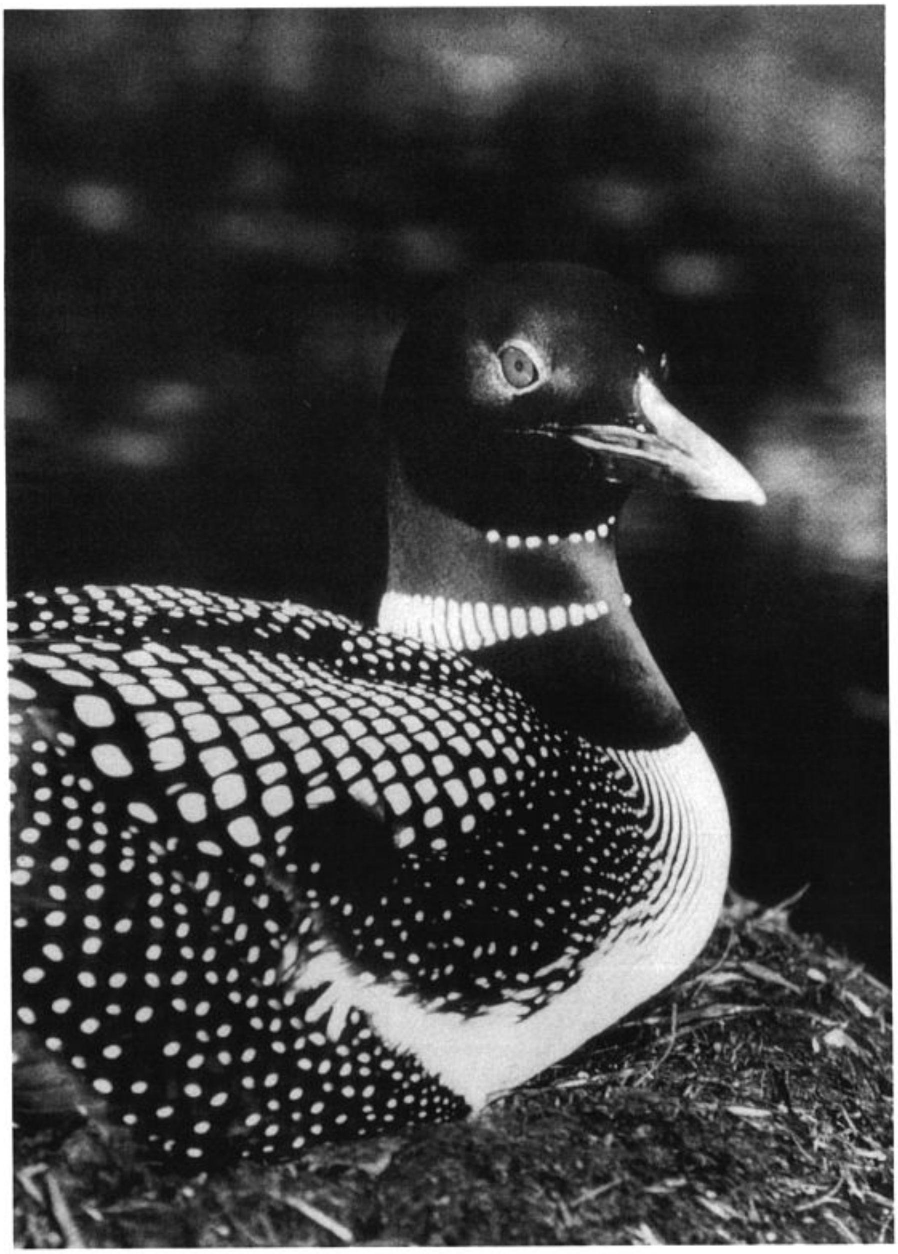
Acid rain and birds: how much proof is needed?

Brent A. Mitchell



THE DELETERIOUS EFFECTS OF ACID rain on aquatic habitats are well documented (Schindler 1988). The possibility that continued deposition of acid will result in further acidification and alteration of watersheds has alarmed both the public and the scientific community. In large areas of geologically sensitive terrain in eastern North America, many lakes have lost over 40% of their original alkalinity. Acidic deposition has been shown to affect adversely phytoplankton, zooplankton, amphibians, and fish. It is logical to project that such adverse affects would ultimately harm many types of birds, but demonstrations of effects on broadly dispersed populations of highly mobile bird species are difficult. Effects of acidification on birds are not direct. Though many species of birds may depend on aquatic systems, they are not trapped by them, unlike their fish or invertebrate prey. Moreover, our ability to separate the specific effects of acid precipitation from the natural factors that affect wildlife populations or communities is limited. This limitation is acute in the case of acid rain effects on forest ecosystems, where a host of subtle and interacting stress agents frustrate simplistic analyses (Addison and Jensen 1987). Despite the difficulties, there is now evidence that many birds, especially those dependent on aquatic systems, are being adversely affected.

