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ACID RAIN AND WILDLIFE:

AN ANNOTATED BIBLIOGRAPHY OF CANADIAN WILDLIFE SERVICE (ONTARIO REGION) LRTAP PROGRAM PUBLICATIONS (1980-1997)

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Canadian Wildlife Service Technical Report Series No. 305

This series may be cited as:

McNicol, D.K.; Mallory, M.L.; Sechley, J.; 1998. Acid Rain and Wildlife: An Annotated Bibliography of Canadian Wildlife Service (Ontario Region) LRTAP Program Publications (1980-1997). Technical Report Series No. 305, Canadian Wildlife Service, Ontario Region.

Issued under the Authority of the
Minister of Environment
Canadian Wildlife Service

© Minister of Supply and Services Canada 1998
Catalogue No. CW 69-5/305E
ISBN 0-662-26399-5

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ABSTRACT

The Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) program began in 1980, with its primary objective being to assess the impacts of acid deposition on wildlife and wildlife habitats in eastern Canada. In Ontario, the first phase of the program (to 1987) focused on identifying wildlife resources potentially at risk to the effects of acid rain and subsequently gaining a better understanding of the pathway of effects through cause-and-effect research. This work ultimately led to the implementation of a long-term biomonitoring program which continues today. Over this time period, the CWS (Ontario Region) LRTAP Program has made significant contributions to national and regional assessments on the acid rain issue, including both the "1990 Assessment" and the more recent "1997 Canadian Acid Rain Assessment - Volume Three - Aquatic Effects", which was prepared as technical support for the development of a "National Acid Rain Strategy". The program has produced many scientific papers and reports both from Environment Canada staff as well as various collaborators (colleagues in other federal and provincial agencies, universities and non-government organizations). These publications often deal with various cross-cutting environmental issues and topics, although the primary focus has always been acid rain and its ecological effects. Scientific results are reported on both abiotic and biotic processes, including aquatic resource risk assessment, toxicological considerations, limnological and other chemical characteristics, as well as broad food-chain relationships (aquatic invertebrates, fish, amphibians, waterfowl, wetland birds, small mammals, wildlife habitat), and predictive modelling and statistics. This report provides a brief, one-page summary of each of those contributions following a style modified from the journal *Quintessence - Excellence in Environmental Contamination and Toxicology*.

RÉSUMÉ

Dans le cadre du programme sur le Transport à grande distance des polluants atmosphériques (TGDPA) amorcé en 1980, le Service canadien de la faune (SCF) avait comme objectif principal, d'évaluer les impacts des polluants acides qui se manifestent sur la sauvagine et ses habitats dans l'est du Canada. La première phase du programme ontarien (1980-1987) convergeait ses efforts à identifier la sauvagine vulnérable aux précipitations acides, qui par la suite assitera à comprendre la chaîne des effets en étudiant son dynamisme. Ce travail a été instrumental afin de mettre en oeuvre un programme de biosurveillance à long terme qui continu encore aujourd'hui. Pendant la période de 1987 au présent, le programme TGDPA du SCF (région de l'Ontario) a fait d'importantes contributions au niveau régional et national relatives aux pluies acides tel que "L'évaluation de 1990" ainsi que la plus récente publication, "Étude 1997 sur les effets des pluies acides au Canada - Volume trois - Évaluation des régimes aquatiques" qui fut la pierre d'angle technique d'où provient "La stratégie nationale sur les pluies acides". Le programme a vu plusieurs manuscrits et rapports scientifiques qui ont été conçu par le personnel d'Environnement Canada ainsi que d'autres collaborateurs (collègues représentant d'autres ministères fédéraux et provinciaux, des universités ainsi que des organismes non-gouvernementaux). Ces publications traitent non seulement sur les problèmes écologiques associés avec les dépôts acides mais se penchent aussi sur une gamme de domaines qui influencent l'environnement. Les résultats scientifiques sont basés sur les conséquences biologiques, chimiques et physiques incluant l'évaluation aléatoire des milieux aquatiques, les analyses des relevés limnologiques et chimiques, et l'établissement des rapports des composantes de la chaîne biologique (tel les invertébrés, les poissons, les amphibiens, la sauvagine, les oiseaux, les petits mammifères, et l'habitat faunique). Ce manuscrit, un répertoire de ces contributions, a été formaté suivant les exigences du journal "Quintessence-Excellence in Environmental Contamination and Toxicology".

ACKNOWLEDGEMENTS

The findings presented in this report and the papers annotated herein were gained through years of work by many individuals involved with CWS (Ontario Region) LRTAP research and monitoring activities. Financial support for this work has been provided by the Long Range Transport of Air Pollutants (LRTAP) Program of Environment Canada, as well as CWS (Ontario Region). Cooperation for this work was provided by several federal and provincial agencies (Algonquin Provincial Park, Fisheries and Oceans Canada, Leslie Frost Centre, National Water Research Institute, National Wildlife Research Centre, Natural Resources Canada (CFS), Ontario Ministry of Energy and Environment, Ontario Ministry of Natural Resources), non-government organizations and environmental consultants (ESSA Technologies Ltd., Geomatics International Inc., Haliburton Forest and Wild Life Reserve, Long Point Bird Observatory, Monenco AGRA Inc., World Wildlife Fund), and universities (Carleton, Guelph, Québec, Queen's, Laurentian, McGill, McMaster, Toronto, Trent, Wales). Valuable advice over the years has been provided by Barry Bendell, Pete Blancher, Lise Brisebois, Jean-Luc DesGranges, Dean Jeffries, Joe Kerekes, Keith Marshall, David Peakall, Ken Ross, Tony Scheuhammer, Mark Wayland and Dan Welsh. Finally, thanks to Paul Madore for translating the abstract.

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1.0 INTRODUCTION

The Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) program began in 1980, with its primary objective being to assess the impacts of acid deposition on wildlife and wildlife habitats in eastern Canada. In Ontario, the program has continued for 17 years, initially focusing on cause-and-effect research on waterfowl and their food chains in acid-sensitive regions (i.e. Boreal Shield Ecozone), and expanding in 1987 to a Biomonitoring Program which tracks chemical and biological change at various trophic levels in small and large lakes across central Ontario (McNicol et al. 1995a). At present, the Ontario program is the only remaining, broad-scale, ecological monitoring program in Canada that gathers data which assess whether SO₂ emission reductions are resulting in habitat improvements for wildlife.

In addition to the direct work of CWS staff on this diverse project, the data collected by university students and other collaborators have produced a substantial number of scientific papers and reports on everything from the occurrence of certain invertebrates in relation to lake characteristics, to waterfowl breeding densities in Ontario, to statistical considerations in predictive chemical modelling. Given the contributions of CWS-Ontario staff to the production of a current, national assessment on the status and trends associated with acid rain in Canada (Jeffries 1997), it seemed timely to summarize the papers and reports from the project in a single, reference-style document.

We hope this report serves three purposes:

- 1) provides a useful reference/summary document on the effects of acid rain and other related stressors (UV-B, Hg, etc.) on wildlife and their habitat in eastern Canada;
- 2) demonstrates that a well-designed study, which when adequately resourced and conducted over a long period of time, can gather enough data of sufficient quality to address meaningful scientific questions as well as provide necessary information to make sound policy decisions (i.e. emission standards); and
- 3) serve as a "background document" to support Project WILDSPACE Ontario: a geospatial integration of diverse wildlife survey and ecological information at multiple temporal and spatial scales in Ontario.

2.0 ACID RAIN AND WILDLIFE: THE PROBLEM

The loss and degradation of habitat is a major wildlife management problem in North America today. This loss may be the result of many large-scale land-use practices, such as hydroelectric power, forestry, recreational developments and industrial pollution. The emission and deposition of acidic substances (primarily sulphur dioxide SO₂ and nitrous oxides NO_x, commonly referred to as "acid rain"), and subsequent environmental effects, have been documented for more than a century and have received considerable attention over the past two decades. Much of eastern Canada is highly sensitive to acid rain since its thin, coarsely-textured soil and granitic bedrock (characteristic of the Canadian Shield) has little inherent ability to neutralize acidifying pollutants. High levels of acid deposition can result in the acidification of lakes, rivers and streams. Along with elevated levels of metals leached from surrounding soils, high acidity can seriously impair the ability of water bodies to support aquatic life, resulting in a decline in species diversity and undesirable impacts on water-dependent wildlife.

Acid rain poses a serious threat to wildlife that rely on aquatic ecosystems in eastern Canada, including many birds, mammals and amphibians. Aquatic birds are adversely affected by acidity through a variety of ecological and ecotoxicological processes that occur at lower trophic levels, but which may ultimately cause reproductive impairment and/or shifts in habitat selection or diet. In southeastern Canada, much of the suitable breeding habitat for many species of aquatic and semi-aquatic birds is threatened by acid precipitation, mainly through

habitat loss and altered density and quality of prey. Fish-eating species (such as the common loon, *Gavia immer*) and many riparian birds prefer large lakes and rivers, but are at risk from the effects of acidification on fish prey and aquatic food webs. Small water bodies (bogs, fens, wetlands, chico swamps, headwater lakes, etc.) are particularly vulnerable to acidification, and also provide the most suitable habitat for most insectivorous waterfowl species. Ecological and ecotoxicological processes at work in lower trophic levels affect aquatic birds (reviewed in Longcore et al. 1993). Some trace metals (notably aluminum and mercury) are mobilized in highly acidic waters and may accumulate in certain fish and invertebrate prey, causing impaired reproduction in waterfowl and loons (Scheuhammer 1991). Other toxicological effects include a reduction in the concentration of usable forms of calcium (Ca) which become less abundant in acidic lakes. This results in invertebrate prey with low Ca concentrations which could lead to Ca stress in avian predators (Blancher and McNicol 1991), as reported in terrestrial systems (Graveland et al. 1994).

Ecologically, species that are not acid-tolerant (e.g. some water striders like *Metrobates hesperius*, mayflies, leeches and gastropods; Bendell 1988, Bendell and McNicol 1991) are lost and acid-tolerant species become dominant (e.g. the dragonfly *Leucorrhinia glacialis*, the hemipterans *Notonecta* and *Sigara*; McNicol and Wayland 1992, Bendell and McNicol 1995). In lakes with and without fish, there is a decrease in overall invertebrate species diversity and prey quality as lakes become more acidified (Bendell and McNicol 1987, Mallory et al. 1994, McNicol et al. 1995b, Doka et al. 1997). In fishless lakes, invertebrate abundance may remain constant or even increase as pH declines. However, in lakes containing fish, acid-tolerant fish species (e.g. yellow perch *Perca flavescens*) persist and become effective, dominant predators on invertebrates. Such conditions lead to reduced invertebrate abundance and poor brood-rearing habitat for some insectivorous waterfowl species (McNicol and Wayland 1992). The ultimate effect of decreasing pH on avian predators varies with the severity of acidification and with the foraging habits of the species, but has clearly led to reproductive effects for some waterbirds, arising from shifts in habitat selection and diet (Longcore et al. 1993).

3.0 ACID RAIN AND THE CANADIAN WILDLIFE SERVICE (CWS) LRTAP PROGRAM

Research and monitoring of the acid rain problem has been carried out under the LRTAP Program, an interdepartmental initiative involving Agriculture Canada, Fisheries and Oceans Canada, Health and Welfare Canada, Natural Resources Canada, and Environment Canada (EC). As part of EC's efforts to study the acid rain problem, the CWS initiated a program in 1980 to assess the impacts of acid deposition on wildlife and their habitats in eastern Canada. The CWS LRTAP Program uses three main approaches to study the acid rain / wildlife issue: research, monitoring, and modelling. Objectives of the first phase of the program were to determine which species and habitats were most at risk from acidification, and to establish cause-and-effect relationships between acidification and biological changes, chiefly in bird communities. The general objective of EC's present monitoring program is to document the current status of and temporal changes in the spatial extent and magnitude of elevated acid deposition and its ecological effects in Canada, and to related these observations to Canadian and US precursor emissions, past and present (D.S. Jeffries, pers. commun.). Monitoring is needed to determine whether emission control programs result in restoration of healthy biotic communities in areas affected by acid rain or whether emission reduction strategies need adjustment. The CWS LRTAP Biomonitoring Program was initiated in 1987 and is comprised of research and monitoring activities. We monitor whole ecosystems, including higher trophic levels which rely on the integrity of various components of the aquatic food web, as well as certain bioindicator taxa (primarily acid-sensitive invertebrates and birds). Using biomonitoring data, we develop models that predict how proposed emission reductions will manifest themselves at the biotic community level.

The CWS LRTAP Program is responsible for assimilating biomonitoring information, integrating and

interpreting the scientific evidence for the purpose of delivering national and regional assessments of the acid rain issue, and making recommendations to policy makers as to the protection and recovery of sensitive aquatic systems. Results of these interpretative efforts have been included in two major national assessments of the acid rain issue (1990, 1997) which provide the scientific basis for management decisions (Jeffries 1997).

Despite the fact that acid rain is considered by many to be a "mature" air issue, the 1997 Assessment concluded that much remains unresolved from both the science and policy perspectives. For example, US SO₂ emission controls required under the Canada-US Air Quality Agreement will not be fully implemented before 2010, and even then, significant parts of southeastern Canada and many thousands of lakes (~ 95,000) will receive deposition in excess of critical loads (i.e. defined as the amount of wet SO₄ deposition that protects 95% of lakes from acidifying to pH levels less than 6.0, where it is known that fish and other aquatic biota begin to decline). In fact, the National Acid Rain Strategy calls for further, although yet-to-be-defined, emission reductions (AETG 1997). Additionally, the importance of NO_x emissions as acidifying pollutants is thought to be increasing (D.S. Jeffries, pers. commun.).

In order to verify the effectiveness of existing (Canadian) or planned (US) emission controls, and to provide scientifically defensible information for future assessment purposes, it is absolutely essential that an effective Environment Canada acid rain monitoring program (including precipitation/atmospheric [AES], surface water chemistry [ECS] and wildlife/habitat [CWS] components) be maintained (D.S. Jeffries, pers. commun.).

3.1 Research

The results of the first phase of the CWS LRTAP Program are contained in two volumes of CWS Occasional Paper Series (Numbers 62 and 67). McNicol *et al.* (1987) describe work on waterfowl and their food chains in small lakes in northern Ontario, while DesGranges (1989) summarizes results of surveys of freshwater bird communities in Québec, as well as phyto-ecological studies of their associated habitats, in relation to acidification. Studies of aquatic systems were also conducted in the Lepreau area of southwestern New Brunswick, where Parker *et al.* (1989, 1992) examined the relationships between wetland acidity, fish presence, invertebrate biomass and habitat use by young waterfowl broods. Scheuhammer (1991) described the results of research at the National Wildlife Research Centre on the fate of heavy metals in waterfowl food chains, as well as laboratory studies of the effects of dietary heavy metals on the reproductive output of birds under controlled conditions. Research in Québec also focused on relationships between acid rain, forest dieback (especially sugar maple stands) and the associated effects on forest bird communities (Darveau *et al.* 1992). CWS, jointly with the Long Point Bird Observatory, implemented the Canadian Lakes Loon Survey in the 1980s. This volunteer-based survey gathers data on the breeding success of common loons (*Gavia immer*) nesting across Canada, including many lakes in acid-stressed regions of eastern Canada. CWS has also played a major role in interdisciplinary studies of calibrated basins, especially in Atlantic Canada, where Kerekes *et al.* (1994) have studied nutrient release in and limnological characteristics of acidified waters in Kejimikujik National Park, particularly as it pertains to the ecology of fish-eating birds.

3.2 Monitoring

Together, these efforts provided the basis for the development and implementation of the CWS LRTAP Biomonitoring Program in 1987. This national program is comprised of research and monitoring activities conducted by the National Wildlife Research Centre and by Regional Offices in Ontario and Atlantic Canada. Instrumental to program delivery are partnerships with various federal and provincial resource agencies, non-government organizations, universities and environmental consultants. Objectives of the program are: to track

biotic changes expected to occur in sensitive aquatic ecosystems as acidifying emissions are reduced, and to evaluate the adequacy of emission control programs to meet environmental objectives to protect aquatic biota important to wildlife. By monitoring ecological responses of waterfowl, loons and their foods to a changing acid deposition environment, the program seeks to verify spatial and temporal aspects of the biological recovery (status) of acidified, damaged and susceptible aquatic systems. Based on the premise that ecosystem health and recovery must be assessed using biotic as well as abiotic indicators, data on waterfowl (and common loon) distribution and production, water chemistry, landscape features and relationships of birds to their food (primarily fish and aquatic macroinvertebrates) are routinely gathered.

Long term ecological data is collected by the CWS in three regions in Ontario east and north of the Great Lakes (Algoma, Muskoka and Sudbury) and one in Nova Scotia (Kejimikujik National Park). While encompassing water systems that span a wide range of physical, chemical and biological characteristics, the CWS program is unique in emphasizing small lakes and wetlands (<20 ha) which constitute the preferred breeding habitat for many waterfowl species. Each study area contains many highly acid-sensitive lakes that exhibit varying degrees of acidification, and are expected to respond differently to reductions in acid deposition. Various biological indicators, such as waterfowl and common loon reproduction, and the quantity and quality of prey (i.e. fish, amphibians, invertebrates) are monitored within the four regions: 240 lakes in each of Algoma and Muskoka, 160 lakes in the more acidified Sudbury area, and 46 lakes in the highly sensitive Kejimikujik area. An extensive series of survey/sampling procedures and data collections are undertaken to characterize the physical, chemical and biological (food chain and waterbird monitoring) status of each study lake. In Ontario, this unique data set now spans a decade and contains information on over 600 water bodies, ranging from large, oligotrophic lakes to small water bodies (wetland, etc.).

The common loon is recognized as an ideal biological indicator of the health of large, oligotrophic lakes (>20 ha). Thus, in addition to CWS regional surveys, the biomonitoring program also uses the volunteer-based Canadian Lakes Loon Survey, administered by the Long Point Bird Observatory, to obtain data on common loon reproduction in lakes across eastern Canada for regional assessments of their breeding success in relation to acid precipitation.

3.3 Modelling

Modelling is an major component of the program because there is no direct means of predicting the nature and extent of aquatic ecosystem recovery from acidification. Modelling enables both scientists and policy makers to make predictions about the eventual status of ecological components of aquatic ecosystems in eastern Canada under various emission scenarios. With more information, improved biological models will be used to evaluate critical loads to ensure the protection and recovery of sensitive surface waters in eastern Canada. The CWS LRTAP Biomonitoring Program will accomplish this through two major modelling efforts.

The Waterfowl Acidification Response Modelling System (WARMS for WINDOWS™; hereafter WARMS) has been developed jointly with ESSA Technologies Ltd. to evaluate effects of acid rain on waterfowl and their habitats in eastern Canada (Blancher *et al.* 1992, McNicol *et al.* 1995c). WARMS is a simple and flexible computer software program (written in Visual Basic) that facilitates the investigation of the effects of changes in lake acidity on waterfowl habitat suitability. Using logistic regression relationships derived for fish (presence/absence) and common waterfowl species (common loon, common merganser *Mergus merganser*, hooded merganser *Lophodytes cucullatus*, mallard *Anas platyrhynchos*, American black duck *Anas rubripes*, wood duck *Aix sponsa*, ring-necked duck *Aythya collaris*, common goldeneye *Bucephala clangula*), WARMS predicts the eventual probability (steady state) that the habitat can support breeding pairs and broods under

various emission scenarios (McNicol et al. 1995c). WARMS can be used to assess current levels of damage to waterfowl populations, predict eventual benefits of various acid deposition scenarios, and assess the suitability of current CWS sites for long term spatial and temporal monitoring.

Recently, WARMS was used to link the most up-to-date SO_4 deposition data and scenario projections to revised waterfowl logistic regression models, to predict eventual habitat suitability conditions for various waterfowl species breeding in eastern Canada (McNicol and Mallory 1997). We used chemical, physical, and biological (fish and waterfowl survey) data collected over 14 years in six distinct regions of eastern Canada (Ontario - Algoma [~240 lakes]; Muskoka [240], Sudbury [160], and province-wide [for common loons; >1500 lakes]; New Brunswick - Lepreau [49]; Nova Scotia - Kejimikujik [46]) to relate the occurrence of waterfowl guilds to characteristics of small and large lakes in these regions. Resultant models indicated that basin size (open water area and depth) and the occurrence of fish (which is accurately predicted by lake size and pH) were two of the key factors identifying where piscivores and diving ducks would occur, whereas the occurrence of dabbling ducks is not predicted as reliably by these factors. These models were then applied to a chemical database representing approximately 5000 lakes in eastern Canada. Results of these analyses suggested that, for piscivores, the 2010 emission scenario (full implementation of the Canada/US Air Quality Agreement) would still leave vast regions of eastern Canada with less than ideal habitat for breeding or rearing chicks. The key limiting factor in our regional prediction capabilities was the availability of current physical and chemical data for lakes across eastern Canada. This will be even more problematic in the future, because new or current lake data is not being collected due to cutbacks to provincial and federal monitoring programs.

An effort to integrate the knowledge (data and models) from atmospheric, aquatic, terrestrial and ecological scientists has recently been completed as part of the 1997 Assessment effort. For a given target objective to protect the ecosystem, the minimum reduction of SO_2 emissions and costs can be determined by running linked models for air, water, land and ecology (Lam et al. 1998). The Integrated Assessment Model (IAM) links source-receptor models to several geochemical and ecological models (including WARMS). For chosen source regions, the IAM can derive optimal emission reduction estimates to achieve specified critical loads at selected receptor sites. The development of the biological models for this exercise are described in Doka et al. (1997), and are linked to the atmospheric and aquatic models to present preliminary predictions under proposed emission scenarios in the 1997 National Assessment (Jeffries 1997).

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5.0 GUIDE TO THE ANNOTATED BIBLIOGRAPHY

5.1 Summary of Publications by Category and Topic

As noted in Section 3, the CWS (OR) LRTAP Program has followed three main categories of study: research, monitoring and modelling. Various topics have been the focus of each of these categories over the duration of the program. Annotations of each of the major publications to date from the CWS (OR) LRTAP Program are contained in Section 5.4, and are provided in descending, chronological order (alphabetically within years). Annotations are provided for all peer-reviewed scientific papers, graduate theses, and technical publications listed in Section 5.2, as well as a few significant, unpublished reports in Section 5.3. However, as a quick reference guide to which publications address each topic, Table 1 summarizes annotations by study topic and category. Each annotation is identified by the reference number (e.g. 97-1), which identifies the year and the publication number within that year. We have adapted the format used by the scientific journal *Quintessence - Excellence in Environmental Contamination and Toxicology*.

Table 1. List of annotated publications by study topic and LRTAP Program category.

Study Topic	Category		
	Research	Monitoring	Modelling
General	93-2, 86-2	98-5, 98-6, 97-2, 96-3, 95-3, REP-4, REP-5	98-2, 97-1, REP-2
Chemistry	87-5	98-1, 98-3, 98-5, 94-3	96-1
Birds ¹	98-4, 97-3, 95-2, 94-2, 94-4, 93-3, 92-2, 91-2, 91-3, 88-2, 87-4, 87-6, 87-7, 87-8, 87-9, 87-10	98-7, 97-5, 95-4, 95-6, 90-1, 90-2	95-7, 92-1, REP-1
Trophic Relations	95-1, 94-1, 92-3, 87-2	96-2	97-1
Fish/Amphibians	87-1, REP-3		
Invertebrates	95-5, 95-8, 93-1, 91-1, 88-1, 87-3, 86-1		
Metals/Calcium	97-4, 97-6, 91-4		

Note: for sections in gray, these documents cover monitoring and modelling that span several taxonomic groups (including birds) and several study groups, and therefore can fit in several sections simultaneously

¹ Term includes Waterfowl, Loons, Birds

5.2 List of Publications

1998 (or pending)

LABERGE, C., D. A. CLUIS, D. K. McNICOL, AND M. L. MALLORY. 1998. Rationalization of a regional network designed for trend detection of lake water quality in the presence of spatial correlation. *Environmetrics* (in prep).

98-1

Monitoring - Chemistry

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5.5 Annotated Bibliographies

On the following pages are the complete annotations for CWS (Ontario Region) LRTAP Program publications listed in Sections 5.2 and 5.3.

Rationalization of a Regional Network Designed for Trend Detection of Lake Water Quality in the Presence of Spatial Correlation

Laberge, C, Cluis, DA, McNicol, DK, Mallory, ML

Environmetrics (1998, in prep)

KEY WORDS: regional scale, spatial autocorrelation, trend detection, global trend, monitoring network, rationalization, Algoma

PURPOSE OF STUDY: To use water quality data collected in small water bodies in the Algoma region to establish a sustainable, water quality survey protocol by reducing the sampling intensity and/or frequency while maintaining a statistical trend detection of 0.5σ with 90% power.

METHODS: Water quality data were collected on 256 lakes (roughly equal clusters within 9 plots) in the Algoma region in 1988, 1992, 1994, 1995 and 1996 as part of the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program. Geostatistical methods were applied to the georeferenced lake locations to determine the distance between lakes and test for spatial autocorrelation. Chemical parameters used in the autocorrelation analyses were: pH, conductivity, alkalinity, calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sulphate (SO_4), silica dioxide (SiO_2), chloride (Cl), dissolved organic carbon (DOC), and base cations (Cb; $\text{Ca} + \text{Mg} + \text{K} + \text{Na}$).

RESULTS: Spatial autocorrelation reduces the independent value of data from correlated sites; hence, the "effective" number of observations is smaller than the actual sample size. Spatial analyses indicated that lakes must be separated by 6 to 9 km to be considered chemically independent for most parameters. Thus, lakes within the same 5×5 km plot (standardized design) must be considered dependent, whereas lakes in different plots could be considered independent. The highest chemical correlations among lakes were for conductivity, Mg and DOC, whereas the lowest correlations were for alkalinity and SiO_2 . The amplitudes of the spatial correlation were highest for acidity-related parameters, particularly SO_4 and pH. These were also key parameters of interest for the monitoring network, and thus, by ensuring adequate regional trend detection for these highly spatially correlated parameters, adequate trend detection for all parameters is ensured. In addition to simply examining the spatial autocorrelation and its effects on trend detection, the effect on statistical power was also considered. Using the effective number of observations, it was determined that a correlation coefficient of only 0.1 would reduce the effective number of independent lakes per plot from 28 down to 5, highlighting the high rationalization potential of the Algoma region.

The network rationalization was based on the following assumptions: a) temporal autocorrelation was negligible (most

lakes exchange water more than once yearly), b) spatial correlation between lakes is present inside plots, c) variance is stationary in time (i.e. adding years would not change trend slope variance), d) trends are monotonic, and e) lakes used must be selected from previously sampled lakes. Considering the need for a trend detection capability of one half standard deviation (0.5σ) in a chemical parameter with 90% power, the spatial correlation within plots, and our ability to choose lakes within plots to maximize inter-lake distances, a choice of 60 lakes per year in Algoma provides a regional trend detection capability of 0.54σ , only slightly higher than our objectives. Hence, seven lakes will be chosen per plot per year (times 9 plots equals 63 lakes per year), to be rotated on a three year cycle, giving a total sample coverage of approximately 190 of the original 240 lakes. Inside the three year cycle, lakes will be rotated to maximize information collected from a large number of lakes. While this will result in some loss in our ability to conduct trend analyses on individual lakes, the reduction of sample size from approximately 240 lakes per year to ~60 lakes per year will result in a substantial cost savings, and maintain our ability to comment on trends at the regional level.

CONCLUSIONS: Network design for trend detection is a complex procedure influenced by several factors. The presence of serial and spatial correlation can mislead trend detection conclusions if they are not accounted for. The rationalization of the CWS (OR) LRTAP Biomonitoring network was used to illustrate the effect of spatial correlation on regional trend detection networks and to show that, in the presence of such correlation, the number of lakes sampled can be largely reduced without a great loss of independent information.

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ACKNOWLEDGEMENTS: The analyses presented were conducted in collaboration with the Institut National de la recherche scientifique (INRS-Eau) at the Université du Québec, Québec, and with STATEX, who developed the customized DETECT software and performed initial analyses.

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PAPER NO.: 98-1

YEAR: 1998

TOPIC: Monitoring - Chemistry

An Integrated Acid Rain Assessment Model for Canada: From Source Emission to Ecological Impact

Lam, DCL, Puckett, KJ, Wong, I, Moran, MD, Fenech, G, Jeffries, DS, Olson, MP, Whelpdale, DM, McNicol, DK, Miriam, YKG, and Minns, CK

Water Quality Research Journal of Canada 33(1): in press (1998)

KEY WORDS: integrated assessment model, decision support system, acid rain, source-receptor model, ecological predictions, emission scenarios, atmospheric transport, critical loads, steady state

PURPOSE OF STUDY: To describe a new approach to integrated assessment modelling by providing an open architecture framework for linking models together in a decision support system, and to provide advice on Canada's post-2000 emission control strategies for acid rain issues.

METHODS: The core design of the Acid Rain Integrated Assessment Model (IAM) by Environment Canada is based on connecting a long range atmospheric transport or source-receptor model to one or more water and soil chemistry models, each of which in turn connects to ecological effects models, such as fishery, wildlife, and forestry impact models. This design requires temporal and spatial consistency, as the output of one model is used as input to another. One can change the sulphur dioxide (SO_2) emission at selected source regions and determine the ecological impact. Conversely, one can set a target of ecological damage level, and then ask for the minimal reduction of SO_2 emission at selected sites, subject to socio-economic constraints. The RAISON for Windows™ system developed by Environment Canada allows data and model results to be displayed in a Geographical Information System (GIS) format, and presented in a linked and interactive system so that predicted results can be obtained with relatively short computational time and user friendly interfaces.

MODEL CALIBRATION AND CONFIRMATION: It was necessary to recalibrate the atmospheric transport model because the soil-water chemistry model and the ecological models were already calibrated and confirmed with steady-state or average conditions for about 10 years. The atmospheric transport model that was most appropriate for our requirements was the source-receptor matrix (SRM) type. While SRMs are simple to use once they are derived, they are computationally intensive, thus only two SRMs were used for this study calibrated for 1980 and 1990. The recalibrated matrix, using observed emission data for 40 source regions in North America, and the observed wet sulphate (SO_4) deposition for the 15 receptor sites, was satisfactory and implemented in the IAM.

CRITICAL LOAD AND OPTIMAL EMISSION CONTROL: The model can be used by starting with setting a new ecological damage level, then deriving new soil and water chemistry conditions, and finally asking for the optimal change in emission sources. The main criterion for determining damage for most aquatic organisms including fish and invertebrates was the condition of $\text{pH} < 6.0$ for lakes that had the original or historical $\text{pH} > 6.0$. The derivation of the relationship between critical load and damage level (measured in percentage of lakes with $\text{pH} < 6.0$) was based on a series of model runs over incremental changes of sulphate (SO_4) deposition loading. From this, we constructed a response curve of SO_4 deposition versus percentage of lakes damaged. Next, we determined the optimal reduction in the emission source for a given decrease in SO_4 load. To start the optimization procedure, we limited the emission reduction

to Canadian and/or U.S. source regions, as well as inputting the maximum percentage reduction at 70%.

SCENARIO TESTING: For scenario testing, the user can change SO_2 emissions by countries, source regions or grid cells over North America, to predict changes in deposition and ecological damage at selected receptor sites. The first step was to replace the emission source input through the option for "adjusting emission", to produce new deposition values at receptor sites. Next, the deposition value was used as input to four soil and water chemistry models (CDR, TD, CDRLTH, TDLTH). Two fisheries and one wildlife model (WARMS) were used in the construction of the expert system model, and derivation of the critical load curve. For example, by choosing the CDR and TD models, the predicted pH for the current and scenario emission fields were used to predict the probability of fish presence from either WARMS or DFO-ESSA models, and determine the optimal level of acceptable ecological damage (percentage of lakes with $\text{pH} < 6.0$). The scenario results using the expert system model choice confirmed that the optimization procedure produced an emission field that satisfied the intended objective.

UNCERTAINTY PROPAGATION: For each model, there are uncertainties associated with input, model coefficients and model structures, data used for model calibration and confirmation, and in some cases uncertainties on model choice. To assess these uncertainties, the causal neural network approach was used, based on a set of variables and a set of directed links between them to produce directed graphs to quantify probabilities of high uncertainty in the causal network using classical probability calculus. The causal network structure could be expanded to include several source regions and receptors to obtain a probability of uncertainty.

CONCLUSIONS: Integrated assessment modelling is a team effort involving scientists, economists, policy makers and advisors. With the help of the RAISON for Windows™ system, objectives of the study have been achieved: the ability to include scenario testing, cost optimization and model uncertainty in the IAM; to have the IAM operational on PC computers; and to have user friendly interfaces with support tools such as linear and nonlinear programming, genetic algorithm, expert system and causal neural network. Future work is needed on including sulphur, nitrogen, VOC and other pollutants, investigating better economic instruments, examining multiple objectives, and further testing on uncertainty propagation.

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EDITORIAL COMMENTS: This paper was originally prepared for consideration in the Special Issue of *Atmospheric Environment* devoted to papers from the 5th International Meeting on Atmospheric Science and Air Quality held in Seattle, Washington. Due to space limitation, this paper was not selected for publication and hence was submitted elsewhere.

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PAPER NO.: 98 - 2

YEAR: 1998

TOPIC: Modelling - General

Chemical Trends and Status of Small Lakes near Sudbury, Ontario, 1983-1995: Evidence of Continued Chemical Recovery

Mallory, ML, McNicol, DK, Cluis, DA, and Laberge, C

Canadian Journal of Fisheries and Aquatic Sciences 55(1) (1998, in press)

KEY WORDS: lake acidification, acid precipitation, small lakes, aquatic ecosystems, Sudbury, recovery, base cations, metals, climate, flushing index, DETECT

PURPOSE OF STUDY: To describe the status of lake chemistry in small lakes in the Sudbury area, to determine whether chemical change (recovery) has occurred from 1983 to 1995, and, if so, to determine whether certain types of lakes are more likely to exhibit changes than others based on *a priori* classifications.

METHODS: For each lake, six physical parameters were recorded: open water area, riparian area, lake elevation, number of lakes in a 500 m radius, and mid-lake depth. A flushing index, representing the rate of water replacement in each lake, was also calculated. Monthly weather records were obtained from the nearby Sudbury airport. Water samples were collected as mid-lake surface grabs or integrated tube samples (for deeper lakes) from a helicopter near autumn lake turnover in 1984, 1985-1987, and 1991-1995. Shoreline surface grab collections were conducted in 1983 (late June) and 1990 (late August). For each lake, the following chemical parameters were determined: pH, alkalinity (or acid neutralizing capacity [ANC]), conductivity, base cations (calcium [Ca], magnesium [Mg], potassium [K], sodium [Na]), anions (sulphate [SO₄], chloride, nitrate+nitrite [NO₃, NO₂]), silica [SiO₂], total inorganic carbon, dissolved organic carbon (DOC), total nitrogen, ammonia, total phosphorus [TP], colour, aluminum [Al], manganese, iron, copper, nickel and zinc. Three classification variables were created that assigned lakes into various categories according to certain physical or chemical characteristics: colour (clear - < 30 Hazen units; coloured - ≥ 30 Hu), bedrock sensitivity (three categories, low, moderate, and high), and lake type (five types: peatlands; connected, rapid-flushing; small, connected; glacial headwater; large, deep). An assumption was made that there was no persistence in water parameters year to year, which was reasonable given that most lakes exchanged their water more than once per year. Trend analyses were restricted to lakes with data for four or more years; lakes with data in three years were used for calculations of means and lakes with data for two or less years were excluded from all analyses. Six lakes that had been sampled only since 1990 were also excluded. A modified version of the DETECT trend detection software was used to examine chemical trends in lakes. Slopes for linear regressions of each chemical variable on year were used to determine the trend for each lake, while statistical significance was assessed using Kendall's Tau. To examine what chemical parameters contributed to the grouping of lakes by status or trends, hierarchical cluster analyses (HCA) were performed using the chemical parameter medians for each lake and the chemical parameter slopes for each parameter and lake from the trend analyses. Principal components analyses (PCA) were conducted using these same medians and slopes to determine how much variance in lake characteristics or trends was explained by the key chemical parameters.

RESULTS: The 161 lakes studied were generally small (median 4 ha, but ranged from 0.1 to >100 ha) and shallow (median 4.5 m) with a small riparian zone and with a couple of other lakes in close proximity. The average study lake was slightly coloured, acid stressed (low pH, low ANC, but ranged from acidified to well buffered) and oligotrophic, with low concentrations of most cations, high concentrations of SO₄, and relatively high concentrations of metals. Flushing rates ranged from daily to more than three years. Most of the core chemical parameters were not correlated with the physical characteristics, except that larger, deeper lakes tended to have higher concentrations of SO₄ and lower concentrations of nitrogen, phosphorous and DOC. Lakes at higher elevations were more acid and dilute. However, chemical parameters were strongly intercorrelated. Eleven variables were used in the HCA and PCA, and it was found that grouping lakes by overall mean chemistry was controlled most strongly by Al and ANC. For 155 lakes

used in trend analyses, more decreasing trends than increasing trends were observed for most chemical parameters, with the greatest change observed for SO₄, where 47% of the lakes recorded significant declines. Also evident were 42% of the lakes exhibiting significant declines in base cations. Sixteen percent of the lakes increased in pH, while 11% increased in ANC. Results indicated that only a portion of the lakes responded significantly in the predicted direction over the time period. Of the 22 chemical parameters used in trend analyses, a mean of 83% of the lakes showed no significant trend. Using trend slopes, grouping lakes was controlled most strongly by ANC, NO₃, NO₂, SiO₂ and Al trends. There were no significant relationships between status HCA groups and classifications based on water colour, bedrock sensitivity, or lake type. However, many significant associations were found among lake classifications and median chemical parameters. In general, pH, ANC, Ca and Mg were higher in connected, rapid-flushing lakes on well buffered substrate; SO₄ was highest in large, clearwater lakes, SiO₂, nitrogen, TP and DOC were highest in coloured, small peatlands and Al was highest in small, sensitive, headwater lakes. No significant relationships were found between trend HCA groups and lake classifications, which suggests that patterns of overall chemical change in lakes were not statistically different among any *a priori* classifications. Improvements in pH and ANC tended to occur in peatlands and connected, rapid-flushing lakes with medium bedrock sensitivity. Increases in ANC were also noted in small, coloured lakes. Declines in nitrogen and NO₃, NO₂ were most pronounced in peatlands, while Al declined in all lakes. Chemical trends were influenced by local climate; pronounced improvements occurred in response to drought conditions (1986 and 1987), but rapid deterioration followed the wet year in 1988, presumably when sulphur stored in the watersheds and exposed sediments was released and flushed into the lakes. With more typical precipitation since 1989, a pattern of gradual improvement has returned.

CONCLUSIONS: These data indicate that reductions in SO₂ emissions can lead to chemical improvements in damaged lakes, but that rates of improvement are strongly influenced by climatic patterns. It remains to be determined whether reductions from sources remote from Sudbury will permit further improvements in these lakes, or whether further local and long range emission reductions will be necessary. It is essential to determine if biota can recolonize recovering lakes, and whether the aquatic food webs that result will be sufficient to support the return of populations of wildlife to pre-acidification levels.

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ACKNOWLEDGEMENTS: The analyses presented were conducted in collaboration with the Institut National de la recherche scientifique (INRS-Eau) at the Université du Québec, Québec, and with STATEX, who developed the customized DETECT software and performed initial analyses.

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PAPER NO.: 98 - 3

YEAR: 1998

TOPIC: Monitoring - Chemistry

Risk-taking by Incubating Common Goldeneyes and Hooded Mergansers

Mallory, ML, McNicol, DK, Walton, RA, and Wayland, ME

Condor, in review (1998)

KEY WORDS: common goldeneye, hooded merganser, incubation, breeding behaviour, nest defense, Sudbury, cavity-nesting, ground-nesting, lake acidification, acid precipitation

PURPOSE OF STUDY: To examine various nest defense behaviours in relation to incubation stage and clutch size, and to test predictions regarding nest defense and nesting habits of the cavity-nesting common goldeneyes and hooded mergansers. To compare defense behaviours of these species with those patterns known for ground-nesting waterfowl.

METHODS: Breeding biology and nest defense data were collected between 1989 and 1995 on female common goldeneyes (*Bucephala clangula*) and hooded mergansers (*Lophodytes cucullatus*) nesting in previously erected nest boxes on small (generally < 20 ha) study lakes (one box per lake) 40 km NE of Sudbury, Ontario (46°54'N, 80°41'W). This work is part of the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program being conducted on 157 Sudbury area lakes to evaluate the chemical and biological response of aquatic ecosystems to changing acid deposition levels. Waterfowl nest boxes were established on 75 of these lakes, with between 46 and 71 boxes available to cavity-nesting ducks each year between 1987 and 1995. This region has many small lakes across a range of pH, chemical and biological (e.g. many lacking fish) characteristics due to the underlying geology and influence of sulphur dioxide (SO₂) emissions from local nickel smelters. Both species are cavity-nesters with one annual breeding attempt, incubation periods of about 30 d and typically lay 8-10 eggs. Between 1989 and 1995, nest defense data were collected on 57 first visits to nests of common goldeneyes (with an additional 33 observations on repeat visits to nests), and on 28 first visits to nests of hooded mergansers (with an additional 12 repeat visits in 1990). Nest boxes were checked about every five days during May and June in 1989 and 1990, not at all in 1991, and at least once during incubation (late May) each year between 1992 and 1995. Successful predation was low (28 of 232 nesting attempts unsuccessful apparently due to predators, 1987-1995). When a nest was visited, the reaction of the female was recorded, with special attention given to four behaviours: the distance of the observer from the nest when the female flushed, the estimated distance she flew before landing, any vocalizations given in flight, and whether she performed any distraction displays. The schedule of nest visits resulted in defense data being collected across the range of incubation stages, determined by egg floatation. Hatching success (percent of eggs that hatched) was determined after incubation was complete.

