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

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FORWARD

The loss and degradation of habitat is a major waterfowl management problem in North America today. Formerly secure habitats in the vast boreal forest of eastern Canada are now affected by large-scale land-use practices, including hydropower and recreational developments, certain forestry practices, industrial effluent pollution and atmospheric contamination. The emission and deposition of acidic substances (primarily sulphur dioxide SO_2 and nitrous oxides NO_x, and commonly referred to as "acid rain") and subsequent environmental effects 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 Canadian Shield) has little inherent ability to neutralize acidic pollutants. As a result, acid rain may contribute to declining growth rates and increased mortality in trees. High levels of acidic 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, such as waterfowl.

Research and monitoring into various aspects of the acid rain problem has been carried out under the auspices of the Long Range Transport of Air Pollutants (LRTAP) Program, an interdepartmental initiative of the federal government involving Agriculture Canada, Fisheries and Oceans Canada, Natural Resources Canada, Health and Welfare Canada and Environment Canada. As a result of combined federal and provincial efforts, Canada has made significant progress towards reducing the environmental threat of acid rain. A Canadian Acid Rain Control Program was formalized in 1985 by establishing federal-provincial agreements to reduce aggregate SO_2 emissions of the seven easternmost provinces to 2.3 million tonnes per year by 1994 (a target which has been achieved). Because more than 50% of the acid rain that falls in eastern Canada comes from the United States, Canada also signed an agreement with the U. S. in 1991 to reduce SO_2 and NO_x emissions, and to establish a permanent national limit on SO_2 of 3.2 million tonnes by the year 2000. In 1995, Canada began to develop a national strategy on acidifying emissions that aims to protect acid-sensitive ecosystems, human health and air visibility beyond the year 2000.

As part of Environment Canada's efforts to study the acid rain problem, the Canadian Wildlife Service (CWS) initiated a research program in 1980 to assess the impacts of acidic deposition on wildlife and wildlife habitats in eastern Canada. Objectives of the first phase of the CWS LRTAP 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 results of this phase of the program are contained in two volumes of the CWS Occasional Paper Series (Numbers 62 and 67); McNicol *et al.* (1987a) 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. 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 studies were also conducted in the Lepreau area in southwestern New Brunswick, where the relationships between wetland acidity, fish presence, invertebrate biomass and habitat use by young waterfowl broods were examined (Parker *et al.* 1989, 1992). CWS and 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 Kejimkujik National Park, particularly as it pertains to the ecology of fish-eating birds. 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.

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
- evaluate the adequacy of emission control programs to meet environmental objectives to protect aquatic biota important to wildlife.

This report contains information pertaining to the CWS LRTAP Biomonitoring Program and is Part 1 of a series of Canadian Wildlife Service Technical Reports which describe various aspects of the program:

Part 1: A Strategy to Monitor the Biological Recovery of Aquatic Ecosystems in Eastern Canada from the Effects of Acid Rain

Part 2: Food Chain Monitoring in Ontario Lakes: Taxonomic Codes and Collections

Part 3: Site Locations, Physical, Chemical and Biological Characteristics

Part 4: Procedures Manual

For more information on the Canadian Wildlife Service LRTAP Biomonitoring Program or to obtain copies of this or any of the reports in this series, please contact:

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ABSTRACT

Acid rain poses a serious threat to wildlife that rely on aquatic ecosystems in eastern Canada, including many birds, mammals and amphibians. Studies conducted by the Canadian Wildlife Service (CWS) since 1980 have shown that aquatic birds are adversely affected by acidity through a variety of ecological and ecotoxological processes that occur at lower trophic levels, but which may ultimately cause reproductive impairment and/or shifts in habitat selection or diet. The CWS LRTAP Biomonitoring Program was established in 1987 to verify the rate, nature and extent of biological recovery of aquatic ecosystems in eastern Canada following the implementation of acid rain control programs in Canada and the United States. 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.

Long term ecological data is collected by CWS in three regions in Ontario (Algoma, Muskoka, Sudbury) and one in Nova Scotia (Kejimkujik 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 (*Gavia immer*) 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 Kejimkujik 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.

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.

Modelling is an extremely important component of the program because there is no direct means of predicting the nature and extent of aquatic ecosystem recovery from acidification. With this biomonitoring information, we can analyse rates of further chemical and biological recovery and how these rates are influenced by the degree of initial damage. Various computer models (e.g. WARMS, RAISON/IAM) are being developed, validated and used to evaluate the effects of acid rain on waterfowl and their habitats in eastern Canada, and most importantly predict the eventual benefits of various acid deposition scenarios to the environment.

The CWS LRTAP Biomonitoring 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.