Research on the effects of acid rain on wildlife did not begin formally in North America until 1980. Because

Common Loon (Gavia immer). *Photograph/S. J. Lang/VIREO/L11/2/003.*

Pacific Loon (Gavia pacifica). *Photograph/D. Roby and K. Brink/VIREO/R05/1/007.*

of their feeding habits, attention has been concentrated on, but not limited to, waterfowl and loons. Studies have centered on changes in food abundance and food quality, and the effects of these on reproductive success. Direct effects of low pH or exposure to metals are important factors behind impaired reproduction and reduced numbers of fish, amphibians, and some groups of invertebrates, but the effects on avian predators of fish and invertebrate prey are still poorly understood (*e.g.*, Stenson and Eriksson 1989).

Because of differing tolerances to acidity, decreases in pH alter prey abundance and diversity. The effect on avian predators varies according to the severity of the acidification and the foraging habits of the bird species (Blancher and McAuley 1987). Fish-eaters such as loons, mergansers, herons, bitterns, ospreys, eagles, and kingfishers are most obviously at risk from declining pH.

Prey abundance for fish-eating birds

Common Loons (*Gavia immer*) require large amounts of food during the breeding season (Parker 1988). Loons feed on small fish, prey that is sensitive to acidification, and the young remain on the natal lake for a long time. Results of studies of loon breeding success in relation to lake acidity have been mixed. In a major study of small lakes in northern Ontario, McNicol *et al.* (1987a) found that brood production of Common Loons and Common Mergansers (*Mergus merganser*) in northeastern Ontario was higher where most lakes have fish and are not acidic compared to an area where most lakes are acidic and fishless. Both species were equally abundant in the stressed and unstressed areas during the nest initiation period. Similarly, Alvo *et al.* (1988) reported a significant positive relationship between successful breeding of loons and pH on 68 lakes near Sudbury, Ontario. (The area immediately surrounding Sudbury is extremely acidified and contaminated with metals due to emissions from large nickel-copper smelters; the study area of Alvo *et al.* was over 30 kilometers away from Sudbury.) But Parker (1988) found no significant difference between lake acidity and loon reproductive success in the Adirondack region of New York State, another area where many lakes have been acidified. One possible explanation is that the heavily acidified lakes of the Sudbury area were considerably more acidic (minimum pH 4.0) than the most acidic lakes (pH 4.7) studied by Parker (Alvo *et al.* 1988). Parker did note that dives for fish were 21% longer in the more acidic lakes. Loon chicks in the Adirondack area were fed newts, tadpoles, and aquatic invertebrates in the absence of fish; they may have had more non-fish prey sources available to them than did the loons near Sudbury (McNicol *et al.* 1987a). Recent work by McNicol in northern Ontario has shown that the probability of both loon chicks fledging from two-chick broods was lower on lakes with pH <6.3 compared to less acidic lakes (D. McNicol *pers. comm.*). Lakes with low pH have fewer types of alternate, invertebrate prey.

In Sweden, Eriksson (1987) found no relationship between breeding success and lake acidification in Arctic Loons (*Gavia arctica*). However, Arctic Loons fed their young aquatic invertebrates in addition to fish. Also, because success of diving birds at detecting fish prey is dependent not only on fish density but also on transparency of water, Eriksson postulated that such birds derive a short-term benefit from the increased water clarity in acidified lakes.

The only other piscivore whose breeding success has been studied in relation to lake acidity is the Osprey

Above: American Black Ducks (Anas rubripes) *Photograph/Steve Holt/VIREO/h21/unacc.*
Below: Osprey (Pandion haliaetus) *Photograph/N. Abel/VIREO/a05/2/010.*

(*Pandion haliaetus*; Eriksson *et al.* 1983). In Sweden decreased production of young has occurred among pairs breeding in areas with many acidified lakes. Distances between occupied nests have been shown to be shorter where large areas of nonacidified lakes surround the nests (Eriksson 1986).

Prey abundance for non-fish-eating birds

Waterfowl, shorebirds, and many passerines consume invertebrates caught in aquatic systems or flying emergent insects that have aquatic larval stages. Decreases in pH eliminate those invertebrate species that are intolerant. Most sensitive are mayflies, molluscs, crustaceans, leeches, some caddisflies, odonates and water striders. Concern for acid rain effects on waterfowl has been popularized by the Izaak Walton League (Hansen 1987). Of particular concern is the status of the American Black Duck (*Anas rubripes*), which has declined significantly in the past 30 years. The American Black Duck breeds over much of eastern Canada and the northeastern United States where soil and water are sensitive to acidification. Acidification of surface waters is disruptive to aquatic food chains (Bendell and McNicol 1987; Bendell 1986; Bendell 1988) and may reduce food availability to waterfowl (Haines and Hunter 1982). Furthermore, the decline of the American Black Duck has been coincident with the progressive decline in the pH of precipitation over the past 30 years.