RESULTS: Year of observation had no influence on nest defense data, so data were pooled for all years. Female common goldeneyes, but not hooded mergansers, allowed observers to approach closer to the nest (first visits only) before flushing as incubation proceeded. Using data from repeat visits to these nests, the pattern was reversed for goldeneyes, suggesting that females modify their defense

behaviours on repeated visits by observers. Many female hooded mergansers (63% of first visits) did not flush until the observer was on the tree. For both species, females landed closer to the nest and vocalized more when they were flushed later in incubation. Goldeneye females that allowed the observer to approach closer before flushing also landed closer to the nest, but this was not true for mergansers. Goldeneye females performed broken wing displays later in incubation, and these displays were associated with remaining on the nest longer before flushing and landing on the water close to the nest. Merganser females performed these displays much earlier in incubation. Whole nest defense was assessed by ranking each of the four measured behaviours then deriving a composite nest defense index for each female by adding the ranks for each individual. Composite nest defense increased as incubation proceeded for both species, although there was considerable variation among females, especially goldeneyes. For both species, intensity of nest defense was not related to hatching success, clutch size, or to whether nests were interspecifically parasitized.

CONCLUSIONS: Both common goldeneyes and hooded mergansers exhibited increased intensity of some nest defense behaviours, and composite nest defense increased for both species as incubation proceeded, consistent with predictions of nest defense theory and with results from other waterfowl species. Hooded mergansers had relatively higher nest defense than common goldeneyes, including giving distraction displays before incubation was half complete. Patterns of nest defense differed from other ground-nesting waterfowl, and thus nest location may be an important factor influencing nest defense.

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EDITORIAL COMMENTS: This paper has received favourable reviews from two referees at the original journal, but was not accepted.

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PAPER NO.: 98 - 4

YEAR: 1998 **TOPIC:** Research - Waterfowl

Recent Temporal Patterns in the Chemistry of Small, Acid-Sensitive Lakes in Central Ontario, Canada

McNicol, DK, Mallory, ML, Laberge, C, and Cluis, DA

Water, Air and Soil Pollution (1998, in review)

KEY WORDS: lake acidification, acid precipitation, small lakes, aquatic ecosystems, Algoma, Muskoka, Sudbury, recovery, base cations, DETECT

PURPOSE OF STUDY: To describe the status of lake chemistry in small water bodies (lakes and wetlands) in central Ontario (Algoma, Muskoka and Sudbury areas), to determine whether chemical change (recovery) has occurred from 1988 to 1996, and, if so, to determine whether certain types of lakes are more likely to exhibit changes than others based on physical or chemical characteristics.

METHODS: For each lake, three physical parameters were recorded: open water area, riparian area, and mid-lake depth. Lake volume ($0.464 \times \text{area} \times \text{depth}$) was also calculated, and used as a surrogate for water retention time. Water samples were collected as mid-lake surface grabs or integrated tube samples (for deeper lakes) from a helicopter near autumn lake turnover. Algoma ($n=235$ lakes) was sampled in 1988, 1992, 1994-1996; Muskoka ($n=216$) was sampled in 1990, 1991 (partial set), 1993, 1995, 1996, and Sudbury ($n=152$) was sampled each year from 1990-1996 (1990, 1992 partial sets). For each lake, twenty-two chemical parameters were determined, but for this paper we used: pH, alkalinity (or acid neutralizing capacity [ANC]), base cations (the sum of calcium, magnesium, potassium, sodium in $\mu\text{eq/L}$), sulphate [SO_4], nitrate+nitrite [NO_2NO_3], dissolved organic carbon (DOC), and total phosphorus [TP]. An assumption was made that there was no persistence in water parameters year to year, which was reasonable given that most lakes exchanged their water more than once per year. Trend analyses were restricted to lakes with data for four or more years; lakes with data in three years were used for calculations of means and lakes with data for two or less years were excluded from all analyses. A modified version of the DETECT trend detection software was used to examine chemical trends in lakes. Slopes for linear regressions of each chemical variable on year were used to determine the magnitude of the trend for each lake, while statistical significant trends were assessed using Kendall's Tau.

RESULTS: The 603 lakes studied were generally small (median ≤ 4.2 ha) and shallow (median ≤ 4.6 m) but ranged from 0.1 to >100 ha) with a relatively large riparian zone. The average study lake was slightly coloured, acid stressed (low pH, low ANC, but ranged from acidified to well buffered) and oligotrophic, with low concentrations of most cations, and high concentrations of SO_4 . For all three areas, median annual changes in pH (+), ANC (+), and SO_4 (-) were in the direction expected if lakes are responding to reduced SO_4 deposition. Roughly half of the lakes in Algoma and Muskoka showed significant declines in lake water SO_4 over the time period, whereas only 27% showed significant declines at Sudbury. In all three areas, approximately one quarter of the lakes had significant increases in pH or ANC. Instead of anticipated improvements in acidity, lakes appeared to offset the SO_4 deposition reduction by declining base cation concentrations; more than 40% of lakes in each area had significant base cation declines. Most lakes had no noticeable change in DOC, NO_2NO_3 or TP. Despite the increases in pH and ANC,

45% of Algoma lakes, 59% of Sudbury lakes and 64% of Muskoka lakes had 1996 pH values below 6.0, where biological damage to aquatic ecosystems may occur. In Algoma and Muskoka, lakes with low ANC ($< 20 \mu\text{eq/L}$) had greater increases in pH, and declines in base cations and SO_4 were greater in lakes with smaller volume. Sudbury patterns mirrored those of Algoma and Muskoka, but were not statistically significant. Lakes with higher colour (DOC) had greater pH increases at Muskoka and smaller declines in base cations at Sudbury, but appeared to be unrelated to chemical change at Algoma.

CONCLUSIONS: These data indicate that reductions in SO_2 emissions can lead to chemical improvements in small, acid-sensitive lakes, as has been observed in larger lakes across northeastern North America. However, it is also clear that rates of improvement are slower than expected, in part due to climatic patterns (e.g. drought conditions), as well as other, unexpected chemical changes (e.g. reductions in concentrations of atmospheric base cations). Moreover, with the recent findings that several environmental stressors (drought, UV-B) have a particularly damaging effect on small, acid-sensitive lakes, it is essential to determine if biota can recolonize recovering lakes, and whether the aquatic food webs that result will be sufficient to support the return of populations of wildlife to pre-acidification levels.

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PAPER NO.: 98-5

YEAR: 1998

TOPIC: Monitoring - Chemistry

Helicopter vs. Ground Surveys of Duck Broods in Northeastern Forested Wetlands

Ross, RK, McNicol, DK, and Esterby, S

Wildlife Society Bulletin (1998, in review)

Key Words: wetlands, helicopter, waterfowl, brood surveys, northern Ontario, detectability, observation ratio, replicates

PURPOSE OF STUDY: To examine the effects of various factors, including waterfowl species, study area, habitat, year, month and time of day, on efficiency of helicopter-based waterfowl brood surveys.

METHODS: The study was conducted in three areas in the Great Lakes-St. Lawrence Forest Region: Algoma, north of Sault Ste. Marie (centred at 47°01'N, 83°55'W), Lake Wanapitei near Sudbury (centred at 46°54'N, 80°41'W), and Muskoka, near Algonquin Park (centred at 45°30'N, 79°06'W). All sites were located on exposed Precambrian Shield, highly dissected by quickly flowing streams and with moderately strong relief. Upland forests were mixed and shoreline species were predominantly conifers. Shoreline cover species associated with brood activity were generally either emergent marsh or ericaceous shrubs. Waterfowl brood surveys were conducted from a Bell 206B helicopter on high skids, equipped with bubble observation windows on the rear doors, with a recorder/navigator sitting in the front and two observers in the rear. The helicopter was flown over all habitat appropriate for waterfowl broods as low as 15 m above the ground and at a speed ranging from a hover to 60 km/h. Surveys were not carried out during periods of low visibility, precipitation, or when wind speeds exceeded 25 km/h. Details of brood sightings (species, age, number of young, presence of hen) were passed to the recorder by intercom and written on sketch maps. Surveys were conducted at the level of the individual wetland basin; the brood survey was carried out over all riparian and littoral habitat within each wetland during June-early July and/or early August, which coincided with the Class IIa age (Gollop and Marshall - roughly 21 days or older for puddle ducks, 30 days or older for diving ducks) of the early and late-nesting ducks, respectively. Efficiency of the brood survey technique was assessed by undertaking replicate counts on specific wetlands 24 h apart in the morning and late afternoon. Replicate aerial surveys were carried out on some plots in the Algoma and Muskoka areas. The shoreline of each wetland was characterized through aerial photograph interpretation, and each wetland was assigned to one of four habitat types: emergent marsh, broad ericaceous shrub, chico swamp, or basin with open shoreline. Aerial counts were compared with ground counts, carried out within 24 h of each other in selected wetlands in each study area, to assess relative efficiency of the two techniques. The effect of time of day was investigated in 1991 through a series of surveys in a single plot in Muskoka, carried out in each of three consecutive days in the two survey periods at three different time periods (morning, afternoon, evening).

RESULTS: Replicate aerial surveys were carried out on a total of 150 separate waterbodies in Muskoka and Algoma. Assessment of aerial survey efficiency was based on comparisons of the ratios of number of broods seen on both of the replicate flights to the number seen on at least one flight. No significant differences were detected in observation ratios among years, survey periods, study areas, time of day, or habitat types. Brood detectability did differ among species. Wood duck were the least detectable (ratio near 0); black ducks, mallards and hooded mergansers were moderately detectable

(ratio=0.34); common goldeneye and ring-necked ducks were highly visible (ratio=0.85). When comparing aerial and ground surveys it was found that a substantial proportion of broods were seen on only one survey, whether air or ground, but numerically (not statistically) more broods were seen from the ground than from the air. Results for individual species suggest that divers, such as ring-necked ducks and common goldeneyes, may be relatively more observable from the ground, while dabblers, particularly the American black duck, may be better seen from the air. However, overall diving duck broods were more observable from the air than those of dabblers. Results from the triplicate surveys for time-of-day effect at Muskoka indicated that there was considerable consistency among surveys even at the species level.

CONCLUSIONS: The advantages of the helicopter survey are: 1) it can be used to cover a large area in a short time, 2) it can be deployed quickly with a small crew, and is not constrained by problems of ground accessibility, 3) broods can be surveyed at a desired age class, 4) it is feasible to undertake replicate surveys, 5) fewer personnel are required, thereby reducing the variability due to differences in observer ability, and 6) the flight characteristics of the helicopter provide a degree of standardization to the procedure. The advantages of a ground survey are: 1) there is a greater ability to make habitat descriptions and measurements, 2) it is possible to work in a wider range of weather and lighting conditions, and 3) survey effort can be varied as required. Both methods have similar operating costs; however, the ground survey is substantially more expensive when salaries are included.

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EDITORIAL COMMENT: This paper has undergone the first set of reviews by referees of the *Wildlife Society Bulletin*, and will be re-submitted pending revisions in accordance with the referees' comments.

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PAPER NO.: 98 - 7

YEAR: 1998

TOPIC: Monitoring - Birds

Species Richness and Species Occurrence of Five Taxonomic Groups in Relation to pH and Other Lake Characteristics in Southeastern Canada

Doka, SE, Mallory, ML, McNicol, DK, and Minns, CK

Canadian Technical Report of Fisheries and Aquatic Sciences 2179, 57 pp (1997)

KEY WORDS: lake acidification, acid precipitation, fish predation, aquatic ecosystems, taxonomic richness, pH minima, proportional occurrence, zooplankton, macroinvertebrates, fish, amphibians, waterfowl, assessment, logistic regression, multiple linear regression, modelling

PURPOSE OF STUDY: To re-evaluate pH criterion for the protection of aquatic biota in Canada from the effects of acid precipitation based on new information (since the 1990 Assessment); to develop new biotic effects models or validate old ones for five taxonomic groups (zooplankton, macroinvertebrates, fish, amphibians, waterbirds); to define pH thresholds for protecting biotic diversity in aquatic ecosystems; to consolidate scientific information for input to the 1997 Canadian Acid Rain Assessment, and to make recommendations for the National Acid Rain Strategy.

APPROACH: Datasets from southeastern Canada (Ontario to Atlantic provinces) were used, along with existing literature, to evaluate pH ranges and minima of five taxonomic groups of aquatic organisms (fish, zooplankton, macroinvertebrates and waterbirds, with some work on amphibians). Data for inclusion in regional analyses came from a variety of sources (federal and provincial government researchers, university researchers), collection periods and regions within southeastern Canada. Fish and zooplankton data covered the broadest range, whereas waterbird, amphibian and benthic macroinvertebrate data came principally from Ontario. The proportional response of species richness in relation to lake pH was determined. The maximum achievable proportion of species present (MPS) was determined for species in each of the four taxonomic groups using species-specific pH ranges.

RESULTS: Responses of Biota to pH - Taxa were sampled in lakes with pHs that ranged between 3.8 - 9.8; however, where the various taxa were present, 95% of lakes had pH \geq 5.1. The pH minima varied for the taxonomic groups but were consistent among regions (notably Ontario and Atlantic Canada) and studies, e.g. pH 4.2 for some waterfowl, 5.0 for snails, 4.8 for trout and fathead minnows (*Pimephales promelas*), 4.5 for common loons (*Gavia immer*). Many zooplankton and other aquatic invertebrates had pH minima around 5.0. The pH minima may not be an accurate estimator of changes in the probability of finding a species as pH decreases, since there is a range of pH over which a species is less likely to occur, but nonetheless may still occur (see proportional response). Recovery of a certain species could be as specific as the species' response to acidification stress. Not only will pH tolerances of taxa be important to assess, but lag times required to permit re-invasion and reproduction must be considered, and these will vary with the characteristics of each species (dispersal ability, fecundity etc).

Proportional Response to pH Shifts - There were slight differences between taxonomic groups and between regions in the proportional loss of taxonomic richness vs pH. Zooplankton (optimal pH 6.7, similar across regions), fish (optimal pH 5.9, gradation of higher pH

in Atlantic region to lower in Ontario), and benthic organisms exhibited similar patterns of loss of taxonomic richness as pH decreased. Both fish and zooplankton would be affected if lake pH declined below pH 5.5, and many benthic invertebrates would be affected below pH 5.3. Overall, evidence from other studies in North America, Europe and these analyses confirms that damage to aquatic ecosystems occurs when pH drops below 6.0 for all trophic levels, and species diversity typically peaks at this pH level.

Response of Biota to Multiple Factors - Although pH minima provide a useful tool in examining species distributions, it is clear that the probability of finding a particular species in a lake and overall taxonomic richness are affected by many factors other than pH (e.g. geographical, physical, chemical variables, trophic relations). To this end, analyses were undertaken to develop models that incorporated effects of other variables (latitude, longitude, tertiary watershed area, tertiary watershed elevation, tertiary watershed annual temperature, lake area, lake depth, pH, dissolved organic carbon [DOC], sulphate [SO₄] concentration, and aluminum [Al] concentration) on the occurrence of various taxa across southeastern Canada.

1. Species- or Taxon-specific Models - A relationship, if any, was determined between a species' presence or absence and lake characteristics. For fish and zooplankton, a representative subset of species was analyzed. The probability of occurrence of pike (*Esox lucius*), pumpkinseed (*Lepomis gibbosus*), brook trout (*Salvelinus fontinalis*), and water fleas (Cladocera) in different regions of southeastern Canada was linked to the pH of lakes. Some other important determinants of species occurrence were lake area (pike, brook trout, brown bullhead, *Ameiurus nebulosus*), elevation (pumpkinseed), latitude (brown bullhead, golden shiner, *Notemigonus crysoleucas*), Al concentration (lake trout, *Salvelinus namaycush*, white sucker, *Catostomus commersoni*, yellow perch, *Perca flavescens*, *Daphnia*). For aquatic invertebrates and waterfowl, pH positively affected all species, and was the only factor related to leech (Hirudinea) occurrence. Other important determinants of species' occurrence were Al concentration (mayflies, snails, common merganser [*Mergus merganser*] breeding pairs), DOC (*Caenis*, amphipods) and lake area (common loon pairs and broods, common merganser pairs). The analyses for the five taxonomic groups indicate that reduced lake pH has a deleterious effect on certain aquatic taxa at several trophic levels. Using the relationships of factors other than pH which contribute to the probability of a species' occurrence in an area, better estimates of the types of systems in which those particular species are at greater risk to pH changes can be made. In addition, more specific pH thresholds can be determined based on a species' range limitations, and the effects of pH alone can be better isolated.

2. Taxonomic Richness Models - Lake characteristics were tested in stepwise multiple regression analyses to determine the factors which most affect taxonomic richness in the four taxonomic groups. For fish and zooplankton, lake area and DOC, in addition to pH, contributed significantly to taxonomic richness. With the exception of Sudbury, taxonomic richness responses in Ontario and Nova Scotia are very similar. The taxonomic richness relationship is steeper for Québec than the other provinces, but the maximum number of fish species is roughly equivalent in all regions. The increase in taxonomic richness with pH is comparable in small or large lakes in Ontario. With all datasets pooled, pH, lake area, DOC, and longitude were important in determining fish and zooplankton taxonomic richness in southeastern Canada (fish highest at pH 8.0, large lakes \approx 1000 ha; zooplankton highest at high pH, high DOC). Ontario data for macroinvertebrates were divided into lakes with and

without fish. Macroinvertebrate species richness increased with increasing pH for fishless lakes but not lakes with fish. Without fish predators, low lake pH negatively affects macroinvertebrate species richness and many acid sensitive species disappear. In both fishless lakes and those with fish, lake size had a positive influence on waterfowl species richness and pH was inversely proportional, but neither relationship was very strong. In lakes with fish, the historically-damaged Sudbury region has lower species diversity than either Muskoka or Algoma regions. The most important result is that the explained variation in each analysis is low, which indicates that many other factors influence waterfowl species diversity in these regions. Because of confounding factors, lake chemistry appears to be a poor predictor of waterfowl species richness at this trophic level.

CONCLUSIONS: Based on the models developed in this assessment, a better understanding of the interactions between lake characteristics and species' response to pH has been achieved. Some limitations to the predictability and applicability of the empirical analyses exist, and other factors (chemical, physical, biological) can influence the presence of certain species, and should be measured at the same time as pH to control for their confounding influences (i.e. a whole ecosystem approach to monitoring). Other biotic effects, such as the presence of predators and metal concentration, should be measured and included in analyses. pH was a consistent and significant variable affecting taxonomic richness of selected taxa in southeastern Canada. The importance of long range transport of air pollutants as a continuing threat to biota cannot be overstated. Empirical evidence provided here supports previous work in confirming the value of pH 6.0 as a target pH below which taxa across many trophic levels may be deleteriously affected. This evidence also aids in quantifying the effects of other variables on biotic richness and the occurrence of specific pH sensitive species in southeastern Canada. Importantly, refinement of our understanding of the effects of lake characteristics (notably acid-related chemistry) on the occurrence of biota and biodiversity will permit researchers to control for these factors when examining effects of concurrent environmental stressors, including UV-B, climate change and toxics. Ultimately, information gained in this study will provide useful models for the management of biodiversity and sustainable ecosystems.

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EDITORIAL COMMENT: This document is the result of a collaborative effort between the Canadian Wildlife Service (Ontario Region) and the Department of Fisheries and Oceans (CCIW) to produce new biological models for the 1997 Canadian Acid Rain Assessment (Dean Jeffries, editor) and the Integrated Assessment Model (Dave Lam, principal investigator). These models will also be used in the CWS LRTAP Waterfowl Acidification Response Modelling System (WARMS) for regional assessments of freshwater biodiversity.

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PAPER NO.: 97 - 1

YEAR: 1997 **TOPIC:** Modelling - General

1997 Canadian Acid Rain Assessment.

Volume three. The Effects on Canada's Lakes, Rivers and Wetlands

Jeffries, DS (editor)

Environment Canada Report (1997)

KEY WORDS: acid rain, sulphate deposition, emission reduction, chemical effects, biological effects, recovery, biodiversity, Integrated Assessment Model, nitrogen-based acidification, UV-B, drought, climate

PURPOSE OF STUDY: To summarize and assess new information (since 1990 Assessment) on the status of and trends in the condition of aquatic resources in Canada (primarily eastern part); to predict future status of these ecosystems under proposed sulphur dioxide (SO₂) emission reductions, and to recommend further reductions (if necessary). The 1997 Assessment was framed around 4 main questions:

- 1) What changes in aquatic effects related to control of SO₂ emissions have been observed since the 1980s?
- 2) Are there interactions between acidity and other atmospheric pollutants or stressors that adversely affect aquatic ecosystems?
- 3) Are the present sulphate deposition objectives sufficient to protect aquatic ecosystems?
- 4) What is the likely effect of full implementation of planned SO₂ controls in Canada and the United States on aquatic chemistry and biology?

METHODS: Chemical data were gathered from all willing and available sources in Canada. Data were retained if they were collected in or since 1985. Biological data were similarly compiled, although some data (notably for fish) collected prior to 1985 were included in analyses to maintain adequate sample sizes and provide adequate regional coverage. A thorough literature review of new chemical and biological information relating acid rain to aquatic ecosystems was conducted, including soliciting unpublished data and manuscripts from a variety of sources. The most recent source-receptor SO₄ deposition data were generated (1982-1986, 1990-1993) and were linked to chemical data and run through a variety of acidification models contained in the Integrated Assessment Model (IAM) to predict future pH and alkalinity of lakes (eventual steady states) under each emission reduction scenario. Four emission scenarios were considered: continuation at 1982-1986 levels, 1990-1993 levels, full Canadian controls (1994) and full U.S. controls (2010). Insufficient data were available for western Canada to undertake exhaustive analyses and predictive modelling; only four clusters situated in southeastern Canada (Algoma, Sudbury, Montmorency, Kejimikujik) contained sufficient data for reliable, intensive analyses and predictions. Chemical results for these clusters were then applied to newly developed biological damage models (species/taxon-specific as well as biodiversity models) to extrapolate estimates of biological damage temporally and spatially. Total chemical and biological results were assessed and interpreted to identify the current status of aquatic resources in eastern Canada, the predicted future status, the relative rate of improvement (regionally), and knowledge gaps.

CONCLUSIONS: *Chemical Effects* - Lakes in Atlantic Canada are the most acid-sensitive, while lakes in Ontario and Québec are moderately sensitive; and lakes in western Canada exhibit low sensitivity to acidification. SO₄ deposition is declining in eastern North America, and this is resulting in declines in lake water SO₄ in Ontario and Québec, but little change in Atlantic Canada. Of 202 lakes monitored since the early 1980s, 56% showed no change in acidity, 33% showed some improvement (mostly around Sudbury), and 11% are becoming more acidified. Lake recovery is moderated by some within-basin biogeochemical processes and other stressors such as drought. While sulphate deposition remains the principal

acidifying agent in Canada, there is some evidence of scattered nitrogen-based acidification, particularly in south-central Ontario and southwestern Québec. Continued nitrogen-based acidification may undermine the ecological benefits expected to accrue from SO₂ emission controls.

Biological Effects: Acidic deposition remains one of the most serious threats to biodiversity at the ecoregion level. Reduced pH negatively affects phytoplankton, zooplankton, benthic invertebrates, fish, and, indirectly, many species of water-dependent birds. Outside of Sudbury, there is little evidence of any substantive biological recovery, and cutbacks to biomonitoring programs will make it increasingly difficult to determine whether it does occur. Some recent monitoring has demonstrated that biological improvements at all trophic levels do occur by reducing SO₄ deposition, but that recovery of acidified lakes will be much slower than originally anticipated, and resultant biological communities may differ substantially from the original, pre-acidification conditions. Biological modelling also demonstrates that species diversity for all taxonomic groups is highest near pH 6.0, reinforcing this value as a key target for determining critical loads to protect sensitive aquatic ecosystems.

Interactions with Other Stressors: Acidic deposition appears to have negative, synergistic effects when considered with other environmental stressors. Mercury and UV-B penetration appear to be higher in acidic lakes, which can be linked to reduced DOC or reoxidation of stored sulphur during periods of drought.

Critical Loads: Using pH>6.0 in 95% of the lakes in each cluster region (Algoma, Sudbury, Montmorency, Kejimikujik), critical deposition loads of <6 kg/ha/yr were determined for Kejimikujik, and 6.9 and 8.0 kg/ha/yr for the other sites. Current exceedences of these loads are ~7-12 kg/ha/yr, and will still be ~6-10 kg/ha/yr under the 2010 emission scenario.

Scenario Predictions: Even under full implementation of the Canada/US Air Quality Agreement (2010), 11-25% of lakes in eastern Canadian clusters will remain chemically damaged (pH<6), approximately 6-15% of fish species richness will be lost, and 3-6% of zooplankton species richness will be lost. This translates to about 95000 damaged lakes representing 890,000 ha, with a net loss of ~162,000 fish populations.

RECOMMENDATIONS: Clearly the Canadian story of aquatic acidification and recovery is not complete, but future assessments will not be possible due to continued government cutbacks and dissolution of monitoring programs. The Assessment recommends, among other points, that:

- a) Lake or river monitoring networks must be maintained or restored;
- b) A few intensive, ecological monitoring sites must be retained;
- c) On-the-ground resurveys of lakes must be completed to verify model predictions;
- d) Canadian biomonitoring programs must be maintained or restored;
- e) Whole-lake experimentation requires reasonable funding to complete critical projects.

EDITORIAL COMMENT: CWS (OR) LRTAP staff were integrally involved in the research, modelling and writing of this document.

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PAPER NO.: 97 - 2

YEAR: 1997

TOPIC: Monitoring - General

Movements on the Nest During Incubation by Cavity-nesting Waterfowl

Mallory, ML, and McNicol, DK

Wildfowl 48, 127-134 (1997)

KEY WORDS: incubation, waterfowl, common goldeneye, common merganser, hooded merganser, cavity-nesting, nest box, temperature, Ontario

PURPOSE OF STUDY: To describe the natural rates of female movement on the nest of wild, incubating cavity-nesting waterfowl, and to describe how females adjust these rates of movement as incubation proceeds.

METHODS: Incubating females (8 common goldeneyes - 3 at Sudbury, 5 at Temagami; 1 common merganser - at Temagami; and 4 hooded mergansers - 1 at Sudbury, 3 at Temagami) were monitored between 1977 and 1990 in previously established nest boxes. Boxes were erected on coniferous trees at the edge of small lakes near Sudbury, Ontario (centred 46°54'N, 80°41'W) and larger lakes and rivers near Temagami, Ontario (centred 47°44'N, 80°20'W). The sites were located within 200 km of each other in northeastern Ontario, and both were situated on Precambrian Shield with a mixed forest cover of the Great Lakes - St. Lawrence and Boreal Forest Zones. Movements on the nest were recorded by customized load cell incubation monitors installed in the nest box and attached to chart recorders. Movements on the nest were depicted on the charts as spikes along a smooth line, and the time between movements was determined by measuring the distance interval between spikes. The number of intervals, the mean interval duration (min), and the duration of the previous trip off the nest (min) were calculated. Incubation sessions were divided into three sessions: morning (after the first departure of the day but before 1200 h), afternoon (after 1200 h but before the overnight session), and overnight (a single continuous overnight session). Data for all females were pooled for each session. Air temperatures recorded at the weather office located at the Sudbury airport (within 50 km of all Sudbury nesting females) were used, and mean daily temperatures were calculated and used for all analyses. No temperature records were obtained for the Temagami area, but temperatures are slightly lower than at Sudbury.

RESULTS: No differences were detected in internal movements on the nest for goldeneyes or hooded mergansers between study sites, so data were pooled for all females within each species. Overall, goldeneyes moved 2.6 times per hour, hooded mergansers 3.4 times per hour, and the common merganser 4.3 times per hour. Females shifted their position on the eggs most frequently in the afternoon and least frequently overnight; however, common goldeneyes moved the least often and common mergansers moved the most often. For both these species, intervals between movements were most variable during the overnight session, but there were no differences in variation of intervals during sessions between species. All three species had the greatest number of movements overnight, probably because this was the longest session. Controlling for length of incubation session, common goldeneyes and hooded mergansers moved on the nest at similar intervals throughout incubation during the morning and afternoon. However, goldeneyes, not hooded mergansers, remained motionless longer between movements during overnight sessions as incubation proceeded. For overnight sessions, longer intervals between movements resulted in fewer movements on the nest at night for goldeneyes and hooded mergansers. Despite an

increase in daylight throughout incubation, the length of overnight sessions did not vary for either species. Intervals between movements at all three time periods were unrelated to the length of previous incubation recesses for both species. For all sessions, goldeneyes had longer intervals between movements than hooded mergansers. Controlling for session length, goldeneyes and hooded mergansers made similar numbers of movements during the morning sessions, hooded mergansers made more movements during the afternoon, and goldeneyes made more movements during overnight sessions. The common merganser moved more frequently than the other two species at all times. Mean daily temperatures between May 1 and July 1 increased significantly (about 13.9 to 16.3°C increase). The mean daily change in temperature (minimum to maximum) was $11.1 \pm 0.2^\circ\text{C}$. Thus, there was a substantial daily and seasonal change in ambient temperature to which females may have adjusted their movements.

CONCLUSIONS: Ambient temperatures may influence the rate of movement on the nest of incubating female waterfowl, but perhaps not as strongly for cavity-nesters as for ground-nesters. Collectively, these data, and those published in earlier studies, suggest that there may be a relationship between body size and movements on the nest among waterfowl, similar to the documented pattern between body size and incubation rhythms. However, relatively little is known about the behaviour of waterfowl while on the nest, and most evidence comes from studies with small sample sizes, and thus further investigation is warranted.

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EDITORIAL COMMENT: This work was conducted as part of a larger study undertaken by the Canadian Wildlife Service (Ontario Region) to investigate the effects of acid precipitation on waterfowl, loons and their habitats in acid-sensitive regions of Ontario as part of Environment Canada's Long Range Transport of Air Pollutants (LRTAP) program. Thanks to Harry Lumsden, Research Scientist with Ontario Ministry of Natural Resources, for providing unpublished data.

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PAPER NO.: 97 - 3

YEAR: 1997

TOPIC: Research - Waterfowl

Leeches as Indicators of Dietary Mercury Exposure in Non-piscivorous Waterfowl in Central Ontario, Canada

McNicol, DK, Mallory, ML, Mierle, G, Scheuhammer, AM, and Wong, AHK

Environmental Pollution 96(2), 177-181 (1997)

KEY WORDS: leeches, dietary mercury, waterfowl, indicators, Muskoka, biomagnification, funnel trap, linear regression

PURPOSE OF STUDY: To determine the potential risk of mercury (Hg) exposure to non-piscivorous waterfowl breeding on acid sensitive lakes in central Ontario based on concentrations of Hg in leeches (Hirudinea) and other benthic organisms.

METHODS: Leeches, a component of the diet of some waterfowl in central Ontario, were collected from 17 small (2-11 ha) lakes in the Muskoka region of central Ontario (centre 45°30'N, 79°06'W) during June 1991 as part of the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program. Funnel traps, baited with beef liver, were set in the near-shore area of all lakes and collected 24 hr later. A total of 113 leeches representing two species (*Percymoorensis marmoratis*, a scavenger, and *Macrobdella decora*, a bloodsucker) and of various sizes were selected and were washed, dried, placed in vials and frozen within 12 hr of collection. Leeches (anterior, mid-section, and/or posterior tip) and reference liver samples were analyzed for total Hg by cold vapour atomic absorption spectrophotometry. Samples were dried, weighed, and then digested. Average chemical conditions of study lakes were described using three-year values (1990, 1991, 1993). Values from 1991 were taken at the same time as the leech collections, while values from 1990 and 1993 were collected during fall turnover of the lakes. Stepwise multiple linear regressions were used to determine if leech Hg concentrations were correlated with certain physical or chemical characteristics of the lakes.

RESULTS: *Percymoorensis marmoratis* were caught in all but one lake, whereas *Macrobdella decora* were not caught in three lakes. Mean Hg concentrations of the bloodsucker *M. decora* and the scavenger *P. marmoratis* from all lakes were not significantly different. The average Hg concentrations of *M. decora* and *P. marmoratis* were 35 ng/g dry weight (dw) and 30 ng/g dw, respectively. In three of 13 lakes where both species were captured, differences were found between species in Hg concentrations, but there was no consistent pattern to these differences. Among lakes with *M. decora*, heavier leeches had lower Hg concentrations and, controlling for body mass, lakes with lower calcium contained *M. decora* with higher concentrations of Hg. Collectively, these two variables explained 39% of the variation in Hg. For *P. marmoratis*, Hg was not correlated with body mass. Among

lakes where *P. marmoratis* were caught, larger lakes and those with higher dissolved organic carbon (i.e. more coloured) produced leeches with higher Hg concentrations. Nonetheless, overall Hg concentrations were low, with 85% of mean Hg concentrations for both species being below 10ng/g ww.

CONCLUSIONS: Leeches had Hg concentrations within an order of magnitude lower than most other aquatic invertebrates collected under similar conditions in other studies. Leeches are not suitable monitors of Hg biomagnification in central Ontario lakes, and do not pose a risk to biota preying on them.

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ACKNOWLEDGEMENTS: The Canadian Wildlife Service acknowledges the contribution made by the Ontario Ministry of Environment and Energy (Dorset Research Centre) for the processing and analyses of leech tissue samples.

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PAPER NO.: 97 - 4

YEAR: 1997 **TOPIC:** Research -Metals/Calcium

Monitoring Nest Box Use by Cavity-nesting Ducks on Acid-stressed Lakes In Ontario, Canada

McNicol, DK, Walton, RA, and Mallory, ML

Wildlife Biology 3, 1-13 (1997)

KEY WORDS: lake acidification, cavity-nesting ducks, waterfowl, nest box, acid-stress, nesting biology, fish status, recovery, Sudbury, logistic regression, nest parasitism, hatch dates, weather

PURPOSE OF STUDY: To evaluate the effectiveness of using nest boxes as tools for monitoring biological recovery of lakes from the effects of acidification.

METHODS: The study area was a 460 km² area north of Lake Wanapitei (46°45'N, 80°50'W), 50 km NE of Sudbury, Ontario. Local small lakes and wetlands (1-20 ha) have been heavily affected by acid deposition from nearby nickel smelters resulting in a high proportion of acid lakes lacking fish and acid sensitive invertebrates. Reduced local sulphur dioxide (SO₂) emissions have resulted in an increase in pH and alkalinity in some lakes since the 1970s. As part of the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program, 157 lakes were selected, spanning a broad range of habitat and chemical characteristics, to evaluate the chemical and biological response of aquatic ecosystems to changing emissions. Waterfowl nest boxes were established on a subset of 75 of these lakes, representing distinct categories of pH and fish presence. All nest boxes were 22 x 25 x 47 cm and were positioned facing open water on live coniferous trees along the shoreline. The direction the boxes faced was recorded. Between 46 and 71 boxes were available to ducks each year from 1987 to 1996. Boxes were usually visited twice each year, during egg-laying or incubation (mid-May), and after hatch (late June); no boxes were checked in 1991. A nesting attempt was considered successful if ≥ 1 egg hatched and unsuccessful attempts were categorized one of three ways: dump nests (where eggs were deposited, possibly from several females, with no chance of being incubated), abandoned nests (where females started incubation but stopped), or depredated nests (lost due to predation). Fish presence was assessed at each lake at least once by placing baited minnow traps in the littoral zone for 24 h. In total, 38 lakes contained fish, while 37 lakes were fishless. Open water area and the number of wetlands within 500 m of study lakes were calculated. Water samples were collected from mid-lake in autumn; the main chemical variable considered in analyses was pH. Eight lakes showed statistically significant changing pH trends (seven positive) over this time. A mean pH value for each lake was used for analyses. Meteorological records from the Sudbury airport from May and June were used. Aerial survey data was collected to examine the fidelity of broods to nesting lakes and to estimate average hatch dates for each species. Multiple logistic regressions were used to determine whether nesting attempts or hatching success were related to box or lake habitat characteristics. Temporal trends were analysed using Spearman correlations.

RESULTS: There was no influence of the year a nest box was established on the time to its first occupancy, so data were pooled for all boxes. Neither waterfowl nesting attempts nor hatching success were significantly related to nest box distance from water, box hole height from the ground, tree base height from water, tree circumference at breast height, density of boxes within 500 m, or the direction the box faced. Tree species had no influence on the proportion of boxes occupied or unoccupied or on the proportion of successful or unsuccessful nests. All boxes varied widely in their use by waterfowl, with relatively even use by individual species over the study period. Nesting attempts increased over the study, along with an increase in interspecific nest parasitism. Thirty-two percent of nests were unsuccessful, and this was constant throughout the study. Common goldeneyes were the most common occupant of nest boxes, occupying about 31% of available boxes. Total production for goldeneyes did not change over the study period and approximately

34% of nests were unsuccessful each year. Goldeneyes showed some site fidelity. Hooded mergansers were the other main species using nest boxes, occupying about 12% of boxes. Total production (total eggs laid, total eggs hatched, number of nesting attempts) of hooded mergansers increased over the study period, although the proportion of unsuccessful nests (28%) was steady over this time. Hooded mergansers showed lower site fidelity. Common mergansers and wood ducks occupied 2% and 1%, respectively, of available nest boxes. Interspecific nest parasitism increased from 0 cases in 1987 to 33% in 1996 for hooded mergansers and goldeneyes, with parasitism being more likely in boxes which had been occupied the previous year. Parasitized nests were as likely as non-parasitized nests to be successful. Hatch dates differed among species, with hooded mergansers and common goldeneyes hatching earlier than wood ducks, and hooded mergansers hatching earlier than common mergansers. The proportion of boxes occupied, the mean number of eggs laid per nest, the proportion of successful nests and mean number of eggs hatched per nest were unrelated to weather conditions. Overall, goldeneyes tended to nest more often on fishless lakes, while hooded mergansers nested more often on lakes with fish. No differences were found for either species among pH classes for nesting attempts or hatching success or for hatching success on lakes with and without fish. All nine nesting attempts by common mergansers occurred on lakes with fish and mean pH >5.0. Wood ducks nested four times out of six attempts on lakes with fish over a broad range of pH. Habitat variables such as pH, open water area and wetlands within 500 m were not significantly related to nesting attempts and hatching success for goldeneyes or hooded mergansers. Fish status was not related to nesting or hatching success. Nesting attempts by goldeneyes were more common on lakes without fish, but goldeneyes showed a significant decrease in their use of fishless lakes over the study. No differences were found for any habitat variable between frequently and less frequently used lakes.

CONCLUSIONS: Biomonitoring programs using waterfowl should identify the limiting step in a species' breeding biology. Results in this study indicate that common goldeneyes and hooded mergansers are not limited at the nesting stage in nest boxes, and changes in productivity will more likely occur at the brood-rearing stage. By using nest boxes, one can control for the nesting stage in years where fledgling production varies, which will improve the ability to identify factors affecting productivity. This will allow for more reliable prediction as to how species will respond to changes in lake conditions, including those following reductions in acid deposition.

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PAPER NO.: 97 - 5

YEAR: 1997 **TOPIC:** Monitoring - Waterfowl

Relationships Between Lake Chemistry, and Calcium and Trace Metal Concentrations of Aquatic Invertebrates Eaten by Breeding Insectivorous Waterfowl

Scheuhammer, AM, McNicol, DK, Mallory, ML, and Kerekes, JJ

Environmental Pollution 96(2), 235-248 (1997)

KEY WORDS: lake acidification, calcium, phosphorus, aluminum, trace metals, breeding waterfowl, insectivorous, macroinvertebrates, eastern Canada, multiple regression

PURPOSE OF STUDY: To determine the calcium (Ca), phosphorus (P), aluminum (Al), and trace metal concentrations of a variety of aquatic invertebrate taxa known to be important food sources for breeding waterfowl in eastern Canada, and examine their relationship with water chemistry parameters including pH, dissolved Ca, total phosphorus (TP), and dissolved organic carbon (DOC).