RÉSUMÉ

Les précipitations acides constituent une grave menace pour la faune de l'est du Canada dont la survie dépend d'écosystèmes aquatiques; on pense ici aux nombreuses espèces d'oiseaux, de mammifères et d'amphibiens. Les études faites par le Service canadien de la faune (SCF) depuis 1980 montrent que les oiseaux aquatiques sont affectés par l'acidité qui se manifeste dans différents mécanismes écologiques et écotoxicologiques qui s'exercent à des niveaux trophiques inférieurs, mais qui peuvent nuire à la reproduction et/ou conduire à la modification du régime alimentaire ou des préférences relatives à l'habitat de ces animaux supérieurs. Le Programme de biosurveillance concernant le TGDPA du SCF a été mis sur pied au milieu des années 1980 pour contrôler la vitesse, la nature et le degré de rétablissement biologique des écosystèmes aquatiques de l'est du Canada suite à la mise en oeuvre de programmes de réduction des précipitations acides au Canada et aux États-Unis. Le programme du SCF tente de contrôler les paramètres de temps et d'espace du rétablissement biologique des plans d'eau acidifiés, endommagés ou sensibles à l'acidification par le moyen de la surveillance de la réponse sur le plan écologique de la sauvagine et du huart ainsi que des organismes dont ils se nourrissent, à des conditions changeantes de dépôt acide.

Le SCF recueille des données écologiques à long terme dans trois régions de l'Ontario (Muskoka, Algoma et Sudbury) et dans une région de la Nouvelle-Écosse (parc national de Kejimkujik). Le programme du SCF s'applique à des plans d'eau représentatifs de toute une gamme de conditions physiques, chimiques et biologiques, mais il se distingue surtout par l'accent mis sur les milieux humides et les lacs aux petites dimensions (< 20 ha) qui constituent les habitats de prédilection pour la reproduction de nombreuses espèces de sauvagine. Chacun des secteurs étudiés comprend de nombreux lacs très sensibles à l'acidité, qui se sont acidifiés à différents degrés et dont on attend des réactions différentes à une réduction des dépôts acides. Différents indicateurs biologiques comme la reproduction de la sauvagine et du huart à collier ainsi que la qualité et l'abondance des ressources alimentaires (c.-à-d. poisson, amphibiens, invertébrés) sont vérifiés dans quatre régions: 240 stations dans le secteurs d'Algoma et de Muskoka, respectivement, 160 dans le secteur davantage acidifié de Sudbury et 46 dans les secteur très sensible de Kejimkujik. On à eu recours à toute une série de méthodes d'échantillonnage et de recensement et une foule de données ont été recueillies afin de déterminer le profil chimique, physique et biologique (surveillance de la chaine trophique et des oiseaux aquatiques) de chaque lac étudié.

Le huart à collier (*Gavia immer*) est un indicateur biologique idéal et reconnu de l'état des lacs oligotrophes de grandes dimensions (> 20 ha). C'est pourquoi le programme de biosurveillance ajoute les résultats de l'Inventaire canadien des huarts à collier, appliqué par des bénévoles et administré par l'observatoire d'oiseaux de Long Point, à ceux des recensements régionaux du SCF, pour obtenir des données sur la reproduction du huart à collier dans différents lacs de l'est du Canada en vue d'évaluer à l'échelle régionale le succès reproductif de cette espèce en fonction des précipitations acides.

La modélisation occupe beaucoup d'importance dans ce programme puisqu'il n'existe pas de façon directe de prévoir la nature et le degré du rétablissement d'écosystèmes aquatiques acidifiés. Grâce aux renseignements obtenus par la surveillance biologique, il devient possible d'étudier le taux de toute nouvelle amélioration de la situation sur le plan chimique ou biologique et d'analyser comment les progrès sont influencés par la situation de départ. Différents modèles informatiques sont élaborés (p. ex., WARMS, RAISON/IAM), validés et appliqués à l'évaluation des effets des précipitations acides sur la sauvagine et sur ses habitats dans l'est du Canada, mais surtout à la prévision des avantages possibles pour l'environnement qu'on associe à différents scénarios relatifs aux dépôts acides.

Le Programme de biosurveillance concernant le TGDPA du SCF est l'organisation chargée d'amasser les données de surveillance biologique, d'en faire l'intégration et d'interpréter les résultats scientifiques en vue de l'élaboration d'évaluations régionales et nationales relatives au problème des précipitations acides; cette organisation est aussi chargée de formuler des recommandations à l'intention du législateur relatives à la protection et au rétablissement des écosystèmes aquatiques sensibles.