Primarily herbivorous outside the breeding season, dabbling ducks such as the American Black Duck depend on protein from animal sources for reproduction. The need for protein is highest for females before and during egg-laying (for egg production) and for ducklings (for rapid growth).

Slow duckling growth and low foraging efficiency caused by competition from fish for insect prey has been demonstrated in limited experimental studies using imprinted American Black Ducks and Common Goldeneyes, (*Bucephala clangula*; DesGranges and Rodrigue 1986; Hunter *et al.* 1986). Eriksson demonstrated that the absence of fish provided some compensatory insect food availability for Common Goldeneyes due to reduced competition (Eriksson 1979) DesGranges and Hunter (1987) concluded that, though competition from fish is a complicating factor, it does not negate the overall negative relationship of acidity to American Black Duck duckling growth and survival. In Maine, McAuley and Longcore (1988a, 1988b) found that young Ring-necked Ducks (*Aythya collaris*) survival was lower on acidic wetlands than on wetlands with higher pH. The difference was observed among older ducklings, ages corresponding to feather growth and maximum weight growth. This study was not complicated by the question of competition with fish because all wetlands studied contained fish.

In an initial study on man-made wetlands in Maryland, Haramis and Chu (1987) observed a reduced biomass of invertebrates in experimentally acidified wetlands compared to controls. American Black Duck broods on the acidified wetlands showed limited growth, altered behavior, and marked reduction in survival. Ducklings on the treated wetlands were more distressed, and spent less time foraging aquatically than did control ducklings. The authors suggested that reduced availability of invertebrate prey might be the cause of reduced growth and survival of juvenile American Black Ducks on acidified wetlands in the wild.

Birds reliant on flying insects that have aquatic larval stages might also be affected by increases in wetland acidity. In a study of Tree Swallows (*Tachycineta bicolor*) near Sudbury, Ontario, Blancher and McNicol (1988) observed a negative influence of wetland acidity on three aspects of reproduction: investment in eggs by laying females, size and growth of nestlings, and number of fledglings produced. Swallows breeding near wetlands where fish were present laid earlier, but had smaller eggs and clutch volumes, and slower growth of primary feathers, than swallows breeding near fishless lakes.

The Eurasian Dipper (*Cinclus cinclus*), an exclusively riverine species, has been shown to be scarce on Welsh and Scottish streams with low pH (Ormerod and Tyler 1987). Delayed clutch initiation, and significantly smaller clutch and brood sizes, were recorded in dippers breeding along acidic streams compared to those breeding elsewhere. Mayfly nymphs and caddisfly larvae are important during rearing of the young, and are especially scarce in acidic waters (Ormerod and Tyler 1986).

Lastly on the topic of food abundance, special note should be taken that many of the studies cited above reported not only changes in the abundance of prey availability, but less diversity in prey species of birds feeding in acid-stressed environments (*e.g.*, McAuley and Longcore 1988b; McNicol *et al.*, 1987a; Blancher and McNicol, 1988).

Food quality

Irrespective of the abundance of prey, the nutritional value of available foods may be adversely affected by acidification. Mineral-rich foods, especially those high in calcium such as snails, clams, crayfish, and amphipods, are important for egg production and for rapid growth in young. But most of these organisms are highly intolerant to acidity. Blancher *et al.* (1987) found that snails, clams, or parts of crayfish were brought to Tree Swallow nestlings in most nests near circumneutral wetlands, but only to a few nests near acidic wetlands. Glooschenko *et al.* (1986) found thinner eggshells with lower calcium content near acidic wetlands compared to buffered sites. Tyler and Ormerod (1985) noted that dippers breeding along calcareous tributaries in the southern Wye River in Wales are known to lay particularly large clutches.

In Scotland and Wales, calcium levels in two insect orders [Stonefly Nymphs (*Plecoptera*) and Caddis larvae (*Trichoptera*)] increased significantly with pH (Ormerod *et al.*, 1988). Calcium-rich prey were found only in circumneutral streams. Differences in pH accounted for some variance in egg mass. The authors related reduced egg-shell thickness to increased stream acidity.

Toxicity of metals

Concern has been raised regarding metal toxicity in birds feeding at or near acid stessed lakes, wetlands, and streams. Acidification increases the solubility and mobility of a range of highly toxic metals such as cadmium (Steinnes 1989), aluminum, and lead. Also, the biological availability of methylmercury is increased at low pH. Prey organisms for many birds have been found to accumulate various metals in these perturbated environments. Conversely, acidification of aquatic systems may reduce the concentration of essential elements such as selenium and calcium in prey, both of which may reduce the toxicity of metals (Wren and Stokes 1988). Of particular interest in the case of birds may be this reduction in calcium, which could have impacts on egg production and growth of young.