METHODS: Aquatic invertebrates were collected from three acid stressed regions in eastern Canada exhibiting a wide range of pH and Ca concentrations. Samples were collected from: 10 lakes in the Carp Hills area of eastern Ontario (45°15'N, 75°55'W), characterized by high concentrations of cations with high buffering capacity; 28 lakes from the Wanapitei area NE of Sudbury (46°54'N, 80°41'W), characterized by many acid lakes damaged by historically high SO₂ emissions from local nickel smelters; and 11 lakes at Kejimikujik National Park in southwestern Nova Scotia, characterized by natural acidity from organic acids leaching from boggy watersheds and low Ca concentrations. Collections of whirligig beetles (gyrinids), backswimmers (notonectids), waterstriders (gerriids), dragonfly larvae (odonates), caddisfly larvae (trichopterans) and snails (molluscs) were made in the spring of 1990 (7 May to 2 June) from the shores of each lake using D-frame dip-nets to obtain 5-10 specimens per-lake from each group. Water samples were obtained in the summer of 1990 and analysed for pH, conductivity, alkalinity (ANC), Ca, Mg, K, Na, SiO₂, Cl, SO₄, TP, DOC, and trace metals (Al, Fe, Ni, Cd, Cu, Mn, Zn, Pb). Raw data for lake chemistry and invertebrate Ca concentrations were not normally distributed. Relationships between Ca concentrations within invertebrate taxa, body weight and lake water chemistry were examined using stepwise multiple regressions. Comparisons of within- and between-lake variability were made using the coefficient of variation for total Ca values determined for each species in each lake.

RESULTS: Carps Hills had the highest, and Kejimikujik the lowest, mean pH, ANC, Ca, TP, DOC and SO₄. High pH lakes tended to have higher ANC, Ca, TP, and DOC, and lakes with high Al tended to have low Ca. Ca concentrations were obtained from 1,928 invertebrates. Typically few molluscs were found in Kejimikujik, fewer caddisflies were collected in Carp Hills, and an acid tolerant dragonfly species (*Leucorrhinia glacialis*) was collected only at Wanapitei. Total Ca for invertebrate taxa was highest at Carp Hills and lowest at Wanapitei. Total Ca was 100 times higher in molluscs (~200-300 mg/g) than in aquatic insects (~0.6-1.8 mg/g). Among insects, Carp Hills caddisflies had the highest mean total Ca, whereas the lowest mean total Ca was found in gyrenid beetles from Wanapitei. For all taxa, except molluscs, total Ca was positively correlated with lake pH and lake water Ca. With the exception of the snail *Physella gyrina*, all taxa had lower total Ca on lakes with high

Al. The main factor explaining invertebrate-Ca was pH, followed by Al, Ca, DOC, and TP. Analysis of P, Al, and trace metals were conducted on pooled invertebrate samples, with Al occurring at the highest concentrations of all metals (12-838 µg/g). Similar concentrations of P and trace metals were found in the notonectids, gerriids, and gyrenids. The libellulid dragonflies had lower Al concentrations, while the limnephilid trichopterans had the highest concentrations of all trace metals, particularly Al, Ni, and Pb. Molluscs had the lowest concentrations of Al. Concentrations of P and metals in invertebrates were typically not correlated with the concentrations of the elements in water.

CONCLUSIONS: Of the aquatic invertebrate taxa analysed, including those eaten by breeding waterfowl, the concentration of Ca was positively correlated with lake pH. The relationship was strongest in caddisfly species, which exhibited up to a 10-fold reduction of Ca in extremely acid (pH 4.0-4.5) lakes. Coupled with the absence of aquatic snails in lakes with pH below 5.3, this indicates that breeding female waterfowl and their young may have difficulty finding enough dietary Ca for optimal egg laying and skeletal growth on acid lakes. The concentrations of potentially toxic, non-essential metals (Al, Pb, Cd) in invertebrates were generally low from a toxicological perspective, and were not correlated with lake water concentrations of these parameters. This indicates that dietary trace metal exposure of insectivorous wildlife breeding in acid stressed habitats is not likely different from circumneutral or alkaline habitats. The concentrations of Pb, Cd, Ni, Zn, and Cu in these invertebrates were not toxicologically significant; instead, the concentrations of P, and the essential trace metals Zn and Cu were within ranges recommended as nutritionally adequate for waterfowl.

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EDITORIAL COMMENT: Acid rain, calcium and birds: a case for osteoporosis? One of the principal effects of acid rain in eastern North America and Europe has been to alter how much calcium is available in our soils and surface waters. Currently available evidence clearly links acid rain to reduced dietary Ca and possible health problems (osteoporosis) in birds, but it is essential that further research be conducted to study the role of nutrient depletion and metal release attributed to air pollutants on bird populations.

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PAPER NO.: 97 - 6

YEAR: 1997

TOPIC: Research - Metals/Calcium

Improving pH and Alkalinity Estimates for Regional-Scale Acidification Models: Incorporation of Dissolved Organic Carbon

Marmorek, DR, MacQueen, RM, Wedeles, CHR, Korman, J, Blancher, PJ, and McNicol, DK

Canadian Journal of Fisheries and Aquatic Sciences
53(7): 1602-1608 (1996)

KEY WORDS: aquatic ecosystems, acid precipitation, waterfowl, lake acidification, pH, alkalinity, dissolved organic carbon, cation denudation rate models, secondary watersheds, eastern Canada, correction factor

PURPOSE OF STUDY: To explore simple approaches to improving regional scale acid neutralizing capacity (ANC) and pH estimates by incorporating effects of dissolved organic carbon (DOC) in chemical acidification models.

METHODS: Observed pH levels were compared to pH predictions from three different titration curves: one from Small and Sutton, one a modification of the Small and Sutton approach, and a third, the ESSA/DFO model. A second set of analyses examined the effect of incorporation of DOC on estimates of ANC. The study area included all of Canada east of Manitoba and south of latitude 52°N. Twenty-six secondary watersheds were used for all analyses, and the data set consisted of 5612 records from three sources: the Canadian Long Range Transport of Air Pollutants and Acid Deposition Assessment report (1990 Assessment), an Ontario Ministry of Environment and Energy data set, and the Québec Lake Survey data set. The lakes were characterized by a wide range of chemical conditions, with pH varying from < 5.4 to almost 8.0, and alkalinity (Gran Alk) varying from 14 to 2003 µeq/L. More than half the DOC values were in the range 2 to 10 mg/L. For the ANC projections incorporating DOC, lakes without sufficient chemical data to calculate CBANC (charge balance ANC), and those records with Gran Alk > 200 µeq/L were excluded.

RESULTS: In comparing the results of the three titration curves, the Small and Sutton curve and its variation both had lower estimates of charge density because the effect of DOC on pH was absorbed by certain parameters in the equation. Variation in DOC changes pH by less than 0.2 units when Gran Alk is > 50 or < 25 µeq/L. Median pH and alkalinity for each secondary watershed compared well with the regional titration curve. The ESSA/DFO curve overestimated pH for all but four secondary watersheds. In general, the regional modified Small and Sutton curve fit the secondary watershed data slightly better than the unmodified curve and the ESSA/DFO curve. Both watershed-specific Small and Sutton curves had a slightly better overall fit and slightly lower bias than the regional modified Small and Sutton curve. The simplified estimate of CBANC overestimated Gran Alk to a greater degree in lakes with higher DOC. A correction factor

(CF) added to the equation substantially improved the fit and reduced the overall bias in Gran Alk estimates. The watershed-specific CF did not improve the fit over the regional CF. A more consistent estimate was obtained with the ESSA/DFO model which subtracted the regional correction factor from alkalinity estimates. In summary, by including a new titration curve and CF in the ESSA/DFO acidification model, a closer correspondence was obtained between predicted and observed current Gran Alk, and lower estimates of original and eventual ANC.

CONCLUSIONS: Although there is no change in the estimated ANC decline since pre-industrial times, results from the revised ESSA/DFO model indicate that the regional pH distributions are shifted towards more toxic levels. These modifications are important in estimating acid precipitation effects on high DOC surface waters frequented by fish, waterfowl and other biota. If the approach used here is to be used outside the present region of study, the titration curve parameters and correction factor should be fit to data from the new area.

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ACKNOWLEDGEMENTS: The Canadian Wildlife Service acknowledges the contribution made by ESSA Technologies Ltd. to the preparation of this paper, the modification of the ESSA/DFO acidification model to incorporate DOC, and the development of the Waterfowl Acidification Response Modelling System (WARMS) software.

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PAPER NO.: 96 - 1

YEAR: 1996

TOPIC: Modelling - Chemistry

The Canadian Wildlife Service LRTAP Biomonitoring Program. Part 2. Food Chain Monitoring in Ontario Lakes: Taxonomic Codes and Collections

McNicol, DK, Mallory, ML, and Bendell, BE

Canadian Wildlife Service Technical Report 246,
32 pp (1996)

KEY WORDS: wetlands, aquatic ecosystems, acid precipitation, recovery, waterfowl, food chain, biomonitoring, fish, macroinvertebrates, amphibians, Ontario, archived specimens, taxonomy

PURPOSE OF STUDY: To document the rate, nature and scope of biological recovery from acidification in aquatic ecosystems of Ontario following implementation of acid rain controls in Canada and the United States.

BACKGROUND: The Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program is comprised of several components. The Food Chain Monitoring Program (FCMP) is designed to detect changes in the composition and abundance of major prey of waterfowl and common loons. Broad scale surveys are conducted by the CWS to monitor waterfowl, loons and their habitats in selected regions sensitive to or affected by acid rain. Acid sensitive invertebrates and birds are used as biological indicators that respond to changes in the aquatic food web arising from the effects of acidification. The program focuses on three areas in Ontario (Algoma, Muskoka, Sudbury), east and north of the Great Lakes, that are characterized by highly acid sensitive lakes and wetlands. Baseline characterization (physical, chemical, fish status) was undertaken for all study lakes. Fish community composition is an important variable because fish are preferred prey for piscivorous waterfowl and fish compete for common invertebrate prey of non-piscivorous species. Invertebrate species composition and abundance are to some extent predicted from the structure of fish communities. Detailed monitoring of macroinvertebrates, amphibians and fish is conducted on a rotating basis for 62 lakes chosen to represent the range of pH and fish status in small (<10 ha) lakes, typical of breeding habitats of waterfowl in this region.

STUDY AREAS: Algoma (centre 47°01'N, 83°55'W) and Muskoka (centre 45°30'N, 79°06'W) study areas are underlain with granitic bedrock covered with glacial till. Forest cover is predominantly mixed hardwoods of the Great Lakes - St. Lawrence Zone. Most sites in Algoma receive wet sulphate (SO₄) deposition of > 20 kg/ha/yr. Nine 5 x 5 km study plots containing roughly 240 lakes have been established. Twenty lakes, with a minimum of 2 per plot, are used in the FCMP. The Muskoka area is highly sensitive to acid deposition and receives the highest SO₄ loading of all three study areas at > 30 kg/ha/yr. Seven 5 x 5 km plots

containing 240 lakes are in the Muskoka study area, and the FCMP uses 20 lakes. The Sudbury area (centre 46°54'N, 80°41'W) has a heterogeneous mixture of surface deposits that have produced lakes with a broad range of pHs surrounding Sudbury. Sulphate deposition from long range sources is less than in Muskoka; historically, local deposition is the highest in the province, although emission controls are currently in place. Roughly 160 small lakes and wetlands are used, with 22 lakes used for the FCMP. The location (geographic coordinates), physical, chemical and biological characteristics of each FCMP study lake is presented in tables.

DATA COLLECTIONS: *Fish and Amphibian Sampling* - fish and amphibians are sampled regularly in all food chain lakes and less frequently at other lakes. Fish collections focused on small, minnow-type prey species and medium-sized fish. Fish collections are dominated by small, non-game species such as cyprinidae, yellow perch and white sucker. Baseline fish sampling was conducted during June to August, and subsequent sampling occurred in June as part of the FCMP. Commercial minnow traps, baited and placed in the nearshore area of each lake for 24 h, are used. All fish and amphibians are collected for later identification.

Invertebrate Sampling - invertebrates are sampled to detect changes in the occurrence, composition and abundance of major waterfowl foods. Aquatic invertebrates which are waterfowl foods or are acid sensitive indicator species were sampled at random sites located in the near-shore area of each lake. More than 25,000 macroinvertebrates from 159 taxa have been collected to date. Major groups were: Coleoptera, Odonata, Hemiptera, Trichoptera, Hirudinea, Gastropoda, and Ephemeroptera. Results of fish and invertebrate sampling have been used to predict responses at critical points along the pH gradient. The number of acid sensitive invertebrate taxa per lake is related to pH and should increase as lakes recover from acidification. Five collection techniques are used: funnel traps to collect leeches, standard wire minnow traps to collect a variety of invertebrates, hoop traps to collect larval trichopterans, sweep nets to collect nektonic invertebrates, and benthic net drags to collect benthic macroinvertebrates. The FCMP is undertaken on core lakes during the middle two weeks of June. Details of the sampling schedule and fish, amphibian and invertebrate sampling procedures are presented in tabular form.

Invertebrate, Fish and Amphibian Collections - specimens are identified by various taxonomists. A list of the taxonomic keys used is presented. Between 1990 and 1994 more than 150 invertebrate, nine amphibian and 24 fish species were collected at FCMP sites. Taxonomically-ordered lists are presented in tables, along with information on the study region, methods and minimum pH of collection. Access to archived specimens can be arranged by contacting the senior author.

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EDITORIAL COMMENT: This report contains information pertaining to the national CWS LRTAP Biomonitoring program which is comprised of research and monitoring activities conducted by the National Wildlife Research Centre and by Regional Offices in Ontario and Atlantic Canada. Instrumental to program delivery are partnerships with various federal and provincial resource agencies, non-government organizations, universities, and environmental consultants. This report is part 2 of a series of CWS Technical Reports which describe various aspects of the program.

Subsequent to the publication of this report, resurvey of the 40 lakes in Sudbury to detect presence/absence of indicator leech species has been undertaken, as well as resurvey of ~50 lakes sampled in 1985 for indicator water strider species. In 1997, a modification of the FCMP protocol (5 benthic samples instead of 10, 10 hoops, 10 sweeps, no leech or fish sampling) was carried out on previously sampled FCMP lakes in Sudbury (n=10) and Algoma (n=8).

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PAPER NO.: 96 - 2

YEAR: 1996 **TOPIC:** Monitoring - Trophic Relations

The Canadian Wildlife Service LRTAP Biomonitoring Program. Part 3. Site Locations, Physical, Chemical and Biological Characteristics

McNicol, DK, Mallory, ML, and Kerekes, JJ

Canadian Wildlife Service Technical Report 248,
215 pp (1996)

KEY WORDS: wetland acidification, acid precipitation, aquatic ecosystems, recovery, biomonitoring, wetland wildlife, habitat characteristics

OBJECTIVES OF PROGRAM: To track biotic changes expected to occur in sensitive aquatic ecosystems as acidifying emissions are reduced. To evaluate the adequacy of emission control programs to meet environmental objectives to protect aquatic biota important to wildlife. This report is a working document showing locations of biomonitoring study areas and water bodies, and provides summary tables of the physical, chemical and biological characteristics of these lakes.

BIOMONITORING PROGRAM: The Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program collects long term ecological data using a whole ecosystem approach in each of three regions in Ontario (Algoma, Muskoka, Sudbury) and one in southwestern Nova Scotia (Kejimikujik). Each region contains many highly sensitive lakes and wetlands that exhibit varying degrees of acidification and are expected to respond differently to reductions in acid deposition. The biomonitoring program is comprised of three main components: 1) monitoring of short term chemical and biological recovery of acid and damaged lakes in the Sudbury area following reductions in local smelter emissions; 2) long term monitoring of small lakes and wetlands which are particularly vulnerable to acidification to establish whether biological recovery occurs at the same rate and to the same degree as in large lakes; and 3) extensive assessment of the reproductive success of fish-eating birds, especially common loons, in relation to recovery of lakes and improved fish populations. A major part of the latter component is the Canadian Lakes Loon Survey (CLLS), a volunteer-based survey program administered by the Long Point Bird Observatory. Locations of CLLS lakes in Ontario and the Atlantic provinces are documented in this report. A modelling component of the program using the Waterfowl Acidification Modelling Response System (WARMS) predicts how emission reductions manifest themselves at the biotic community level.

STUDY AREAS: The Atlantic region study area is in Kejimikujik National Park in SW Nova Scotia. This area has forest cover which is a mosaic of softwood, hardwood and mixed stands; the Park represents the most acid sensitive system in Canada. Forty-six lakes are studied, many of which are coloured due to dissolved organics, so the waters tend to have high DOC, low calcium and are naturally acid. Many lakes have pH <5, but

only one is fishless. Kejimikujik receives the lowest SO₄ deposition of the four monitoring locations. Location of the study site within the Maritimes, as well as key study lakes in the study site are included. The Algoma (centre 47°01'N, 83°55'W) and Muskoka (centre 45°30'N, 79°06'W) study areas are located within the Canadian Shield, underlain by Precambrian granitic bedrock. Forest cover is mixed hardwoods of the Great Lakes-St. Lawrence Zone. In Algoma, bedrock is covered by thin deposits of glacial ground moraine, while in Muskoka bedrock is covered with shallow glacial till. Roughly 240 lakes, many of which were naturally fishless, are studied in each of Algoma and Muskoka. SO₄ deposition in Algoma varies with most areas receiving >20kg/ha/yr, the least of the Ontario study areas. SO₄ deposition at Muskoka is the highest of all study areas, averaging >30kg/ha/yr. The Sudbury area (centre 46°54'N, 80°41'W) has a heterogeneous mixture of surficial deposits that have produced lakes with a broad range of pHs. Combined SO₄ deposition from local and long range sources is slightly less than Muskoka but greater than Algoma. Maps of Algoma, Muskoka and Sudbury block and plot locations within Ontario, and detailed maps of lake locations within each plot are included in the report. Maps of CLLS lake locations in Atlantic Canada and Ontario are also provided, as well as a provincial breakdown of volunteer effort in the CLLS between 1990-1994.

DATA COLLECTIONS: Physical Data - Habitats in all study plots have been characterized for several morphometric variables (UTM coordinates, tertiary watershed, elevation above sea level, water area, mid-lake depth, shoreline length, area of the riparian zone, total number of streams entering and exiting the lake, and number of islands) and data are presented in tables. A mapping system (Spatial Analysis System, SPANS) was used to characterize the landscape and to help explain relationships between ecological variables and chemical and physical data.

Chemical Data - Chemical analyses were performed on water samples collected regularly from all study lakes, with some data available from other sources. Tables for Kejimikujik present data on chloride, sulphate, calcium, magnesium, potassium, sodium, pH, colour and total phosphorus. In Ontario, variables measured include: pH, alkalinity, conductivity, calcium, magnesium, potassium, sodium, chloride, silica, sulphate, water colour, dissolved organic carbon, total inorganic carbon, ammonia, nitrate+nitrite, total Kjeldahl nitrogen, total phosphorus, aluminum, manganese and iron. Sudbury lakes also include data on copper and nickel. Mid-lake samples are collected from a helicopter during fall turnover of the lakes. Details of collection procedures are presented.

Biological Data - Fish species composition has been assessed at 638 sites in Ontario and ten sites in Kejimikujik, both because fish are preferred prey for piscivorous species such as loons and common mergansers and fish compete with insectivores for common macroinvertebrate prey. Presence of breeding pairs and broods of common loons and common mergansers in Kejimikujik Park were determined by ground surveys. Presence of indicated breeding pairs and broods of eight common waterfowl species (common loon, common merganser, hooded

merganser, American black duck, mallard, ring-necked duck, wood duck, common goldeneye) and beavers was determined from helicopter surveys of all study lakes in Ontario. Tables for Kejimikujik present data on fish species captured, and occurrence of common loon and common merganser pairs or chicks on study lakes. Tables for Ontario lakes contain data on fish and amphibian species captured, occurrence of waterfowl pairs or broods on study lakes, and beaver activity. Certain Sudbury lakes (n~70 annually) also have duck boxes erected along their shorelines, and tables containing information on physical characteristics of duck box locations and duck box use since 1987 are presented.

Food Chain Monitoring Program - The FCMP has been undertaken on a total of 62 small (<20 ha) lakes across a range of pH in each Ontario study area. Detailed maps of each study lake, included types of surrounding vegetation, duck box location, and locations of recent water, leech, minnow and invertebrate sampling are presented. Aquatic invertebrates, amphibians and fish have been monitored because they are prey for some waterfowl species and/or are acid-sensitive indicator species. Collecting invertebrates permits detection of changes in the occurrence, composition and abundance of target groups, many of which are important food for waterfowl. Details of trapping procedures are also presented

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PAPER NO.: 96 - 3

YEAR: 1996 **TOPIC:** Monitoring - General

Lake Acidity, Fish Predation, and the Distribution and Abundance of Some Littoral Insects

Bendell, BE, and McNicol, DK

Hydrobiologia 302(2), 133-145 (1995)

KEY WORDS: littoral insects, abundance, lake acidity, acid precipitation, fish predation, waterfowl, aquatic invertebrates, Sudbury, benthos, nekton, regression analysis

PURPOSE OF STUDY: To determine the relationship among lake acidity, fish predation and the abundance and distribution of aquatic insects known to be important foods for waterfowl.

METHODS: Aquatic insects that are important waterfowl foods were sampled in 20 small (1.9-7.8 ha), headwater lakes, covering a wide range of pH, in the Wanapitei area (centred at 46°55'N, 80°45'W), 40 km NE of Sudbury, Ontario. The area has been affected by sulphur dioxide (SO₂) emissions from smelters at Sudbury and from long range transport of air pollutants. As a result, many lakes are acid and fishless, while other lakes in the area are well buffered and remain unacidified. Fish presence or absence was determined by placing baited minnow traps at five to six locations equidistant around the littoral zone of each lake for 24 h. Fish were preserved for later identification to species and counting. Eight lakes supported fish with 11 species recorded. Twelve lakes were fishless, but of those, five were non-acid, headwater lakes that were naturally fishless due to their geographic isolation. During the spring and summer months (May to August) of 1984-1987, macroinvertebrates were sampled in the littoral zone several ways as follows: a) nekton were sampled using a water column sampler, which flushed waterboatmen (active at the substrate level) up from the bottom for collection with a net; b) larval dragonflies were sampled from benthic samples using a D-frame net; c) a relative measure of Odonate abundance was obtained by sampling the exuviae left by emerging adults along shoreline transects; and d) larval caddisflies were sampled from a canoe or from shore by visually searching and collecting them. To test whether the mean number of organisms in samples from fishless lakes was greater than in samples from lakes with fish, a *t*-test was performed on log-transformed data. The relationship between lake pH and the abundances of major invertebrate taxa within fishless lakes was done using regression analysis. Summer pH values were used here.

RESULTS: The mean number of Corixidae in lakes without fish (66.6 m⁻²) was significantly greater than in lakes with fish (3.5 m⁻²). In lakes without fish, densities varied but were not correlated with lake pH. Of the 10 species of adult corixids recorded, *Hesperocorixa scabricula* was the most common (67%). The mean densities of Anisoptera larvae in lakes with fish (18.6 m⁻²) did not differ from those in lakes without fish (28.3 m⁻²). Greater differences were found among exuviae samples, with densities in transects around lakes without fish (69.2 m⁻¹) significantly greater than those in lakes with fish (13.8 m⁻¹). Both larval and exuvial samples were dominated by three Libelluloid species, *Leucorrhinia glacialis*, *Libellula julia*, and *Cordulia shurtleffi*, particularly in fishless lakes. Four lakes with fish (including the white sucker, a large benthivorous fish) supported a distinct assemblage of Anisoptera, dominated by *Gomphus* spp including *Didymops transversa*. Within fishless lakes, the overall abundance of both anisopteran larvae and exuviae decreased significantly with increasing pH, although each dominant

species responded differently. Twenty-three Anisoptera species were found as exuviae and 17 as benthic larvae. Among fishless lakes, species richness ranged from four to 14 species and was positively correlated with lake pH. The mean number of Zygoptera exuviae, predominantly *Enallagma* spp., in shoreline transects around fishless lakes (13.0 m⁻¹) was significantly greater than that in lakes with fish (0.3 m⁻¹). Among fishless lakes, there was no relationship between the number of Zygoptera exuviae and lake pH. There was no significant difference in densities of limnephilid and phryganeid Trichoptera larvae in fishless lakes and those in lakes with fish. Among fishless lakes, the number of Limnephilidae and Phryganeidae tended to increase with pH due to high densities of *Limnephilus* in high pH fishless lakes. Numbers of *Banksiola* spp. were inversely related to pH.

CONCLUSIONS: The major aquatic insect groups in this study show similar patterns of distribution and abundance with respect to lake acidity. Each group has taxa that are highly tolerant of acid conditions, and those taxa also have behavioural and physical characteristics which suggest they are more vulnerable to vertebrate predators. Differences in the distribution and abundance of invertebrates with respect to both acidity and fish have diverse implications for breeding waterfowl. Some potentially important waterfowl foods may be eliminated by acidification or others may become more abundant as a result of the loss of fish predators. The net effect on waterfowl will depend on the nutritional value and availability of the insects, and differences in the requirements and foraging behaviours of waterfowl species.

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PAPER NO.: 95 - 1

YEAR: 1995 **TOPIC:** Research - Trophic Relations

The Diet of Insectivorous Ducklings and the Acidification of Small Ontario Lakes

Bendell, BE, and McNicol, DK

Canadian Journal of Zoology 73(11), 2044-2051 (1995)

KEY WORDS: waterfowl diet, lake acidification, acid precipitation, duckling, foraging, prey, insectivorous, Ontario, macroinvertebrates, fish predation, ANOVA

PURPOSE OF STUDY: To determine if diet composition of insectivorous ducklings is related to lake acidity and fish presence, by these factors affecting distributions and abundances of prey.

METHODS: Ducklings of common goldeneye, ring-necked duck, hooded merganser, and American black duck were collected in 1984, 1985, and 1986 from 22 lakes in the Ranger Lake area (46°55'N, 83°35'W), 40 km NE of Sault Ste. Marie, and 36 lakes in the Wanapitei area (46°55'N, 80°45'W) 40 km NE of Sudbury, Ontario. Both areas receive acid deposition from long range transport, but the Wanapitei area has a greater proportion of lakes which are acid and without fish. Ducklings were dissected after collection, and the esophagus, proventriculus, and gizzard preserved to later identify any prey contents. The combined esophageal, proventricular, and gizzard contents were used to estimate the number of individual prey taxa consumed; the hard parts of many taxa were used in identification; however, few soft-bodied prey were identifiable. Numbers of prey consumed were compared between ducklings and between groups of lakes classified by pH (pH <5.5, acid; pH >5.5, non-acid) and fish presence/absence (from results of minnow trapping).

RESULTS: A total of 137 ducklings (various ages) were collected from lakes ranging in pH from 4.2-7.4 at Wanapitei, and 4.6-7.1 at Ranger Lake. Date of duckling collection differed among the species, and generally reflected normal patterns of breeding chronology, with American black ducks (*Anas rubripes*) appearing on study lakes in early June, closely followed by hooded mergansers (*Lophodytes cucullatus*) and common goldeneyes (*Bucephala clangula*), with ring-necked ducks (*Aythya collaris*) not appearing until mid-July. At Wanapitei, most (53%) lakes from which collections were made were acid and fishless, while at Ranger Lake most (64%) of the lakes were non-acid and contained fish. Invertebrate communities between the two areas were very similar when differences in pH and fish were considered. Foods identified most frequently were those with hard body parts, larval Odonata, aquatic Hemiptera, aquatic Coleoptera, and larval Trichoptera. Odonata were the most important food for each duckling species. Soft-bodied prey, Hirudinea, Amphipoda, and Ephemeroptera, were poorly represented in gizzards, and represented a small portion of pre-digested diet contents (from the esophagus and proventriculus). Using ANOVA procedures, results showed that on acid lakes: a) more Anisoptera larvae were consumed by each species, except black duck, which was due mainly to greater consumption of *Leucorrhinia* by goldeneye and ring-necked ducks, b) hooded mergansers differed from other species by eating twice as many Aeshnidae larvae on acid lakes, and c) nearly four times more recently-emerged, teneral Odonata were consumed by black ducks. On non-acid lakes there was: a) more Trichoptera larvae consumed, particularly by common goldeneyes, and b) more Ephemeroptera consumed, particularly by black ducks. There were no differences between acid and non-acid lakes in the number of sponges (common in diet of ring-necked ducks) or molluscs consumed. Comparing diets in relation to fish presence/absence there was: a) more nekton

consumed on lakes without fish (common goldeneyes and hooded mergansers consumed the most, ring-necked ducks and black ducks took relatively few), and b) differences in the type of nekton consumed on each type of lake, with more Notonectidae (mainly *Notonecta spp*) eaten on fishless lakes and *Graphoderus* (Coleoptera) eaten only on fishless lakes. Hooded mergansers differed from other ducklings in that they consumed many *Dytiscus* larvae (Coleoptera) from lakes with and without fish.

CONCLUSIONS: Diets of ducklings of insectivorous species varied with lake acidity and fish presence in patterns consistent with those observed in the distribution and abundance of some of their prey. Each duckling species was able to exploit those invertebrate prey which were most abundant in acid and fishless lakes, and to compensate, in part, for the reduced biomass of acid sensitive invertebrates. Diet differences among duckling species were related to differences in foraging behaviour and collection date (which reflects hatch date). There is a balance between the negative effects of lake acidity, such as the loss of acid sensitive prey, and the positive effects, such as the loss of other competing insectivores (such as fish and amphibians). The net effects of food abundance on waterfowl will depend on the degree of lake acidification, the degree of acid sensitivity of competitors and their effectiveness as insectivores.

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EDITORIAL COMMENT: A complete list of all taxa identified in gut contents of each species is available upon request.

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PAPER NO.: 95 - 2

YEAR: 1995 **TOPIC:** Research - Waterfowl

The Canadian Wildlife Service LRTAP Biomonitoring Program, Part 1. A Strategy to Monitor the Biological Recovery of Aquatic Ecosystems in Eastern Canada From the Effects of Acid Rain

McNicol, DK, Kerekes, JJ, Mallory, ML, Ross, RK, and Scheuhammer, AM

Canadian Wildlife Service Technical Report 245,
28 pp (1995)

KEY WORDS: wetland acidification, acid precipitation, aquatic ecosystems, recovery, emission controls, biomonitoring, wetland wildlife, loon, eastern Canada

PURPOSE OF STUDY: To track biotic changes expected to occur in sensitive aquatic ecosystems as acidifying emissions in North America are reduced. To evaluate the adequacy of emission control programs to meet environmental objectives to protect aquatic biota important to wildlife.

BACKGROUND: In eastern Canada, 73% of water bodies surveyed, mostly small headwater lakes and wetlands, were located in areas that had a low potential to reduce acidity and thus were considered sensitive to acidification. In Ontario, 43% of the Precambrian Shield portion of the province receives >10 kg/ha/yr wet SO₄ deposition, and supports approximately 192,000 pairs of nesting loons and ducks. Waterfowl were selected as indicators of the biological responses to reduced acid deposition and chemical recovery due to their dependence on the immediate aquatic environment for nest sites, brood protection and food. The common loon is a good indicator species because it is conspicuous, is found across eastern Canada, and its principal food source is fish. Research has indicated a strong negative influence of lake acidity on loon reproductive success. Fish species richness and abundance is adversely affected by increased acidity of wetlands and lakes. Several species of fish have tolerances in the range of pH 5-6; however, below pH 5, few fish survive. Fish exhibit greater tolerance to low pH in highly organic waters, such as is found in Kejimikujik National Park, Nova Scotia. Acidification can increase trace mineral content of fish and invertebrates, posing a risk to wildlife preying on them. A possible consequence is that the reproductive success of piscivores is lower on acid lakes. Several species of invertebrates have pH tolerances in the range of pH 5-6, and many species are influenced by the presence of fish predators. The loss of fish from lakes usually results in decreased diversity but high abundance of acid tolerant invertebrates. Insectivorous waterfowl, such as common goldeneye, are better able to adjust their breeding habits in response to altered habitats than are piscivorous waterfowl. Insectivores will utilize fishless, acid lakes with abundant macroinvertebrates, but prefer lakes with greater diversity of fauna, and avoid lakes containing acid tolerant fish competitors.

BIOMONITORING PROGRAM: The Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program collects long term ecological data using a whole ecosystem approach in each of three regions in Ontario (Algoma, Muskoka, Sudbury) and one in southwestern Nova Scotia (Kejimikujik). Each region contains many highly sensitive lakes and wetlands that exhibit varying degrees of acidification and are expected to respond differently to reductions in acid deposition. The CWS LRTAP Biomonitoring Program is comprised of three main components: 1) monitoring of short term chemical and biological recovery of acid and damaged lakes in the Sudbury area following reductions in local smelter emissions; 2) long term monitoring of small lakes and wetlands which are particularly vulnerable to acidification to establish whether biological recovery occurs at the same rate and to the same degree as in large lakes; and 3) extensive assessment of the reproductive success of fish-eating birds, especially common loons, in relation to recovery of lakes and improved fish populations. A major part of the latter component is the Canadian Lakes Loon Survey (CLLS), a volunteer-based survey program administered by the Long Point Bird Observatory. There are two major modelling components of the program: 1) the Waterfowl Acidification Response Modelling System (WARMS) is used to evaluate effects of acid rain on waterfowl and their habitats in eastern Canada, and is comprised of an existing acidification model linked to fish and waterfowl models; 2) the Integrated Assessment Model (IAM) integrates the knowledge from atmospheric, aquatic, terrestrial and ecological scientists, as well as socio-economists, so that the optimum reduction of SO₂ emissions and costs can be determined.

STUDY AREAS: Algoma (centre 47°01'N, 83°55'W) and Muskoka (centre 45°30'N, 79°06'W) study areas are underlain by Precambrian granitic bedrock, with mixed hardwoods of the Great Lakes-St. Lawrence Forest Zone. In Algoma, bedrock is covered by thin deposits of glacial ground moraine, while in Muskoka bedrock is covered with shallow glacial till. Roughly 240 lakes, many of which were naturally fishless, are studied in each of Algoma and Muskoka. SO₄ deposition in Algoma varies with most areas receiving >20kg/ha/yr, the least of the Ontario study areas. SO₄ deposition at Muskoka is the highest of all study areas, averaging >30kg/ha/yr. The Sudbury area (centre 46°54'N, 80°41'W) has a heterogeneous mixture of surficial deposits that have produced lakes with a broad range of pHs. Combined SO₄ deposition from local and long range sources is slightly less than Muskoka but greater than Algoma. The CWS (Atlantic Region) study area is in Kejimikujik National Park in SW Nova Scotia. This area has forest cover which is a mosaic of softwood, hardwood and mixed stands; the Park represents the most acid sensitive system in Canada. Forty-six lakes are studied, many of which are coloured due to dissolved organics, so the waters tend to have high DOC, low calcium and are naturally acid. Many lakes have pH <5, but only one is fishless. Kejimikujik receives the lowest SO₄ deposition of the four monitoring sites. Under modelling scenarios, Sudbury and Algoma lakes would improve in response to lower deposition inputs, but reductions do not return lakes to conditions predicted prior to industrialization.

DATA COLLECTIONS: Habitats in all study plots were characterized for several physical variables, and lakes are sampled regularly for chemical analyses. Fish species composition has been assessed at all sites. A Food Chain Monitoring Program (FCMP) has been undertaken on a total of 62 small (<20 ha) lakes across a range of pH in each Ontario study area, and collects information on aquatic invertebrates, amphibians and fish. Non-game fish species, including Cyprinidae, yellow perch and white sucker, dominate collections from these lakes. Diversity of aquatic invertebrates increases rapidly as pH increases, and certain species are key indicators of acid stress. There is no evidence to date of improvements in the distribution of leeches in small acid stressed lakes near Sudbury, but surveys suggest that certain waterbird populations are responding to chemical improvements in breeding habitats. Common loons and hooded mergansers have increased from 1985-1995 where the average lake pH is >5.5. No change in cavity-nesting duck densities at Sudbury have been observed to date. At Kejimikujik, loon breeding density has remained fairly stable since 1988, yet the number of young produced/pair at Kejimikujik is lower than in Ontario. Successful breeding is due to pH, fish availability, and nutrient supply. Annual variability in breeding success is due to changing water levels.

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PAPER NO.: 95 - 3

YEAR: 1995 **TOPIC:** Monitoring - General

Trends in Waterfowl Populations: Evidence of Recovery from Acidification

McNicol, DK, Ross, RK, Mallory, ML, and Brisebois, LA

Restoration and Recovery of an Industrial Region, Gunn, J (ed), Springer Verlag, NY, Chapter 16, 205-217 (1995)

KEY WORDS: lake acidification, acid precipitation, waterfowl, fish predation, macroinvertebrates, aquatic habitat, wetlands, Sudbury, regional trends, recovery, WARMS, SPANS, piscivores, insectivores

PURPOSE OF STUDY: To examine trends in waterfowl populations breeding in the Sudbury area as possible evidence of reversibility of acidification. Relationships between the distribution, density, and productivity of waterfowl and various habitat parameters, including pH, are examined.

WATERFOWL AND HABITAT PARAMETERS: The Sudbury study area comprised a 17,000 km² region from southwest (approx. 82°W 46°N) to northeast (approx. 80°W 48°N) of Sudbury, Ontario, generally defined as the zone influenced by past sulphur emissions from Sudbury smelters. The area receives substantial acid precipitation from nearby smelters and from long range transport of air pollutants; many lakes had pH <6.0 in the early 1980's and approximately 25% of lakes continue to have pH less than 5.0 and are fishless. After reductions in sulphur dioxide emissions in the 1970's, acid lakes distant from Sudbury showed marked increases in pH and alkalinity and declines in sulphate between 1980 and 1987, but further improvements to water quality have not been observed. Habitat parameters (including food webs) and waterfowl populations were studied from 1983-1993. Waterfowl that commonly breed in the area include the common loon *Gavia immer*, common goldeneye *Bucephala clangula*, common merganser *Mergus merganser*, hooded merganser *Lophodytes cucullatus*, American black duck *Anas rubripes*, ring-necked duck *Aythya collaris*, mallard *Anas platyrhynchos*, and wood duck *Aix sponsa*. Surveys of breeding populations were undertaken in 83 2x2 km plots across the region (1985-1993), with intensive surveys of waterfowl breeding ecology conducted on 174 lakes and wetlands in the Wanapitei study area (centred at 46°55'N, 80°45'W), 40 km NE of Sudbury. Maps of the distribution of pH, number of wetlands, open water area, and the average breeding densities (indicated breeding pairs per 100 km²) of the eight waterfowl species in the Sudbury area are presented (maps constructed using SPANS) and compared. Few consistent relationships have been found between waterfowl densities, production, and habitat parameters. Invertebrate communities, however, are highly influenced by the presence or absence of fish; small acid lakes contain few fish and large populations of a few acid tolerant invertebrate taxa; larger lakes (>8 ha) contain some acid tolerant fish (e.g. yellow perch) which, coupled with acid stress, reduce invertebrate abundance and diversity.

WATERFOWL SPECIES ACCOUNTS: Patterns in waterfowl species' distribution, density, and productivity, are discussed individually in the context of their habitat requirements (diet, nesting and brood-rearing), and in relation to the recovery of Sudbury area lakes.

Common Loon: feeds primarily on small fish, and are at risk from acid precipitation due to reduced availability and quality of prey. Loons breed less frequently on acid lakes (pH <5.5), and nest attempts on these lakes are often unsuccessful due to higher chick mortality. At Sudbury, breeding densities correlate positively with lake area and pH. Numbers of loons have increased recently in the Sudbury area in medium (5.5-6.3) and high (>6.3) pH areas, presumably related to recovery in water quality and biological communities (most notably fish).

Common Merganser: feeds on small fish, and prefers large, clear lakes and rivers with pH >6.0 that contain fish. Fewer than 1,600 pairs nest in the Sudbury area, with the lowest densities near Sudbury where fish populations continue to be stressed. Production was related to pH, but no population trends were noted among pH classes. While loons raise only one or two chicks and are restricted to their nesting lakes, common mergansers raise many, highly mobile young which tend to move progressively downstream to lakes with a greater food supply.

Common Goldeneye: one of the few species that can exploit acidified environments. Goldeneyes compete with fish for invertebrate prey, thus goldeneyes prefer fishless lakes, most of which are very acid (pH <5.0). Breeding densities have increased on lakes where recovery should be rapid (pH 5.5-6.3), perhaps because invertebrate prey abundance and diversity increased, but fish have not yet been re-established; as pH continues to rise and fish return to many fishless lakes, goldeneye populations are expected to decrease.

Hooded Merganser: prefers small, non-acid, naturally-fishless lakes. Adults feed on small fish, but ducklings feed on aquatic invertebrates and thus compete with fish for prey. Higher breeding densities are found in areas of clustered lakes. Increases in populations were noted at pH extremes, possibly because at low pH young have an easier time finding invertebrate prey in the absence of fish and at high pH adults find an abundance of fish prey. The plastic nature of its feeding habits may allow this species to take advantage of any habitat improvements after recovery.

American Black Duck: is highly adapted to boreal conditions and shows a strong preference for small, clustered ponds. Populations have increased recently, which probably reflects reductions of hunter bag limits. The relationship between black duck populations and pH is unclear and currently under study.

Ring-necked Duck: prefers small, productive wetlands. They have a diverse diet and production of young is highest in lakes at each pH extreme, similar to hooded mergansers. It is possible that at intermediate pHs (5.0-6.3) the combination of fish predation and pH adversely affect invertebrate populations. Due to the lack of relationship between ring-necked duck production and pH, this species has remained relatively stable across pH classes.

Wood Duck: prefers more southerly marshes and small lakes, and is virtually absent in more boreal habitat. Populations have increased recently, but this is unrelated to pH changes. The increase likely reflects an expansion of the species' range due to the sharp increase in numbers in southern Ontario.