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Over the past fifteen years, many individuals, agencies and groups have contributed to CWS LRTAP research and monitoring activities across Canada. We take this opportunity to thank everyone who has been involved in this effort and apologize to those who have been inadvertently omitted. 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 regional and headquarters programs. In addition, we have benefitted from cooperative investigations with other federal and provincial agencies (Algonquin Provincial Park, Atmospheric Environment Service, Bedford Institute of Oceanography, Canadian Museum of Nature, Fisheries and Oceans Canada, INRS-Eau, Kejimkujik National Park, Lesley 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, Royal Ontario Museum, U.S. Fish and Wildlife Service), 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., Whitefish Point Bird Observatory, Wildlife Habitat Canada, World Wildlife Fund [Wildlife Toxicology Fund]), and universities (Carleton, Dalhousie, Guelph, Québec, Queen's, Laurentian, McGill, McMaster, Toronto, Trent, Wales).

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1.0 INTRODUCTION

1.1 Acid Rain and Emission Controls

Acid rain has been documented for more than a century (reviewed in Cowling 1982), and is caused by atmospheric pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x) which may be transported great distances by prevailing winds before being deposited as sulphuric and nitric acid. For example, more than 50% of the acid rain that falls in eastern Canada comes from sources in the United States (U. S.) (RMCC 1990). Much of eastern Canada is sensitive to acid rain since its thin, coarsely textured soil and granitic bedrock has little ability to neutralize acidic pollutants. As well, this highly sensitive region, which covers 43% of Canada's land area, receives more acidic deposition than any other region. As a result, acid rain may contribute to declining growth rates and increased mortality in trees, and can result in acidification of lakes, rivers and streams. Along with metals leached from surrounding soils, 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.

Since the mid-1970s, research on acid rain and its effects on North American flora and fauna accelerated. Once the magnitude of the environmental damage was recognized, significant progress towards reducing the threat of acid rain was made (Table 1). Canada has been a leader in taking steps to reduce or reverse the effects of acid-causing emissions on its environment. A Canadian Acid Rain Control Program was formalized in 1985 as an agreement between the seven easternmost provinces and the federal government to reach a 50% reduction in annual SO_2 emissions from 1980 levels to 2.3 M tonnes per year by 1994 (a target which has been achieved). At the same time, Canada agreed under the Helsinki Protocol to cap its national SO_2 emissions at 3.2 M tonnes by 1993. National SO_2 emission limits were confirmed by the Canada-U.S. Air Quality Agreement in 1991, which also established a 100,000 tonne reduction in NO_x emissions from stationary sources by the year 2000. Similar initiatives will result in a 4.5 M tonne reduction in U.S. emissions by January 1995, and an additional 4.5 M tonne reduction by 2000 (Government of Canada 1992).

Emission of SO_2 and subsequent deposition as sulphate (SO_4) is the primary cause of anthropogenic acidification of lakes and streams in southeastern Canada. Sulphate deposition will decrease over much of southeastern Canada under the Canada-U.S. Air Quality Agreement. However, North American emissions of NO_x have remained fairly constant and may increase after the year 2000. The cumulative deposition of nitrogen pollutants (NO_3, NH_3) can also contribute to acidification (Jeffries 1995). There is concern that further increases in N deposition or even maintenance of existing levels over the long term may eventually undermine improvements expected to result from the SO_2 control program. Under the Sofia Protocol, Canada is committed to consider nitrogen-based acidification when developing a domestic NO_x control program (Table 1).

In 1995, Canada began to develop a national strategy on acidifying emissions to protect acid-sensitive ecosystems, human health and visibility, and ensure the achievement of its international commitments beyond the year 2000. Yet, even with significant reductions of acidifying pollutants, damaged aquatic ecosystems will persist in some regions of eastern Canada. Over the past decade, one third of the lakes and streams monitored in areas that receive high levels of acidic deposition showed evidence of improvement, about half that many continued to acidify, and the rest remained unchanged (Clair *et al.* 1995), despite the fact that the area of eastern Canada receiving 20 kg/ha or more of wet sulphur per year has declined by nearly 58% from 1980 to 1992.

Table 1. Chronology of acid rain control strategies relevant to Canada.