Aluminum

Nyholm and Myherberg (1977) reported impaired reproductive capacity in the Pied Flycatcher (*Ficedula hypoleuca*) near an acidified lake in Sweden. Egg-shell quality, clutch size, hatching success, and incubation were poorer in nest boxes placed closer to the lake than nest boxes more distant. Similar impaired breeding was observed in the Bluethroat (*Luscinia svecica*), Reed Bunting (*Emberiza schoeniclus*) and Willow Warbler (*Phylloscopus trochilus*). Aluminum was found in the bone marrow of the affected Pied Flycatchers (Nyholm 1981). However, Ringed Turtle-Doves (*Streptopelia risoria*) fed elevated aluminum levels in laboratory diets failed to exhibit impaired reproduction or growth (Carriere *et al.* 1986). This discrepancy may be explained by differences in species response to aluminum or by higher concentrations of phosphorus and calcium in the experimental diet than in the natural food organisms. Ormerod *et al.* (1988) found no evidence that aluminum in prey adversely affected dipper eggs in streams in Scotland and Wales. Moreover, aluminum concentrations in invertebrates showed no relationship with stream acidity.

D.W. Sparling (*pers. comm.*1988) fed three-day old American Black Ducks and Mallards (*Anas platyrhynchos*) diets of varying concentrations of calcium, phosphorus, and alumi-

Ringed Turtle-Dove (Streptopelia risoria). *B. Schorre/VIREO/S08/2/025.*

num. Except for one concentration containing extremely high aluminum (10,000 ppm), all concentrations were derived from studies of aquatic invertebrates in Canada. All ducklings on the diet lowest in calcium and phosphorus and 5000 ppm aluminum died within two weeks. A diet of normal calcium and phosphorus but very high aluminum had 92% mortality within 46 days. More American Black Ducks died on a greater range of diets than Mallards. Results indicate that both species are sensitive to aluminum, and that Black Ducks may be more sensitive to diets varying in these three elements than are Mallards.

Mercury

Although the mechanisms are poorly understood, acidification of surface waters may enhance the accumulation of methylmercury, cadmium, and lead in fish (Wiener 1987). Methylmercury accumulates in the food chain, and dietary methylmercury is readily absorbed by birds. At the top of the food chain, birds can accumulate toxic amounts of methylmercury.

L. Alexander has recovered thousands of dead Common Loons along the Gulf coast of Florida since 1983, most of which have been found to have high mercury concentrations in their tissues (McIntyre 1989).

In Ontario, Barr (1986) related successful use of territories by breeding Common Loons and levels of mercury contamination in lakes along a 100-mile downstream course from a major mercury source. His results suggest reductions in egg laying and in nest and territorial fidelity at mercury concentrations from 0.3 to 0.4 ppm in prey.

Nesting Eastern Kingbirds (*Tyrannus tyrannus*) from an acid-stressed area near Sudbury, Ontario, had higher mercury concentrations in the liver and feathers than populations breeding beside buffered lakes, and the rate of mass loss of eggs was faster on acid wetlands (Glooschenko *et al.* 1986).

Ringed Turtle-Doves (*Streptopelia risoria*) subjected to chronic, low-level dietary exposure to cadmium, lead, and methylmercury had an increase in the percentage of infertile eggs in the highest dose group (representing maximum concentrations likely to occur in prey organisms) and increased incidence of hatchling mortality (Scheuhammer 1987).

Erikkson et al. (1989) compared metal contents in liver tissues of 42 non-fledged Common Goldeneyes from acidic, circumneutral, and limed lakes in Sweden. They found no significantly different concentrations of any of the 12 metals analyzed between acidic and circumneutral sites. However, though the mean concentration of mercury was low-intermediate, "single individuals from acidic lakes were so highly contaminated that the risk of behavioral disturbances is not negligible."

Forest birds

Evidence of the fact of forest declines and the roles of various air pollutants in those declines is mounting (MacKenzie and El-Ashrey 1988). While many air pollutants have been implicated in effects observed in close proximity to point sources, there is substantial controversy over whether observed declines in remote sites can be attributed to anthropogenic agents either directly or indirectly (Mitchell 1987). Trees are long-lived and subject to a wide range of interacting biotic and abiotic stresses, the mechanisms of which are poorly understood. The roles of various airborne pollutants in the decline of forests are complex and beyond the scope of this paper.

As in the case of aquatic systems, changes in forest communities will affect bird populations (Schreiber and Newman 1988). The extent of forest decline in North America is thus far unknown, and few studies have been conducted on the effects of forest decline on bird populations. However, researchers at the University of Quebec at Montreal are monitoring six passerine species as bio-indicators of the progression of maple dieback (P. Blancher, *pers. comm.*).

What's missing?

Due to the high costs of reducing pollutant emissions causing acid rain and related air pollutants, many criticisms have been made of evidence of acid-related effects on natural systems.