Mallard: selects fertile, marsh breeding habitat which is the least affected by pH depression. Mallards are the most abundant duck in the Sudbury area, particularly in the southern portion, and the population is stable in all pH ranges.

FUTURE IMPLICATIONS FOR WATERFOWL: Waterfowl breeding in areas affected by acid precipitation must be monitored for a long period to establish whether a trend of improvement in populations is occurring as lake chemistries recover. The Waterfowl Acidification Response Modelling System (WARMS, software developed jointly by CWS and ESSA Technologies Ltd.), uses pH, lake area, dissolved organic carbon, total phosphorus, and fish presence to predict waterfowl species responses to changing lake chemistry that might arise from emission reductions. WARMS uses an underlying acidification model (ESSA/DFO cation denudation rate) and fish and waterfowl models to estimate eventual steady-state conditions for pre-acidification (original), current, and eventual values of pH, fish presence, and waterfowl breeding parameters under various emission scenarios. Lake pH is predicted to improve dramatically in the Sudbury area, and this will result in the return of fish to many lakes. The return of fish should result in increases in populations of common mergansers, while hooded mergansers and black ducks are expected to increase due to changes in invertebrate assemblages. Broods of common goldeneyes are predicted to decline to pre-acidification levels as fish return. Fish presence, pH, and waterfowl broods are all lower currently, and under future scenarios than levels predicted before acidification.

CONCLUSIONS: While populations of all local waterfowl species should remain stable or move toward pre-acidification levels, continued biological monitoring of Sudbury area lakes is required to refine these predictions, establish rates of recovery, and most importantly, verify that current abatement programs will indeed restore the capacity of sensitive aquatic habitats in the Sudbury area to sustain healthy populations of plants and animals, including waterfowl.

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EDITORIAL COMMENT: This paper was published as Chapter 16 of a book "*Restoration and Recovery of an Industrial Region*, Gunn, J (ed), Springer-Verlag, New York, NY" designed to serve as a model (textbook) for the recovery of industrially-affected ecosystems, using the remarkable improvements in the Sudbury region as an example. Other chapters in the book included input from provincial and municipal government officials, university researchers and local industry.

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PAPER NO.: 95 - 4

YEAR: 1995 **TOPIC:** Monitoring - Waterfowl

Evaluating Macroinvertebrate Responses to Recovery from Acidification in Small Lakes in Ontario, Canada

McNicol, DK, Bendell, BE, and Mallory, ML

Water Air and Soil Pollution 85(1), 451-456 (1995)

KEY WORDS: lake acidification, macroinvertebrates, fish, recovery, Ontario, communities, logistic regression, richness, threshold, modelling, probability

PURPOSE OF STUDY: To determine relationships between macroinvertebrate communities and pH across a broad, affected region in Ontario, to determine the effect of fish on these relationships, and to evaluate whether such data are suited to document biotic responses to lake recovery, and determine what organisms will be key to assessing recovery.

METHODS: Roughly 638 lakes in three regions of Ontario were sampled for fish (10,000 specimens collected): Algoma (46°55' N, 83°35' W); Muskoka (45°23' N, 79°20' W); and Sudbury (46°55' N, 80°45' W). These predominantly small (<8 ha) lakes, with median pHs around 5.7, represented damaged, sensitive and well-buffered waterfowl habitats. Lakes with moderate pH (pH 5-6) predominate in Muskoka, while Algoma and Sudbury contain more acid lakes (pH<5). Macroinvertebrates (25,157 specimens collected) were sampled from 62 core lakes (20 in Algoma, 20 in Muskoka, 22 in Sudbury). Fish and macroinvertebrate sampling occurred in June (1991 - Muskoka, 1992 - Algoma, 1994 - Sudbury) to coincide with peak activity for most waterfowl broods. Sampling methods, intensity and target organisms followed procedures outlined in the Food Chain Monitoring Program, part of the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program. Taxonomic richness was calculated as the number of unique taxa in a lake or sample type. Acid sensitive species (e.g. Gastropoda, Hirudinea, Ephemeroptera (other than *Leptophlebia*), *Hyalella azteca* and *Limnephilus* were tested to determine if their distributions were related to pH.

RESULTS: Twenty-five species of small, non-game fish (16 species in Muskoka; 15 in Algoma; 22 in Sudbury) predominated the sampling, including Cyprinidae, yellow perch and white sucker. Macroinvertebrates representing 159 taxa (Muskoka, 113 taxa; Algoma, 114 taxa; Sudbury, 102 taxa) were collected, with Coleoptera (34 spp), Odonata (27 spp), Hemiptera (25 spp) Hirudinea (12 spp), Gastropoda (12 spp) and Ephemeroptera (9 spp) being the most abundant. Lakes without fish were found across the range of pH and size; however, the number and species richness of fish increased at high pH. Lake size affected the probability of finding fish, with smaller lakes having a much lower probability of supporting fish than larger lakes. Therefore, to determine relationships between pH and macroinvertebrates, the effects of fish were separated. Across regions, average taxonomic

richness and abundance of macroinvertebrates was positively correlated with pH in fishless lakes, but not in lakes with fish. Acid tolerant taxa were more abundant in lakes without fish, yet for acid sensitive taxa, richness was positively correlated with pH for lakes with or without fish. The amphipod *Hyalella azteca* and gastropods (dominated by *Ferrissia parallela* and *Helisoma anceps*) were found in lakes with and without fish, were the most acid sensitive groups, and exhibited predictable distribution patterns with respect to pH, having a 50% probability of being found in lakes with pH 6.1 but never found below pH 5.3. Ephemeroptera, dominated by *Caenis* spp, had a 50% probability of being found in lakes with pH 5.3, but were not found below pH 5.1. *Limnephilus* spp and Hirudinea were collected to pH 4.8. Cumulative patterns in the appearance of acid sensitive taxa with pH increases are modelled.

CONCLUSIONS: To understand changes in macroinvertebrate responses to lake acidity, one must take into account changes in fish populations arising from changes in pH. The range of pH of 5.2-5.5 is an important threshold to support recolonization of acid sensitive macroinvertebrate taxa. As no single taxon reliably covers a broad enough range to totally represent all potential biotic responses, several sensitive taxa across a broad pH gradient are needed to provide sufficient coverage of biotic recovery. Monitoring acid sensitive macroinvertebrates enables one to assess biotic recovery for lakes where pHs vary; however, the influence of fish on taxonomic richness and abundance must be considered.

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EDITORIAL COMMENT: This paper was published as part of the peer-reviewed Proceedings from the 5th International Conference on Acidic Deposition held in Goteborg, Sweden, 26-30 June 1995.

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PAPER NO.: 95 - 5

YEAR: 1995

TOPIC: Research - Invertebrates

Using Volunteers to Monitor the Effects of Acid Precipitation on Common Loon (*Gavia immer*) Reproduction in Canada: the Canadian Lakes Loon Survey

McNicol, DK, Mallory, ML, and Vogel, HS

Water Air and Soil Pollution 85(1), 463-468 (1995)

KEY WORDS: lake acidification, acid precipitation, recovery, common loon, *Gavia immer*, reproduction, Ontario, volunteers, logistic regression

PURPOSE OF STUDY: To assess the utility of gathering data on common loons using volunteers, to examine relationships between lake pH, lake area and loon reproductive success in Ontario, and to demonstrate how these data can be used to track biotic recovery of large, acid sensitive lakes in eastern Canada.

METHODS: Data are collected on lakes of all sizes across Ontario (the principal region of study), but lakes between 2 and 500 ha were used in these analyses (because these lakes typically have less than 3 pairs, so reliability of volunteer data is higher). Volunteers recorded numbers of breeding pairs of loons, the maximum number of downy or small young, and the minimum number of large young on a lake during late nesting (mid-late June), early post hatch (mid July) and when large young are present (late August). Lakes were identified by name and geographic coordinates. Alkalinity, pH and area data were obtained from federal and provincial sources. Records of high quality (i.e. those that were reliable, that represented 100% coverage of a lake, and had good data for all variables) were included for statistical analyses. Out of 4236 volunteer reports covering 1529 lakes (including 76 staff-surveyed lakes), 1730 reports, representing 721 lakes, were used for this study.

RESULTS: Most of the regions in Ontario affected by acid precipitation, and much of the principal breeding range of the common loon were covered by this survey. Advantages of using volunteers outweigh the disadvantages for such data collection, and include cost effectiveness and large regional coverage. Disadvantages of using volunteers include difficulty in ensuring that the same lakes are surveyed each year, especially when loons are not found, and difficulty in obtaining data for acid or small lakes since there are fewer cottagers on these types of lakes. This latter limitation necessitated augmentation by staff surveys so that trends over a broad range of lake types and the potential for recovery could be established. Loon production values (0.78 large young/pair) were comparable to other studies and suggest that volunteer surveys produce realistic data. Results were modelled using logistic regression to describe the probability of loon breeding success. The probability that loons produced at least one large young on a lake was related first to area and then pH. When loons did produce young, they were more likely to produce two chick broods on high pH lakes, and in general loon breeding success was lower on lakes with low pH after controlling for lake area.

To determine whether breeding success of loons exhibited any temporal trends in relation to pH, differences in the productivity (large young / pair) of loons nesting on 101 lakes over three time periods was compared (1987-1988, 1989-1990, 1991-1993). Average productivity was constant on lakes above pH 6.5, while there was a marked decline below pH 6.5. Over the period from 1987 - 1993, 23% of the lakes demonstrated improved loon productivity, 42% declined and 35% had no change. Declines in productivity below pH 6.5 were due to increased numbers of no nesting attempts and unsuccessful attempts. The possibility that these trends reflect variations due to factors other than water chemistry cannot be ruled out, but the patterns observed for low pH lakes are cause for concern.

CONCLUSIONS: The common loon relies on a healthy and diverse fisheries resource to successfully raise its young, and it is threatened by the effects of acid precipitation on sensitive lakes. The most important factor influencing loon reproductive success is the size of the nesting lake; however, loons avoid breeding on acid lakes, and if breeding is attempted, they are less successful on acid lakes. It is speculated that adult loons may have difficulty finding enough food to successfully rear chicks on acid stressed lakes. Over the period of the study, the reproductive success of loons declined on lower pH lakes, while it remained stable on high pH lakes, although trends were not conclusive.

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ACKNOWLEDGEMENTS: The Canadian Wildlife Service (Ontario Region) acknowledges the Long Point Bird Observatory which administers the volunteer-based Canadian Lakes Loon Survey, and the many dedicated volunteers that contributed the information presented in this paper. If you are interested in participating in this volunteer survey or would like more information, please contact: The Canadian Lakes Loon Survey c/o Long Point Bird Observatory, P.O. Box 160, Port Rowan, ON, N0E 1M0.

EDITORIAL COMMENT: This paper was published as part of the peer-reviewed Proceedings from the 5th International Conference on Acidic Deposition held in Göteborg, Sweden, 26-30 June 1995.

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PAPER NO.: 95 - 6

YEAR: 1995

TOPIC: Monitoring - Loons

Assessing Biological Recovery of Acid-Sensitive Lakes in Ontario, Canada

McNicol, DK, Mallory, ML, and Wedeles, CHR

Water Air and Soil Pollution 85(1), 457-462 (1995)

KEY WORDS: acid precipitation, recovery, fish, lakes, wetlands, modelling, logistic regression, Ontario, waterfowl, WARMS, emission reduction scenarios

PURPOSE OF STUDY: To estimate current damage to breeding habitats of selected waterfowl species (including common loons) in three acid sensitive regions of Ontario, and predict eventual benefits of sulphur dioxide (SO₂) emission reduction scenarios, by applying the Waterfowl Acidification Response Modelling System (WARMS).

BACKGROUND: The WARMS software was developed by ESSA Technologies Ltd to help the Canadian Wildlife Service (CWS) examine the possible effects of acid precipitation on waterfowl and their breeding habitats in eastern Canada. WARMS is based upon a model of the effects of atmospheric acid deposition on lake chemistry (the ESSA/DFO Acidification model - a cation denudation rate model) that has been modified to incorporate the effects of dissolved organic carbon on acidity projections - see Marmorek et al. 1996). This steady-state model is combined with user-defined relationships between physical and chemical lake characteristics and indicators of waterfowl reproductive success (e.g. presence/absence of breeding pairs or broods) to estimate the effects of acid deposition on waterfowl habitat suitability. WARMS is intended to be used as a gaming tool to facilitate more complex analyses: by manipulating various relationship parameters, users can test hypotheses about the effects of acid precipitation on waterfowl.

METHODS: Three regions of Ontario were selected for the analysis: two 100 x 100 km blocks at Algoma (47°01'N, 83°55'W; 170 lakes) and Muskoka (45°30'N, 79°06'W; 668 lakes) and an irregularly shaped area stretching southwest to northeast of Sudbury (roughly 17000 km²; 228 lakes). All three sites have more acid stressed lakes than likely occur naturally, with Sudbury experiencing the most historical damage due to local SO₂ smelter emissions. The analysis using WARMS is based on deposition values derived from 1980 SO₂ emission values, lake chemistries derived from federal and provincial sampling, and an acidification model (ESSA/DFO) that predicts eventual steady-state chemical status of lakes based on current lake chemistry, watershed morphology, runoff, observed SO₂ deposition, and constant values of watershed neutralization. The acidification model simulates sulphur deposition and excludes nitrate and ammonium as they are assumed to have no net acidifying effect. This acidification model is linked to fish, waterfowl and common loon models developed for these regions to predict probabilities of finding a breeding pair or brood of each species on each lake based on lake characteristics and predicted chemical change. The fish model uses a predictive logistic equation derived for small fish species. Three scenarios are simulated: 1) emissions remain constant at 1980 levels; 2) emissions are reduced by 50% of 1980 levels in Canada only; and 3) emissions are reduced by 50% in Canada and the US, following full implementation of SO₂ control programs.

RESULTS: *Chemistry Predictions* - original, current and eventual pH distributions varied under each scenario. Muskoka and Sudbury had similar pH distributions with a smaller pH range, whereas Algoma had a broader pH range. Lake chemistries at Algoma and

Muskoka deteriorate under scenario 1; scenario 2 results in further damage at Muskoka as deposition remains high, and many lakes are sensitive. Algoma exhibits only a slight decline in pH as most deposition arises from the US. Scenario 3 results in improvements to Algoma, and maintenance of conditions at Muskoka. Because of the extent of historical damage, all three scenarios result in improvements in Sudbury lake chemistries. However, none of the proposed emission reductions return lakes to conditions predicted prior to industrialization.

Fish and Waterfowl Predictions - scenario 1 results in further loss of fish, with Sudbury suffering the greatest damage. Scenarios 2 and 3 result in increased numbers of lakes containing fish, with the most dramatic change in Sudbury, and the least in Algoma. Nonetheless, scenario 3 still results in 10% of lakes still lacking fish compared to original conditions. Brood relationships for common merganser and common loon (both of which rely on fish as prey and fare poorly under acid conditions), common goldeneye (an insectivorous diving duck), and black duck (typically a generalist but insectivorous during the breeding season) were examined. Effects on waterfowl broods were greatest at Sudbury and lowest in Algoma. Predicted presence of mergansers and loons is higher than other species in Muskoka, yet habitat for these species has deteriorated due to declines in lake pH and loss of fish habitat. Scenario 3 is required to maintain current piscivore habitat suitability in Muskoka; the other scenarios result in continued habitat decline. Goldeneye habitat suitability is expected to decline at all sites under all scenarios (to original, pre-acidification levels). Under all scenarios, little change is expected for black duck habitat in Algoma, with some decline in Muskoka.

CONCLUSIONS: WARMS was developed to estimate responses of waterfowl, loons and their breeding habitats to predicted changes in acid deposition following SO₂ emission reductions. Predicted responses by waterfowl to emission reductions are a result of changes in the fish status in lakes. Fish-eating species suffer under scenarios where fish are reduced. In contrast, the common goldeneye may benefit in the absence of fish, but suffer under low pH since the diversity of invertebrates declines.

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EDITORIAL COMMENT: This paper was published as part of the peer-reviewed Proceedings from the 5th International Conference on Acidic Deposition held in Goteborg, Sweden, 26-30 June 1995. The present version of WARMS for Windows (version 2.4, April 1996) includes several important new features (for more information, contact Don McNicol).

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PAPER NO.: 95 - 7

YEAR: 1995

TOPIC: Modelling - Waterfowl

Lake Acidity and the Seasonality, Distribution and Abundance of Macroinvertebrates and Waterfowl Broods Near Sudbury, Canada

Sinden, SK

MSc Thesis, University of Wales, Cardiff College
123 pp (1995)

KEY WORDS: lake acidification, headwaters, acid precipitation, waterfowl broods, macroinvertebrates, phenology, fish predation, Sudbury, recovery, littoral zone, nekton, benthos

PURPOSE OF STUDY: To determine the relationship between lake acidity and the phenology of aquatic insects known to be important foods for waterfowl.

METHODS: Ten small headwater lakes and wetlands in the Wanapitei area (46°45'N, 80°45'W), 40 km NE of Sudbury were studied. This area has been affected by acid precipitation due to emissions from local smelters and from long range transport of air pollutants resulting in a high proportion of acid lakes (range of pH 4.1-7.6). Recent reductions in local SO₂ emissions has resulted in some biological and chemical recovery. The lakes selected for the study varied in fish community (no fish, low predation, high predation), water chemistry (pH, total phosphorus, DOC) and recovery status. Nine of the lakes were <7 ha, while the other was 12 ha in size. Fifteen random sites in the littoral zone of each lake were used for macroinvertebrate sampling, collected on five occasions during the summer (18-23 May, 8-12 June, 30 June - 3 July, 13-16 July, 3-7 August). Water samples were taken at each lake at each macroinvertebrate sampling. Five of the sites were used to sample nektonic macroinvertebrates by sweep net, performed using a D-frame dip net swept ten consecutive times in an arc in water 0.3 to 1 m deep over the bow of a forward-moving canoe. Another five of the sites were used for benthic net drags, conducted by dragging a D-frame dip net along the surface of the sediment for 0.5 m in water < 1 m deep. The last five sites were used for trichopteran larvae sampling using a hoop tossed into water < 0.5 m deep to define an area for visual sampling; trichopteran cases were hand picked from the substrate or vegetation. These techniques are identical to those used in the Canadian Wildlife Service (Ontario Region) LRTAP Biomonitoring Program (Food Chain Monitoring Component - see Paper No. 96-2). All samples were preserved for later identification to genus. Fish community status was determined using baited minnow traps placed in the littoral zone of each lake for 24 h. Waterfowl surveys were made from the ground and from the air as part of the CWS (OR) LRTAP Biomonitoring Program (see Paper No. 95-3).

RESULTS: Fish were absent in five of the ten lakes and larval Odonata, Trichoptera, Coleoptera and Hemiptera were all more abundant in these lakes. Eleven species of fish were found, four cyprinids and seven non-cyprinids (eg. yellow perch, white suckers). No correlation was found between Odonata, Coleoptera or Hemiptera abundance and lake pH, while Trichoptera showed a positive correlation with pH. In most lakes, Odonata were dominated by *Leucorrhinia* spp. *Libellula julia*, and *Cordulia shurtleffi*. *Leucorrhinia* spp occurred in the highest densities and tended to be more abundant in acid, fishless lakes. Trichoptera were dominated by *Limnephilus* spp and *Banksiola* spp, with the former favouring

neutral lakes at pH >5.5. Coleoptera were dominated by immature *Hydaticus* spp and mature *Gyrinus* spp. For Hemiptera, Notonectidae dominated in lakes without fish, while Gerridae dominated in lakes with fish. Six species of waterfowl, one piscivore and five insectivores, were common to the area: common merganser (*Mergus merganser*, piscivore), common goldeneye (*Bucephala clangula*), hooded merganser (*Lophodytes cucullatus*), wood duck (*Aix sponsa*), ring-necked duck (*Aythya collaris*) and American black duck (*Anas rubripes*). Duck broods, except common merganser, were most commonly found on acid, fishless lakes. Mean brood size of ring-necked ducks differed between lake types (neutral/fish, neutral/fishless, acid/fish, acid/fishless). Number of broods of ring-necked ducks and wood ducks showed the highest correlation with Odonata and Coleoptera abundance, while numbers of broods of the other four species showed high correlations with Trichopteran abundance. Mean brood size of wood ducks and common mergansers were related to numbers of Odonata, Trichoptera and Coleoptera, while mean brood size of ring-necked ducks was related to numbers of Trichoptera, Hemiptera and Coleoptera around brood hatch date.

CONCLUSIONS: The four main invertebrate groups important as waterfowl food (Odonata, Trichoptera, Hemiptera, Coleoptera) were found in higher numbers in fishless lakes, but their numbers varied seasonally. Thus, fish predation seems to be the most important factor affecting invertebrate abundance. pH did not appear to have a strong influence on the abundance of most groups of macroinvertebrates in these Sudbury area lakes. Waterfowl broods appear to exploit the macroinvertebrates which are the most abundant.

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EDITORIAL COMMENTS: As part of the CWS (Ontario Region) LRTAP Biomonitoring Program, the objectives of this thesis were to provide data that would test the appropriateness of the timing of the Food Chain Monitoring Program with respect to the chronology of invertebrate emergence and abundance (i.e. waterfowl foods) in small lakes and wetlands in central Ontario. Data were also gathered to correlate waterfowl brood phenology and the availability of key foods in lakes and wetlands, particularly in relation to lake chemistries. CWS wishes to acknowledge the contribution made by Dr. Steve Ormerod, Ms. Sinden's supervisor, in supporting this project.

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PAPER NO.: 95 - 8

YEAR: 1995

TOPIC: Research - Invertebrates

Presence or Absence of Fish as a Cue to Macroinvertebrate Abundance in Boreal Wetlands

Mallory, ML, Blancher, PJ, Weatherhead, PJ, and McNicol, DK

Hydrobiologia 279/280, 345-351 (1994)

KEY WORDS: lake acidification, acid precipitation, seasonal variation, macroinvertebrates, fish predation, waterfowl, habitat selection, wetlands, ranks, linear regression, variance, boreal, Ontario

PURPOSE OF STUDY: To test whether the presence or absence of fish is a reliable indicator of invertebrate prey abundance for waterfowl rather than sampling the invertebrates themselves.

METHODS: Data on fish and invertebrate abundance and water chemistry in 30 small, acid, oligotrophic, organic peatlands from two areas in northeastern Ontario (Ranger Lake, 46°55'N, 83°35'W, 40 km NE of Sault Ste. Marie, and Wanapitei, 46°55'N, 80°45'W, 50 km NE of Sudbury) were collected in 1985. The presence or absence of fish was determined using baited minnow traps. During each of five sampling periods (late May, early June, late June, mid-July, mid-August), five samples of invertebrate populations were collected per wetland using a dip-net, with one sweep through the water column and one sweep along the benthic surface around the perimeter of the open water pool. Organisms were counted and identified to family. Based on dietary studies of four common waterfowl species in these study areas (common goldeneye, hooded merganser, American black duck, and ring-necked duck), the number of macroinvertebrates that were important food for waterfowl were added in each sample. Macroinvertebrates included Odonata, Trichoptera, Corixidae, Notonectidae, Dytiscidae, Gyrinidae and Hirudinea. Wetlands were ranked from fewest to greatest number of invertebrates. To test whether invertebrate abundance at one time could predict the rank of wetlands at other times, the rank of each wetland at one sampling period was compared to its combined rank determined from the remaining four periods.

RESULTS: Of the 30 wetlands studied, 12 contained fish (eight species, mostly cyprinids) and 18 were fishless. There was no effect of study area on macroinvertebrate numbers, thus the two study areas were combined for the analyses. Invertebrate abundance differed among sampling periods, fish status (presence or absence) and individual wetlands. Of the variance in invertebrate abundance, 21% was explained by differences among sampling periods (numbers were higher in July and August), 48% by differences among wetlands, and 36% by fish status (abundance was higher in fishless wetlands in all sampling periods). When the influences of sampling period were removed, fish status explained 76% of the variance in invertebrate abundance. Invertebrate abundance

also differed among wetlands with the same fish status, suggesting that factors other than the presence or absence of fish influence the relative abundance of invertebrates. For example, invertebrate abundance was positively related to pH in fishless wetlands, but not wetlands containing fish. There was a large amount of variation in the rank of a wetland (based on invertebrate abundance) among sampling periods. Classifying wetlands on the basis of fish status was as accurate as that obtained by using invertebrate samples directly. The difference between predicted wetland rank and the actual rank of a wetland was slightly less where the predictions were based on fish status compared to predictions based directly on invertebrate abundance.

CONCLUSIONS: Fishless wetlands generally had more macroinvertebrates per sample than wetlands with fish. The presence or absence of fish appears to be a reliable cue to present and future invertebrate abundance in a wetland. Such a cue could be used by waterfowl (particularly insectivores, such as common goldeneye and hooded merganser) to assess relative food resources among wetlands, and would be most effective where temporal variation in invertebrate abundance is large. It is likely that historical changes in acidity, resulting from anthropogenic inputs, may reduce or alter the reliability of fish status as a cue to invertebrate food resources. Further research is needed to assess long term effects of acidification on fish status, invertebrate abundance and waterfowl distribution.

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EDITORIAL COMMENT: This paper was published as part of the peer reviewed Proceedings of the "Aquatic Birds in the Trophic Web of Lakes" Symposium held in August, 1991 at Sackville, New Brunswick, Canada (*JJ Kerekes, ed.*).

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PAPER NO.: 94 - 1

YEAR: 1994

TOPIC: Research - Trophic Relations

Habitat Quality and Reproductive Effort of Common Goldeneyes Nesting Near Sudbury, Canada

Mallory, ML, McNicol, DK, and Weatherhead, PJ

Journal of Wildlife Management 58 (3), 552-560 (1994)

KEY WORDS: habitat quality, common goldeneyes, reproduction, acid precipitation, female quality, aquatic invertebrates, *Bucephala clangula*, ANCOVA, clutch size, breeding experience, Sudbury, nest parasitism

PURPOSE OF STUDY: To examine the relationships of habitat quality and female quality on female reproductive effort in common goldeneyes nesting in an acid-stressed area.

METHODS: This study was carried out on 24 of the approximately 378 small lakes and wetlands in the Wanapitei study area, 40-70 km NE of Sudbury, Ontario (centred at 46°55'N, 80°45'W) and covering 460 km². The area has been affected by acid precipitation from nearby smelters and from long range transport of air pollutants, resulting in a high proportion of acid waterbodies that are now fishless. The lakes in this study were small (average 5.8 ha) and acid (average pH 5.3). Female goldeneyes nested in previously established nest boxes; approximately 50% of available boxes were used in a given year and most females (80%) nesting in the area chose the boxes compared to 20% which used natural cavities. Habitat quality was indexed by the relative abundance of food resources (aquatic macroinvertebrates), which was indirectly assessed by the presence or absence of fish in the wetland (fish absent = high quality, fish present = low quality). Fish presence was determined using minnow traps. For many waterfowl, female body mass in early incubation is an indicator of female quality. In 1989-1990, female goldeneyes were captured in their nest boxes and banded (if not previously done) and weighed. Female mass was also recorded in the nest box by remote monitors to determine incubation mass loss. A mass loss regression was calculated from this data. Female quality was assessed by their mass at the onset of incubation (calculated from the mass loss equation) and by breeding experience (females were considered experienced if they had been captured on the study area in a previous year). Common goldeneyes regularly parasitize nests of conspecifics, and to eliminate the confounding effects this would pose, parasitized nests were not included in the analyses. Egg mass was highly correlated with length and width, thus the latter measures were taken throughout incubation. Clutch mass was determined as the sum of the masses of each egg in a clutch.

RESULTS: Mean clutch size was 8.3, mean egg mass was 66.2 g and mean clutch mass was 541.1 g for 31 unparasitized nests. Clutch initiation dates, clutch size and egg masses were similar in all years. Habitat quality affected mean clutch mass (clutches on lakes without fish averaged 566.1 g; with fish,

504.9 g) and clutch size (average 8.7 vs 7.5 for lakes without and with fish, respectively), but not egg mass, clutch initiation date, or female mass. Female quality affected nest initiation date (heavier and experienced females nested earlier), and nest initiation date affected clutch mass (earlier clutches were heavier). However, clutch mass was not correlated with female quality. Clutches were larger on lakes without fish and for early-nesting females, but clutch size was not correlated with female mass or experience. Egg mass was not related to clutch initiation date, clutch size, or female mass, but did show a weak positive correlation with female experience (average mass 70.0 g vs 65.3 g for experienced vs inexperienced females, respectively).

CONCLUSIONS: The amount of resources female goldeneyes invested in a clutch was greater in lakes without fish, which was an indicator of high quality habitat with respect to invertebrate food abundance. It appears that female goldeneyes can modify their reproductive effort (in this study, primarily through changes in clutch size) in response to the food supply, as has been found for other insectivorous birds. The benefits of the absence of fish in acidified lakes may mask the adverse effects of acidity, such as the loss of certain mineral-rich foods, costs associated with raising young on lakes containing a simplified, acid tolerant food web, and chronic, sublethal effects on physiology and survival. A more thorough understanding of the breeding biology of goldeneyes in acid stressed areas and an assessment of how and why the birds respond to acidification are needed.

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EDITORIAL COMMENT: This work was conducted as part of a larger study undertaken by the Canadian Wildlife Service (Ontario Region) to investigate the effects of acid precipitation on waterfowl, loons and their habitats in acid-sensitive regions of Ontario as part of Environment Canada's Long Range Transport of Air Pollutants (LRTAP) program..

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PAPER NO.: 94 - 2

YEAR: 1994

TOPIC: Research - Waterfowl

Trends in Small Lake Water Chemistry Near Sudbury, Canada, 1983-1991

McNicol, DK, and Mallory, ML

Water Air and Soil Pollution 73, 105-120 (1994)

KEY WORDS: water chemistry, lake acidification, aquatic ecosystem, waterfowl, pH, precipitation, trace metals, Sudbury, recovery, flushing index

PURPOSE OF STUDY: To determine whether chemical recovery, documented in large lakes after reduction in sulphate deposition in the Sudbury area, was also occurring in the small lakes which are vital habitat for breeding waterfowl.

METHODS: The Wanapitei study area, located 40 km NE of Sudbury (centred at 46°55'N, 80°45'W) and extending over 460 km², has been affected by nearby smelting emissions and by long range air pollution. The study was limited to small (1-10 ha) and shallow (0.6-15 m) lakes (most of which have no inflow from other surface waters). Locations (geographic coordinates) of all lakes sampled are provided in an appendix, with core, study and secondary lakes designated. Small lakes provide important breeding habitat for waterfowl, and there is a lack of information on their chemistry and recovery from acidification. Surface area and linear distance from the smelter at Copper Cliff were determined for each lake, as well as a flushing index (FI) representing the rate of water replacement. The yearly FI for each lake is the product of surface area (ha) and mid-lake depth (m) divided by the product of watershed area (ha) and mean annual precipitation (m yr⁻¹). Water samples (mid-lake surface grabs from a helicopter) were collected in late October/early November, i.e. after the autumn water turnover, in 1984, 1986, 1987, and 1991. Samples were also obtained as shoreline surface grabs in late June 1983 and late August 1990, although the former were subsequently excluded from analysis because they had been obtained just a few weeks after the spring snowmelt. A total of 23 chemical parameters were measured for each lake (pH, conductivity, alkalinity [ANC], calcium [Ca], magnesium [Mg], sodium [Na], potassium [K], chloride [Cl], sulphate [SO₄], silica [SiO₂], dissolved organic carbon [DOC], total phosphorus [TP], ammonia [NH₃], total Kjeldahl nitrogen [TKN], nitrate+nitrite [NO₂NO₃], aluminum [Al], manganese [Mn], iron [Fe], copper [Cu], nickel [Ni], zinc [Zn], lead [Pb], cadmium [Cd]).

RESULTS: There were 97 "study" lakes (small and shallow by the size criteria set up in this study) and 55 "secondary" lakes (whose size exceeded the size limits). The study lakes were found to: a) replace water twice as often as secondary lakes; b) be more acid; c) have lower ANC and levels of base cations (sum of Ca+Mg+K+Na) and SO₄; and d) have higher concentrations of trace metals, particularly Al, Mn, and Ni. The Al and Mn concentrations were significantly correlated with pH, while Ni levels were somewhat correlated with distance from the smelter. Comparisons between 1984 and

1991 results obtained from 68 of the 97 study lakes indicated significant reductions in concentrations of SO₄, Al and Mn, and an increase in acidity over time. There seemed to have been no improvement in ANC over the study period. A decline in average pH was observed from 5.50 ± 0.11 in 1984 to 5.38 ± 0.11 in 1991. Conditions seemed to improve between 1983 and 1987, but worsened again between 1987 and 1991. For all lakes an increase in Ca and Mg concentrations were noted between 1984 and 1987, while Al levels decreased. Between 1987 and 1991 this pattern was reversed. Annual precipitation varied markedly over this period: the average for this area is 861 mm, but only 704 mm was recorded for 1987.

CONCLUSIONS: Most of the lakes studied over a nine year period remain acidified or seriously acid stressed, and 77% have ANC's of 40 µeq/L or lower. In addition, pH levels in 58% of these lakes are 5.5 or lower, a condition under which biological damage to aquatic organisms occurs. Taking steps to return these highly acid waters to pH levels above 5.0 may allow recolonization with some acid tolerant fish and invertebrate species, which would restore acceptable aquatic ecosystem conditions for boreal waterfowl species. While measures to reduce local emissions (like those from the nearby smelter in this study) have been beneficial, sustained and significant recovery of small lakes, whose water chemistry responds quickly to atmospheric precipitations, is only to be expected with further reductions in acidifying pollutants.

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EDITORIAL COMMENT: "Acidification of soils and waters is one of the most important environmental problems. This problem has been studied extensively, but there is still limited information on how a catchment responds to changed deposition of acidifying compounds. This article contributes to filling that knowledge gap." *Hans M Seip, cited in QUINTESENCE, Excellence in Environmental Contamination and Toxicology* 1(2): 55 (1994).

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PAPER NO.: 94 - 3

YEAR: 1994

TOPIC: Monitoring - Chemistry

Movements and Survival of Common Goldeneye Broods Near Sudbury, Ontario, Canada

Wayland, M, and McNicol, DK

Canadian Journal of Zoology 72 (7), 1252-1259 (1994)

KEY WORDS: common goldeneye, *Bucephala clangula*, lake acidification, acid precipitation, broods, habitat, survival, Sudbury, Ontario, discriminant function analysis, logistic regression, daily survival rates, prey biomass, juxtaposition, brood movements

PURPOSE OF STUDY: To determine if movements and survival of common goldeneye broods are affected by food availability and proximity of neighbouring lakes in an acid-stressed area.

METHODS: The 460 km² Wanapitei study area (46°55'N, 80°45'W), 40 km NE of Sudbury, Ontario, contains 378 small lakes (1-20 ha), the size preferred by breeding common goldeneyes. Nest boxes were erected on 68 of these lakes in 1986 and 1988. Lakes ranged from clear, rock-bottomed headwater lakes to dark-coloured (high humic content) wetlands. Because of poor buffering capacity and proximity to smelters at Sudbury, many of the lakes were acid (pH <5.0) and lacked fish and acid sensitive invertebrates. In 1989 and 1990, female goldeneyes were captured in their nest boxes, banded, and individually marked with nasal discs. Hatch dates and number of ducklings were determined by visiting the nest, and then broods were located by surveying the nearby lakes. At each brood survey, ducklings were counted and ages estimated as class I (<21 days old) or II (21-45 days old). Broods were surveyed on average every seven days. Mortality was assumed to have occurred when brood size decreased between visits (consistent over time). Food availability was determined by sampling invertebrates in the water column and in the sediment (five samples of each method per lake). Invertebrates were sorted, identified, counted, dried and weighed, and a single measure of prey biomass was derived for each lake from the two sampling techniques. Mean distance to the three nearest neighbouring lakes (lake juxtaposition) was determined from aerial photographs. Only lakes between 1 and 20 ha were considered. Brood movements were measured as the shortest linear distance between the origin and destination lakes. Stepwise discriminant function analysis was used to determine whether prey biomass and lake juxtaposition contributed to the differentiation between nesting and initial brood-rearing lakes and between initial and subsequent brood-rearing lakes. The effect of brood movements on duckling survival was evaluated by a) regressing number of deaths against duckling age and linear distance moved, and b) using logistic regression analysis to determine whether the likelihood of a death occurring between successive sightings was related to whether the brood had moved or not. Daily survival rates for each brood were calculated separately for the two different age-classes (I and II).

RESULTS: There were 33 brood movements from the nesting lake to a brood-rearing lake by 17 broods recorded over the two years. Four broods did not move from their nesting lake, and seven broods undertook 17 secondary movements from one rearing lake to another. Distances travelled between nesting and initial brood-rearing lakes (mean 1400 m) were greater than those between rearing lakes (mean 162 m). Prey biomass and lake juxtaposition contributed significantly to the separation between nesting and initial brood-rearing lakes, suggesting that movements from nesting to initial rearing lakes were related to food and landscape. Compared to

nesting lakes, brood-rearing lakes contained higher prey biomass (standardized index of -0.32 for nesting lakes, 0.41 for brood-rearing lakes), and were more clustered (mean distance to neighbouring lakes 792 m for nesting lakes, 427 m for brood-rearing lakes). Movements from one brood-rearing lake to another were unrelated to prey biomass or lake juxtaposition. Secondary brood movements occurred more frequently when brood-rearing lakes were clustered than when isolated. Twenty-eight broods were observed a total of 191 times over the two years. Out of 227 ducklings, 106 losses were recorded. At least five females lost entire broods, and at least 49 ducklings survived to 45 days of age. Survival estimates using ducklings as replicates were 0.53 and 0.31 for 1989 and 1990, respectively, with an overall rate for the two years of 0.41. Using broods as replicates, the survival rates of age class I (0.96 for both years) and age class II (1.0 for both years) did not differ between years. After controlling for duckling age, there was no effect of distance moved on the number of duckling deaths recorded during the intervals in which movements occurred. After controlling for duckling age and interval length, the likelihood of a death occurring during an interval was not related to whether a movement occurred during that interval. Daily survival rates of class I and II ducklings on high-prey lakes did not differ from that on low-prey lakes. Within-lake invertebrate sampling variability was high, suggesting that the designation of lakes as high or low prey may not reflect large differences between lakes. The daily survival rate for class I ducklings on clustered lakes was higher than for isolated lakes, but there was no difference noted for class II ducklings.

CONCLUSIONS: An abundant invertebrate supply and the close proximity of neighbouring lakes are important in the selection of brood-rearing lakes for common goldeneyes. Duckling survival was not affected by prey abundance, but may be influenced by prey quality. Brood survival was higher on clustered lakes, possibly because they are better able to move if conditions on the lake become less favourable. The relatively high densities of invertebrates, likely the result of an acidification-induced eradication of fish populations in many lakes in the Sudbury area, coupled with the high density and extreme clustering of many of these lakes, have probably created a situation favourable to the survival of goldeneye broods. This conclusion must be regarded cautiously until more information is available concerning the effects of dietary calcium on growth and survival of goldeneyes, and until comparative survival studies are done in more typical habitat.

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PAPER NO.: 94 - 4

YEAR: 1994

TOPIC: Research - Waterfowl

Gastropods from Small Northeastern Ontario Lakes: their Value as Indicators of Acidification

Bendell, BE, and McNicol, DK

Canadian Field-Naturalist 107(3), 267-272 (1993)

KEY WORDS: gastropoda, lakes, northeastern Ontario, acid precipitation, lake acidification, indicator, calcium, phosphorus, Sudbury, benthic sampling, linear regression, visual searches, littoral zone

PURPOSE OF STUDY: To document the distribution and relative abundances of gastropods in headwater lakes because they are a potentially important source of calcium for breeding waterfowl. To assess the value of gastropods as an indicator of acidification of small, calcium-poor lakes.

METHODS: Invertebrates were sampled in 20 small (1.9-7.8 ha) headwater lakes in an area 40 km NE of Sudbury, Ontario (centred 46° 54'N, 80° 41'W). Many lakes in the area are acid due to sulphur dioxide emissions from nearby smelters at Sudbury and from long range transport of air pollutants, and as a consequence many have lost their fish populations. Nonetheless, some lakes remain unacidified and have retained their fish populations, and others are naturally fishless although high in pH. In 1985, benthic samples were taken twice (July and August) from 10 randomly selected sites per lake in water <1.0 m deep using a D-frame net which removed a strip of substrate. Macroinvertebrates, including gastropods, were removed for later counting and identification. The sampling procedure was repeated in 1988 and 1989 as part of another study (see Paper No. 92-3). Between June and mid-July, 10 benthic samples were collected once from eight additional lakes with pH <5.0, 12 with pH 5.0-5.5, and 10 with pH 5.5-6.0. Benthic sampling, however, did not effectively sample gastropods occurring at low densities in these small, oligotrophic lakes. There was little submerged aquatic vegetation in our study lakes, and gastropods were often associated with woody detritus. Therefore, a more intense survey was undertaken in late August-early September 1985 in 15 of 20 previously sampled lakes with pH >5.0. Ten 5 m sections of shoreline were visually searched by two persons, with all substrate, detritus and vegetation in the littoral zone in each sector (< 0.5 m depth) covered within 0.5 h. The pH of surface water was determined during July 1985, and in 1984 and 1986 surface water samples were taken for more complete chemical analysis, including pH, alkalinity, major ions (including calcium), and nutrients (including total phosphorus).