YEAR	ACTION
Late 1970s	Long Range Transport of Air Pollutants (LRTAP) Program established to investigate the occurrence and effects of airborne pollutants being transported within and into Canada
1979	Canada signed the United Nations (UN ECE) Convention on Long Range Transboundary Air Pollution to reduce and prevent long-range transboundary air pollution
1980s	Canada-U.S. conducted extensive research and assessment programs on acidic deposition. In Canada, this work was carried out by the federal/provincial Research and Monitoring Coordinating Committee (RMCC). In the U.S., the National Acid Precipitation Assessment Program (NAPAP) was the focal point for acid rain research
1985	Canada signed the UN ECE Helsinki Protocol and agreed to reduce national annual SO_2 emissions by at least 30% below 1980 levels by 1993
1985	Canadian Acid Rain Control Program established to reduce total SO_2 emissions in the seven easternmost provinces by 40% of the 1980 level (to 2.3M tonnes) by 1994
1988	Canada signed the UN ECE Sofia Protocol to freeze NO_x emissions in 1994 at 1987 levels (or about 2M tonnes)
1990	U.S. Clean Air Act amended to include SO_2 and NO_x emissions controls
1991	Canada-U.S. Air Quality Agreement signed which includes mutual obligations for the reduction of SO_2 and NO_x emissions
1994	Canada signed the UN ECE Oslo Protocol which recognizes the concept of critical loads and establishes an emissions cap of 1.75M tonnes of SO_2 in eastern Canada

1.2 Acid Rain and the Canadian Wildlife Service (CWS)

Research and monitoring of the acid rain problem has been carried out under the Long Range Transport of Air Pollutants (LRTAP) Program, an interdepartmental initiative involving Agriculture Canada, Fisheries and Oceans Canada, Health and Welfare Canada, Natural Resources Canada and Environment Canada. As part of Environment Canada, the Canadian Wildlife Service (CWS) initiated a research program in 1980 to assess the impacts of acidic deposition on wildlife and their habitats in eastern Canada. Its objectives 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 results of this phase of the program are contained in two volumes of the CWS Occasional Paper Series (Numbers 62 and 67); McNicol *et al.* (1987b) 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 in 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) summarized the results of research at the National Wildlife Research Centre (NWRC) on the fate of heavy metals in avian 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 decline) 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 early 1980s, a volunteer-based survey of the breeding success of Common Loons (*Gavia immer*) on acid-stressed lakes in Canada.

CWS has also played a major role in interdisciplinary studies of calibrated basins, especially in Atlantic Canada, where Kerekes *et al.* (1994) studied nutrient release in and limnological characteristics of acidified waters in Kejimkujik National Park, particularly as it pertains to the ecology of fish-eating birds. CWS (Atlantic Region) acid rain studies in Kejimkujik National Park showed that target loadings of SO_4 should not be considered as a rigid threshold number, but should be viewed within the context of a load-receptor relationship. This means that a more sensitive, aquatic system could suffer greater or similar impact from a given acidic depostion than that of a more buffered system exposed to higher rates of atmospheric deposition (Kerekes 1989a). It was also shown that anthropogenic acidity causes additional acidity in humic, organic waters which are naturally acidic (Kerekes *et al.* 1986b), and the role of various sources of acidity affecting surface waters in Nova Scotia was clarified (Kerekes *et al.* 1986a).

Together, these efforts provided the basis for the CWS LRTAP Biomonitoring Program which began in 1987. This national program is comprised of research and monitoring activities conducted by the NWRC and by Regional offices in Ontario and Atlantic Canada. The mandate of the program is to verify the progress of acid rain control measures in Canada and the U.S., and to determine if these measures will provide the necessary environmental protection to support the recovery of healthy biotic communities in aquatic ecosystems in eastern Canada.

1.3 Why is Biological Monitoring Necessary?

In the 1980s, research on acid rain was directed towards convincing governments of the severity of the acid rain problem in North America. Today, efforts are focused on describing the effectiveness of emission controls and determining the response of very sensitive aquatic and terrestrial ecosystems to declining rates of acidic deposition. It remains unclear whether emission reductions outlined in Table 1 will be sufficient to meet environmental objectives. Monitoring is needed to verify that control programs actually achieve the desired results (i.e. restoration of healthy biotic communities in areas affected by acidic precipitation), and to determine whether emission reduction strategies require further adjustments.

In ecosystems affected by anthropogenic stressors, biological responses "tend to integrate the independent and interactive effects of many stressors, a property that makes them more robust indicators of ecosystem condition than the concentrations and loadings of individual chemicals" (Cairns *et al.* 1993). Clearly, the adequacy of acid rain control programs must be measured in terms of the capacity of aquatic habitats to sustain healthy populations of plants and animals, both fish and wildlife, and cannot simply be assessed in terms of measured reductions in acidic deposition or improvements in water quality. Hence, biological monitoring (hereafter biomonitoring) is necessary to confirm that the steps taken to improve damaged ecosystems are having an effect.