Most of the field studies reviewed here are largely correlative because causal relationships are difficult to document in the field. Experimental studies are easier to control and thus establish causal relationships. These studies have helped to identify mechanisms of effects observed in the field. But extrapolation of their results to the wild must be reviewed with caution. For example, though studies on experimental ponds yield important information on the sensitivity of American Black Ducks to pH, the ponds hardly resemble the natural breeding habitat of the species—often temporally flooded pools and ditches. Little is known about acid "pulses" in these ephemeral pools and shallow wetlands. Experimental studies must be carefully designed, and positive results should serve to increase interest in and funding for related work in the field.

Much of the most important work has been conducted in areas hardest hit by air pollution, Schindler's "sledgehammer blows" (1987). They can not alone predict responses of ecosystems to chronic, increasing, low-level changes in soil and water chemistry Nevertheless, they are meaningful as they have: 1) established some of the mechanisms of acidification effects, 2) begun to define pH levels at which effects become apparent in some species, 3) prompted public concern, 4) justified increased monitoring, and 5) added to the bundle of arguments for abatement of air pollutant emissions

Work to date certainly justifies continued and increased study. A thorough understanding of tolerances of birds is not only important to identifying what populations are at risk, but can also make these species useful as bio-indicators of ecosystem stress (*e.g.*, McNicol *et al.* 1987b; Ormerod and Tyler 1987). This may be especially true with respect to gaseous and particulate pollutants, little studied in relation to wildlife (Newman and Schreiber 1988). Will we one day have an avian/cadmium counterpart to fish/pH indicators—a modern canary in a coal mine? We won't know without more toxicological information

Unfortunately, it is now impossible to compare data from studies of natural "control" sites; no place is untouched by atmospheric pollution Differences now are only of degree of perturbation. As one investigator put it, "the 'Grand Experiment' has been going on for at least 30 years." Science is only now learning how to observe it in meaningful ways.

Research priorities and current efforts

Research efforts are underway to build on the correlative evidence for acid rain's effects on birds, to investigate the mechanisms behind observed effects, and to take a more holistic approach to observing ecosystem response to anthropogenic stress (Table 1).

The U.S. Fish and Wildlife Service acid rain program has two main components, research into biological effects and mitigation (R. K. Schreiber, *pers. comm.*). Mitigation is done in cooperation with the states, and is largely restricted to liming of lakes and streams for protection of fishery resources. Research is divided into bird work conducted at Patuxent National Wildlife Research Center in Maryland and fish studies at the Columbia National Fishery Research Laboratory in Missouri.

At Patuxent, researchers are continuing with original work, expanding the number of experimentally acidified ponds. For example, Sparling's prepared diet studies will be extended by lacing ponds with metals and allowing duck broods to feed on affected prey. C. E. Grue is feeding European Starlings (*Sturnus vulgaris*) the same diets used in Sparling's study.

Several midwestern states are beginning to look at levels of mercury in Common Loons. For example, work has been done in Minnesota to monitor mercury content of loon feathers (P. Strong, *pers. comm.*).

Blancher (*pers. comm.*) outlines the approach taken by the Canadian Wildlife Service's Long-Range Transport of Airborne Pollutants Program. A team of biologists is developing a model designed to link lake acidity to waterfowl production in acid-sensitive regions of eastern Canada. In theory it will be able to estimate the impact of changes in acid emissions on the potential for waterfowl to produce young. A waterfowl reproductive study has been initiated, focusing on the breeding condition of Common Goldeneyes, and survival of marked broods in relation to wetlands acidity. Detailed work on the abundance of important waterfowl foods in relation to wetlands acidity and fish community type is continuing.

Scheuhammer is continuing his work (1987) on toxic effects of dietary metals. A current study looks at reproductive effects of cadmium, lead and aluminum in combination with low levels of calcium. Another study to investigate effects of mercury in combination with low levels of selenium is planned.

Finally, a program to monitor long-term trends in waterfowl production and status of important prey in three acid-stressed regions of eastern Canada is continuing. Waterfowl production is being assessed by aerial survey in almost 500 wetlands in Ontario, and an additional 40 lakes in Nova Scotia. The Canadian Wildlife Service supports a volunteer-based loon monitoring program, the Ontario Lakes Loon Survey, organized by the Long Point Bird Observatory. Nearly 500 lakes are surveyed yearly by volunteers.

Importance of monitoring

The Ontario Lakes Loon Survey is an example of public involvement in monitoring sometimes referred to as "citizen science" (Bolze and Beyea *et al.* 1989). There is tremendous amateur interest in birds, which has often been organized to obtain invaluable information on number, distribution, and reproductive success. Similar bird surveys are conducted from New England to the Great Lakes, organized by groups such as the Loon Preservation Committee and supported in part by the North American Loon Fund.

A similar "citizen science" initiative has recently been organized by the National Audubon Society. Monitoring precipitation rather than affected species, the Citizen's Acid Rain Monitoring Network depends on volunteer samplers across the United States. It was set up to bring acid rain into the public eye on a daily basis and to produce a nationwide groundswell of activism for the reduction of acid rain.