RESULTS: Eleven species of pulmonate gastropods were found among 11 of 15 lakes sampled with the visual technique. Benthic sampling was less effective, with only 21 occurrences of species in lakes, compared to 39 occurrences with the visual search technique. Neither technique adequately recorded the most widespread gastropod found in visual searches, the limpet *Ferrissia* sp. A total of 1,519 gastropods were collected by visual searches, and 49% of these were from a single lake. This lake had lower calcium levels than most lakes, but had the highest total phosphorous concentration. Overall, densities were low with the average

number of gastropods found in visual searches of lakes with pH >6.0 only 1.7 m⁻¹ of shoreline. *Ferrissia* was the only gastropod occurring below pH 6.0, where it occurred in two of six lakes. At least one of either the tadpole snail, *Physella gyrina*, and the ramshorn snail, *Helisoma anceps*, occurred in each lake with pH >6.0; together, they comprised 71% of all gastropods collected by visual searches. The number of gastropod species was 3.6 in lakes of pH 6.0-7.0 and 5.5 in lakes of pH >7.0. There was a significant correlation between mean total phosphorous concentrations and the log_e number of gastropods in visual searches. Among lakes with pH >6.0, four lakes with fish did not differ from five without fish in the number of individuals or species of gastropods. Gastropods were not found in any benthic samples from 13 lakes with pH <5.0.

CONCLUSIONS: Gastropod distribution was limited by acidity below pH 6.0. Above pH 6.0, gastropod numbers were positively correlated with total phosphorous concentrations, which suggests a relationship to food resources and nutrient supply. The response of gastropods to acidification is best described by a model which assumes a minimal pH threshold above which populations do not respond to changes in pH, but below which they disappear over a narrow range of pH. Although gastropods are among the most acid sensitive organisms, monitoring them will not provide an early warning of acidification above pH 6.0, and before other sensitive organisms are affected. Species are often missed in sampling programs, and may be more difficult to monitor than other acid sensitive groups.

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EDITORIAL COMMENT: The authors would like to thank Dr. Francis Cook of the Canadian Museum of Nature for his assistance in the publication of this work.

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PAPER NO.: 93 - 1

YEAR: 1993

TOPIC: Research - Invertebrates

Acidic Depositions: Effects on Wildlife and Habitats

Longcore, JR, Boyd, H, Brooks, RT, Haramis, GM, McNicol, DK, Newman, JR, Smith, KA, and Stearns, F

Wildlife Society Technical Review 93-1, 42 pp (1993)

KEY WORDS: wildlife, terrestrial ecosystem, acid precipitation, habitat, sensitivity, acid neutralizing capacity, watersheds, North America, soils, trace metals, vegetation, mammals, birds, food web, reproduction, amphibians, reptiles

PURPOSE OF STUDY: To review current information on the effect of acid precipitation on wildlife, with emphasis on the terrestrial ecosystem.

SENSITIVITY OF HABITAT TO ACIDIC DEPOSITIONS: Effects of acidic depositions are variable and depend upon the type of underlying bedrock. Acid-neutralizing capacity (ANC) is related to mineral solubility and properties of the soil. Most of northeastern North America and the Rocky Mountain area (91% of NE and SE states, 46% of land area in Canada) are sensitive to acidic deposition. Many of these sensitive areas receive enough wet sulphate deposition (> 20kg/ha/yr) that they are acidified.

CHANGES IN ACIDIC DEPOSITION: Acid precipitation has occurred throughout the NE United States (US) since 1950-1955, with 65% of the acidity caused by H_2SO_4 and 30% by HNO_3 . The area receiving acid precipitation has expanded southward and westward with intensification of acidity in the NE and SE regions of the US. In eastern Canada, significant decreases in amounts of sulphate in precipitation (up to 30%) have been recorded in the last decade.

EFFECTS ON HABITATS: Soils - Acid rain may adversely affect soil productivity and other soil characteristics (including decreased pH and increased trace metal concentrations), potentially causing soils to become so acidified that they no longer support vegetation. Loss of vegetation from watersheds may lead to increased soil erosion and increased sedimentation in streams, which would adversely affect aquatic organisms. Decreased decomposition of organic matter and carbon mineralization, and a shift in microbial communities from bacteria to fungi have been observed as a result of soil acidification. Aluminum (Al) and heavy metals eventually reach streams and lakes where they adversely affect aquatic life. Acidification of soil may lead to changes in invertebrate populations, especially earthworms.

Water - In the eastern US, 18% to 25% of waterbodies have pHs <5.0. A National Surface Water Survey indicated that ANC was <0 in 5% of lakes in the Northeast, 2% in the Upper Midwest, and pH was <5.0 in 12% of Florida lakes. Lakes in the west generally had pHs >6.0 and higher ANC than in the east. Forty-three percent of Canada's land area is sensitive to acidic depositions. A particular area of concern is east of

Manitoba where acidic depositions are high. Approximately 800,000 water bodies exist in this area, many of which are already acidic. The Atlantic provinces contain the highest proportion of acidic lakes, due to their greater sensitivity.

Terrestrial Vegetation - Although at risk, there is little solid evidence that acid precipitation is deleteriously affecting terrestrial vegetation or ecosystems. However, effects on forest vegetation may affect birds through habitat structural change (eg. declines in sugar maple forests in Québec). Acidity may have depressed the Ca:Al ratio in forest soils and leaves, causing Ca declines in invertebrates and potentially Ca stress in breeding birds.

Aquatic Macrophytes - Acidification has caused reduced growth and productivity of freshwater plants, reduced numbers or diversity of vascular macrophytes, replacement of macrophytes (an essential substrate for many aquatic invertebrates) by *Sphagnum*, and increased metal residues in tissues.

EFFECTS ON MAMMALS: Mammals are not directly affected by acidification, but indirect effects may occur due to habitat degradation and changes in the quality or quantity of food, including forest and lichen dieback. The decline and loss of prey animals in aquatic habitats may adversely affect mammalian predators (eg. shrews, mink, otters), especially for obligate consumers and small mammals with restricted habitats or home ranges. The quality of foods may change through contamination of heavy metals (particularly mercury [Hg]), which is especially important for mammals that eat aquatic organisms from surface waters. However, conclusive evidence that mammals are adversely affected by metals mobilized by acid rain is lacking.

EFFECTS ON BIRDS: Birds are also not directly affected by acidification, but are deleteriously affected through habitat degradation that leads to disruptions in food webs and contamination of foods. Birds are affected by toxicological changes in the food web, as toxic metals move up the food chain, and ecological changes, as acid sensitive prey species are lost and replaced by acid tolerant species.

Toxicological effects - Evidence of direct toxic effects of acidification on birds is sparse. Instead, risk comes from ingestion of prey species which have accumulated heavy metals, especially Hg. Fish-eating birds and mammals are at greatest risk from dietary Hg which is increased in acidified wetlands, but are likely not at risk from increased Al at low pH.

Ecological effects - The main risk of air pollutants to birds is from long term deterioration of habitat and disruption of food webs, especially through the effects on quality and quantity of food organisms. Many forage fish, invertebrates and amphibians experience impaired reproduction in acidic environments, and loss of organisms begins when the pH of lakes falls below 6.0. The nutritional value (particularly Ca

levels) and number of aquatic taxa usually declines with increasing acidity, which will affect avian predators. For some insectivorous birds, feeding conditions can improve when fish competitors disappear as wetlands acidify. Acidification may alter aquatic plant communities used as food, cover, or nesting sites for birds. Few studies have examined the effects of wetland acidity on avian reproduction, but reproductive impairment may be associated with reduced food abundance, availability, or quality. Soil mineralization and acidity do not seem to affect riparian bird species. However, changes in terrestrial habitats caused by acid rain affect specialist species with narrow habitat requirements.

EFFECTS ON AMPHIBIANS AND REPTILES: Many species of amphibians are sensitive to increased acidity and toxic metals associated with acidified environments. Acidic water can affect reproduction of amphibians by causing mortality of embryos and larvae, while adults seem to be fairly tolerant of acidity. However, acidity can affect habitat selection of some species, which seek substrates with neutral pH. Most amphibian breeding sites are small ponds that are low in buffering capacity. Indirect effects of acidification on amphibian distribution, abundance and recruitment may occur through changes in the food web. Few data are available on effects of soil acidity on the distribution of terrestrial amphibians.

CONCLUSIONS: Documented effects of acidic depositions on wildlife in terrestrial habitats are scarce, and effects in aquatic environments are complex. Because most effects on wildlife are indirect, the resulting severity varies geographically and with each species. Evidence indicates that the acidification process is reversible and that wetland ecosystems can recover, although the process is gradual. This fact underscores the urgency to fully implement and comply with provisions of the US/Canada Air Quality Agreement through enforcement of the 1990 Clean Air Act, to reduce as rapidly as possible industrial and vehicular emissions. It is necessary to determine threshold amounts of SO_2 and NQ that affect biological systems to predict ecological response to these pollutants as emissions are curtailed.

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EDITORIAL COMMENT: The Wildlife Society occasionally appoints *ad hoc* committees to study and report on selected conservation issues. This review paper presents information compiled by the Technical Advisory Committee on Acid Rain and Wildlife, chaired by Jerry R. Longcore and edited by John D. Gill, for use in development of a "Position Statement" published as the official position of The Wildlife Society on the acid rain issue.

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PAPER NO.: 93 - 2

YEAR: 1993

TOPIC: Review - General

Nest Site Selection by Common Goldeneyes in Response to Habitat Features Influenced by Acid Precipitation

Mallory, ML, Weatherhead, PJ, McNicol, DK, and Wayland, ME

Ornis Scandinavica 24(1), 59-64 (1993)

KEY WORDS: common goldeneye, lake acidification, acid precipitation, habitat, nest site selection, *Bucephala clangula*, Sudbury, discriminant function analysis, fish predation, cavity-nesting, aquatic invertebrates

PURPOSE OF STUDY: To examine the effects of habitat quality on nest site selection by common goldeneyes in an acid stressed area.

METHODS: There are 378 small lakes and wetlands (between 1-20 ha) in the Wanapitei study area (40 km NE of Sudbury, Ontario, centred at 46°55'N, 80°45'W, and covering 460 km²); however, this study was restricted to only 96 small wetlands typical of goldeneye breeding habitat in this region. The area has been affected by acid deposition from nearby smelters and from long range transport of air pollutants, resulting in a high proportion of acid waterbodies that are now fishless. Other lakes in the area underlain by well-buffered bedrock have remained unacidified and support healthy fish populations. Wetlands were classified as containing or lacking fish based on sampling with minnow traps. General chemical conditions were quantified using pH as an index. Nest site selection was studied in 1989 and 1990 for common goldeneyes (*Bucephala clangula*) nesting in previously established nest boxes. Between 47 and 68 nest boxes were available, with only one nest box available per wetland. All nest boxes were of standard size (22x25x47 cm) erected on large trees facing open water. In addition to goldeneyes, three other cavity-nesting species used the boxes (hooded mergansers *Lophodytes cucullatus*, common mergansers *Mergus merganser*, wood ducks *Aix sponsa*). A nest box was classified as used if it contained at least one goldeneye egg. Nest sites that were used by the same, individually-marked female in successive years were only included once in any analysis. In addition to determining whether the adjacent wetland contained fish, four other habitat variables were measured: number of distinct waterbodies within 1 km radius, pH, area of open water, and distance to nearest water body. Discriminant function analysis was used to characterize the nesting habitat of used and unused boxes in wetlands with and without fish.

RESULTS: Common goldeneye pairs were observed more often and preferentially used nest boxes on fishless wetlands (40 vs 7 pairs observed on wetlands without vs with fish, respectively). However, the preference for these nest boxes was weaker than the preference for the use of these wetlands. The choice of nest box by goldeneyes may have been affected by other differences between wetlands with and without fish; for instance, fishless wetlands were more acid (average pH 5.2, vs 6.1 for wetlands with fish), smaller (average 4.7 ha, vs 7.8 ha for wetlands with fish), and closer (average distance to nearest wetland 182 m, vs 284 m for wetlands with fish) to other waterbodies than wetlands with fish. Characteristics of nest sites other than the presence or absence of fish in the

adjacent wetland were examined to determine if any factors affected nest site choice. Goldeneye nest site choice was not influenced by any of the measured variables on wetlands containing fish, but on fishless wetlands, occupied boxes had significantly fewer waterbodies within a 1 km radius (i.e. they were more isolated).

CONCLUSIONS: Common goldeneye breeding pairs prefer acid wetlands as nesting sites because they benefit from an absence of fish and thus an abundance of aquatic invertebrates. Goldeneyes used fishless wetlands preferentially over wetlands with fish during the prelaying and egg-laying periods, and preferred nest boxes erected in fishless wetlands; thus these wetlands can be considered "high" quality. However, many goldeneyes nested on "poorer" quality wetlands, although sites were still available on the high quality wetlands, which suggests that they use information other than the availability of food resources when selecting nest sites. In summary, preferred nesting habitat for goldeneyes is available in the acid stressed Sudbury area due to reduced fish populations following acidification. However, continued acidification here or elsewhere in the breeding range of this species may lead to further changes in aquatic invertebrate communities (such as reduced species diversity, reduced prey quality, and direct toxic effects). Such impacts may eventually lead to detrimental effects of breeding common goldeneyes.

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EDITORIAL COMMENT: This work was conducted as part of a larger study undertaken by the Canadian Wildlife Service (Ontario Region) to investigate the effects of acid precipitation on waterfowl, loons and their habitats in acid-sensitive regions of Ontario as part of Environment Canada's Long Range Transport of Air Pollutants (LRTAP) program..

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PAPER NO.: 93 - 3

YEAR: 1993

TOPIC: Research - Waterfowl

Towards a Model of Acidification Effects on Waterfowl in Eastern Canada

Blancher, PJ, McNicol, DK, Ross, RK, Wedeles, CHR, and Morrison, P

Environmental Pollution 78, 57-63 (1992)

KEY WORDS: lake acidification, waterfowl, fish, model, acid precipitation, logistic regression, Ontario, piscivores, insectivores, probability, breeding, regional

PURPOSE OF STUDY: To calibrate relationships between lake chemistry and morphometry, fish presence and the presence of breeding waterfowl in order to make predictions of the effects of acid precipitation on some waterfowl species in Eastern Canada, by incorporating results into an existing model of the effects of acid precipitation on lakes.

METHODS: Two study areas were used: Ranger Lake is 40 km NE of Sault Ste. Marie (46°55'N, 83°35'W), and Wanapitei is 40 km NE of Sudbury (46°55'N, 80°45'W). Both areas receive in excess of 20 kg/ha/yr of wet sulphate deposition. Wanapitei has received higher rates of sulphate deposition than Ranger Lake because of its proximity to smelters at Sudbury, and as a result has many acid lakes. Four types of data were used: waterfowl (number of breeding pairs and broods), lake chemistry (pH, dissolved organic carbon [DOC], total phosphorus [TP]), lake area, and fish numbers, collected as part of the Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) program. Waterfowl breeding pair data were collected by helicopter surveys of 711 lakes between 1980 and 1987. Of these lakes, 189 (94 at Ranger Lake, 95 at Wanapitei) also had data on chemistry, area, and fish. Ground surveys were conducted on 287 lakes at least twice during the brood-rearing periods to count and age broods. Only observations of broods beyond the downy stage of development (i.e. class II or III ducklings) were used as an indicator of fledging success and brood habitat use in this study. Of these lakes, 210 (104 at Ranger Lake, 106 at Wanapitei) also had data on chemistry, morphometry and fish. Sampling for water chemistry was conducted from April to November. Most lakes were sampled in more than one year during the period 1980-1987 and many were sampled more than once per year, although a single mean value for each chemical variable was used for each lake. The three chemical variables used (pH, DOC, TP) were chosen because they represent acidity status, organic condition and nutrient status, respectively. Lake areas (ha) were obtained from aerial photographs. Estimates of the occurrence of fish species were obtained using baited minnow traps, which is an effective technique for sampling non-game fish species and determining presence or absence of fish. Multiple logistic regressions were used to estimate coefficients relating waterfowl presence to lake characteristics. The standard data unit for these analyses was the 'lake-year', where one lake-year is data for an individual lake for a single year.

RESULTS: Most of the 212 lakes included in analyses were small (<30 ha), oligotrophic (total phosphorus, TP < 10 µg/L), and with dissolved organic carbon (DOC) < 10 mg/L. Lake pHs were distributed over a range from very acid to circumneutral. Fish were absent from 67 lakes, including some isolated headwaters with circumneutral pH. Two piscivorous species (common loon *Gavia immer* and common merganser *Mergus merganser*) were associated with large, high pH lakes with low DOC and TP and containing fish, at both the pair and brood stages. Common goldeneye *Bucephala clangula* pairs were observed on small, acid lakes with no fish and high TP. Broods of goldeneye and hooded merganser *Lophodytes cucullatus* tended to be found on fishless lakes, but no other comparisons showed differences related to pH. Black ducks *Anas rubripes* and ring-necked ducks *Aythya collaris* were associated with high DOC lakes at the pair stage, but not the brood stage. Logistic regressions confirmed that the two piscivores were more likely to be found on large lakes and those with fish than small or fishless lakes.

Broods of common mergansers were not observed on any of the 67 lakes without fish. A significant relationship to pH was apparent for both species even when the effect of fish presence had been removed; common merganser broods were associated with lakes of higher pH, while loon pairs and broods were less frequently found there. Lake pH and the presence of fish were not important factors in the distribution of breeding pairs of insectivores, except for goldeneyes, which avoided lakes with fish. Broods of three of the four species were most likely to be found on lakes without fish and with high pH (independent of fish presence). Only the ring-necked duck did not show a significant relationship to fish presence or pH. However, this is the species for which our surveys were poorest; sample sizes were small due to the age criterion used which excluded most ring-neck broods, since they tend to breed later than other species. Broods of common mergansers showed an increase in probability of presence as pH climbed above 6.0. Broods of other species also showed positive slopes versus pH for at least part of the pH range, but loons and goldeneyes also had a negative slope over some pHs. For the latter two species, predicted reaction to pH change would depend on the initial pH of the lakes.

CONCLUSIONS: The probability of observing broods of several species of waterfowl can be described as a function of lake pH. However, use of a simple presence/absence term for fish may mask differences in fish communities that are important to piscivores. When linked to models that predict the change in acidity of lakes from a knowledge of sulphate deposition, it is possible to estimate regional effects of changes in acid deposition on waterfowl. A true validation of these relationships is not possible until there is an adequate time series of data from lakes that have had pH changes.

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ACKNOWLEDGEMENTS: The Canadian Wildlife Service acknowledges the contribution made by ESSA Technologies Ltd. to the preparation of this paper and the development of the Waterfowl Acidification Response Modelling System (WARMS) software.

EDITORIAL COMMENTS: This paper was published as part of the peer reviewed Proceedings of the International Symposium "Acidic Deposition: Its Nature and Impacts" held in Glasgow, Scotland 16-21 September, 1990 (*FT Last and R Watling, editors*). This work led to the development of biological equations in WARMS (Paper No. 95-7), and the finding that DOC has a significant effect on regional acidification models (Paper No. 96-1), and contributions to the recent Integrated Assessment Model (Paper No. 98-2) and the 1997 Canadian Acid Rain Assessment (Paper Nos. 97-1, 97-2).

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PAPER NO.: 92 - 1

YEAR: 1992

TOPIC: Modelling - Waterfowl

A Comparison of Three Techniques for Monitoring Avian Nest Attentiveness and Weight Change

Mallory, ML, and Weatherhead, PJ

Journal of Field Ornithology 63 (4), 428-435 (1992)

KEY WORDS: incubation, common goldeneye, nest attentiveness, weight change, reproduction, cavity-nesting, Sudbury

PURPOSE OF STUDY: To compare different equipment for monitoring incubation and weight change of nesting common goldeneyes.

METHODS: This study was carried out in 1989 and 1990 on 24 of the approximately 378 small lakes and wetlands in the Wanapitei study area, 40-70 km NE of Sudbury, Ontario (centred at 46°55'N, 80°45'W). Female common goldeneyes (*Bucephala clangula*) nested in previously established nest boxes. Three systems were used to monitor nesting females in their boxes: a plunger system (a custom, mechanical system), a load cell system (an electronic, strain gauge sensor system), and a balance system (an A&D Engineering EW3000B electronic balance system). These systems were installed in nest boxes just prior to or early in incubation, and operated until the system failed or incubation was completed. Using data collected from the systems, and qualitative and quantitative data concerning installation and site visits, we assessed the utility of each of these systems as a monitoring tool.

RESULTS: The plunger system was effective in controlled trials, but high humidity in the field caused the recording paper to swell and bind, rendering the monitor ineffective. As well, installation of these systems required many changes to existing nest boxes, and their size made them cumbersome to work with on the nesting tree. Despite the field limitations, this was the least expensive system (~\$175 US each) to build, and could be useful in controlled environment studies. The load cell system was the most expensive to construct (~\$2610 US) and required two solar panels per system to keep the rechargeable battery from running out of power. However, the system was effective under all weather conditions, was durable during transport in the field, required relatively few modifications to install in existing boxes, could be checked once a week, and gave continuous and accurate measurements of both nest attentiveness and female mass. The major limitation of this system was the loud click made by the Rustrak recorder, requiring the recording components to be situated away from the nest to minimize disturbance of the female. The balance system used less energy and measured mass more accurately than the load cell system. The custom timer allowed the researcher to adjust the recording frequency, so that nearly continuous records could be obtained. This system also had some considerable limitations. If the female was moving on the nest at the time the unit was about to record a weight, a "****" would be printed on the recording paper. This could pose a problem on windy days or for nests located on smaller trees where movement would be more

common. As well, two of the recorders stopped following a thunderstorm after water entered the nest box. They worked properly for the rest of incubation after they were reset. This system was also the most fragile, so particular attention was taken to secure it inside a backpack during transport. Finally, because the recording unit was a printer, the system had to be checked every four days or the printer paper would bind in the recording chamber.

Important considerations are that both the load cell and balance systems must be sized to fit in the nestbox, which may limit their applicability for some small cavity-nesters. As well, these systems required long cables, and care must be taken to protect the cables on the ground from large mammals (snapping lines) and small mammals (chewing).

Finally, we noted that the balance system may have had a negative effect on developing embryos, depending on when it was installed. Three of four clutches in nests monitored with balance systems that were installed more than one day prior to incubation failed to hatch, whereas clutches of all of the females monitored from late in the first week of incubation hatched. We suspect that electronic fields emitted from the balance may have interfered with early development of the primitive streak in embryos:

CONCLUSIONS: The load cell and balance systems provide reliable, accurate data on nest attentiveness and weight loss, and could be easily adapted to monitor ground nesting species as well. Use of systems similar to these allows researchers to gather information on many aspects of avian incubation simultaneously, permitting more integrated assessments of female nesting behaviour and its effects on reproductive success.

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EDITORIAL COMMENT: This work was conducted as part of a larger study undertaken by the Canadian Wildlife Service (Ontario Region) to investigate the effects of acid precipitation on waterfowl, loons and their habitats in acid-sensitive regions of Ontario as part of Environment Canada's Long Range Transport of Air Pollutants (LRTAP) program.

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PAPER NO.: 92 - 2

YEAR: 1992 **TOPIC:** Research - Waterfowl

Distribution of Waterfowl Broods in Sudbury Area Lakes in Relation to Fish, Macroinvertebrates, and Water Chemistry

McNicol, DK, and Wayland, M

Canadian Journal of Fisheries and Aquatic Sciences
49(suppl 1), 122-133 (1992)

KEY WORDS: lake acidification, acid precipitation, epibenthos, nekton, macroinvertebrates, insectivorous waterfowl, lake acidity, fish predation, littoral zone, habitat selection, discriminant analyses, ordination analyses, TWINSpan, DECORANA, Sudbury

PURPOSE OF STUDY: To determine whether the distribution of insectivorous waterfowl broods was related to the composition of littoral macroinvertebrates found in lakes with differing degrees of acid stress and types of fish predation.

METHODS: Sixty-five small (80% below 10 ha), mostly headwater lakes were surveyed in the Wanapitei area (40 km NE of Sudbury, 46°55'N, 80°45'W). The area has a history of high sulphur dioxide deposition, but due to the variable buffering capacities of the bedrock and soils, there is a broad range of lake pHs. All lakes were sampled between 1983-1987 for pH, conductivity, alkalinity (ANC), calcium (Ca), dissolved organic carbon (DOC), total phosphorus (TP), and size. Environmental variables, except pH, were log transformed and stepwise discriminant analyses used to identify those variables that discriminated among groups of lakes as defined by their fish category or macroinvertebrate assemblage. Each lake was sampled for fish using baited minnow traps. Lakes were classified into three fish categories: 1) fishless lakes, 2) lakes containing only small cyprinids, brook stickleback, or lowa darter, and 3) lakes containing yellow perch or white sucker. One-way ANOVAs were used to examine effects of fish category on macroinvertebrate assemblage characteristics. Each lake was sampled for littoral macroinvertebrates in two ways: 1) epibenthic organisms were collected from sediment removed from a strip with a D-frame sweep net, and 2) sweep samples were collected in the water column to sample nekton (free-swimming insects). Macroinvertebrates were preserved in alcohol and later sorted, counted, and identified to genus or species. Lakes were grouped according to the degree of similarity in their macroinvertebrate assemblages using multivariate grouping procedures (TWINSpan and DECORANA). Waterfowl surveys were conducted between 1983 and 1987, and lakes were surveyed for broods at least twice each year, in June and July. Relationships between waterfowl brood use of lakes and a) fish categories, or b) macroinvertebrate assemblages, were examined using G-tests of independence or Fisher exact tests.

RESULTS: Of the 65 lakes sampled, 26 were fishless, 11 contained only small fish (especially *Phoxinus* spp) and 28 contained yellow perch and/or white suckers. The combination of pH, area and DOC provided the best distinction among fish categories, with fishless lakes being more acid and lower in DOC. Lakes with yellow perch/white sucker were deeper than the other two categories of lakes, while small fish lakes were higher in DOC. Sixty-five taxa were identified in benthic samples (in all lakes) and 37 taxa in sweep samples (only in 53 lakes; 12 lakes without nekton were yellow perch/white sucker lakes). Lakes were grouped according to their macroinvertebrate assemblages on an initial level (separated by fish status and pH) and a subsequent more detailed level (separated in addition by ANC, area and TP). At the first level, fishless and small fish lakes were associated with group 1 benthic assemblages (dominated by libelluloid dragonflies and including corixids and ceratopogonids), while yellow perch/white sucker lakes were associated with group 2 benthic assemblages (impoverished fauna dominated by the dragonfly *Gomphus*). Group 1 lakes had lower pH than did group 2 lakes. At the second level of discrimination, buffering capacity was important in distinguishing between a taxonomically-rich subgroup 1a and the taxonomically-poor subgroup 1b. Fishless lakes exhibited benthic assemblage characteristics that differed from both types of lakes with fish, and assemblages differed between lakes with small fish and those with yellow perch/white suckers. For nektonic assemblages, group 2 (nekton scarce or

absent, surface-dwelling *Gyrinus* and *Dineutes* common) lakes were predominantly yellow perch/white sucker lakes, while group 1 (abundant nekton, including corixids, notonectids and dytiscids) were both fishless and lakes with small fish. Fishless lakes were associated with subgroup 1a assemblages (corixids abundant, other nektonic taxa present), suggesting that the absence of fish plays a major role in developing abundant nektonic fauna. Four species of insectivorous waterfowl were common: common goldeneye, hooded merganser, ring-necked duck, and black duck. Broods of goldeneye and black duck were seen more often on fishless lakes; ring-necked ducks preferred fishless lakes to yellow perch/white sucker lakes but not to lakes with small fish. Hooded merganser broods showed no preference for any lake type. Benthic faunas associated with fishless or small fish lakes were preferred over those in yellow perch/white sucker lakes. All waterfowl species were found more often on benthic group 1 lakes. Goldeneyes selected acid, fishless lakes over nonacid, fishless or small fish lakes. For nekton assemblages, ring-necked ducks and black ducks preferred group 1 lakes, which reflects their preference for lakes containing nekton found predominantly in fishless or small fish lakes. Both goldeneye and black duck broods preferred lakes which contain an abundant nektonic fauna (subgroup 1a), while use of lakes by mergansers was not related to nektonic assemblages.

CONCLUSIONS: The distribution of waterfowl broods in small acid stressed lakes in the Sudbury area was influenced by differences in invertebrate prey assemblages in lakes with differing degrees of acid stress and types of fish predation. Insectivorous waterfowl broods preferred lakes containing an abundant macrobenthic and nektonic fauna. There was an overall preference for fishless lakes over lakes with small fish, and the latter were preferred over lakes with yellow perch/white suckers. The distribution of broods (other than goldeneyes) was not related to differences in acidity. The effects of lake acidification are mediated primarily through effects on fish assemblages. In areas where fish assemblages have not been seriously affected, effects of acidification on waterfowl are likely related to direct effects on macroinvertebrates. In situations where emission controls curtail further loss of fish populations, impoverishment of macroinvertebrate faunas in small lakes may continue, possibly leading to increased competition between remnant fish populations and waterfowl for a diminishing prey resource.

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EDITORIAL COMMENT: This paper is published in a supplemental issue of the *Canadian Journal of Fisheries and Aquatic Sciences* which contains a series of 14 papers detailing Aquatic Acidification Studies in the Sudbury, Ontario, Canada Area (B. Keller, ed). Some of the information contained here was originally presented as a poster paper entitled "Macroinvertebrate, fish and waterfowl interactions in acid-stressed lakes of Ontario, Canada" at the 4th International Conference on Acidic Deposition: Its Nature and Impacts, held in Glasgow, Scotland, 16-21 Sept 1990.

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PAPER NO.: 92 - 3

YEAR: 1992

TOPIC: Research - Trophic Relations

An Assessment of Leeches (Hirudinea) as Indicators of Lake Acidification

Bendell, BE, and McNicol, DK

Canadian Journal of Zoology 69(1), 130-133 (1991)

KEY WORDS: leeches, Hirudinea, lake acidification, scavengers, parasitic species, indicators, Sudbury, artificial surfaces, funnel traps, cocoons, littoral zone

PURPOSE OF STUDY: To determine the distribution of leeches across a wide pH range in acid stressed lakes near Sudbury, and to assess the value of using leeches as indicators of lake acidification.

METHODS: Leeches were surveyed on lakes in the Wanapitei area, 40 km NE of Sudbury, Ontario (centre 46°54'N, 80°41'W). Lakes in the area span a wide range of pH and many are acid as a result of SO₂ emissions from local smelters and long range transport of air pollutants. Two survey techniques were developed for the study. First, artificial surfaces for cocoon deposition by *Nephelopsis obscura*, a common erpobdellid leech, were made of 20 x 20 cm pieces of 2.5 cm thick Styrofoam SM. Ten surfaces were anchored to float on the surface in 1 m deep water at random locations in 20 lakes between June 25 and 28, 1986, and recovered 30 days later. The smooth surface of styrofoam SM was assumed to mimic the undersurface of floating leaves where this species commonly deposits cocoons. To test this assumption, similar-sized surfaces made of rough, bead board (irregular surface) were placed 1.5 m from each of eight randomly placed Styrofoam SM surfaces on two additional lakes. Second, funnel traps were made from 1.5 L glass mason jars, baited with 50 g beef liver. A plastic funnel with an opening of 1.1 cm was cut to fit the mouth of each jar. Jars were filled with water and placed on their sides in water no deeper than 0.5 m in the littoral zone of 40 small (1.0 - 12.1 ha) lakes, including the 20 previously sampled. Five traps were placed equidistant around the shoreline for a 24-h period between June 24 and July 3, 1987. Trapped leeches were narcotized in carbonated soda water, then preserved in 70% ethyl alcohol for later identification. Lake pH values were determined for each lake at the time of sampling.

RESULTS: Baited funnel traps caught leeches from nine species in 24 lakes (all 20 with pH >5.5, but only four of 20 with pH <5.5). Leeches were not caught in any lake with pH <4.9. In the pH range 4.9-5.5, only four species were recorded, and there were significantly fewer leeches in lakes of pH <5.5. In seven lakes with pH 5.5-6.0, the mean number of leeches was 3.0 compared with 4.2 in 13 lakes with pH >6.0, but this difference was not significant. Among lakes with pH >5.5, there was no relationship between the number of leeches and lake pH. The most commonly caught leech in bait traps was *Percymoorensis marmoratis*, with 35.7 ± 8.0 (SE) individuals per lake in 20 lakes of pH >5.5. Slightly

fewer *Macrobdella decora* and *Nephelopsis obscura* were caught but with more variability among lakes, with means of 34.9 ± 20.5 (SE) and 15.2 ± 8.1 (SE), respectively. Baited traps failed to catch *N. obscura* on three lakes where cocoons had been deposited on artificial surfaces. Cocoons of *N. obscura* were deposited on artificial surfaces on 10 of 13 lakes with pH ≥ 5.2 at densities of 1.2 - 63.5 cocoons per surface per lake. Cocoons were deposited at a lower pH than the lowest level at which adults were caught in funnel traps (pH 5.6), but nonetheless the two methods were consistent. No cocoons were deposited in seven lakes with pH below 5.0. On the two additional lakes tested, there were significantly more cocoons deposited on Styrofoam surfaces (38.9 and 14.3) than on bead board (18.3 and 7.0).

CONCLUSIONS: Baited funnel traps are a useful technique for determining the presence of leeches in small lakes, but their effectiveness varies among species. They are most effective at sampling scavenger species, such as *Percymoorensis marmoratis*, and least effective at sampling parasitic species, including several glossiphoniids. In this study, leeches were absent under acid conditions, generally below pH 5.5. Several species disappeared over a narrow range of pH, which suggests that acidity, or a chemical or biological factor correlated with pH, was responsible and suggests their use as a reliable indicator of acidification. Absence of leeches from acid habitats is likely due to lack of suitable prey or presence of potentially important predators at low pH. However, our data do not confirm that leeches are especially sensitive to acidity, but are affected at levels similar to those that adversely affect other acid sensitive organisms, including fish and other invertebrates.

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PAPER NO.: 91 - 1

YEAR: 1991

TOPIC: Research - Invertebrates

Tree Swallow Diet in Relation to Wetland Acidity

Blancher, PJ, and McNicol, DK

Canadian Journal of Zoology 69(10), 2629-2637 (1991)

KEY WORDS: tree swallow, *Tachycineta bicolor*, diet, wetland acidity, acid precipitation, wetlands, Sudbury, nest boxes, nestlings, adults, food bolus, faecal sac, logistic regression, calcium, diversity

PURPOSE OF STUDY: To determine whether the acidity of adjacent wetlands affects the composition of the diet of tree swallows, as has been found for other avian species.

METHODS: A population of tree swallows from the Wanapitei area 40 km NE of Sudbury, Ontario (centred at 46°55'N, 80°45'W) was studied. Nest boxes were placed around 56 small wetlands (1.2-26.7 ha) representing a range of pH (3.72-7.56) and dissolved organic carbon (DOC, 1.9-30.4 mg/L). Fish were absent from 32 of the wetlands. Water chemistry data were averages of 2-4 samples from 1986 to 1987. Diet was sampled several ways. First, pipe-cleaner ligatures were temporarily placed around nestling throats which prevented them from swallowing, when nestlings were 6-9 days old, and again when they were 10-13 days old to collect food boluses. Second, nestling faecal sacs were collected and stored in alcohol for later prey identification. Third, in 1987, 30 16-day-old nestlings, from different wetlands spanning the range of wetland characteristics, were collected for stomach content analysis, and 44 nestlings found dead in 1986 and 1987 were dissected and stomach contents analyzed. There were no differences in stomach contents of these two groups, therefore samples were pooled. Fourth, at the end of the breeding seasons, nesting material was sorted and prey items were collected, excluding insects known to be parasites in the nests. Fifth, in 1986, food boluses were collected from adults, trapped as they were attempting to feed nestlings. Finally, diet of adult swallows was determined by stomach content analysis of 20 females collected during egg-laying 1987 and six females, and one male collected later that season. Insects, identified to family and to genus or species for some aquatic taxa, were designated as terrestrial or aquatic based on larval habits. Length and dry weight of intact items were measured. For samples with prey parts, the minimum number of individuals that could account for all the parts was determined. To reduce effects of individual diets, diet was calculated as an aggregate percentage from samples containing at least five food items and minimum dry mass of 10 mg. Multiple logistic regressions were used to relate diet composition to wetland characteristics. Emergence of aquatic insects was quantified using floating pyramidal traps in the littoral zone of 33 wetlands. Abundances were calculated as total dry biomass/number of days of trap operation. Relations between abundance of prey in traps and wetland characteristics were evaluated with stepwise regressions. Five to 20 benthic invertebrate samples were collected by sweep net, Ekman dredge, and visual searching as part of other studies. In 1987, feeding rates of nestlings were determined.

RESULTS: A total of 12,825 food items were identified in tree swallow diets, including 987 from adults, 9,819 from nestlings, and 2,019 from nests. Chironomid midges were the most abundant item eaten by nestlings, comprising 34% of the items in food boluses. Other numerically important species were mayflies, dipterans, and homopterans. Based on dry mass, a better indicator of importance in the diet, the most important invertebrates in food boluses were horseflies (*Tabanus*, 15%) and burrowing mayflies (*Hexagenia*, 13%). Chironomidae and Muscidae were small, but important by virtue of their abundance. Food identified from nestling stomachs and faeces, and from the nest material, contained high proportions of less digestible items. Adult diets were determined from stomach samples and may have the same bias towards less digestible items. Assuming the bias is the same for adults as for nestlings, adjusted values were calculated for adults; these values indicated that Diptera were 70-75% of the adult diet, with egg-laying females also consuming mayflies (15%). Mollusc shells and bones, providing calcium, constituted 4% of nestling food boluses, 10% of nest contents, and 0.2% of egg-laying females' stomach contents. Food of aquatic origin was 65% of the nestling diet by mass, compared to 32% for terrestrial items, and was 71% and 55% of the diet of egg-laying females and other adults, respectively. There were changes in prey type in nestling diets with

wetland pH; specifically a decrease in mayflies from 30% to 11% from high (>6.0) to low pH (<5.0); abundance of mayflies was also greater in fishless or large wetlands. An increase in aquatic Diptera from 16% in high pH wetlands to 38% at acid wetlands did not appear to be directly related to pH. Nestlings at acid wetlands received more odonates (16%) than at other wetlands and caddisflies were important at intermediate pHs. The number and type of calcium-rich items differed among wetlands. At high pH, these items were mollusc (clam and snail) shells; at lower pH, snail shells were less important and bones were more important. Presence of chironomids, black flies, or terrestrial taxa was not related to pH or other wetland characteristics. Relations between diet and wetland characteristics often reflected prey availability. Mayfly emergence and odonate mass was greater in fishless wetlands and mayfly emergence was also positively related to wetland pH. Chironomid emergence was only weakly related to wetland measures. Overall, emergent trap catch was negatively related to pH. The number of different taxa and the proportion of aquatic taxa fed to nestlings was greater at higher pH wetlands. Broods were fed about 20 times per hour and feeding rate increased with brood mass but was not related to any wetland characteristics. Bolus size or mass of individual items was unrelated to wetland parameters.

CONCLUSIONS: Prey of aquatic origin form a major part of the diet of tree swallows at acid stressed wetlands near Sudbury. Wetland acidity is an important factor determining the diet of tree swallows. Increasing wetland acidity was associated with a switch in diet from mayflies to dipterans, a decline in diversity of prey eaten, and a change in size and types of calcium-rich items fed to nestlings. The lower diversity of prey taxa in acid environments has a potential cost since it increases the likelihood of a food shortage (especially for the swallows' prey, which is patchy in time and space) and that some nutritional needs are not met (for instance, particularly calcium). The decreased availability of mayflies and calcium-rich foods may play a role in the lower clutch sizes and poorer nestling growth of swallows at acid wetlands documented in related work (Paper No. 88-2).

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EDITORIAL COMMENT: A complete list of all taxa identified in tree swallow diets is available upon request.

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PAPER NO.: 91 - 2

YEAR: 1991

TOPIC: Research - Birds

Acid Precipitation, Female Quality, and Parental Investment of Common Goldeneyes

Mallory, ML

MSc Thesis, Carleton University, 101 pp (1991)

KEY WORDS: lake acidification, acid precipitation, common goldeneye, female quality, clutch mass, nest site selection, incubation rhythm, fish presence, habitat quality, nest parasitism, discriminant function analysis, wetland isolation, Sudbury, *Bucephala clangula*, parental investment, nest box

PURPOSE OF STUDY: To determine whether female common goldeneyes adjusted their level of parental investment in relation to their own physical condition and the quality of their nesting habitat (assessed by the presence or absence of fish).

