to fledge.

The major unanswered question in this and similar experiments is whether imprinting or other learning or behavioral experiences will prevent cross-fostered birds from recognizing birds of the same species (conspecifics) as suitable mates or will otherwise compromise their breeding ability. Were they to fail to breed with conspecifics, or were they to interbreed with individuals of their foster parents' species, the experimental efforts would at best be a failure and conceivably could lead to the production of unwanted wild hybrids.

There have been only a few observations of the breeding behavior of cross-fostered birds. In experiments conducted on Skokholm Island off Wales, M. P. Harris of Oxford transferred herring gulls (*Larus argentatus*) to the nests of closely related lesser black-backed gulls (*Larus fuscus*) and vice versa, and several years later found many mixed pairs, where otherwise none might have been expected. Whether this bodes ill for eagles cross-fostered to buzzards or, of greater immediate interest in the United States, whooping cranes (*Grus americana*) cross-fostered to sandhill cranes (*Grus canadensis*) remains to be seen.

The latter fostering arrangement is of particular interest because sandhill cranes will interbreed with whooping cranes in captivity. In a highly publicized experiment the USFWS is attempting to create a second flock of wild whooping cranes for insurance by moving eggs from whooping crane nests in northern Canada to the nests of sandhill cranes at the Grays Lake National Wildlife Refuge in Idaho. Last spring (1975) 13 eggs were moved, and as of early this year four or five of the young were alive and well with their foster parents at the sandhill cranes southern migratory terminal in New Mexico.

The hybridization risk may be great for these whooping cranes, for even if all four show up at Grays Lake to mate three or four springs from now, they will have to find each other among hundreds of pairs of breeding sandhill cranes that look just like their foster parents. Of course, if mixed pairings occurred biologists could remove the eggs and substitute purebred whooping crane eggs in their place. They even might trap and remove the sandhill crane parent of a hybrid pair, so that the second generation of whooping cranes in Idaho, unlike the first, would be raised by a conspecific parent.

Other novel intensive management schemes now being tested include providing feeding stations or "restaurants" for carrion-eating griffon vultures (*Gyps fulvus*) in Spain and for the California condor (*Gymnogyps californianus*) at the Sespe Sanctuary near Los Angeles. Feeding may be essential for the birds' survival when their customary food sources have failed because of human activity. It is also used to try to encourage birds to feed at protected locations close to their nest sites rather than far afield, which is the aim for the condor, and to eschew long-distance migratory flights where they may pick up pesticides or be shot. This is part of the rationale for Project Sea Eagle, which each year provides 35 tons of relatively pesticide-free provender—dead farm animals and slaughterhouse offal—for white-tailed sea eagles (*Haliaeetus albicilla*) wintering along the Baltic coast of Sweden.

Competition for nest sites from other birds, due to population dislocations caused by humans, threaten a petrel, the cahow (*Pterodroma cahow*), and Kirtland's warbler (*Dendroica kirtlandii*). For the former, Bermudian David Wingate, a government conservation official, has for 15 seasons provided baffles that narrow the mouths of cahow nest burrows so that the commoner, larger, later-arriving white-tailed tropic birds (*Phaethon lepturus*) cannot enter the burrows to build their nests, during which endeavor they invariably destroy the cahow egg or chick.

In Michigan, biologists and conservationists, now working under federal aegis as the USFWS Kirtland's Warbler Recovery Team, trap and kill brown-headed cowbirds (*Molothrus ater*), socially parasitic birds which have recently arrived in the region and which reduce warbler productivity by up to two-thirds in some breeding colonies by laying their eggs in the warblers' nests. The warblers thus far have failed to rally, however, perhaps because they are limited by other factors as well. Their survival is not assured.

Techniques to assist failing populations fall roughly into two broad categories. One is fieldwork, in which the bird or its immediate environment is manipulated, but the bird otherwise remains free in its natural habitat. The second is captive breeding, which has been, and may again be, a valuable last resort to save a species that is so stressed in its natural environment that extinction is imminent.

Limited Success at Captive Breeding

The nene goose (*Branta sandvicensis*) appears to have been stayed from oblivion by captive breeding on its native island of Hawaii and at the Wildfowl Trust in England, which now has more nene geese in its pens than it knows what to do with. More than 1000 captive-bred nene geese have since been returned to the wild, but the data so far are inadequate to demonstrate either that the released birds are breeding normally, or that the population as a whole can again sustain itself in the face of many, continuing environmental stresses caused by man.

Currently, a costly last-ditch effort is under way to breed the Mauritius kestrel (*Falco punctatus*), believed to be the world's most endangered bird. The total population, wild and captive, is estimated by Cornell University biologist Stanley Temple, who directs the breeding project, to be only nine birds.

Despite a few notable successes, captive breeding poses serious problems compared to field techniques. Some species, like the whooping crane, have proved to be difficult to breed, rear, and maintain in captivity in the numbers that might be required to stock new wild populations. Captive-bred young that are destined for release require special handling to ensure that they do not become too trusting of or dependent on humans, which could jeopardize their lives in the wild. Preparing them for release is still a challenge: birds turned loose unprepared for the rigors of fending for themselves in the wild often die soon.

One of the initially most successful releases to the wild occurred last year, when Cornell University raptor researchers released 16 captive-bred peregrine falcon nestlings at sites in the Northeast. Twelve of the falcons survived and dispersed from their man-made aeries, and at least five were alive and well 6 months later.

The peregrine and a few other raptors are unusual, however, in being the subjects of a long history of human manipulation across the line that divides wild life and behavior from tame. This expertise is inherent in the practice of falconry, and the Cornell workers—Tom Cade, Stanley Temple, and James Weaver—have invested their considerable knowledge of falconry and bird-handling skill in the release effort. They used a falconry technique called hacking to ease the Cornell-born birds into a free-flying life: the young falcons were allowed to fly free, to develop their strength and hunting ability, but were fed periodically at an artificial aerie until they could provide for themselves. The Cornell group also may have contributed to basic avian biology: it is not known whether fledged raptors learn to hunt by following their parents' example or simply rely on parental handouts of food while they learn to hunt for themselves. The fact that 12 peregrine fledglings learned to hunt and kill successfully without adult peregrines suggests that the young, of this species at least, do not rely on parental example to develop their hunting skills.

The manipulative efforts on behalf of the peregrine and other birds cannot yet be credited with carrying any of them wholly out of danger. Nevertheless, the cahow almost certainly would be extinct by now, and the nene goose would have vanished from the wild and might not survive even in captivity, without human intervention. Kirtland's warbler would be down to a few dozen birds—past the pale, if not yet extinct.

Equally important, perhaps, a new scientifically based area of endeavor has been created in the field of conservation, where there has often been much emotional opposition to scientists and their manipulative techniques. Intensive efforts to save threatened birds also have begun to shift the emphases of wildlife management and wildlife biology toward the preservation of nongame species as well as game and have provided a new, activist approach to ornithological research that in some ways resembles clinical research as much as it does the nonactivist models of classic natural science.—DAVID R. ZIMMERMAN

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