Such large-scale, long-term monitoring projects are critical in perceiving ecosystem response to chronic, low-level perturbations. But few governments are willing to dedicate sufficient resources to support such long-term monitoring. Schindler (1987)

Table 1. Major ecosystem studies on the effects of air emissions in North America.

Name of study	*Ecosystem (location)*	*Pollutant stress*
Experimental Lakes Area (ELA) Watershed Studies	Northern coniferous forest (Ontario)	Acid deposition
Turkey Lake Forest Watershed Study	Northern deciduous forest (Ontario)	Acid deposition
Dorset Watershed Studies	Northern forest (Ontario)	Acid deposition
Montmorency Experimental Forest Study	Northern coniferous forest and associated lakes (Quebec)	Acid deposition
Kejimkujik Calibrated Catchment Program	Northern coniferous forest (Nova Scotia)	Acid deposition
Kaybob Gas Plant Study	Transition montane boreal forest (Alberta)	SO_2
San Bernadino Mountain Study	Mixed coniferous forest (California)	Oxidants
Hubbard Brook Ecosystem Project	Northern mixed deciduous coniferous forest (New Hampshire)	Atmospheric deposition including acid and tace element
Walker Branch Watershed Study	Mixed deciduous forest (TN)	Atmospheric deposition, including acid and trace element
Whitecourt Gas Plant Study	Mixed coniferous forest (Alberta)	SO_2
Integrated Lake-Watershed Acidification Study (ILWAS)	Northeastern deciduous forest (New York)	Acid deposition

From Schreiber and Newman 1988

has noted that useful monitoring projects for the future must be inexpensive enough to withstand vagaries in public funding. They must also be simple and verifiable, so that they are little affected by personnel changes. Most importantly, they must be highly sensitive to changes in ecosystems. To satisfy these demanding criteria it is important that monitoring be developed as a science in its own right.

Implications for public policy

Clearly, much work needs to be done to document effects of acidification on birds, to establish the causal relationships, and to interpret these findings across broad areas and whole populations. But the evidence to date indicates negative effects, notably on species of high public appeal, especially Common Loons and American Black Ducks. Though the extent and mechanisms of all pollutant effects are not known, there is certainly cause for concern.

Unfortunately, uncertainty in one area is often used to argue postponement of public policy action, no matter how clearly indicated by evidence from other areas of knowledge.

Evidence of indirect affects of atmospheric pollution on birds adds to the proof of direct effects on aquatic environments, synergistic effects on forests and human health hazards to provide an overwhelming argument for emission abatement.

For details on the extent of abatement minimally required see Schindler (1988). For a discussion of possible mechanisms for abatement see Harrington (1988). For a review of air pollution and birds in Europe see Goriup (1989).

ACKNOWLEDGMENTS

Peter J. Blancher, Donald K. McNicol, and R. Kent Schreiber provided invaluable information and commented on an early draft of the manuscript. Any errors in fact or interpretation are my own.

Common Loon (Gavia immer). *Geoff LeBaron/VIREO/L05/2/004.*

LITERATURE CITED

ADDISON, P., and K. JENSEN. 1987. Long-range air pollution effects on the forest ecosystem. *Trans. 52nd N. A. Wildl. & Nat. Res. Conf.* pp. 665–676.

ALVO, R., D. J. T. HUSSELL, and M. BERRILL. 1988. The breeding success of Common Loons (*Gavia immer*) in relation to alkalinity and other lake characteristics in Ontario. *Can. J. Zool.* 66: 746–752.

BARR, J. F. 1986. Population dynamics of the Common Loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Canadian Wildlife Service Occasional Paper No. 56.

BENDELL, B. E. 1988. Lake acidity and the distribution and abundance of water striders (Hemiptera: Gerridae) near Sudbury, Ontario. *Can. J. Zool.* 66(10): 2209–2211.

—— 1986. The effects of fish and pH on the distribution and abundance of backswimmers (Hemiptera: Notonectidae). *Can. J. Zool.* 64(12): 2696–2699.

—— and D. K. MCNICOL. 1987. Fish predation, lake acidity and the composition of aquatic insect assemblages *Hydrobiologia* 150: 193–202.

BLANCHER, P. J., and D. K. MCNICOL 1988. Breeding biology of Tree Swallows in relation to wetland acidity *Can. J. Zool.* 66(4): 842–849.

——, C. J. FURLONGER and D. K

Table 2. Relationship of wetland acidity to reproductive success in nine studies.