METHODS: The study was conducted in May-July of 1989 and 1990 at the Wanapitei study site (centre 46°45'N, 80°45'W, 40 km NE of Sudbury), using waterfowl nest boxes previously erected on 71 small lakes and wetlands, and was a component of an ongoing program (started in 1986) examining the use of nest boxes by cavity-nesting in relation to changing lake chemistries. Study lake size varied (1.0-29.2 ha) as did pH (4.19-7.31, determined from August 1990 littoral grab samples). Fish presence was determined in a previous study using five baited minnow traps set for 24 h around the shore of each lake. Because the presence of fish reliably predicts macroinvertebrate abundance in these small lakes, lakes were scored as either containing or lacking fish, irrespective of community composition. Lake isolation parameters (distance to nearest water body, number of water bodies within 1 km) were determined from 1:15,840 aerial photographs and 1:50,000 topographic maps. Isolated lakes were arbitrarily defined as those where the nearest water body was greater than 500 m. and/or where there were fewer than three discrete water bodies within a 1 km radius of the study lake. During the prelaying and egg laying periods, lakes and boxes were checked to determine where pairs were foraging, 30 min time-activity budgets of those pairs (or lone females) and what boxes were being used. Remote incubation monitoring equipment were installed in occupied nest boxes early in incubation to record incubation rhythms and changes in female mass (see Paper No. 92-2). During visits to the nest, all eggs were counted, numbered, and length and breadth were recorded to calculate egg mass. Female mass was determined for all females captured and weighed during incubation, at which point females were also equipped with a unique set of plastic nasal saddles for identification.

RESULTS: *Pre-incubation activity budgets* - Prior to incubation, pairs of common goldeneyes were significantly more common on fishless lakes than lakes with fish. For females foraging on fishless lakes, the presence of another goldeneye pair on the lake resulted in a decrease in the amount of time females spent resting.

Nest Site Selection - For 78 common goldeneye nesting attempts (1987-1990, including data from two years of ongoing work prior to the start of this thesis), nest boxes were occupied significantly more often on fishless lakes than those available on lakes containing fish. Box use was also more common on lakes that had been occupied in the previous year. Using discriminant function analysis, nest site selection by goldeneyes was also found to be more common on relatively isolated, fishless lakes. Using a mass loss equation (that calculated mass loss for incubating females) and clutch mass, female prelaying mass was estimated. It was determined that heavier females initiated nests earlier than lighter females, but that there was no relationship between female mass and habitat quality.

Reproductive Effort - Approximately 20% of common goldeneye nests were thought to be parasitized intraspecifically (using four methods of parasitism detection). For apparently unparasitized nests,

mean nest initiation date was 10 May, with mean clutch size of 8.3 ± 0.2 (SE) eggs ($n=47$) and mean egg mass 65.1 ± 0.2 g ($n=403$). Heavier females laid clutches of greater mass, although this appeared to be unrelated to females breeding experience (as determined by the occurrence of previously banded females). Nest initiation dates did not differ across habitat types, but females nesting on lakes containing fish laid clutches of less mass (lake isolation was not correlated with clutch mass). Clutch size was not correlated with egg size, and variation in goldeneye clutch mass was achieved by varying clutch size, not egg size. Collectively, then, both female quality and habitat quality influenced goldeneye reproductive effort.

Reproductive Behaviour - Incubation rhythm data (nest attentiveness [time on nest each day], recess duration, recess frequency) were collected for 17 common goldeneye females. Fish presence had no significant influence on any of these behavioural parameters. However, goldeneyes nesting on clustered lakes spent more time on the nest each day and took shorter incubation recesses. Female goldeneyes lost approximately 21% of their pre-incubation body mass over the 31 day incubation period. There were no significant effects of habitat quality on mass loss by female goldeneyes. Although habitat quality appeared to affect certain aspects of goldeneye reproductive behaviour, this did not appear to affect the number of eggs hatched per nest (hatching success). However, total nest loss was significantly higher on clustered lakes, presumably due to interference from prospecting females and/or nest parasitism.

CONCLUSIONS: This study demonstrated that effects of acidification on local lakes have influenced female goldeneye breeding behaviours. Prior to incubation, female goldeneyes forage almost exclusively on fishless lakes and prefer these sites for nesting. Female goldeneyes that possess larger nutrient reserves prior to egg laying initiate nests earlier and lay clutches of greater mass, achieved by laying more eggs per clutch. Larger clutches are laid by females nesting on fishless, usually acid lakes. Goldeneyes nesting on clustered, fishless lakes also are more attentive to their nests but begin brood rearing in relatively poorer condition than females nesting on more isolated lakes. These results confirm hypotheses presented in earlier research that suggested that goldeneyes may derive short term benefits from habitat alteration (i.e. loss of fish) resulting from acidification, but that the long term consequences of breeding on these damaged habitats remain to be determined.

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EDITORIAL COMMENT: This work was conducted as part of a larger study, conducted by the Canadian Wildlife Service (Ontario Region), to investigate the effects of acid precipitation on waterfowl, loons and their habitats in acid sensitive regions of Ontario, as part of Environment Canada's Long Range Transport of Air Pollutants (LRTAP) program. We thank Dr. Pat Weatherhead, Carleton University, for his supervision and contributions to this work.

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PAPER NO.: 91 - 3

YEAR: 1991

TOPIC: Research - Waterfowl

Effects of Acidification on the Availability of Toxic Metals and Calcium to Wild Birds and Mammals

Scheuhammer, AM

Environmental Pollution 71, 329-375 (1991)

KEY WORDS: lake acidification, acid precipitation, mercury (Hg), cadmium (Cd), lead (Pb), aluminum (Al), calcium (Ca), aquatic wildlife, toxicity, toxic metals, risk, nutrition, reproductive success, case study

PURPOSE OF REVIEW: An analysis of the literature on the effects of acidification on wildlife inhabiting aquatic or semi-aquatic environments is presented, highlighting the influence of the toxic metals Hg, Cd, Pb, and Al and the essential dietary mineral, Ca.

BACKGROUND: Reduced pH levels in aquatic environments can result in decreased availability of fish and a reduction in the diversity of invertebrates. In general, the quality as opposed to the quantity of the food source changes, including reduced caloric food content and bioavailability of selenium and Ca. The toxic effects of dietary metal exposure on reproductive processes are evaluated as these effects occur at low levels of exposure.

Hg: Concentrations of mercury (Hg) in fish are negatively correlated with pH. Methylmercury (MeHg), and not inorganic Hg, is readily adsorbed in animals, and therefore it is a better indicator of potential health risks. Carnivores accumulate more Hg than omnivores, which accumulate more than herbivores, due to concentrations of MeHg in different food sources. Fish muscle contains high levels (from >50-100%) of MeHg while invertebrates contain <50%, while amphibians (which are not well-studied in this respect) and plants are not important links in the transfer of Hg along food chains. Therefore, piscivorous birds and mammals are at greater risk. Toxic effects are neurological and can lead to death at exposure levels that are otherwise non-toxic. Reproductive impairment is observed at 1/5 the concentration that results in overt toxicity. Nest desertions were observed in common loons feeding on fish and crayfish containing Hg of 0.3-0.4 µg/g, and with levels >0.4 µg/g in prey, egg laying was severely decreased. MeHg is also efficiently transferred through the placenta and concentrated in fetal tissues. Feather and eggs of birds, and fur of mammals are good integrators of dietary MeHg exposure. Hg is mainly deposited in feathers (the amount varies according to dietary habits) during their formation, and resists leaching. MeHg concentrations of >20 µg (dry wt) in primary feathers is indicative of Hg levels that threaten reproductive success. Hg also accumulates in the albumin and concentrations of >9 µg (dry egg albumin) can cause reproductive effects in loons.

Pb: Absorption of inorganic Pb salts from food is higher in immature animals than in adults, and tends to accumulate in the bones of mammals and birds (90% of total body burden). Pb in skeletal tissues is stable with a several year half-life and these tissues are good indicators of cumulative Pb exposure. Kidneys accumulate the highest levels of Pb of the soft tissues with a half-life of 2-3 weeks and coupled with blood and liver are good indicators of recent Pb exposure. Absorption of Pb is strongly influenced by nutritional factors, with decreased levels of dietary protein or Ca effective in increasing uptake of Pb in both mammals and birds. Concentrations in mammals of 10-20 µg/decilitre in blood results in reproductive impairment. There is no evidence that amphibians or invertebrates

from acidified environments accumulate Pb to lethal levels, nor that any signs of Pb intoxication are evident in wildlife preying on these organisms. Submerged aquatic plants can accumulate >100 µg/g Pb (dry wt) and may be a concern for herbivores using aquatic habitats.

Cd: Mammals and birds tend to accumulate Cd in the liver and kidney as a stable protein complex of Cd-metallothionein. The intestinal uptake of Cd is increased in diets deficient in Ca, zinc or iron. The ability of metallothionein to complex Cd in the renal cortex decreases at concentrations of 100-200 µg/g (wet wt) in mammals and birds and results in Cd-associated toxicities. High levels of Cd (81-480 µg/g (dry wt) vs typical levels of <12-13 µg/g) have been found in wild vertebrates and aquatic birds in areas removed from industrial sources of Cd contamination due to transfer from food items. Invertebrates accumulate high concentrations of Cd and may be of toxicological significance. The relationship between Cd and pH is complex and is affected by other parameters unrelated to lake-pH. In general, piscivores and insectivores are not at risk for Cd-induced toxicity due to environmental acidification. For herbivores (which accumulate more Cd in target organs than herbivores), factors such as proximity to sources of industrial pollution, natural Cd enrichment of soils, and plant species composition are more important than lake-pH for Cd accumulation in plants.

Al: The gastrointestinal absorption of dietary Al is low. Toxicity is primarily due to the disruption of Ca and phosphorus (P) metabolism by Al, and results in bone abnormalities. If P concentrations are kept high (an Al:P ratio of 1:1) resultant toxicities related to Al are minimized. Fish, mammals and birds contain low concentrations of Al; aquatic invertebrates may accumulate high levels of Al, yet P concentrations averaged 5-10 times the Al content. Al accumulation by aquatic invertebrates decreases with increasing acidity, even though soluble Al increases under these conditions. Aquatic macrophytes can accumulate high, toxicologically relevant levels of Al in acidified lakes and ponds, and may be of concern for aquatic herbivores even in the presence of adequate dietary levels of Ca and P.

Ca: Ca is an essential element for mammals and birds and it is critical during reproduction. Ca is readily mobilized in medullary bone and transferred to the oviduct for eggshell formation as dietary Ca levels are insufficient to meet this demand. Depletion of medullary Ca results in increased synthesis of a Ca-binding protein that increases Ca dietary absorption, thus adequate dietary Ca is required. Commercial feeds typically contain 1-3% Ca, which are an order of magnitude higher than that available in aquatic invertebrates or plant-type foods from acidified environments. Piscivores can obtain Ca from fish bones, but omnivores and insectivorous birds need alternate Ca sources. High-Ca food sources in aquatic environments include calcified shells (clams, snails, amphipods, crayfish), but these food sources decline rapidly below pH 6.5 and by pH 5 these organisms are absent. Several studies have concluded that aquatic environments with pH less than 5.3 lack Ca-rich food required for non-piscivorous birds.

METAL ACCUMULATION CASE STUDY: As part of a broad, Canadian Wildlife Service (Ontario Region) study of the influences of acid precipitation on the diet of waterfowl breeding in small lakes of central Ontario, American black duck (n=30), ring-necked duck (n=38), common goldeneye (n=30), hooded merganser (n=27), and common merganser (n=21) ducklings were sampled between 1984-1986. These species were chosen because they were common and represented different ecological niches: black ducks and ring-necked ducks feed on the surface, whereas hooded mergansers and

goldeneyes are pursuit divers and common mergansers are piscivores. Collections were conducted at the Wanapitei (centred 46°55'N, 80°45'W, 40 km NE of Sudbury) and Ranger Lake (centred 46°55'N, 83°35'W, 40 km NE of Sault Ste. Marie) study sites on lakes with known water chemistries. After diet analysis was completed, carcasses were forwarded to NWRC for tissue metal analyses (liver and kidney). Metals were also determined in certain invertebrates that are key prey items for waterfowl (dragonflies [Anisoptera, n=7 lakes], backswimmers [Notonectidae, n=10 lakes], whirligig beetles [Gyrinidae, n=14 lakes], and waterstriders [Gerridae, n=8 lakes]).

For invertebrate prey, Cd and Pb were highest in waterstriders and backswimmers, and lowest in whirligigs and dragonflies, and Hg concentrations were low across groups. Collectively, analyses of invertebrate prey items suggested that concentrations of Cd, Pb and Hg were not sufficiently high to be of concern.

Concentrations of Zn ranged between 25 and 55 µg/g (wet weight) and were species specific (highest in black ducks, lowest in common mergansers), and did not differ between study sites. Concentrations of Hg (0.1 to 1.9 µg/g ww) were lowest in black ducks and highest in common mergansers, and generally increased with piscivorous tendency in species. Hg levels were higher at Ranger Lake, which was not surprising because Hg concentrations are anomalously low near Sudbury, possibly due to the confounding effect of high local selenium emissions. Concentrations of Pb (0.05-0.45 µg/g ww) in duckling kidneys did not differ by study location or duckling age, and tended to be higher for low pH lakes. Nonetheless, levels were not of toxicological significance. Cadmium concentrations (0.2-0.6 µg/g ww) were higher at Ranger Lake, and tended to increase with increasing pH at Wanapitei, but again were not high enough to be of concern. Concentrations of Al did not differ by study site or duckling age, and ranged from <0.01 µg/g to 1.6 µg/g wet weight, with highest concentrations found in goldeneyes.

Although some significant correlations were found, in general these data showed that dietary exposure of ducklings to toxicologically relevant levels of Cd, Pb, or Al is unlikely to occur in acidified environments, and metal accumulation in duckling tissues were generally unrelated to pH. Since metal concentrations in invertebrate prey were not sufficiently high to be toxic, the risk of metal-induced effects on health and reproductive success of waterfowl inhabiting acidified habitats is low.

SUMMARY: Due to the negative relationship between Hg and wetland pH, piscivorous wildlife living in acidified wetlands risk higher exposure to MeHg than those living in buffered environments. There is no evidence, however, that non-piscivorous wildlife are at risk in the same environments. The concentrations of Pb, Cd and Al in prey of most piscivorous or insectivorous wildlife in acidified habitats is not high enough to be of any health or reproductive concern. These metals may be of concern if the availability of dietary Ca or P is low, and these toxic metals are high. Certain macrophytes growing in low pH environments can accumulate Pb and/or Al to levels known to be toxic but these relationships need further study as does the bioavailability of Ca, P, Mg and Se in acidified environments. High-Ca aquatic invertebrates and plants in acidified wetlands appear to be scarce.

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EDITORIAL COMMENT: This review paper was published in a Special Issue of Environmental Pollution (Vol. 71, Nos. 2-4) entitled "pH-related Changes in Metal Biochemistry and Effects on Aquatic Systems", A.M. Scheuhammer, J.P. Dempster and W.J. Manning (eds.), which contains a series of 8 review papers on this topic. The metal accumulation case study described in this review paper was part of a collaborative effort between the Canadian Wildlife Service (Ontario Region) and the National Wildlife Research Centre (NWRC), with all collections being performed by CWS (OR) staff at the Wanapitei and Ranger Lake study sites, and all analyses performed by NWRC. Duck specimens were originally collected as part of a CWS (OR) study examining the diet of breeding waterfowl (adults and young) in relation to lake acidity and fish presence in Ontario lakes, to determine if diet composition is related by these factors to differences in the distribution and abundance of potential prey or foraging behaviour (Paper No. 95 - 2).

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PAPER NO.: 91 - 4

YEAR: 1991 **TOPIC:** Research - Metals/Calcium

Waterfowl as Indicators of Acidification in Ontario, Canada

McNicol, DK, Ross, RK, and Blancher, PJ

Transactions of the International Union of Game Biologists
19, 251-258 (1990)

KEY WORDS: acid precipitation, waterfowl, risk, aquatic ecosystems, indicators, monitoring, trophic relations, Ontario, common merganser, common goldeneye

PURPOSE OF REVIEW: To evaluate the advantages of using selected waterfowl species as indicators of acidification, and to describe the acidification problem in Ontario, review how waterfowl are being affected, and discuss the suitability of two species as indicators of acid stress.

ACIDIFICATION PROBLEM IN ONTARIO: Much of eastern Canada receives over 10 kg/ha wet excess sulphate (SO_4) deposition, with southern portions of Ontario and Quebec receiving over 20 kg. The soils and bedrock of much of Ontario (40%) have low potential to neutralize acid inputs before reaching surface waters. Watersheds in the Sudbury area have low average pHs (5-6) and acid neutralizing capacities (alkalinity <100 $\mu\text{eq/L}$) due to decades of local and long range SO_4 deposition. In most watersheds in northeastern Ontario, surface waters have low pHs (<7.0) and alkalinity (<200 $\mu\text{eq/L}$), while those in northwestern Ontario show little evidence of acidification. There are more than 170,000 lakes in the Precambrian shield portion of Ontario (540,000 km^2) and of this area, 23% falls within a moderate (>10 kg/ha SO_4 , pH >7.0) and 20% within a high (>10 kg/ha SO_4 , pH <7.0) risk area. Common species are common loon, common merganser, common goldeneye, hooded merganser, ring-necked duck, and American black duck. Of the 373,000 pairs of breeding ducks and loons on the Precambrian shield in Ontario, more than 50% nest in high and moderate risk areas. A long term atmospheric, chemical and biological monitoring program has been initiated in eastern Canada, with the Canadian Wildlife Service (Ontario Region) monitoring effects of acid deposition on waterfowl, loons and their habitats in acid sensitive areas in Ontario.

EFFECTS OF ACIDIFICATION ON WATERFOWL: There is evidence that changes in the composition, abundance and nutritional value of aquatic prey communities, resulting from acidification, can have a negative impact on avian breeding success. Because waterfowl rely on various components of the aquatic food chain, their response to acid stress is linked to changes at the ecosystem level, and is not greatly affected by the pH tolerance of individual target organisms. Long term studies of habitat selection and reproductive success are necessary to assess the changing suitability of the habitat to support healthy reproduction. Two species selected for evaluation as indicators of acid stress are the common merganser (*Mergus merganser*, an obligate piscivore which inhabits large lakes [>20 ha] and rivers) and common goldeneye (*Bucephala clangula*, an insectivore, which prefers smaller, glacial lakes). Three major impacts of increased wetland acidity which affect waterfowl are i) loss of fish, ii) altered predator-prey relationships, and iii) loss of acid sensitive invertebrates.

PISCIVORES: The common merganser and common loon (*Gavia immer*) are threatened by the effects of acidification on fish populations. Fish species richness increases with pH, and the proportion of lakes without fish increases below pH 5.5. Cyprinid

species are rarely found below pH 5.5, while yellow perch and white suckers are more tolerant of acidity and may be found at pH 4.8. Cyprinids were the predominant food for common merganser ducklings, and consequently these ducklings were only found on lakes above pH 6.0. Reduced density and diversity of fish in acidifying wetlands affects common mergansers by reducing the quality and quantity of suitable food, making this species a good early indicator of acidification in large lakes.

NON-PISCIVORES: The loss of acid sensitive organisms generally allows an increase in abundance of acid tolerant species; for example, there is an increase in benthic and nektonic invertebrates in lakes with no fish predators. Common goldeneyes prefer fishless wetlands with their high abundance of invertebrates. However, on lakes at low pH, birds encounter a reduced resource of acid sensitive prey (molluscs, mayflies, leeches, some caddisflies, dragonflies and crustaceans) and possible reduced quality of prey (energy and mineral, e.g. calcium content). The relative abundance and richness of benthic and nektonic invertebrates is higher in lakes above pH 6.3 due to the abundance of acid sensitive taxa. On acid lakes (pH <5.5), goldeneye ducklings feed primarily on a few acid tolerant invertebrate taxa (mainly nekton), whereas on non-acid lakes (pH >5.5), they use an assortment of benthic prey. The absence of fish in acid sensitive systems has resulted in improved reproductive success for goldeneyes; however, on naturally fishless lakes and lakes with fish, reproductive success was greater at high pH (>6.3) compared to low pH. A reproductive cost may be associated with raising young on wetlands whose food web has become simplified. Increased fledging success by goldeneyes would reflect improved water quality (increased pH) and an enhanced prey resource base, including more nutritious, acid sensitive invertebrates.

CONCLUSIONS: Ecosystem-level monitoring to evaluate the adequacy of SO_2 emission controls in North America is needed. Bio-indicators should be employed which respond to ecological changes in the food web within the range of critical thresholds for most sensitive aquatic biota. The fish-eating common merganser may be a useful early indicator of acidification effects of large lakes, while the insectivorous common goldeneye may be a useful indicator of acid stress on small lakes.

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EDITORIAL COMMENT: This paper was published in the Transactions of the 19th Congress of the International Union of Game Biologists (IUGB) held 8-13 September, 1989 in Trondheim, Norway, as part of a series of 17 papers presented in the session "Pollution and Wildlife" (S. Myrberget, editor).

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PAPER NO.: 90 - 1

YEAR: 1990

TOPIC: Monitoring - Waterfowl

Status Report on the Effects of Acid Precipitation on Common Loon Reproduction in Ontario: The Ontario Loon Lakes Survey

Wayland, M, and McNicol, DK

Canadian Wildlife Service Technical Report 92, 26 pp (1990)

KEY WORDS: acid precipitation, common loon, lake acidification, reproduction, *Gavia immer*, volunteers, monitoring, lake area, Ontario Lakes Loon Survey, acid sensitivity index, discriminant analysis, production, chick survival

PURPOSE OF STUDY: To assess the effects of lake acidification and size on the success of common loons breeding in Ontario using volunteers, and to make recommendations to improve the survey.

BACKGROUND: As part of the Canadian Wildlife Service (Ontario Region) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program, a volunteer-based project known as the Ontario Lakes Loon Survey (OLLS) was expanded in 1987 to study the effects of lake acidification on common loon (*Gavia immer*) reproduction in Ontario. Administered by the Long Point Bird Observatory (LPBO), the OLLS consists of a series of surveys conducted by a network of volunteers, augmented by surveys conducted by CWS and LPBO staff. The Ontario Lakes Loon Survey was initiated by LPBO in 1981 and has operated annually since then with assistance from the CWS and other contributors.

METHODS: Survey lakes spanned the province of Ontario, with the majority located in central and northeastern regions, characterized by mixed hardwood or boreal forest underlain by Precambrian granitic bedrock covered with shallow, non-calcareous soils. The area currently receives over 10 kg/ha annual wet SO₂ deposition. Volunteer surveys were conducted in 1987 and 1988, and augmented by CWS staff surveys on lakes near Sudbury (centred at 46°55'N, 80°45'W) and Ranger Lake (centred at 46°55'N 83°35'W, 40 km NE of Sault Ste. Marie). Total alkalinity, pH, and lake area data were obtained from published sources. Study lakes ranged in alkalinity from 0 to 3346 µeq/L, in pH from 4.3-8.8, and in size from 10-486 ha. Approximately 40% of the lakes were well buffered (alkalinity >100 µeq/L) and more than 50% had pH values >6.3. Lakes were given an acid sensitivity index using Ontario Ministry of Environment guidelines (acid, alkalinity ≤ 0 ueq/L; extremely sensitive, 0 ≤ alkalinity ≤ 39.9 ueq/L; moderately sensitive, 40 ≤ alkalinity ≤ 199.9 ueq/L; low sensitivity, 200 ≤ alkalinity ≤ 499.9 ueq/L; not sensitive, alkalinity ≥ 500 ueq/L). Volunteers across the province were used to help with the survey administered by LPBO. Surveys were typically conducted at three time periods: late June/early July (around hatch date for most loons in Ontario), late July (when young are still small), and late August (when young are more than half the size of their parents). Common loon reproductive effort and success was recorded (number of breeding pairs (BP), maximum number of downy or small young (DY or SY) <6 weeks old, and minimum number of large young (LY) >6 weeks old). Surveying and reporting was also done on lakes without loons. Only lakes 10-500 ha were included in the analyses because smaller lakes are seldom used by loons, and larger lakes were difficult to accurately survey (hence surveyor reliability declines). Four levels of loon production were used: no attempts, unsuccessful (where BP were present but no LY were produced), low success (where only one LY was produced) and high success (where two or more LY were produced). Stepwise discriminant analysis was used to identify the variables which discriminated among levels of breeding pair production and levels of chick survival.

RESULTS: In 1987, volunteers returned 494 records on 414 lakes, while CWS surveyed 77 lakes, for a total of 491 lakes surveyed; in 1988, volunteers returned 484 records on 398 lakes, while CWS surveyed 60 lakes, for a total of 458 lakes surveyed. During the two year period, 1115 records on 949 lakes were received. After

eliminating records for lakes repeated in both years (retaining the 1988 data) and those for lakes outside the size criteria, data for 387 lakes remained. More than 80% of these lakes were within the south-central part of the province which is sensitive to acidification and receives high acid deposition; yet, only 54 acid or extremely sensitive lakes were surveyed. Of the 387 lakes, 218 (including 53 CWS surveyed lakes) had data on loon reproductive status, lake area and lake chemistry, while 111 (including 23 CWS surveyed lakes) had data on survival between DS and LY stages. Breeding loons were successful on rearing at least one chick to the LY stage young on 76% of 215 lakes. Breeding pairs produced an average of 1.26 DY and 1.04 LY. Survival between the DY and LY stages was 0.88 for 142 lakes. Lake area was the only variable that discriminated significantly among the four levels of loon production, with the effect dominated by the fact that loons tended not to attempt to breed on small lakes. Acid sensitivity status of the lakes discriminated significantly between lakes with low and high chick survival; chick survival was significantly lower on acid or extremely sensitive lakes. Moreover, analyses suggested that survival of one chick broods was apparently independent of lake chemistry, whereas survival of two chick broods was reduced on lower pH lakes. It is probable that loons experience difficulty rearing both chicks when faced with a possible shortage of fish on acid stressed lakes..

CONCLUSIONS: Data provided by volunteers appeared to produce realistic values of loon production, and thus the OLLS appears to be a useful method of monitoring the effects of acid precipitation on large lakes in Ontario. Despite this, it was clear that much data was "wasted" due to incomplete information collection by volunteers, or missing data for physical or chemical characteristics of lakes. Both of these problems need to be addressed to maximize the full utility of the survey. Nonetheless, volunteer data did demonstrate that use of lakes by breeding pairs of loons was influenced more by lake size than by either pH or alkalinity, but that reduced pH appeared to negatively influence the survival of two chick broods. However, this conclusion should be viewed as preliminary, given the limited time frame of the study. Clearly continued monitoring of loon reproduction over the long term is required.

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EDITORIAL COMMENT: This volunteer survey of loons has been expanded nationally (Canadian Lakes Loon Survey) and continues to collect valuable information on the status of common loons breeding on lakes across Canada. If you are interested in participating in this volunteer survey or would like more information, please contact: The Canadian Lakes Loon Survey c/o Long Point Bird Observatory, P.O. Box 160, Port Rowan, ON, N0E 1M0.

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PAPER NO.: 90 - 2

YEAR: 1990 **TOPIC:** Monitoring - Loons

Lake Acidity and the Distribution and Abundance of Water Striders (Hemiptera: Gerridae) Near Sudbury, Ontario

Bendell, BE

Canadian Journal of Zoology 66(10), 2209-2211 (1988)

KEY WORDS: lake acidification, acid precipitation, water strider, Hemiptera: Gerridae, indicators, Sudbury, density, quadrats, linear regression, fish predation

PURPOSE OF STUDY: To examine the relationship between lake acidity and water strider distribution and abundance in small lakes near Sudbury, Ontario, and to determine whether water striders would make effective biological indicators of freshwater acidification.

METHODS: Fifty-three lakes, across a range of pH and size (1.0-19.5 ha), in the Wanapitei area (40 km NE of Sudbury, centre 46°54'N, 80°41'W), were surveyed for water striders in August 1985. Many lakes in the area are acid as a result of emissions from nearby smelters and from long range transport of air pollutants, and consequently have lost their fish populations. Each lake was surveyed by canoe with specimens (generally adults) of each water strider species observed around the shoreline counted and collected. At the time of the surveys, the pH of the lake was recorded. Observations during the 1985 survey indicated that *Rheumatobates rileyi* was more abundant on non-acid lakes than acid lakes; therefore, a quantitative sampling program was undertaken in 1986 to study the relationship between *R. rileyi* abundance and lake acidity. Quantitative samples were taken by collecting water striders trapped in a floating quadrat (0.5 m²) tossed from the water's edge or a canoe onto the water surface, 0.5-2.5 m from shore at 30 randomly selected sites per lake. The quadrat was not effective for sampling other, larger and more agile species. Water striders were preserved for later counting and identification. The selection of lakes for quantitative sampling in 1986 resulted in the comparison of, fishless, acid lakes with non-acid lakes containing fish. Low populations of *R. rileyi* in fishless, acid lakes could be due to the absence of fish predation on predators of *R. rileyi*, such as *Notonecta* spp. Therefore, sampling of *R. rileyi* was repeated in 1987 on 3 small (2.0-2.4 ha), high pH (6.7-7.6) fishless lakes and 4 small (1.0-3.1 ha), high pH (6.6-7.9) lakes containing fish.

RESULTS: Eight species of water striders were recorded on the 53 lakes surveyed in 1985, and five of these species were common. *Gerris comatus* and *G. buenoi* were found together on almost all lakes. *Gerris marginatus*, *G. remigis* and *Limnoporus dissortis* were recorded on some of the lakes, and over a wide range of pH. In general, the Gerrinae showed no patterns of distribution with respect to pH. In contrast to the Gerrinae, *Metrobates hesperius*, *Trepobates inermis*, and *Rheumatobates rileyi* had patterns of distribution and

abundance related to lake acidity. *Metrobates hesperius* was absent from all lakes with pH <5.1. The mean pH of lakes on which *M. hesperius* and *T. inermis* occurred (pH 6.2 and 6.0, respectively) was significantly higher than the mean pH of lakes from which they were absent (pH 5.5 and 5.5, respectively). There was a highly significant positive relationship between lake acidity and the density of *R. rileyi* as determined from quadrat counts in 1986. This relationship was not the result of an absence of predators at low pH, since the mean density of *R. rileyi* on fishless lakes sampled in 1987 did not differ from that on lakes with fish, for lakes of similar size and pH.

CONCLUSIONS: The distributions of *M. hesperius* and *T. inermis* and population densities of *R. rileyi* were related to lake acidity, while *Gerris* spp. showed no such relationships. *Metrobates hesperius* was often conspicuously abundant on high pH lakes and strikingly absent from acidified lakes, and its distribution was not affected by fish predation. Thus, this species may be an effective monitor of acidification and related changes in lakes and rivers. Several hypotheses are proposed to explain the observed reduction in the distribution and abundance of some water strider species on acid lakes. However, an understanding of the mechanism responsible for restricting it from acid lakes is needed to enhance its effectiveness as an indicator of acidification.

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PAPER NO.: 88 - 1

YEAR: 1988 **TOPIC:** Research - Invertebrates

Breeding Biology of Tree Swallows in Relation to Wetland Acidity

Blancher, PJ, and McNicol, DK

Canadian Journal of Zoology 66(4), 842-849 (1988)

KEY WORDS: tree swallow, *Tachycineta bicolor*, wetland acidity, acid precipitation, reproductive success, wetlands, Sudbury, nest boxes, nestlings, clutch volume, growth rate, principal components analysis, multiple regression, trophic relations, subadults

PURPOSE OF STUDY: To determine if tree swallow reproduction is influenced by wetland acidity, as has been found for other avian species.

METHODS: A population of tree swallows from the Wanapitei area 40 km NE of Sudbury, Ontario (centred at 46°55' N, 80°45' W) was studied. The area has a high proportion of acid lakes due to long range transport of air pollutants and emissions from nearby smelters. Many of the more acid wetlands lack fish. There were 51 wetlands in the study (ranging in size from 1.2-25.5 ha), selected to cover a range of pH (4.05-7.60), dissolved organic carbon concentration (DOC, 3.0-20.2 mg/L), and presence or absence of fish determined using fish traps. Most wetlands had riparian development, but ranged from clear, rocky headwater lakes to dark-coloured pools in peatlands. Tree swallow nest boxes were placed around 38 wetlands in the spring of 1985 and a further 13 in the spring 1986. Nestlings were individually marked, and their mass and body measurements recorded several times prior to fledging to determine growth rates. An index of the maximum growth rate was calculated as the instantaneous rate of growth at the inflection point of the fitted logistic growth curve; these indices were used to compare growth rates among wetlands. Principal component analysis was performed on five measurements of nestling size and three measures of growth rate to obtain a single overall index of nestling size. Other reproductive measures were related to pH, DOC, wetland area, and nesting dates by stepwise multiple regression.

RESULTS: Fish were present in 23 of the wetlands which had, on average, higher pH and were larger than fishless wetlands (mean pH 6.35, area 9.0 ha and pH 5.25, area 4.1 ha, respectively). Tree swallows laid eggs in 82% of available nest boxes (n=116). Of 439 eggs that were still intact at the end of incubation, 90% hatched. Compared to subadults, adults laid eggs an average of 9 days earlier, laid larger clutches (mean 5.8 vs 4.8), and fledged more young (mean 3.4 vs 1.7), thus for these variables only adult females were used for the analyses. Average laying date was not related to pH or DOC, but egg laying was three days earlier at wetlands with fish than without fish. Mean clutch size was positively related to pH and DOC. Egg volume was positively related to wetland area and was greater in wetlands without fish, but was not related to pH or DOC. The total investment by females was estimated by combining clutch size and egg volume into "total clutch volume". Clutch volume was positively related to pH, and was higher at wetlands without fish. Neither mass loss by unpipped eggs during incubation nor hatching success were related to any wetland variables measured. Hatchday mass was strongly correlated with egg volume, and nestling mass at age four days was correlated with hatchday mass, but as nestlings aged the relationship waned until not significant at age 16 days. Further analyses using nestling size were restricted to 16-day old nestlings and growth statistics to reduce any effect of egg volume and hatchday mass on growth measures. Principal component scores of nestling

size/growth rate were positively related to pH and negatively influenced by the presence of fish. The positive relationship between pH and nestling size was significant for most individual size or growth variables. There was also a positive relationship between pH and brood size at age 16 days. There was no influence of DOC or wetland size on any of the nestling size/growth measurements. Fledgling production by adult females was not related to wetland conditions or timing of nesting; however, the number of fledglings per successful nest (one in which at least one young fledged) was positively related to wetland pH. Clutches at acid wetlands (pH <5.0) were smaller (0.8 eggs fewer) than those in more neutral wetlands (pH >6.0), and this was reflected in the number of young produced, with 1.3 fewer fledglings per successful nest in acid wetlands than neutral ones.

CONCLUSIONS: Wetland acidity negatively affected: a) the investment by laying females in eggs, b) size and growth of nestlings and, c) the number of fledglings produced. The mechanism for this effect may be through a reduction in the availability of aquatic insect prey in acid wetlands, especially mayflies which are particularly acid sensitive. Several taxa of aquatic invertebrates are known to be sensitive to wetland acidity, and several studies have documented changes in avian reproductive success with changes in food abundance. This interpretation is supported by the result that swallow reproduction was lower on wetlands with fish, since fish consume many of the same insects and may reduce food availability to swallows. It is also possible that the lower reproductive success of tree swallows is related to a deficiency in the diet, particularly calcium. Several invertebrates (e.g. crayfish, molluscs such as snails or clams) which provide a high mineral content are sensitive to acidity and are less common in diets of swallows near acid wetlands.

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PAPER NO.: 88 - 2

YEAR: 1988

TOPIC: Research - Birds

Cyprinid Assemblages, and the Physical and Chemical Characteristics of Small Northern Ontario Lakes

Bendell, BE, and McNicol, DK

Environmental Biology of Fishes 19(3), 229-234 (1987)

KEY WORDS: cyprinids, lake acidification, lithophilous assemblage, drainage area, fish community, Ranger Lake, minnow traps, littoral zone, refugia, MANOVA

PURPOSE OF STUDY: To determine the relationships between cyprinid fish communities and the physical and chemical characteristics of small, northern lakes.

METHODS: Fish species, water chemistry, and physical characteristics were recorded for 58 small (1.4 - 23.1 ha), often headwater, lakes in the vicinity of Ranger Lake (46°55'N, 83°35'W), 40 km NE of Sault Ste. Marie, Ontario. Cyprinids were sampled between June 30 and August 3, 1983, using large, baited minnow traps placed for 24 h at depths between 0.3 and 2.5 m at each of five sites equidistant around the shoreline. Composite water samples were taken from each lake between June 12-17 using plastic tubing lowered through the epilimnion and metalimnion in stratified lakes or to a depth of 1 m above the bottom in shallow lakes. Conductivity, pH, calcium concentration, and alkalinity were determined. Lake areas and shoreline length were determined from aerial photographs (scale 1:15,840), and upstream drainage areas were estimated from topographic maps (scale 1:50,000).

RESULTS: Seven cyprinid species were common in the 58 study lakes: northern redbelly dace, *Phoxinus eos*; finescale dace, *P. neogaeus*; pearl dace, *Semotilus margarita*; fathead minnow, *Pimephales promelas*; common shiner, *Notropis cornutus*; creek chub, *Semotilus atromaculatus*; blacknose dace, *Rhinichthys atratulus*. Species which were captured rarely were the golden shiner, *Notemigonus crysoleucas*, and blacknose shiner, *Notropis heterolepis*. Non-cyprinids captured were white sucker, *Catostomus commersoni*, brook stickleback, *Culaea inconstans*, Iowa darter, *Etheostoma exile*, and brook charr, *Salvelinus fontinalis*. The six major cyprinid taxa can be divided into two groups: i) common shiner, creek chub, and blacknose dace are typical stream-dwelling species which use gravel beds as spawning sites; they are characterized as lithophilous, and ii) *Phoxinus* spp, fathead minnow, and pearl dace do not require hard substrates for spawning; they are characterized as non-lithophils. Non-lithophils were widespread, whereas lithophilous cyprinids were absent from 25 lakes. Lithophilous species were found significantly more often in association with other lithophilous species, while fathead minnows and pearl dace occurred independently of lithophils, and *Phoxinus* spp occurred more often in the absence of lithophils. Of non-cyprinid species, the non-lithophilous brook stickleback occurred with lithophilous cyprinids in only 10 of 25 lakes, while the lithophilous white

sucker occurred with lithophilous cyprinids in 20 of 27 lakes. Differences between the two groups of lakes were highly significant. Using MANOVA procedures, it was determined that lakes with lithophilous species had higher mean drainage areas, higher alkalinity (adjusted for pH), and tended to have higher calcium concentrations than lakes containing only non-lithophilous species.

CONCLUSIONS: Small lakes in the Ranger Lake area of northeastern Ontario supported two cyprinid assemblages, consisting of lithophils and non-lithophils. Lithophilous species were restricted in their distribution, and occurred more frequently in lakes with large drainage basins. Drainage basin size may relate to the availability of stream habitat, the inflows of which may provide refuge from low winter oxygen levels, since lithophilous species may be sensitive to oxygen levels. Lakes with small drainage areas have low buffering capacity, and consequently, fish and other sensitive organisms in small, headwater lakes are more likely to suffer losses at a given level of acid deposition than lakes with large basins.

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PAPER NO.: 87 - 1

YEAR: 1987 **TOPIC:** Research - Fish/Amphibians

Fish Predation, Lake Acidity and the Composition of Aquatic Insect Assemblages

Bendell, BE, and McNicol, DK

Hydrobiologia 150, 193-202 (1987)

KEY WORDS: lake acidification, acid precipitation, aquatic insect assemblages, macroinvertebrates, nekton, fish predation, ordination, TWINSpan, DECORANA, Ontario, sweep net, littoral zone, species richness

PURPOSE OF STUDY: To examine the hypothesis that the abundance, diversity, and assemblage characteristics of aquatic insects change with respect to fish populations, and that pH-related changes in these parameters are a result of the pH sensitivity of fish rather than the aquatic insects sampled.

METHODS: Aquatic macroinvertebrate communities were examined in 36 small (1.5-7.5 ha), low alkalinity (0-215 µeq/L) lakes across a range of pH in each of two areas of northeastern Ontario. Lakes in the Wanapitei area (centre 46°54'N, 80°41'W), 40 km NE of Sudbury, have received acid precipitation with high sulphate loadings from local emissions, and many of the lakes are now acid and fishless. Lakes in the Ranger Lake area (46°55'N, 83°35'W), 40 km NE of Sault Ste. Marie, have received moderate levels of acid precipitation. There have been no reported losses of fish populations due to lake acidity, although some lakes are naturally fishless. Aquatic insects were sampled using a standardized sweep net procedure. Ten samples, each consisting of ten consecutive sweeps with a dip net from a canoe, were taken at equidistant points around the shoreline of each lake in water 0.3 to 1 m deep. Sampling was conducted mid to late July 1983, with insects identified to as specific a taxonomic level as possible. The presence or absence of fish and estimates of gross differences in their abundances, were obtained using large, baited minnow traps. Water samples were collected in early June and pH determined. Each lake was scored for the presence or absence of major insect taxa. Resulting matrices were examined using statistical ordination programs (TWINSpan and DECORANA). Lakes were ordered such that those with similar insect assemblages were grouped together and insect taxa with similar distributions among lakes were also grouped.

RESULTS: Fish were not found in four of 18 lakes sampled in the Ranger Lake area and eight of 18 lakes in the Wanapitei area. Among lakes with fish, a total of 12 fish species (mostly cyprinids) were recorded. Fishless lakes and those with very few fish shared many more insect taxa in common than with other lakes with fish regardless of pH, and had lower pH (significant at Wanapitei only) than lakes with many fish. Taxa that were common among fishless lakes in both areas were nektonic (e.g. Notonectidae, Corixidae, the dytiscid beetle *Graphoderus liberus*, and the dipteran *Chaoborus americanus*). Fishless lakes in both areas had similar insect assemblages, even though those lakes at Ranger Lake had

higher average pHs (5.8) than those at Wanapitei (4.7). At Wanapitei, differences in aquatic insect assemblages were related to pH because of the loss of fish populations resulting from lake acidification. There was a significantly higher number of insects in samples from fishless lakes than those with fish in both areas, largely due to the abundance of nekton. Several lakes with fish and without nekton nonetheless had numbers of insects comparable to those in fishless lakes because of large numbers of water striders, particularly *Rheumatobates rileyi*. Fishless lakes also had significantly greater species richness than lakes with fish (average number of taxa in fishless lakes 11.9 and 13.5, in lakes with fish 5.3 and 6.0 for Wanapitei and Ranger Lake, respectively). Lakes with fish and without fish in the Wanapitei area supported two distinct and separate insect assemblages, while there was a broader degree of overlap in the Ranger Lake area.

CONCLUSIONS: Many of the changes in the macroinvertebrate assemblages that are observed to coincide with acidification are related to changes in predator-prey relations and not direct toxic effects of lowered pH on the macroinvertebrates themselves. Such changes may occur not just because of changes in pH, but also as a result of winter anoxia, over-fishing or other pollutants which cause fish mortality. Therefore, caution must be used in developing biological indicators of acidification because of their possible indirect relationship to pH.

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PAPER NO.: 87 - 2

YEAR: 1987

TOPIC: Research - Trophic Relations

Estimation of Nektonic Insect Populations

Bendell, BE, and McNicol, DK

Freshwater Biology 18, 105-108 (1987)

KEY WORDS: nekton populations, aquatic insects, sweep net, water column sampler, Hemiptera: Corixidae and Notonectidae, sampling techniques, littoral zone, Sudbury, linear regression, confidence intervals, absolute vs relative estimates

PURPOSE OF STUDY: To assess the accuracy of relative estimates of nektonic insect populations (sweep net samples) with absolute estimates (from water column sampler) in shallow lake water. To further assess the reliability of absolute estimates derived from regression functions calculated from relative estimates.

METHODS: Fifteen small lakes (1.9 - 7.8 ha) in the Wanapitei area (46°55'N, 80°41'W), 40 km NE of Sudbury, Ontario were sampled for nekton between late July and early August, 1984. A water column sampler was constructed by gluing two clear polycarbonate sheets (62 x 124 x 0.05 cm) into a cylinder 1.20 m high and 0.38 m in diameter. When placed in the water, the cylinder trapped a column of water over 0.11 m² of substrate. Trapped organisms were exposed by slowly lowering into the column a white acrylic disc (36 cm in diameter) attached to a pole. As the disc was lowered, organisms were forced above it, and were captured with a small net. The disc was repeatedly lowered until all organisms were removed. Water column samples were taken at 15 randomly selected sites around the shoreline of each lake at a depth of 34 - 105 cm. Ten consecutive sweeps of a 625 cm² D-frame sweep net were taken from a canoe at 10 sites per lake in water 0.33 - 1.0 m deep. Absolute population estimates obtained from column samples and relative estimates obtained from net samples were compared using linear regression. The reliability of the regression functions for predicting absolute abundances from relative estimates were assessed by constructing simultaneous confidence intervals for predicted values and simultaneous tolerance intervals using the Bonferroni procedure.

RESULTS: The mean overall density of corixids from water column samples was 42.5 m⁻² (range 0 - 433.6 m⁻²). For *Buenoa*, the mean overall density was 16.0 m⁻² (range 0 - 70.8 m⁻²). The numbers of organisms taken was not correlated with water depth. The mean number of organisms per lake in net samples was 2.5 (range 0 - 12.6) for corixids, and for *Buenoa* it was 10.7 (range 0 - 41.1). Eleven species of adult corixids were found and one, *Hesperocorixa scabricula*, accounted for 67% of all adults in both column and net samples. Even so, immatures accounted for the majority of specimens for both groups, which meant that the abundance data necessarily represented multi-species groupings. The variation of the mean number per lake of *Buenoa* and corixids in column samples was high. However, at the highest densities of both

organisms, standard errors from 15 samples were less than 20%. As a result, estimates of high density populations can be made with an acceptable level of precision from a reasonable number of samples. At lower densities, the effort to obtain precise estimates becomes prohibitive, and using indirect techniques is a viable alternative. The mean number of *Buenoa* in column samples and net samples was highly correlated ($r=0.98$). The relationship of the mean number of corixids in column and net samples was best described by a regression using the log-transformed number of corixids per column sample. Absolute population estimates were generally not reliable when derived from relative estimates based on simultaneous prediction and tolerance intervals for predictions from linear regressions.

CONCLUSIONS: The mean numbers of Corixidae and *Buenoa* taken in shallow waters from a lake in net samples (a relative estimate of abundance) were strongly related to the mean number taken in column samples (an absolute estimate of abundance), thus it is reasonable to use net sample data as population indicators for comparative purposes. However, prediction intervals and tolerance intervals indicated that it is not reasonable to predict absolute abundances from relative estimates using regression functions.

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PAPER NO.: 87 - 3

YEAR: 1987

TOPIC: Research - Invertebrates

Influence of Wetland Acidity on Avian Breeding Success

Blancher, PJ, and McAuley, DG

Trans North Am Wildl Nat Res Conf 52, 628-635 (1987)

KEY WORDS: wetland acidity, acid precipitation, avian breeding, trophic relationships, North America, piscivores, insectivores

PURPOSE OF REVIEW: To present findings from eastern North American studies of avian reproductive responses to wetland acidification, and to assess possible mechanisms linking wetland acidity to effects on avian reproductive success. Avian studies were sorted into three groups, based on their feeding habits: 1) birds that are primarily piscivores; 2) birds that feed mainly on aquatic invertebrates, either in the water or at the water's surface; 3) birds that feed on flying insects from aquatic habitats.

TROPHIC RELATIONSHIPS: *Piscivorous Birds* - Loons, mergansers, herons, bitterns, terns, gulls, ospreys, eagles, and kingfishers consume large numbers of fish and breed near waters that are sensitive to acidification. The osprey shows a significant decline in offspring production in heavily acidified areas. Common loons are influenced by acid rain because they feed on small fish, a resource sensitive to acidity, and the young remain on the natal lake. However, results are mixed for studies of loon reproduction in relation to lake acidity. Brood production of loons and common mergansers in northeastern Ontario was 88% lower in an area with a large proportion of acid, fishless lakes compared to a non-acid area. In contrast, there was a high fledging rate of common loons in the Adirondack Mountains of New York where many lakes are acid. Breeding success of individual pairs of loons also showed mixed results. Loons breeding near Sudbury, Ontario had lower success on lakes with low alkalinity (low capacity to buffer acid); the reduced success was attributed to high brood mortality. However, in the Adirondacks, fish biomass was greater on lakes with higher pH, but breeding success of loons was unrelated to lake pH.

Insectivorous Birds - Waterfowl, shorebirds and many passerines eat aquatic invertebrates obtained from wetlands. Survival of ring-necked ducklings in Maine was lower on wetlands where pH was low, but there were no differences observed in clutch size or hatching success in relation to wetland pH. Decreases in growth rates of black ducks have been attributed to low wetland pH.

Aerial Insectivores - Flying insects that have aquatic larval stages are important prey for flycatchers, swallows, goatsuckers, blackbirds, warblers and waxwings. In four species of songbirds nesting near acid lakes in Sweden, birds laid soft-shelled eggs, produced small clutches and eggs had low hatchability. Impairment of this magnitude has not been shown for birds breeding near acid lakes in North America. For nestlings of eastern kingbirds near Killarney, Ontario, tarsus growth was correlated positively with pH and alkalinity, and negatively with sulphate, manganese and zinc, which are elevated in acid wetlands. A canonical correlation showed a negative association between measures of kingbird nestling growth and chemical variables associated with acidification. The size of swallow nestlings near Sudbury, Ontario was positively related to wetland pH, as were clutch size and fledgling production. There is evidence of a change in swallow diet as wetland pH decreases, with mayflies and molluscs fed to nestlings more frequently at high pH's, flies and terrestrial insects more frequently at low pH.

MECHANISMS: A decline in the number of fish from acidified lakes has been implicated in the reduced breeding success of loons and ospreys. Reduced adult foraging success has also led to nestling mortality and a subsequent decline in osprey populations in acidified areas of Sweden. Fish density was lower in acid lakes in the Adirondacks, but there was no corresponding reduction in loon breeding success, partially because loons also include invertebrates in their diet and may forage for fish in non-acid lakes. Lower invertebrate abundance in more acid wetlands may account for reduced breeding success of ring-necked ducks, black ducks, goldeneyes and dippers.

For other birds which feed on aquatic invertebrates, prey abundance may not be reduced at low pH; pH may affect certain invertebrate taxa, but not the total biomass of emerging insects. For goldeneyes, food abundance can be greater at low pH when there are no fish competing for this resource, but in areas with fish, goldeneyes may suffer from lower food abundance at low pH. Where food is abundant, food *quality* may affect avian reproduction. Invertebrates from acid lakes may be less nutritious than those from lakes with higher pH, or invertebrates with high mineral content may be sparse or absent in lakes with high pH. There is some evidence to suggest that the abundance of prey containing calcium, which is important for eggshell formation and growth of nestlings, affects reproductive success of dippers, kingbirds and tree swallows.

CONCLUSIONS: The few studies that have examined avian reproduction in relation to wetland acidity suggest that the latter can have an adverse effect on the former. Where breeding success is not related to wetland acidity, other measures such as foraging rate, nestling growth or chemical content of eggs and nestlings may be related to wetland acidity. There is evidence that low food abundance in areas of low pH is responsible for poorer avian reproduction in those areas. More research is needed to assess the importance of metal toxicity and reduced quality of food on avian reproduction. It is difficult to demonstrate the influence of habitat acidity on avian reproduction because there are many other factors which affect reproductive success. Carefully-designed studies with large sample sizes are needed to thoroughly address this question.

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EDITORIAL COMMENT: This paper was published in the Transactions of the 52nd North American Wildlife and Natural Resources Conference held in Québec City, Québec, 20-25 March, 1987, as part of a series of nine papers presented in a special session "Acidification and Wildlife" (D. B. Peakall and R. J. Hall, co-chairs).

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PAPER NO.: 87 - 4

YEAR: 1987

TOPIC: Research - Birds

Peatland Water Chemistry in Central Ontario in Relation to Acid Deposition

Blancher, PJ, and McNicol, DK

Water Air and Soil Pollution 35, 217-232 (1987)

KEY WORDS: water chemistry, lake acidification, acid precipitation, peatland, Ontario, minerotrophy, ombrotrophy, bogs, poor fens, organic anions, anion deficit, factor analysis, multiple regression

PURPOSE OF STUDY: To assess the influence of acid deposition on peatland water chemistry, as part of a study on the effects of acid precipitation on wetland-dwelling wildlife in central Ontario.

METHODS: Two study areas were used: the Ranger Lake area (46°55'N, 83°35'W), 40 km NE of Sault Ste. Marie, and the Wanapitei area (46°55'N, 80°45'W), 40 km NE of Sudbury, both located within the low boreal wetland region of Canada. The Wanapitei area receives a greater loading of sulphate and H⁺ from long range transport of air pollutants and from local emissions than does the Ranger Lake area. As a result, many lakes in the Wanapitei area are acid (pH <5.0). Fifteen peatlands were studied at Ranger Lake, 16 at Wanapitei; all had central pools of open water and at least 3 m depth of organic peat. Wetlands were of two types: those with no obvious signs of minerotrophic influence (bogs), and those where a seasonal flow of water was evident (poor fens). Wetlands were mapped from aerial photographs, seasonal fluctuations in water level recorded, peat depth measured, and the presence of inflows and outflows of water was used as an indicator of minerotrophic influence. Water samples were collected from all peatlands during the spring, summer and fall of 1985. Mat surface water was collected by pressing the sampling bottle into wet depressions in the peat surface; pool water was collected near the pool edge. Several analyses were performed on filtered water samples: alkalinity, pH, conductivity, major ions (Ca, Mg, Na, K, SO₄, Cl, SiO₂), nutrients (NH₃, NO₃ + NO₂, PO₄), carbon (TDC, DOC, DIC, water colour) and trace metals (Fe, Al, Mn, Zn, Cu, Ni). A factor analysis was performed on all the water chemistry variables (62 water sampling sites, 186 water samples). Ionic composition of each water sample was calculated and the anion deficit, the difference between the sum of cations and sum of anions, was used as an additional measure of organic anions present (the latter calculated from DOC and pH using Oliver's formulae). Multiple regressions were used to examine the relationship between bog acidity and other chemical parameters. Fen samples were not included in the regressions because mineral buffering present in fens would confound analyses for bog waters.

RESULTS: Peatlands ranged in size from 1.1 to 6.3 ha (except for one large bog of 26.8 ha at Wanapitei). Poor fens tended to be larger than treed bogs, and had larger central pools, but the differences were not significant. Pool water levels in both study areas dropped from May to August. Peat depths ranged from 4.8 to 11.6 m, with no differences between areas. Three of the factor analysis axes explained 82% of the variation in water chemistry. The first factor reflected the concentration of organic constituents in the water (high loadings for total dissolved carbon, dissolved organic carbon, water colour and anion deficit). Two nutrients (PO₄, NH₃) loaded highly, as did several metals (Zn, Pb, Cu, Fe, Al), chloride, and K. Factor 1 separated pool samples from mat samples; mat water had a greater concentration of organic compounds than pool water. Among pool samples, there were no differences between study areas in Factor 1

scores, but among mat samples, both bogs and fens had higher organic scores at Wanapitei than at Ranger Lake. The strength of the mineral influence was reflected in the second axis. Ca, Mg, Na, silica, pH, alkalinity, and measures of ionic strength, such as conductivity, sum of cations, and sum of anions, loaded positively on Factor 2. This factor could be considered a measure of mineral buffering capacity. Fen pools had higher Factor 2 scores than bog pools, indicating a greater mineral influence in fens. Among mat samples, fens and bogs did not differ. Wanapitei bogs scored higher on Factor 2 than Ranger Lake bogs; fen samples did not differ. The chemical variables associated with Factor 3, Mn, sulphate, Ni, Cu and Al, are linked to acid deposition from smelting activities, and thus Factor 3 is a measure of the strength of deposition influence on peatland waters. Factor 3 separated water samples taken at Wanapitei (high scores) from Ranger Lake (low scores), indicating a greater deposition influence in Wanapitei peatlands. Bog pools scored higher than fen pools on Factor 3. Seasonal differences were only evident in Factor 1 for fen pools; for mat samples, seasonal differences were marked for Factors 1, 2, and 3 (high in August when water levels were lowest and elements were most concentrated). The composition of cations was similar in the two study areas. In bog pools, H⁺ was the predominant cation, but in fen pools it was relatively unimportant. The anionic composition of peatland waters was dominated by SO₄ and organic anions. SO₄ ions were more important at Wanapitei (due to higher concentration of SO₄ rather than a decrease in organic content of the water) than Ranger Lake; the reverse was true for organic anions. There was a positive relationship between H⁺ concentration and DOC in both study areas, indicating the presence of organic acidity. Organic C explained most of the variation in acidity in November, but only 29% in May, when SO₄ and Ca were relatively more important.

CONCLUSIONS: Organic concentrations differentiated open pool samples from mat water. Pool water also differed from mat water in the degree of seasonal change observed. The major chemical differences between Wanapitei and Ranger Lake reflected higher concentrations of sulphate and metals at Wanapitei, which is consistent with the high level of acid deposition near Sudbury. The results here do not show a complete dominance of acidity by sulphate ions, as seen in some bogs in industrialized areas, but do indicate inputs of anthropogenic acidity in bog waters at Wanapitei. These findings could have serious implications for wetland-dwelling biota.

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PAPER NO.: 87 - 5

YEAR: 1987

TOPIC: Research - Chemistry

Diet of Nestling Tree Swallows (*Tachycineta bicolor*) near Sudbury, Ontario, Summer 1986

Blancher, PJ, Furlonger, CL, and McNicol, DK

Canadian Wildlife Service Technical Report 31, 14 pp (1987)

KEY WORDS: lake acidification, acid precipitation, preliminary, tree swallow, *Tachycineta bicolor*, diet, nestling, aquatic, terrestrial, mollusc, food bolus, neck collars, Sudbury, calcium

PURPOSE OF STUDY: To describe the importance of aquatic prey (particularly those sensitive to pH) in the diet of tree swallows, relate diet information to reproductive data, and to examine the merits of several methods used to collect diet information.

METHODS: As part of an investigation into the effects of acid precipitation on wetland-dwelling wildlife, the biology of tree swallows (*Tachycineta bicolor*) was studied near Sudbury, Ontario between 1985 and 1987. Tree swallow habitat selection, reproduction and diet were examined. In 1986, reproduction was poorer for swallows breeding near low pH wetlands compared to swallows breeding near less acid wetlands. Preliminary diet data collected in 1986, and presented here, suggested that this difference might be related to a change in the quality and quantity of prey of aquatic origin available to swallows as wetland pH changes. These results provided the methodological information required to plan and undertake a detailed study of tree swallow diets in 1987 and test these hypotheses.

The study lakes were situated in the Wanapitei study site, 40 km NE of Sudbury (centred at 46°55'N, 80°45'W). Fifty one wetlands were used, ranging in size from 1.2-25.5 ha, and pH from 4.05-7.60. Most had shorelines with ericaceous shrubs associated with *Sphagnum* mat, but wetlands ranged from clear, rocky headwater lakes to dark-coloured pools in well-developed peatland. Two to four tree swallow nest boxes were erected at 1-2 m height around the edge of the wetlands (spring 1985, n=35; spring 1986, n=13). Diet information was collected using six methods: food boluses (collected from the mouth of adults), neck collars (ligatures placed around the throat of young so they could not swallow the food delivered by adults), nestling stomachs (prey items in stomachs of dead nestlings were identified), regurgitations (pellets brought up by young), faeces (hard parts were identified from samples collected opportunistically), and spillage in nests (undigested prey and prey remnants left in nests, excluding parasites and their larvae). Samples were collected from late June and July, and underrepresent June nestling diets. Prey items were identified to Family and classified as aquatic or terrestrial in origin.

RESULTS: The six collection methods provided 2,783 prey items, with neck collars and food boluses providing the most data. Dipterans (true flies) were the most common prey items, comprising more than 40% of items fed to nestlings, digested or found in the nest. The most common flies were the dance flies (Empididae), midges (Chironomidae) and muscid flies (Muscidae), with large Tabanidae (horseflies) also important, due to their relatively large

size. Homopterans (notably aphids) were also important, and together with dipterans made up 72% of items fed to nestlings. Prey items high in calcium, including sphaeriid clam shells, snails, crayfish chelipeds, bones and pieces of eggshell, were found in spillage samples. Differences in composition of diets, according to collection methods, reflected the effects of digestion on organisms: hard-bodied prey like dragonflies, beetles and wasps dominated digested samples, whereas soft-bodied prey like aphids, spiders and mayflies dominated food fed to nestlings. About half of the prey fed to nestlings were aquatic in origin. Because some aquatic prey are sensitive to pH (e.g. mayflies, molluscs), diet composition was examined in relation to wetland pH. Mayflies were not found in 11 samples of food fed to nestlings where wetland pH < 5.0, but were 8% of diet items for wetlands with 5.0 < pH < 6.0, and 30% of items at pH > 6.0. Mollusc shells were more common from nests where wetland pH was above 6.0. Prey items averaged 6 mm, with items of terrestrial origin typically smaller than aquatic items. However, libellulid dragonflies as large as 35 mm were taken. Items more than 10 mm long made up 16% of aquatic prey but only 3% of terrestrial prey, suggesting that despite similarity in numerical contribution to diet (i.e. ~ 50%), items of aquatic origin may be more important.

CONCLUSIONS: This study demonstrated that insects of aquatic origin are a major component of tree swallow diets near Sudbury, and it also emphasized the importance of prey items high in calcium (which are less available on acid lakes and wetlands). From a methodological viewpoint, this study suggested that neck collar techniques provide the most data (which tends to be unbiased with respect to prey representation), but that other methods (faeces, regurgitations, spillage) also provide useful data that can be collected with little disturbance to nesting birds.

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EDITORIAL COMMENT: A detailed list of prey items identified and their body lengths is presented. Data presented in this technical report were used with data collected in 1987 (see Paper No. 91 - 2).

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PAPER NO.: 87 - 6

YEAR: 1987

TOPIC: Research - Birds

Wildlife Resources at Risk through Acidification of Wetlands

Longcore, JR, Ross, RK, and Fischer, KL

Trans North Am Wildl Nat Res Conf 52, 608-618 (1987)

KEY WORDS: wetland acidity, acid precipitation, sensitivity, aquatic birds, waterfowl, common loon, osprey, risk, North America, risk

PURPOSE OF STUDY: To evaluate the potential risk to which water-dependent birds may be exposed from the effects of acid deposition.

METHODS: Studies which focused on seven species of aquatic birds (common loon, osprey, common merganser, hooded merganser, common goldeneye, black duck, and ring-necked duck) were examined. Study areas included the Canadian provinces east of Manitoba and those states in the United States within the breeding range of the American black duck. Several variables were determined from the literature: 1) area used for breeding, 2) density of breeding species, 3) percentage of breeding range sensitive to acid deposition, and 4) estimated number of breeding pairs in sensitive habitat. Bedrock areas composed of noncalcareous minerals with total alkalinity < 200 $\mu\text{eq/L}$ were considered sensitive to acidification, and the amount of each species' range sensitive to acidification was determined using a planimeter and published maps. For New York, New Hampshire, Vermont and Maine, the amount of a species' range sensitive to acidification was obtained from maps of total alkalinity < 100 $\mu\text{eq/L}$; for states south of New York, values were based on maps with total alkalinity of < 200 $\mu\text{eq/L}$. In Canada, sensitivity to acidification was based on bedrock geology and Calcite Saturation Index (CSI). Vulnerable areas are any sensitive areas that receive > 20 kg/ha/yr of wet sulphate deposition. Breeding ranges of species were obtained from the published literature and recent, unpublished surveys from several sources. The potential effects of increased acidification were evaluated based on the following criteria: percentage of breeding range that is sensitive; calcium shortage during egg-laying; age at breeding; fidelity to breeding site; mobility of prefledged young; adaptability to alternative foods; exposure to toxic metals; and amount of legal harvest.

RESULTS: About 17% of the area evaluated is sensitive to acid deposition. The black duck is the only species whose breeding range lies almost entirely within the area affected by acid deposition in the Northeast. Seventeen percent of the black duck breeding range extends over habitat that is sensitive. The primary breeding range of the hooded merganser is also within the vulnerable area. All other species breed throughout prairie Canada as well as within the evaluated 'risk' area. The osprey population in the U.S. is concentrated in coastal habitats and only a few inland populations are likely affected by acid rain. Calcium-rich foods, such as clams and snails, do not survive in acid water and thus dietary sources of calcium may be limited for birds. Calcium deficiencies likely affect the non-piscivorous black duck, ring-necked duck and common goldeneye the most; fish-eating species can obtain calcium from the bones of fish as long as fish are available. Studies suggest that calcium deprivation in acidified systems may be important. Black ducks and ring-necked ducks breed in their first year and thus are less at risk than the other species which breed in their second or third year. All seven species return to breed near their natal areas, and thus will continue to attempt to breed in the sensitive areas in which they were raised or had previously bred. Lower offspring survival on low pH areas may affect recruitment. Black ducks in Maine avoid wetlands most sensitive to acidification during breeding; however in Ontario, small, acid sensitive headwater lakes are heavily used by black ducks. Piscivores, particularly common loons and common mergansers, use the most vulnerable lakes, and therefore are at

greater risk because fish become depleted in acid lakes. Goldeneyes use acid ponds and may temporarily benefit from loss of fish; however, goldeneye populations are declining. Anatids have young that can leave unfavourable habitats by travelling overland, but they are exposed to predators and also may not be able to move far enough to reach a non-acid wetland. Loons and ring-necked ducks do not travel overland and during nesting must use their natal lakes and wetlands. Hence, their chicks are at risk to the effects of acidification of headwater lakes and wetlands where they breed. Osprey chicks are altricial and are especially vulnerable to local habitat quality, unless adults range widely in search of food. Breeding and non-breeding common loons have been known to use fishless lakes and feed on invertebrates. Hooded mergansers eat fish, but are primarily insectivores and may eat a variety of organisms. The invertebrate diet of ring-necked ducks is less diverse on acid wetlands and ducklings did not survive well, but they will eat alternate foods (eg. sponges). Goldeneyes are attracted to acid wetlands because of the lack of competition from fish for invertebrate food. However, the survival of ducklings may be extremely low on acid wetlands. Black ducks eat a variety of invertebrates, but some of the important species are susceptible to low pH. Fish-eating birds are likely to be exposed to toxic metals, especially mercury which accumulates in fish in an inverse relationship to pH. Common loons and black ducks accumulate mercury, but not at levels to affect reproduction. The effects of acid deposition likely occur over the long term and affect recruitment to populations. Subtle changes in population size resulting from habitat degradation may be obscured by high mortality from hunting, except for the common loon and osprey. If recruitment is low and other causes of mortality are high, then the effects of acidification may exacerbate the risk to the species.

CONCLUSIONS: Research on the acidification process and its influence on aquatic ecosystems has documented adverse effects on fish and invertebrates important as food for birds. Determining the effects of acidification on migratory birds and quantifying the severity of these effects will be difficult and must be viewed in terms of "risk" criteria. Acid rain may contribute to declines in avian populations in concert with several other variables.

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EDITORIAL COMMENT: This paper was published in the Transactions of the 52nd North American Wildlife and Natural Resources Conference held in Québec City, Québec, 20-25 March, 1987, as part of a series of nine papers presented in a special session "Acidification and Wildlife" (D. B. Peakall and R. J. Hall, co-chairs).

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PAPER NO.: 87 - 7

YEAR: 1987

TOPIC: Research - Birds

Studies of the Effects of Acidification on Aquatic Wildlife in Canada: Waterfowl and Trophic Relationships in Small Lakes in Northern Ontario

McNicol, DK, Bendell, BE, and Ross, RK

Canadian Wildlife Service Occasional Paper 62, 76 pp (1987)

KEY WORDS: acid precipitation, waterfowl, lake acidification, aquatic ecosystems, trophic relationships, Ontario, factor analysis, aquatic invertebrates, fish

PURPOSE OF STUDY: To investigate the effects on waterfowl of ecological changes in aquatic ecosystems associated with acid precipitation and to determine which species and habitats might be most at risk from acidification.

METHODS: To develop a framework in which to study the effects of acid precipitation on waterfowl, a pilot study was conducted from 1980-1982 in a moderately acid stressed, but largely unaffected area of northeastern Ontario (Ranger Lake). As a result of these studies (summarized in Appendix 3 of this report) on waterfowl populations, water chemistry and food chain interactions, we hypothesized that the adverse effects of lake acidification on waterfowl breeding in small, headwater lakes and wetlands would be mediated through changes in the abundance and availability of food resources that could be altered and/or lost as a consequence of that acidification. Also, between 1980-1985, the distribution, breeding density and habitat preferences of waterfowl were examined throughout much of northeastern and central Ontario as part of a broader systematic survey of breeding waterfowl populations in the province using aerial survey counts of indicated nesting pairs.

In 1983, trophic relationships were studied on 123 small (0.6-27.2 ha) headwater lakes in the Ranger Lake area (46°55'N, 83°35'W), 40 km NE of Sault Ste. Marie, and the Wanapitei area (46°55'N, 80°45'W), 40 km NE of Sudbury, Ontario. Lakes in both areas cover a range of pH, but those in the Wanapitei area are more acid stressed due to emissions from nearby smelters at Sudbury and from long range transport of air pollutants. Waterfowl population densities and distributions were determined by helicopter during nest initiation (May). Ground surveys were also conducted on all waterbodies during the brood-rearing period (June-August) to assess adult and brood activities. Basic habitat characteristics (area of open water, shoreline length, length of shoreline with well-developed littoral zone, etc.) were determined from aerial photographs. Water samples were taken in early June. Chemical analyses included: alkalinity, pH, conductivity, concentrations of major ions, nutrients and trace metals. Estimates of non-game fish species occurrence and abundance were obtained using baited minnow traps placed at five sites equidistant around the shoreline of each lake in July. Aquatic invertebrates were sampled in late July, using a standardized

sweep net procedure consisting of samples of 10 consecutive sweeps at 10 points equidistant around the shoreline of each lake in water <1 m deep. Invertebrates were preserved for later identification to genus and species level.

RESULTS: Waterfowl Risk - although breeding densities were relatively low (about one indicated pair per km²) throughout much of northeastern and central Ontario, and no significant trends in population levels were noted between 1980-1985, the number of waterfowl breeding in acid sensitive areas was estimated at 105,000 pairs. Boreal species (common goldeneye, hooded merganser, ring-necked duck, American black duck) commonly breed on small lakes, beaver flowages and wetlands most vulnerable to acidification, whereas primarily fish-eating species, the common loon and common merganser, used large lakes and rivers. Dabbling ducks (wood ducks, blue-winged teal, green-winged teal, mallard) used well buffered wetlands often associated with agricultural lands.

Pilot Study - a pilot study to examine waterfowl productivity, water chemistry and food chain interactions was conducted in the Ranger Lake area between 1980-1982. A complete description of sampling methodologies and the major findings of these studies, specifically as they pertain to the comparative studies implemented in 1983, is presented in an appendix, complete with figures and tables summarizing the work. Unique information presented in this part of the report includes evidence of the effects of the "acid shock" phenomenon on small lakes sampled in the Ranger Lake area during snowmelt.

Also, the major aquatic macrophyte taxa in 34 lakes were recorded and classified on the basis of fish assemblages. Floating-leaved and submerged vegetation differed according to fish species richness, with macrophytes generally absent in lakes also lacking fish; perhaps the geographic isolation of headwater lakes sampled in this study has restricted the access of both fish and macrophytes, as has been observed elsewhere.

Water Chemistry - lake environments were characterized, using factor analysis, into four components of variation: i) Factor 1, an "acidity" axis, explained 36% of the variation among lakes, ii) Factor 2, the "ionic strength" axis, explained 24% of the variation, iii) Factor 3, the "eutrophication" axis (wetland productivity status), explained 14% of the variation, and iv) Factor 4, the "morphometry" axis, explained 11% of the variation. Bedrock lithology explained much of the variability observed on the acidity and ionic strength axes, and was a balance between mineral acid inputs and acid-neutralizing capacity. Organic acids did not contribute significantly to the acidity of the lakes studied.

Trophic Relationships - differences in fish species composition and abundance were found between the two study areas, the most striking being that 43% of the lakes at Wanapitei had no fish, compared to 12% without fish at Ranger Lake. Of 30 acid lakes (pH <5.5) at Wanapitei, 66%

were fishless, and the rest supported simple cyprinid communities or were dominated by yellow perch. Species richness was significantly positively related to pH at Wanapitei, but not at Ranger Lake. At Ranger Lake, fish presence or absence was unrelated to pH. Fishless lakes from both areas had similar aquatic insect assemblages, irrespective of pH. Invertebrate species richness was greater in fishless lakes. The greater number of insects in fishless lakes was largely due to the presence of nekton.

Waterfowl - at least one breeding pair of waterfowl were found in 59% of lakes from Ranger Lake and 76% from Wanapitei, with the common loon being the most frequently observed species, followed by ring-necked duck and common goldeneye. There were no significant differences between the Ranger Lake and Wanapitei study areas in the occupancy of comparable wetlands by waterfowl. Insectivorous species (common goldeneye, hooded merganser) preferred small lakes (<20 ha, particularly those 1.5-4.0 ha). Piscivores (common merganser, common loon) occupied larger waterbodies, and for common mergansers, streams and rivers were used as well. Waterfowl presence was not affected by ionic strength of the lake. Few differences were noted relating waterfowl use and either Factors 3 or 4, but loons preferred oligotrophic (Factor 3), large lakes (Factor 4). The distribution of nesting pairs was positively correlated with lake acidity, and those lakes occupied by broods were less acid than unused areas. Insectivorous species preferred fishless lakes, whereas piscivores preferred lakes with fish. The presence of small, non-game fish was not the major factor influencing the distribution of piscivores; other important factors were lake size (larger), irregular shoreline, and eutrophication were all preferred. The presence of fish reduced the likelihood of a lake supporting common goldeneye or hooded merganser, suggesting that fish may be competitors for insect prey. Omnivorous species, such as ring-necked duck and black duck, showed no preference for acid or fishless lakes, but did prefer shallow, nutrient-rich wetlands.

CONCLUSIONS: The loss and degradation of habitat is a major problem affecting populations of waterfowl in North America. As prairie habitat is destroyed by agricultural drainage, wetlands in the boreal forest are becoming increasingly important for breeding waterfowl. In northeastern and central Ontario, substantial input of atmospheric pollutants is threatening the quality of aquatic habitat for waterfowl. Reproductive success of waterfowl may be lower in areas receiving high levels of acid deposition due to indirect effects of reduced invertebrate or fish prey numbers or quality, or to direct toxic effects. More information is needed to determine whether acidity is limiting both invertebrate and fish prey to the detriment of waterfowl.

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EDITORIAL COMMENTS: "This report contains the results of research carried out under the auspices of the Long Range Transport of Air Pollutants program, and interdepartmental research initiative of the federal government. The Canadian Wildlife Service (CWS) research program was started in 1980 to assess the impacts of acid deposition on wildlife and wildlife habitats in eastern Canada. A major objective of the CWS research was to compare avian breeding and feeding ecology data collected from sensitive headwater habitats receiving different rates of acid loading. The first paper describes the work on waterfowl and their food chains in Ontario. A forthcoming one will include the results of surveys of freshwater bird communities in Québec, as well as phyto-ecological studies of their associated habitats, in relation to acidification (note: published as DesGranges, JL: *Can Wildl Serv Occ Pap* 67, 76 pp (1989)). Other important areas of interest are the influence of long range deposition and acidification on metal uptake by wildlife prey organisms and the toxicity of low level metal exposure to aquatic birds. Research was conducted at the National Wildlife Research Centre on the fate of heavy metals in waterfowl food chains, as well as laboratory studies of the effects of dietary heavy metals on the reproductive output of birds under controlled conditions (note: published as Scheuhammer, AM: *Environ Pollut* 71, 329-375 (1991)). CWS has also played a major role in the Kejimikujik Calibrated Catchment program, studying nutrient release in and limnological characteristics of acidified waters in Kejimikujik National Park, Nova Scotia (note: J Kerekes, lead investigator, CWS (Atlantic Region)). Together these volumes provide a summary of the first phase of the CWS LRTAP Program. Current studies are designed to establish a more definite cause-and-effect relationship between acidification and biological changes, chiefly in bird communities, to provide the basis for a biomonitoring programme which will track the changes expected to occur as emissions are reduced to the target loading (i.e. 50% of 1980 levels by 1994), and to evaluate the adequacy of that target loading for protecting biota". Adapted from the foreword by DB Peakall and AW Diamond, March 13, 1987, *Can Wildl Serv Occas Pap* 62 (1987).

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Disponible également en français

PAPER NO.: 87 - 8

YEAR: 1987

TOPIC: Research - Waterfowl

Waterfowl as Indicators of Wetland Acidification in Ontario

McNicol, DK, Blancher, PJ, and Bendell, BE

International Council of Bird Preservation Technical Publication 6, 149-166 (1987)

KEY WORDS: acid precipitation, waterfowl, lake acidification, indicators, wetland, Ontario, risk, food habits, macroinvertebrates, benthos, nekton, biomonitoring, trophic relations

PURPOSE OF STUDY: To summarize current information on waterfowl-acid rain relationships in Ontario, and to identify the suitability of using breeding waterfowl as indicators of wetland acidification.

METHODS: Studies on waterfowl habitat selection and aquatic food chains were conducted from 1983 to 1985 in two areas of northeastern Ontario. The first, Ranger Lake (centred at 46° 45'N 80° 45'W), 40 km NE of Sault Ste. Marie, receives moderate levels of wet sulphate deposition (20-30 kg/ha/yr) and represents a largely unaffected but acid sensitive area. The other, Wanapitei (centred at 46° 55'N 83° 35'W), 50 km NE of Sudbury, receives high acid loading levels, and represents a heavily acid stressed area which has undergone substantial lake acidification. Food habits of ducklings of several species from acid (pH < 5.5) and non-acid (pH > 5.5) lakes in both study areas were examined in 1984 and 1985. Foraging birds (mostly ducklings) were collected by shotgun, and the numbers of food items of each major type estimated from the oesophagus, proventriculus and gizzard combined. Benthic macroinvertebrates were sampled in 20 lakes at Wanapitei (pH range 4.2 - 7.5) using random, one-half metre benthic drags with a sweep net. Free-swimming (nektonic) invertebrates were sampled using a water column sampler on 15 lakes at Wanapitei, both with and without fish, across a range of pH. Small, non-game fish species were sampled with wire minnow traps in 124 lakes in both study areas. On a broad scale, the location and number of waterfowl pairs nesting in 2 x 2 km plots was determined using helicopter surveys during early May. Surveys of individual wetlands were also conducted at Ranger Lake and Wanapitei. Ground surveys were conducted in June and July of 1983 to assess habitat use by adults and broods, and to collect data on water quality and lake morphometry.

RESULTS: Approximately 105,000 pairs of waterfowl nest in sensitive terrain in northeastern and central Ontario that is receiving wet sulphate deposition in excess of 10 kg/ha/yr. A broad range of pH was found in both study areas; however, 66% of lakes at Wanapitei were acid (pH < 5.5), compared to only 9% at Ranger Lake. Lake acidity was correlated with a reduction in fish populations and a simplification of fish communities. Of the 30 acid lakes at Wanapitei, 20 were without fish. At Ranger Lake, the occurrence of eight fishless lakes was unrelated to pH, and likely a result of winter anoxia or biogeographic isolation. There was no difference between study areas in the proportion of lakes occupied by nesting pairs. The ratio of broods to breeding pairs at Ranger Lake was 1:2 for piscivores and omnivores, and 1:1 for insectivores; at Wanapitei, the ratio was lower for all groups, particularly piscivores (1:17). Fish-eating species (common loon, common merganser) were more common on lakes with fish. Insectivores, such as common goldeneyes and hooded mergansers, were observed more frequently on fishless lakes, while omnivores, such as ring-necked ducks and black ducks, showed little preference for either type of lake. Insect

assemblages from fishless lakes in both areas, regardless of pH, shared more taxa in common than with lakes containing large numbers of fish. These differences were explained by the increased occurrence of large, nektonic organisms, notably backswimmers, water boatmen, diving beetles, and phantom midge larvae, which replace fish as the top predators in fishless lakes, regardless of pH. Fewer benthic species tolerated acid conditions. Certain crustaceans and molluscs were rare at pH < 5.0, while Ephemeropterans were absent below pH 5.6. Some benthic organisms, such as Odonata, showed a shift in species composition in relation to pH. Feeding habits of non-piscivores differed between acid and non-acid conditions. In non-acid lakes, goldeneye and hooded merganser ducklings took large numbers of nektonic prey, but both species increased this consumption under acid conditions, presumably due to increased availability. Generalized feeders, such as ring-necked ducklings, took more surface insects (especially water striders) on non-acid lakes. The surface-feeding black ducks took large numbers of emerging Odonata on acid lakes and emerging Ephemeroptera on non-acid lakes. All four non-piscivores modified their feeding habits between acid and non-acid conditions such that on acid lakes, diets of non-piscivores converged due to the reliance on a few abundant prey.

CONCLUSIONS: Food availability may be a limiting factor in the distribution and reproductive success of some waterfowl species. Reproductive performance of most species, particularly piscivores, is lower in acid stressed areas than in unaffected areas. Thus, the breeding success of common loons might be a useful early indicator of the effects of acidification on fish populations. A biomonitoring protocol which measures the impact of acid inputs on waterfowl reproduction must include monitoring of some aspects of the food-chain.

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EDITORIAL COMMENT: This paper was published in "The Value of Birds" (AW Diamond and FL Fillion, eds), based on the Proceedings of the 19th World Conference of the International Council for Bird Preservation, held in Kingston, Ontario, June 1986. The paper was among 13 presented in the session "Birds as Bio-Indicators of Environmental Conditions" (DB Peakall and H Boyd, co-chairs).

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PAPER NO.: 87 - 9

YEAR: 1987

TOPIC: Research - Waterfowl

Avian Trophic Relationships and Wetland Acidity

McNicol, DK, Bendell, BE, and McAuley, DG

Trans North Am Wildl Nat Res Conf 52, 619-627 (1987)

KEY WORDS: waterfowl, wetland acidity, avian trophic relationships, acid precipitation, North America, piscivores, insectivores

PURPOSE OF STUDY: To summarize findings of studies on three major effects of wetland acidity on avian trophic relationships: the loss of fish, altered predator/prey relationships, and loss of acid sensitive invertebrates.