	Study[a]								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Acidity association[b]	*Common Loon*		*Ring-necked Duck*		*American Black Duck*		*Eastern Kingbird*	*Tree Swallow*	*Eurasian Dipper*
Date of egg laying	nd	0	nd	nd	nd	nd	nd	0	—
Clutch Size	0	nd	0	nd	nd	nd	nd	—	—
Eggshell thickness	nd	nd	nd	nd	nd	nd	—	nd	—
Egg water loss	nd	nd	nd	nd	nd	nd	—	0	nd
Egg hatchability	0	nd	0	nd	nd	nd	nd	0	0
Growth of young	nd	nd	nd	—	—	+[c]	—	—	nd
Foraging efficiency	—	—	nd	nd	—	+[c]	nd	nd	—
Survival of young	—	0	—	—	—	nd	nd	nd	nd
Breeding success	—	0	nd	nd	nd	nd	nd	—	nd
Food abundance	0	—	—	—	—	+[c]	0	nd	—

[a] 1 = Alvo et al (1988); 2 = Parker (1988); 3 = McAuley and Longcore (1988a; 1988b); 4 = Haramis and Chu (1987); 5 and 6 = DesGranges and Hunter (1987); 7 = Glooschenko et al. (1986); 8 = Blancher and McNicol (1988); 9 = Ormerod and Tyler (1987), Ormerod et al. (1988)

[b] nd = no data presented; 0 = no relationship observed; – = negative relationship; + = positive relationship with acidity.

[c] Lack of fish and low pH wetlands probably explains this result.