LOSS OF FISH: Surveys reveal that most fish species are absent below pH 5.0 and many, with the exception of salmonid and centrarchid species, are lost in the pH range 6.0-5.0. The decline in percids is primarily from the loss of darters at pH <5.8. Cyprinids are common above pH 5.5, but not below this level. Some more acid tolerant species, such as yellow perch and centrarchids, occur frequently between pH 5.5-5.0, but reproduction and growth may be reduced at low pHs. In general, the species richness, density, biomass, and perhaps size and weight of fish declines as wetlands acidify. Differences in the prey base result in narrower choices of fish prey. Thus, fish-eating birds are at most risk from declining pH. Common loons and common mergansers avoid fishless lakes, and of those lakes with fish, these species tend to use lakes more frequently if the pH is above 5.5. A decline in fish density may result in reduced breeding success and foraging efficiency of piscivorous birds. Some studies have found that loon chicks prefer fish species such as cyprinids, which are less abundant on acid lakes, and that fledging success rates were lower on acid lakes, while other studies have not found this relationship. Acid lakes may contain greater densities of non-fish prey (newts, crayfish, tadpoles, insects) which may be fed to loon chicks. However, many non-fish prey are vulnerable to wetland acidity, and acid tolerant insects alone cannot sustain loon chicks to fledging.

PREDATOR/PREY RELATIONSHIPS: Fish may alter the species composition and abundance of macroinvertebrates which are commonly eaten by waterfowl and other aquatic birds. Invertebrate populations are often limited by fish. Nekton have been reported to increase in the absence of fish. Because acidity can decrease or eliminate fish populations, acidification may increase the availability of some invertebrates and thus be of benefit to certain, but not all, insectivorous waterfowl species. Fish and waterbird interactions can be summarized as follows: there is an inverse relationship between the occurrence of fish and the use of water bodies by common goldeneyes and oldsquaw; in the absence of fish, there is an increase in numbers and size of potential prey of common goldeneyes, oldsquaw, black ducks, and mallards; there is an overlap in diets of common goldeneye and yellow perch, and between black ducks and

brook trout; feeding efficiency of mallards, common goldeneyes and black ducks increases on fishless lakes; and finally black duck ducklings grow faster on fishless lakes.

ACID SENSITIVITY OF INVERTEBRATES:

Waterfowl, shorebirds and many passerines eat aquatic invertebrates obtained directly from wetlands, or flying insects that have aquatic larval stages. Acidification of wetlands eliminates invertebrate prey, such as mayflies, molluscs, some caddisflies, and some crustaceans, which are intolerant of acidity. A strong relationship exists between the breeding densities of dippers, abundance of invertebrate prey and acidity of streams. For tree swallows, mayflies represent a greater proportion of nestling diets on non-acid wetlands (pH >6.0), while terrestrial insects were used more often at low pH wetlands. For waterfowl, the number of odonate larvae consumed, particularly *Leucorrhinia glacialis*, was greater under acid conditions. The net effect is that all duckling species become more reliant on a few acid tolerant insect taxa. Diets of ring-necked ducks become less diverse on acidic (pH <6.1) wetlands. Reduced prey diversity might adversely affect duckling growth and survival. Even when food is abundant, the nutritional and caloric value of certain foods may be adversely affected in acidifying wetlands. Waterfowl prey items that are rich in calcium are generally intolerant to acidity. Under acid conditions, ducklings move more quickly and spend more time searching for food, which may result in decreased growth and survival of ducklings.

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EDITORIAL COMMENT: This paper was published in the Transactions of the 52nd North American Wildlife and Natural Resources Conference held in Québec City, Québec, 20-25 March, 1987, as part of a series of nine papers presented in a special session "Acidification and Wildlife" (D. B. Peakall and R. J. Hall, co-chairs).

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PAPER NO.: 87 - 10

YEAR: 1987

TOPIC: Research - Birds

The Effects of Fish and pH on the Distribution and Abundance of Backswimmers (Hemiptera: Notonectidae)

Bendell, BE

Canadian Journal of Zoology 64(12), 2696-2699 (1986)

KEY WORDS: backswimmers, lake acidification, acid precipitation, fish predation, Hemiptera: Notonectidae, curvilinear regression, Sudbury, sweep net, water column sampler, littoral zone, *Notonecta*, *Buenoa*

PURPOSE OF STUDY: To determine the relative importance of lake pH and the presence of fish on the distribution and abundance of backswimmer (Hemiptera: Notonectidae) species in small, headwater lakes near Sudbury.

METHODS: Populations of backswimmers were sampled in 17 small (1.9-7.8 ha), headwater lakes in the Wanapitei area (centre 46°54'N, 80°41'W), 40 km NE of Sudbury, Ontario. There were nine fishless lakes and eight containing fish. Many of the lakes are acid due to sulphate deposition resulting from local emissions and from long range transport of air pollutants. This has led to the loss of fish populations in many lakes. However, some lakes are well buffered and remain unacidified; of these lakes, some are naturally fishless (three of the high pH lakes in this study are fishless), presumably due to their biogeographic isolation. In late July and early August 1984, ten samples per lake were collected using a standardized sweep net procedure from a canoe at randomly selected points in the littoral zone of each lake in water <1 m deep. To estimate population densities of backswimmers on fishless lakes, concurrent samples were taken using a custom-designed water column sampler placed at 15 random sites per lake. *Buenoa* spp, unlike *Notonecta*, were separated on the basis of adults only. Because densities of backswimmers in lakes with fish might be so low that sweep net samples may miss some species, three additional samples per lake were taken with aquatic light traps. Values of pH were recorded for each lake at the time of sampling.

RESULTS: Five species of backswimmers were commonly recorded in the study lakes: *Notonecta undulata*, *N. insulata*, *N. borealis*, *Buenoa macrotibialis*, and *B. limnocastoris*. Lakes were scored for presence of a species, which typically indicated a breeding population. Backswimmers were conspicuously abundant in all fishless lakes, irrespective of pH. In lakes with fish, backswimmer populations were either totally absent or their densities were so low that they were unrecorded in net samples from six of eight lakes. For *Notonecta*, there was no evidence of a relationship between pH and abundance in fishless lakes from net sampling (relative population estimates) or column sampling (absolute estimates). For *Buenoa*, extremely dense populations were found in lakes with the highest pH. Among fishless lakes,

numbers of *Buenoa* were positively correlated with pH in net samples and column samples, the latter relationship being best described by a curvilinear function.

CONCLUSIONS: The presence or absence of fish is evidently the most significant factor in determining the abundance and distribution of backswimmers in small, headwater lakes near Sudbury. Populations may suffer from direct fish predation, or from competition with fish for common prey. The distribution of backswimmers may also reflect competitive interactions and subsequent differences in the preference of each species for certain habitat characteristics, such as different water depths and cover. However, the present study suggests that fish predation may be a major selective force determining adaptive differences among species. Competitive interactions among backswimmers would likely only be important within high density populations in fishless lakes. The form of the relationship between pH and abundance of *Buenoa* in fishless lakes suggests that the effects of pH on *Buenoa* densities are nontoxicological and indirect.

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PAPER NO.: 86 - 1

YEAR: 1986

TOPIC: Research - Invertebrates

Investigations into the Effects of Acid Precipitation on Wetland-dwelling Wildlife in Northeastern Ontario

Blancher, PJ, and McNicol, DK

Canadian Wildlife Service Technical Report 2, 153 pp (1986)

KEY WORDS: wetland acidification, acid precipitation, peatlands, bog, fen, wildlife, Ontario, floristic composition, minerotrophic, ombrotrophic

PURPOSE OF STUDY: To describe the physical, chemical, floristic, and faunal character of peatlands in northeastern Ontario, and to determine differences in water chemistry related to variation in acid deposition. To examine floristic composition in relation to chemistry of peatlands, and to examine the responses of wetland wildlife to changes in acidity.

STUDY AREAS: Thirty one peatlands from two study areas in northeastern Ontario were studied: 15 from the Ranger Lake area (Algoma), at 46° 55'N 83° 35'W, 40 km NE of Sault Ste. Marie; 16 from the Wanapitei area, at 46° 45'N 80° 45'W, 40 km NE of Sudbury. Selected wetlands in both areas, located primarily on Precambrian granitic bedrock, were characterized as treed bogs (eight at Wanapitei, seven at Ranger Lake), tree-covered with a central pool and surrounded by a *Sphagnum* mat, and poor fens (eight in each study area), dominated by sedges, shrubs and *Sphagnum* surrounding the central pool. Both types of peatlands were classed as moderately to highly sensitive to acidification. Wanapitei lies within a zone of high sulphate deposition from nearby smelters, and has historically received much higher annual inputs of sulphate deposition than Ranger Lake.

METHODS: Some initial water sampling and mapping was conducted in 1984, while the rest of the sampling was conducted in 1985. Wetlands were mapped from aerial photographs and physical measurements were made. Peat was sampled at several depths from each site. Water samples, for chemical analyses, were collected from the pools and from the mat surface for all wetlands during spring, summer and fall of 1985. Peatlands were visited five to seven times each between early May and early August and flowering vascular plants were noted. During August and September, the vegetation of each peatland was sampled quantitatively and major vegetational stands (48 stands at Ranger Lake and 47 at Wanapitei) were delineated. Fish populations were assessed using cylindrical minnow traps placed in the littoral zones of each peatland and left for 24 h. The edges of all pools were checked for amphibian egg masses each spring. Sweep net samples were taken from the shore in the littoral edges of pools, and invertebrates, fish and tadpoles were counted and identified. Odonate emergence was quantified every two weeks from late May to mid-August. The presence of adult amphibians at peatland pools was noted during regular visits,

and pitfall traps were placed around the pools to catch small mammals. Pools were surveyed for waterfowl both from the air and from routine ground visits. Hour-long qualitative observations were made at each pool for evidence of birds obtaining prey from the aquatic environment. Tree swallow (*Tachycineta bicolor*) nest boxes were placed at the pool edge of 30 peatlands, checked throughout the breeding season, and several parameters of breeding success were recorded.

RESULTS: Water Chemistry - Peatlands ranged from 1.1 to 6.3 ha, fens being slightly larger with larger central pools than bogs. All peatland pools showed a drop in water level from May to August. There were no consistent differences between bogs and fens or between Wanapitei and Ranger Lake in water level drop nor in peat depth and humification profile. Water chemical variables fell into two groups: mineral and organic. A detailed summary of chemical values used in this study is presented in an appendix. Fen pools at both areas had greater mineral influence, while organic variables were unimportant in comparisons between peatland types. Mat samples had more organics and less minerotrophic conditions than pool samples, but mat water had no influence on pools of different size. Bog pools were more acid, fen pools had higher pH, sulphate and metals, and all pools showed a higher proportion of sulphate anions at Wanapitei relative to Ranger Lake, which indicated a greater influence of mineral acidity at Wanapitei.

Vegetation - The vegetation stands were divided into four groups: minerotrophic, oligotrophic, shrubs, and trees, representing varying degrees of minerotrophy and dryness/shade. Average prominence values for the 60 plant taxa described in this study are presented. Overall, the two study areas had very similar vegetational composition, but two general trends were apparent: the ratio of *Sphagnum* to other moss was lower and the total abundance of sedges was lower at Wanapitei than at Ranger Lake.

Trophic Relations - Twelve of the 31 peatland pools had fish (eight species, predominantly cyprinids and sticklebacks), including all eight fen pools at Ranger Lake and four of the eight fen pools at Wanapitei, all of pH >4.8. All bog pools were isolated hydrogeographically, had low pHs (3.99-4.94) and were fishless. Several species of amphibians bred in peatland pools, but few were successful at pHs lower than 4.5, and none at pHs lower than 4.3; both these pH tolerance levels were higher than the pH at all bog pools at Wanapitei. The seasonal pattern of odonate emergence was similar in both study areas. Fishless pools, especially those with relatively high pH (4.94 vs 4.15), contained higher abundances of many insect groups, particularly nektonic taxa and some benthic groups. A detailed list of invertebrate taxa identified, with notes regarding distribution and relative abundance, is provided in an appendix. Some species (gastropods, leeches, amphipods) were more abundant at higher pHs regardless of the presence or absence of fish. Many non-insect invertebrate taxa were absent below pHs 4.5 - 5.5. As a result of lower pH in fen and bog pools, peatlands at Wanapitei are less likely to have fish and have a lower abundance of most aquatic

organisms compared to Ranger Lake. Adult amphibians were evident in most peatlands, although some species were absent from or less abundant in some peatlands at Wanapitei, unrelated to pH.

Wildlife - Ten species of small mammals, typical of the habitat, were recorded, with masked shrews (*Sorex cinereus*) being the most abundant. There were no consistent differences in mammalian species composition between fens and bogs or between Wanapitei and Ranger Lake. Forty-eight bird species were resident in the peatlands. Few differences were noted in species composition at Ranger Lake compared to Wanapitei, although Wanapitei was lacking in pool residents relative to Ranger Lake. Many bird species relied at least partially on the aquatic environment for food. Tree swallow reproduction was similar in the two study areas, but more birds nested and were more successful in fens compared to bogs in both areas.

CONCLUSIONS: To date, relatively little work has been done in the coloured waters (high humic content) of wetlands, particularly concerning wetland-dwelling wildlife, primarily because many of these wetlands are naturally acid, but also because they exhibit a relatively complex water chemistry. Geochemical and biological studies of headwater lakes and wetlands (including peatlands) threatened by acid rain are needed. This study documented the wildlife inhabiting peatlands in northern Ontario and showed differences in peatland acidity that parallel levels of acid deposition, negative responses of aquatic organisms to acidity, and the potential for an impact on wildlife. More detailed study of wildlife responses to available prey is needed in order to assess the impact of acid precipitation on wetland-dwelling wildlife.

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PAPER NO.: 86 - 2

YEAR: 1986 **TOPIC:** Research - Wildlife

Intensive Validation of Waterfowl Habitat Suitability Models for Ontario

Shutler, D, McNicol, DK, Ross, RK, and Walton, RA

Canadian Wildlife Service (Ontario Region) LRTAP Progress Report (1997)

KEY WORDS: habitat model, validation, Ontario, waterfowl, anatids, common loon, lake acidification, acid precipitation, logistic regression, concordance, trophic relations, landscape indices, principal components analyses

PURPOSE OF STUDY: To better understand relationships that govern habitat suitability, distribution and productivity for waterfowl species which commonly breed in the forested landscape of northern Ontario, by developing and validating appropriate habitat suitability models, and evaluating their generality in space and time.

BACKGROUND: Loss and degradation of habitat is a major waterfowl management problem in the vast boreal forest of eastern Canada. The threat of acidification of aquatic ecosystems in Ontario, east and north of the Great Lakes, prompted the Canadian Wildlife Service (Ontario Region) to implement a LRTAP Biomonitoring Program in 1987 to assess the effects of acid rain on waterfowl and their habitats, and to evaluate biotic responses to emission control programs. Based on the premise that ecosystem health and recovery must be assessed using biotic, as well as abiotic indicators, data on waterfowl and common loons, water chemistry, landscape features, and relationships of birds to their food (primarily fish and aquatic invertebrates) were gathered in three areas of central and northeastern Ontario (Algoma, Muskoka, Sudbury). This unique dataset spans several years, and contains information on over 600 water bodies, including large oligotrophic lakes, small headwater lakes, wetlands, bogs/fens, chico swamps, etc. The range of ecological parameters examined in this work is much more exhaustive than in any previous study of waterfowl breeding in Ontario, and provides the essential ecological data needed to develop "habitat suitability models for waterfowl breeding in the northern Great Lakes - St. Lawrence and southern Boreal ecoregions".

METHODS: Data were collected from the three CWS (OR) LRTAP study areas: Algoma (47°01'N, 83°55'W, 40 km NE of Sault Ste. Marie), Muskoka (45°30'N, 79°06'W, at the SW corner of Algonquin Park), and Sudbury (46°54'N, 80°41'W, 40 km NE of Sudbury). In all study areas, there were numerous oligotrophic lakes, bedrock of Precambrian granite, and upland vegetation of the Great Lakes-St. Lawrence transitional with Boreal forests. No lakes < 0.1 ha were used. Water chemistry sampling, done from helicopters, occurred between the last weeks of September and October in the same seven block-years in which waterfowl surveys were done (Algoma, 1988, 1992, 1994; Muskoka 1990, 1993; Sudbury

1993, 1994). The landscape was divided into open water, riparian vegetation and upland forest categories, and variables in each of these categories were used to develop landscape indices which were identified as potentially important waterfowl habitat associations. Fish communities, classified as fishless, competitor, or non-competitor, were sampled using minnow traps baited and placed in shallow water close to shore in all major habitat types within a water body. Beaver occupancy was assessed by helicopter surveys in fall 1994. Waterfowl distribution and productivity were determined using helicopter surveys: breeding pair surveys occurred in early- to mid-May, and brood surveys were done late June/early July and late July/early August. Stepwise logistic regression was used to develop models to predict which sites would be occupied by waterfowl, first for each block and year separately (single-block-year models), secondly for all three blocks together in various combinations of one year each (trio-block-year models), and thirdly using all combinations of blocks and years (seven-block-year models). To avoid statistical problems with correlated variables, variables were screened. On the seven-block-year data, principal components analysis (PCA) was used to deal with correlated variables. All models were then validated (tested) for their generality.

RESULTS: Habitat associations were mostly landscape-related for piscivores, mostly chemistry-related for divers, and mostly unidentified for dabblers. Common loon pair distribution was influenced by water chemistry, and pairs were more common on large lakes with fish. Loon broods were also more common on large lakes, but with non-competitor fish. Common merganser pairs were more common on larger lakes with fish. Merganser broods were more common on larger lakes at lower elevations and in lakes with competitor fish. Hooded merganser pairs were more common on lakes with low values for several chemistry variables (i.e. more dilute lakes), on those lakes which did not have competitor fish communities, and on lakes in Muskoka. Hooded merganser broods were more common in Muskoka on lakes without competitor fish. Ring-necked duck pairs were more common on lakes with low values for some water chemistry variables, and on lakes with extensive riparian habitat which do not have competitor fish communities. Ring-necked duck broods were more common on lakes with well-developed riparian shorelines and without competitor fish. Common goldeneye pairs were more common on fishless lakes with low ionic concentrations. Pairs were the most common in Algoma and the least common in Muskoka. Goldeneye broods were more common on fishless lakes. There were few consistent associations for mallards, black ducks, or wood ducks except that black ducks were more common in Algoma and Muskoka than in Sudbury, and wood ducks were more common in Muskoka than in the other two blocks. Predictive strength of the models varied among waterfowl classes. The concordance of models built from the seven-block-year data set revealed that models developed in one space may have little generality elsewhere. Within-block-year validations indicated that models were not distorted by a few observations. Among-

block-year validations indicated that variation in space and time were not additive in reducing predictive power of models. Among-trio-block-year validations indicated that inclusion of data from separate times and spaces improved reliability of models. However, models varied substantially in their capacity for being generalized, particularly for dabblers.

CONCLUSIONS: Some previously documented waterfowl habitat associations were supported while others were not. Validations indicated that some models could not be applied reliably to different times and spaces. Adding information from a wider geographic and temporal base will not necessarily increase model concordance. Models might be improved by identifying more precise measures of habitat suitability or by increasing accuracy of waterfowl surveys, but the feasibility of this is questioned.

FURTHER APPLICATIONS AND RESEARCH: In addition to increasing our general understanding of the ecology of individual species or guilds, models provide an important baseline against which effects of future habitat or population changes can be assessed. By identifying key habitat features, models are useful tools allowing us to predict which species will be most vulnerable to specific environmental changes and to what extent. Currently, information is needed to determine the impact on biodiversity of ecosystems related to further habitat degradation, UV-B radiation, and climate change. Because waterfowl rely on the integrity of many components of the aquatic food chain, they are excellent indicators of the health of this ecosystem. The models developed here provide important baseline information on these bird species in central and northern Ontario, and suggest species towards which continued monitoring efforts should be directed.

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EDITORIAL COMMENTS: This paper was originally submitted for publication in Ecological Monographs in September 1995, but was rejected in November 1995 following two critical reviews.

ACKNOWLEDGEMENTS: The Canadian Wildlife Service (Ontario Region) wishes to thank members of the Scientific Advisory Group (K. Abraham, D. Hussell, D. Dennis, R. Helie, J.-P. Savard, T. Clark, D. Jackson, and D. Welsh) for their guidance and input to this project.

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PAPER NO.: REP - 1

YEAR: 1995 **TOPIC:** Modelling - Waterfowl

WARMS for Windows® Version 2.4 - User's Guide

ESSA Technologies Limited

Canadian Wildlife Service (Ontario Region) LRTAP Program Progress Report (1996)

KEY WORDS: WARMS, logistic regression, acidification, fish, waterfowl, models, deposition multipliers, tertiary watersheds, Monte Carlo simulations, confidence limits, data management capabilities

PURPOSE OF STUDY: To develop an interactive, predictive modelling software to assess the influence of acid deposition on waterfowl.

SOFTWARE COMPONENTS: The Waterfowl Acidification Response Modelling System (WARMS) is a modelling software package designed for the Canadian Wildlife Service LRTAP program. It uses an underlying acidification model that is linked to fish and waterfowl models to predict eventual relative changes in habitat suitability for waterfowl species. However, the software can be used to model any biotic responses to changing lake chemistries, provided data are available in input datasets for the biotic model variables.

The acidification model (ESSA/DFO; Marmorek et al. 1990) predicts eventual chemical status of lakes (alkalinity [Alk], pH, cations, and sulphate [SO_4]) based on watershed morphometry and runoff, current lake chemistry (i.e. as current as is available in input data sets; updated November 1997), observed (assumed) levels of SO_4 deposition, and assumed values of acid neutralization in watersheds (SO_4 reduction in lakes, and background or original SO_4). While similar to other cation denudation rate models (e.g. Small and Sutton 1986), recent modifications to the model (Marmorek et al. 1996) better reflect the role that dissolved organic carbon (DOC) plays in projections of Alk and pH. DOC is often a significant constituent in water bodies used by waterfowl and is especially dominant in surface waters of Atlantic Canada (RMCC 1990). The model simulates sulphur deposition only; nitrate and ammonium deposition are assumed to have no net acidifying effect.

DATABASES: The default chemistry files in the WARMS model (*.lak files) are derived from four datasources: the 1990 National Assessment on Acid Rain, Aquatic Effects (RMCC 1990), the Québec Lake Survey (Dupont 1993), the Acid Precipitation in Ontario Study database (Neary et al. 1990), and the 1997 Canadian Acid Rain Assessment (Jeffries 1997). These are compiled by secondary watershed ($n=27$), and include 5663 lake records (range: 11-755 lakes per watershed), with the greatest representation coming from lakes in Ontario. These lake records include all of the chemical variables described below, and many also include lake area. Mandatory data required to run acidification models

(and hence the subsequent linked fish and waterfowl models) are: alkalinity, DOC, calcium, magnesium, sodium, potassium, and SO_4 . pH and chloride data are also usually included in the input record for each lake. Unless data is available in the input dataset, WARMS uses default watershed values for wet S deposition, dry S deposition, chloride, runoff, drainage area index (rr1), and nonacid S deposition. Default emission values are those from 1980 levels (original datafiles), or 1982-1986 emissions (updated 1997 files), and are translated to deposition values at the secondary or tertiary watershed level using transfer matrices from Olson et al. (1983). These related emissions at 40 sites (15 in eastern Canada and 25 in the United States) to deposition at fifteen sites (twelve in eastern Canada, three in the United States). Because receptor sites are often not co-located with study sites, wet and dry SO_4 deposition are interpolated for secondary watersheds using equations from Patterson et al. (1981).

BIOLOGICAL MODELS: Fish and waterfowl logistic regression models have been built into the software, based on relationships described in Blancher et al. (1992). The fish model predicts the probability of presence of small, non-game fish in lakes using chemistry and lake size. Waterfowl models (for common loon, common merganser, common goldeneye, hooded merganser, American black duck, ring-necked duck; updated models for piscivore, dabbler and diver guilds [breeding pairs and broods]) predict the suitability of habitats to support indicated breeding pairs or broods of these species. Default model formats are logistic regressions, but linear relationships can also be used. Fish models and some waterfowl models require lake area as a mandatory variable; hence, those lakes in the data bases lacking lake area are not included in the final model output. Also, if the fish status of a lake is already known (i.e. present or absent), this can be placed in the input "fish" field in the data record, and it will override any calculation of fish probabilities.

SOFTWARE FEATURES: The software is designed to run in Microsoft Windows®, and is written in Visual Basic. It includes basic facilities (File Menu) for choosing default or creating new scenarios, loading existing lake chemistry files, re-running saved scenarios, and for saving output files from completed model runs. The Scenario Menu allows the user to simulate different relative levels of deposition for the lake files being used, as well as loading default or new biological models (for waterfowl, fish or other biota), and for examining these relationships through 2- or 3-D graphics facilities. The Data Menu allows the user to build new lake datasets by merging or filtering existing lake datafiles (i.e. data management facility). It also allows the user to examine and edit the data in the files. The Monte Carlo Menu allows the user to create lake data files based on random selections from existing data files and on randomly-generated data, from which the user can run Monte Carlo analyses to calculate confidence limits on predictions. The Display Menu provides the choice of viewing the model output in either graphical or tabular formats, including the choice of output data to be viewed. Finally, a Help Menu is available that provides an on-

line help function (also available by pressing F1 at any operation) for model operation.

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EDITORIAL COMMENTS: The Canadian Wildlife Service acknowledges the contributions made by ESSA Technologies Ltd., including D Marmorek, R MacQueen, and J Korman, and in particular Chris Wedeles and Mirosław Kuc, in the development of the WARMS software. The software is jointly owned by ESSA Technologies Ltd. and the CWS (OR), and is available for use only with joint permission.

Currently, efforts are underway to improve the existing *.lak files and build more complete files for Ontario and elsewhere in eastern Canada. Revised SO₂ emission-deposition transfer matrices have been developed based on the 1982-1986 and 1990-1993 emissions data, and from this new secondary watershed sulphate load files have been created (from Isaac Wong). Lake chemistry files have been updated with more information from Ontario, Quebec and the Atlantic provinces based on data accumulation for the 1997 Canadian Acid Rain Assessment. Finally, revised logistic regression models have been developed to predict waterfowl habitat suitability for species and guilds, and loon chick survival.

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PAPER NO.: REP - 2

YEAR: 1996 **TOPIC:** Modelling - Waterfowl

Distributions of Larval Amphibians in Small Lakes of Central Ontario: Risks From Anthropogenic Acidification and Increased UV-B

Mallory, ML, McNicol, DK, Weeber, RC, Green, DM, Cook, FR, Davies, J, Kerr, JB, Seburn, C, and Seburn, D

Wildlife Toxicology Fund Progress Report, 19 pp (1996)

KEY WORDS: amphibians. *Rana*, *Bufo*, *Pseudacris*, *Notophthalmus*, lake acidification, acid precipitation, Algoma, Muskoka, Sudbury, UV-B, cloud cover logistic regression, ANCOVA, risk

PURPOSE OF STUDY: To characterize the relationship between amphibian tadpole numbers in Ontario lakes and physical and chemical attributes of the lakes. To link patterns of UV-B irradiance to lake chemistry and amphibian distribution in a preliminary risk assessment.

METHODS: Amphibian populations were sampled in 682 lakes across a range of pH in each of three areas of northeastern Ontario which form part of the Canadian Wildlife Service (Ontario Region) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program study between 1988-1994. Algoma (centre 47°01'N, 83°55'W) and Muskoka (centre 45°30'N, 79°06'W) study areas are located within the Canadian Shield, underlain by Precambrian granitic bedrock. The 256 lakes from the Algoma area (NE of Sault Ste. Marie) have received moderately acid precipitation, with some naturally fishless lakes present. Sulphate (SO₄) deposition at Muskoka in central Ontario is the highest of the three sites and many of the 259 lakes are fishless. Sudbury area (centre 46°54'N, 80°41'W) has received acid precipitation with high SO₄ loadings from emissions at smelters near Sudbury, and many of the 167 lakes are now acidic and fishless. Tadpoles were captured in baited minnow traps set near the shore of lakes for 24 h. Water chemistry data were means of three to four annual samples taken during autumn sampling for each lake between 1988 to 1995. Physical attributes of lakes were determined from 1:15,840 aerial photographs or 1:50,000 topographical maps. Logistic regressions were conducted to determine if there were links between amphibian presence and lake characteristics. UV-B irradiance was modelled using data on cloud cover and ozone depth from nearby weather stations.

RESULTS: Amphibians occurred in 46% of all lakes. Seven species were found: red-spotted newts (*Notophthalmus viridescens*) and tadpoles of bullfrogs (*Rana catesbeiana*), green frogs (*R. clamitans*), mink frogs (*R. septentrionalis*), wood frogs (*R. sylvatica*), spring peepers (*Pseudacris crucifer*) and American toads (*Bufo americanus*). Green frogs were found in 17% of lakes, mink frogs 13%, followed by bullfrogs and newts in 9% of lakes. Other species were found in <3% of lakes. Amphibians were captured in 60% of Muskoka lakes, 49% of Sudbury lakes and 27% of Algoma lakes. Mink and green frog tadpoles occurred most frequently in Muskoka and Sudbury lakes (19 - 20% of lakes), bullfrogs in Sudbury (18% of lakes) and newts in Muskoka (15% of lakes). Wood frog tadpoles were only found in Muskoka and

Sudbury lakes. Only three lakes contained four species, while 218 lakes contained one species and in the majority (411) of lakes no amphibians were collected. (The sampling technique (minnow traps) appears to provide good, qualitative data on presence/absence, but we acknowledge that there is large uncertainty associated with these data in the absence of resampling/verification efforts). Species richness was negatively associated with the Algoma study area, fish presence, silica (SiO₂) concentrations, and total phosphorus concentrations. Numbers of amphibian species were positively associated with dissolved organic carbon (DOC), nitrate+nitrite, distance to and number of nearby wetlands, and elevation. Logistic models with 75% or higher concordance were constructed for all amphibians, bullfrogs, mink frogs and red-spotted newts. In general, these models suggested that amphibians occurred more frequently in fishless, higher elevation lakes with lower conductivity and SiO₂ levels, higher pH, SO₄, and high DOC. Nonetheless, the relationship between the occurrence of each species and lake characteristics was complex.

In UV-B analyses, ANCOVA was used, with julian date and cloud cover as covariates, and site and year as main effects. UV-B irradiance increased over the years of sampling, notably in the spring (March-June) when most species are breeding, and was consistently highest at Muskoka.

CONCLUSION: A large number of lake attributes may be important determinants of amphibian presence. Amphibian distribution in small, central Ontario lakes is influenced negatively by fish presence, lake acidity and lake nutrient status. UV-B exposure has increased and the effects of this may act in concert with the effects of acidification to make many habitats unsuitable for successful reproduction. The potential for deleterious synergistic impacts of anthropogenic pollution on lake food webs clearly warrants concern because lake chemistries have changed little over a decade and UV-B appears to be increasing.

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EDITORIAL COMMENTS: This manuscript has been submitted to the Wildlife Toxicology Fund as a final report, and has also been reviewed by Drs. Davies, Green, and Kerr.

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PAPER NO.: REP - 3

YEAR: 1996 **TOPIC:** Research - Fish/Amphibians

The Canadian Wildlife Service LRTAP Biomonitoring Program Database and Reporting System - User's Manual

McNicol, DK, and Brisebois, LA

*Canadian Wildlife Service (Ontario Region) LRTAP
Program Progress Report*, 56 pp (1995)

KEY WORDS: ORACLE, relational database, feature codes, tables, Ontario, Nova Scotia

BACKGROUND: The purpose of this initiative was to develop a database management and reporting system that will allow researchers and managers to input, query and retrieve data on the Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program.

DATABASE DESCRIPTION AND REQUIREMENTS:

Monenco AGRA Inc. were asked to assist in developing the CWS LRTAP Biomonitoring Database and Reporting System in 1991, based on their experience in developing a similar system for the Department of Fisheries and Oceans (DFO) LRTAP program. The CWS LRTAP Biomonitoring Database and Reporting System operates in a relational database and is based on a similar and parallel database constructed for the Department of Fisheries and Oceans National LRTAP Biomonitoring Program. The CWS LRTAP database permits the integration and coordination of the vast network of all biomonitoring data, and serves as a common repository for data collected in a series of biomonitoring sites. The CWS LRTAP Biomonitoring Database and Reporting System resides in an ORACLE® RDBMS v. 6.0 software application (note: this has been migrated to a Personal ORACLE® v. 7 for Windows® application). The application consists of Menus and Screens which allow the user to query the database and perform various operations. A variety of tools are used in the application, notably including REPORTWRITER and SQL*PLUS. The application is designed to run on DOS PC computers. Minimum hardware requirements for the original database system are: IBM compatible PC, MS-DOS 3.1 or later (now requires Microsoft Windows 95 for migrated database), 25 Mb of hard disk space, and 8 Meg RAM.

The User's Manual describes the complete process of starting up the ORACLE database, logging on to the system, calling up the CWS LRTAP data, and retrieving data. The development of the CWS LRTAP Database and Reporting System including the design and entity relationships is summarized in a series of reports from Monenco Information Systems Inc (see Bibliography).

DATABASE CODES DOCUMENT: Associated with the User's Manual, a second document entitled "Database Codes" was prepared, which lists all of the codes used in entering/retrieving data in the CWS LRTAP ORACLE Database. Data stored in the database is referenced through predefined database tables and codes. Tables included in the database include: Feature Codes (codes for entry of data into various tables), Collection Methods, Project Table, Study Area Table, Location Table, Sample Table, Fish/Invertebrate Table, Chemistry Table, Access Codes, All Waterfowl Tables, and Tissue Analysis Tables. Associated with these tables are arbitrary codes which identify all types of data entered, varying from lake elevations to wetland types to sampling accuracy to chemical constituent. Also

available is a complete list of access codes for all wildlife (amphibians, fish, birds, mammals) for which data are collected in the CWS LRTAP Biomonitoring program.

SITE LOCATIONS DOCUMENT: As a companion to the User's Manual and Database Codes Documents, a third document titled "Complete List of Site Locations and Corresponding Database Codes" is available. This reference lists all sampling site locations currently stored in the database, with particular reference to the "overlapping" enumeration practices for various sampling sites in Ontario.

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ACKNOWLEDGEMENTS: The Canadian Wildlife Service acknowledges the contribution made by Monenco/AGRA Inc, and notably Rob Sayer, for their work in the development of the Database and Reporting System. As well, CWS also acknowledges the input and support of Pete Blancher, Joe Kerekes and Tony Scheuhammer for their suggestions during the development of the database. Mark Mallory and Ken Ross provided valuable input and support during all phases of this effort, while Mark Wayland and Barry Bendell were involved early on.

EDITORIAL COMMENTS: The CWS LRTAP Biomonitoring Program Database and Reporting System has been updated to a Windows format, and is being linked through ODBC software with the more commonly used Microsoft Access® software for direct comparison/amalgamation with other data in CWS Ontario Region (Project WILDSpace Ontario), and for direct output/linkage to MapInfo GIS software. Data residing in the database is batch loaded annually, and is current to 1995. Data which supports certain ORACLE tables remains incomplete at this time (Jan 1998).

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PAPER NO.: REP - 4

YEAR: 1995

TOPIC: Monitoring - General

A Strategy to Monitor the Biological Recovery of Aquatic Ecosystems in Eastern Canada from the Effects of Acid Rain

McNicol, DK, Kerekes, JJ, and Mallory, ML

Atmospheric Environment Service Internal Report, pp 128-142, in Beattie, B (ed), Environment Canada, Bedford, NS (1994)

KEY WORDS: aquatic ecosystems, waterfowl, biomonitoring, foodchain, recovery, lake acidification, acid precipitation, WARMS

PURPOSE OF STUDY: To describe the Canadian Wildlife Service (CWS) Long Range Transport of Air Pollutants (LRTAP) Biomonitoring Program. This program aims to collect chemical and biological data on acid sensitive aquatic ecosystems in eastern Canada, and to determine whether such ecosystems are recovering in response to reduced SO₂ emissions. The Program will deliver on Environment Canada's responsibility to: i) verify the progress of the biological recovery of acidified, damaged and susceptible aquatic systems, including small lakes and wetlands important to wildlife; ii) make predictions about the eventual status of biological components of these systems under various acid deposition scenarios; and iii) make recommendations about the suitability of critical loading rates for the protection and recovery of sensitive aquatic ecosystems of importance to wildlife.

STRATEGIC APPROACH: There are four strategies employed under the CWS LRTAP Biomonitoring Program. The first, whole ecosystem health, is monitored via a) monitoring aquatic birds, their foods and habitats, b) Canadian Lakes Loon Survey (CLLS), and c) assessment of wildlife health risks. The second strategy involves biological indicator species (acid sensitive invertebrates and birds). Thirdly, long term monitoring of chemical and biological parameters is conducted at reference sites. Finally, modelling biological effects of acidity is conducted to predict how reduced emissions will manifest themselves in acid sensitive aquatic ecosystems, using CWS LRTAP Biomonitoring Database and Reporting System, a relational database encompassing the vast network of all biomonitoring data, and b) the Waterfowl Acidification Response Modelling System (WARMS), a computer model used to assess the current level of damage to habitats and waterfowl populations, evaluate the suitability of biomonitoring study sites, test the response of waterfowl to various emission reduction scenarios, and predict eventual benefits of these scenarios to waterfowl production.

BIOMONITORING STUDY SITES: There are four major study sites: Kejimikujik National Park (SW Nova Scotia), Algoma (near the eastern shore of Lake Superior, Ontario), Muskoka (central Ontario), and Sudbury (broad area from Killarney to Temagami, Ontario). CLLS volunteer lakes are scattered across Canada with concentrations in Ontario located principally on the Precambrian Shield in central and northeastern portions of the province. Ontario study lakes are small (<20 ha) and include a range of pH. CLLS lakes are large with high pH and Kejimikujik lakes are large with naturally low pH. Physical, chemical and biological characteristics of CWS LRTAP Biomonitoring study sites are presented in tables and graphs. Biomonitoring data collections in Ontario lakes, including details of the Food Chain Monitoring Program (FCMP), are presented.

KEJIMIKUJIK: Biomonitoring at Kejimikujik collects data on a number of piscivorous birds (notably common loons). This data is used to establish the effects of pH and annual environmental factors on the stability and breeding success of a whole population. At Kejimikujik, the successful breeding of piscivores is controlled by the amount of fish available, which is controlled by nutrient supply. Loon populations have remained stable at Kejimikujik since 1988, however, the number of young produced is lower than at lakes with high pH elsewhere in Atlantic Canada. Loon breeding success is also affected by water levels and the amount of fish.

ONTARIO: The Ontario biomonitoring study lakes represent a large sample of small lakes and wetlands over a large geographic area and at various stages of recovery from acid deposition. Sudbury has the highest proportion of acidified lakes due to historical local deposition, such that local lakes provide a natural experiment to study short term recovery of biotic communities. Elsewhere (Algoma and Muskoka), biomonitoring sites vary substantially in their current and historic levels of acid deposition. Three types of data are collected: physical, chemical, and biological (both food chain and waterbird monitoring). The FCMP samples aquatic invertebrates and fish in a subset of lakes (n = 20) in each study area. These data are used to assess biological recovery at lower trophic levels as a basis for interpreting patterns of waterfowl responses. Certain invertebrate and fish species, on which waterfowl prey, are sensitive and respond quickly to chemical changes. Waterfowl breeding success and productivity are monitored to determine whether chemical improvements attributable to reduced acid deposition result in improvements in waterfowl populations and ecology in affected areas. The waterbird component consists of waterfowl surveys (breeding pairs and brood production), nest box use, and common loon surveys. Lakes in the Sudbury area have been recovering due to reduced local SO₂ emissions from 1972 to 1993. Evidence suggests there has been some biological recovery. Some invertebrates and fish have re-invaded lakes where they previously had not survived. Several species of waterfowl show steady population increases in the Sudbury area (common loon, hooded merganser).

MODELLING: WARMS was developed as a simple and flexible software tool to evaluate effects of acid rain on waterfowl and their habitats in eastern Canada. It is composed of an underlying acidification model (DFO/ESSA) and fish and waterfowl models (CWS). Estimates of pre-acidification, current and eventual pH and alkalinity are used by the biological models to estimate the probability of fish presence/absence and waterfowl breeding success using logistic regression relationships derived for each species. WARMS predicts the probability of observing pairs and broods of waterfowl under various emission scenarios. For example, as SO₂ emissions decline in the Sudbury area, fish presence is predicted to improve and, correspondingly, habitat suitable for broods of piscivores (such as common loons and common mergansers) is expected to increase. Suitable habitat for broods of black ducks and hooded mergansers is also expected to increase. Habitat suitable for broods of the insectivorous common goldeneye is predicted to decline to pre-acidification levels, since this species exploits habitats where fish populations are reduced.

FUTURE WORK: The collection of biomonitoring data from Kejimikujik, the Ontario areas, and from the loon surveys will continue. WARMS predictions on future waterfowl responses will be expanded to watersheds elsewhere in eastern Canada (and adjusted where necessary such as at Kejimikujik): the software itself will be revised to a WARMS for Windows™ format, with improved file management, graphical and statistical capabilities.

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PAPER NO.: REP-5

YEAR: 1994

TOPIC: Monitoring - General