adapted from Blancher and McAuley, 1987

MCNICOL 1987 Diet of nestling Tree Swallows (*Tachycineta bicolor*) near Sudbury, Ontario, Summer 1986. Canadian Wildlife Service Technical Report Series No. 31.
—— and D. G. MCAULEY. 1987. Influence of wetland acidity on avian breeding success. *Trans. 52nd N. A. Wildl. & Nat. Res. Conf.*, pp. 628–635.
BOLZE, D. and J. BEYEA. 1989. Citizen Science and Acid Rain. *Environmental Science and Technology.* 23(6):645–646.
CARRIERE, D., K. L. FISCHER, D. B. PEAKALL, and P. ANGHERN. 1986. Effects of dietary aluminum sulphate on reproductive success and growth of Ringed Turtled-Doves (*Streptopelia risoria*). *Can. J. Zool.* 64: 1500–1505.
DESGRANGES, J. L. and M. L. HUNTER, JR. 1987. Duckling response to lake acidification. *Trans. 52nd N. A. Wildl. & Nat. Res. Conf.* pp. 636–644.
—— and J. RODRIGUE. 1986. Influence of acidity and competition with fish on the development of ducklings in Quebec. *Water, Air, and Soil Pollution* 30: 743–750.
ERIKSSON, M. O. G. 1979. Competition between freshwater fish and Goldeneyes (*Bucephela clangula*) for common prey. *Oecologia* 41: 99–107.
——. 1986. Fish delivery, production of young and nest density of Osprey (*Pandion haliaetus*) in southwest Sweden. *Can. J. Zool.* 64: 1961–1965.
—— 1987. (The production of young in Black-throated Diver, *Gavia arctica*, in southwest Sweden). *Vär Fågelvårld* 46: 172–186. (In Swedish, English summary).
——, L. HENRIKSON, and H. G. OSCARSON. 1983. (Acid-rain—a future danger for the Osprey, *Pandion haliaetus*). *Vår Fågelvärld* 42: 293–300. (In Swedish, English summary).
ERIKSSON, M. O. G., L. HENRIKSON, and H. G. OSCARSON. 1989. Metal contents in liver tissue of non-fledged Goldeneye, *Bucepala clangula*, ducklings: A comparison between samples from acidic, circumneutral, and limed lakes in south Sweden. *Arch. Environ. Contam. Toxicol.* 18: 255–260.
GLOOSCHENKO, V., P. BLANCHER, J. HERSKOWITZ, R. FULTHORPE, and S. RANG. 1986. Association of wetland acidity with reproductive parameters and insect prey of the Eastern Kingbird (*Tyannus tyrannus*) near Sudbury, Ontario. *Water, Air, and Soil Pollution* 30: 553–567.
GORIUP, P. D. 1989. Acidic air pollution and birds in Europe. *Oryx* 23(2): 82–86.
HAINES, T. A. and M. L. HUNTER. 1982. Waterfowl and their habitat: Threatened by acid rain? Pages 177–188 *in* Fourth International Waterfowl Symposium, Jan. 30, 31, and Feb. 1, 1981, New Orleans, La. Ducks Unlimited, Chicago, 265 p.
HANSEN, P W 1987 Acid Rain and Waterfowl The Case for Concern in North America. Izaak Walton League of America, Arlington, Virginia, 39 p.
HARAMIS, G. M. and D. S. CHU. 1987. Acid rain effects on waterfowl: Use of Black Duck broods to assess food resources of experimentally acidified wetlands. Pages 173–181 *in* A. W. Diamond and F. L. Filion, editors. The Value of Birds. International Council for Bird Preservation Technical Publication No. 6.
HARRINGTON, W. 1988. Breaking the deadlock on acid rain control. *Resources* 93: 1–4.
MCAULEY, D. G. and J. R. LONGCORE. 1988a. Survival of juvenile Ring-Necked Ducks on wetlands of different pH. *J Wildl. Manage.* 52: 169–176.
—— 1988b. Foods of juvenile Ring-Necked Ducks: relationship to wetland pH. *J. Wildl. Manage.* 52: 177–185.
MCINTYRE, J. W. 1989. The Common Loon cries for help. *National Geographic* 175(4): 510–524.
MACKENZIE, J. J. and M. T. EL-ASHREY. 1988. Ill winds: Airborne pollution's toll on trees and crops. World Resources Institute, Washington. 74 pages.
MCNICOL, D. K., B. E. BENDELL and R. K. ROSS. 1987a. Studies of the effects of acidification on aquatic wildlife in Canada: waterfowl and trophic relationships in northern Ontario. Canadian Wildlife Service Occasional Paper No. 62.
MCNICOL, D. K., P. J. BLANCHER and B. E. BENDELL. 1987b. Waterfowl as indicators of wetland acidification in Ontario. ICBP Technical Publication No. 6.
MITCHELL, B. A. 1987. Air pollution and maple decline. *Nexus* 9(3): 1–13.
NEWMAN, J. R. and R. K. SCHREIBER. 1988. Air pollution and wildlife toxicology: An overlooked problem. *Environmental Toxicology and Chemistry* 7: 381–390.
NYHOLM, N. E. I. 1981. Evidence of involvement of aluminum in causation of defective formation of eggshells and of impaired breeding of wild passerine birds. *Environmental Research* 26: 363–371.
—— and H. E. MYHRBERG. 1977. Severe eggshell defects and impaired reproductive capacity in small passerines in Swedish Lapland. *Oikos* 29: 336–341.
ORMEROD, S. J., and S. J. Tyler. 1987 Dippers (*Cinclus cinclus*) and Grey Wagtails (*Motacilla cinerea*) as indicators of stream acidity in upland Wales. Pages 191–208 *in* A. W. Diamond and F. L. Filion, editors. The Values of Birds. International Council for Bird Preservation Technical Publication No. 6.
ORMEROD, S. J. and S. J. TYLER. 1986. The diet of Dippers *Cinclus cinclus* wintering in the catchment of the River Wye, Wales *Bird Study* 33 36–45
ORMEROD, S. J., K. R. BULL, C P CUMMINS, S. J. TYLER, and J A VICKERY. 1988. Egg mass and shell thickness in Dippers *Cinclus cinclus* in relation to stream acidity in Wales and Scotland. *Environmental Pollution* 55 107–121.
ORMEROD, S. J., N. ALLINSON, D HUDSON, and S. J. TYLER. 1986 The distribution of breeding dippers (*Cinclus cinclus* (L.); Aves) in relation to stream acidity in upland Wales *Freshwater Biology* 16: 501–507.
PARKER, K. E. 1988. Common loon reproduction and chick feeding on acidified lakes in the Adirondack Park, New York. *Can. J. Zool.* 66: 804–810
SCHREIBER, R. K. and J. R. NEWMAN 1988. Acid Precipitation effects on forest habitats: Implications for wildlife *Conservation Biology* 2(3): 249–259
SCHEUHAMMER, A. M. 1987. Reproductive effects of chronic, low-level dietary metal exposure in birds. *Trans 52nd N. A. Wildl. & Nat. Res. Conf*, pp. 658–664.
SCHINDLER, D. W. 1988. Effects of acid rain on freshwater ecosystems. *Science* 239: 149–157.
——. 1987. Detecting ecosystem responses to anthropogenic stress. *Can. J. Fish Aquat. Sci.* 44: 6–25.
SPARLING, D. W. 1988. Dietary effects of Al, Ca, and P on Black Duck and Mallard ducklings. Abstracts of the Ninth Annual Meeting of the Society Environmental Toxicology and Chemistry, November 13–17, 1988, Arlington, Virginia.
STEINNES, E. 1989. Cadmium in the terrestrial environment: Impact of long-range atmospheric transport. *Toxicological and Environmental Chemistry* 19: 139–145.
STENSON, J. A. E. and M. O. G. ERIKSSON. 1989. Ecological mechanisms important for the biotic changes in acidified lakes in Scandinavia. *Arch Environ. Contam. Toxicol.* 18: 201–206.
TYLER, S. J. and S. J. ORMEROD. 1985 Aspects of the breeding biology of Dippers *Cinclus cinclus* in the southern catchment of the River Wye, Wales *Bird Study* 32: 164–169.
WIENER, J. G. 1987. Metal contamination of fish in low-pH lakes and potential implications for piscivorous wildlife. *Trans. 52nd N. A. Wildl. & Nat Res. Conf.*, pp. 645–657.
WREN, C. D. and P. M. STOKES. 1988 Depressed mercury levels in biota from acid and metal stressed lakes near Sudbury, Ontario. *Ambio* 17(1): 28–30

——QLF/Atlantic Center for the Environment,
39 South Main Street,
Ipswich, MA 01938