Most early acid rain/wildlife research documented aspects of the decline of aquatic and terrestrial ecosystems, particularly the exclusion/loss of species from severely affected areas (reviewed in Longcore *et al.* 1993). Because control programs have only begun to take effect, most predictions on biological recovery are based on those patterns observed during the decline phase or following experimental manipulations, such as the recovery of Lake 223 in the Experimental Lakes Area after artificial acidification. We have very few examples of biological recovery in areas experiencing chemical recovery, and those few examples (e.g. Sudbury area lakes) are based on a very short time period. Thus, biomonitoring data are required to refine models used to describe ecosystem recovery. Furthermore, even with a 50% reduction in SO_2 in eastern Canada, damaged aquatic ecosystems will persist in some areas (RMCC 1990). Biomonitoring is required to determine how extensive the biological impacts of these residual regions are, and whether remedial measures may be required for certain critical habitats. Also, ecosystems that develop following recovery may be quite different from original conditions (Schindler *et al.* 1989), as evidenced by liming studies in Scandinavia. Biomonitoring will determine whether recovering ecosystems are similar to those unaffected by acid rain.

1.4 Target and Critical Loads

The concept of the "target load" was developed in the early 1980s, and was based on the effects of acidic precipitation on sport fisheries. Because most sport fish are lost at pH 5.3, 20 kg of wet SO_4 per hectare per year was established as the environmental objective of Canadian efforts to reduce acid rain, a target loading which presumably would not lead to further deterioration of aquatic systems (RMCC 1990). However, scientists are now suggesting that for many acid-sensitive ecosystems, this target may be too high since the capacity to buffer acid rain is significantly lower than 20 kg/ha/yr in some areas (Kerekes 1989a, Beattie and Keddy 1995). Recently, the European concept of the "critical load" has been adopted in Canada. Defined as "the highest deposition of acidifying compounds that would not cause chemical changes leading to long term harmful effects on the overall structure or function of the aquatic ecosystem" (RMCC 1990), the critical load concept is based on a whole ecosystem approach. Using available information from all aspects of aquatic ecosystems, pH 6 was determined as a suitable chemical threshold for deriving critical loads. Above this pH, most aquatic organisms (not just sportfish) are not negatively affected; below this value, certain organisms begin to disappear from lakes. Using pH 6 as the chemical threshold, the critical loads for eastern Canada are ≤ 8 kg/ha/yr wet SO_4 deposition for the sensitive Maritime provinces and most of Québec, < 16 kg/ha/yr for southern Québec and central Ontario, and > 20 kg/ha/yr for southwestern and northern Ontario (RMCC 1990).

2.0 BACKGROUND

2.1 Resources at Risk

Waterfowl represent an important socio-economic resource in North America by providing recreational and hunting opportunities. The loss and degradation of aquatic habitat has serious implications for waterfowl breeding in the vast boreal forest of eastern Canada, an area whose importance to continental waterfowl populations is only beginning to be appreciated. Formerly secure habitats are now being threatened by large-scale land-use practices, including hydroelectric and recreational developments, certain forestry practices, industrial effluent pollution and atmospheric contamination (NAWMP 1986). In eastern Canada (Ontario through the Maritimes south of 52° N), Hélie *et al.* (1993) determined that of 881,634 water bodies surveyed, 73% were located in areas that had a low potential to reduce acidity and thus were considered sensitive to acidification. Of these, roughly half a million have a surface area less than 5 ha (mostly small headwater lakes and wetlands). In Ontario, 43% of the Precambrian Shield portion of the province (540,000 km^2) currently receives >10 kg/ha/yr wet SO_4 deposition, an area which contains more than 170,000 water bodies (90% under 20 ha; McNicol *et al.* 1990), and supports an estimated 192,000 pairs of nesting loons and ducks.

Small water bodies are particularly vulnerable to acidification, and also provide the most suitable breeding habitat for most insectivorous duck species, including Common Goldeneye (*Bucephala clangula*), Hooded Merganser (*Lophodytes cucullatus*), Ring-necked Duck (*Aythya collaris*), Wood Duck (*Aix sponsa*), American Black Duck (*Anas rubripes*) and Mallard (*Anas platyrhynchos*) (McNicol *et al.* 1987b, Parker *et al.* 1992).

Table 2. Bird species probably affected by long term effects of acidic depositions on their foods in aquatic environments (modified from Longcore *et al.* 1993).

POTENTIAL EFFECT	FEEDING HABITAT	SPECIES
Reduced biomass of fish, aquatic invertebrates, amphibians	Lakes and Rivers	Common Loon (*Gavia immer*) Common Merganser (*Mergus merganser*)
	Littoral Zone of Lakes and Wetlands	Great Blue Heron (*Ardea herodias*) American Bittern (*Botaurus lentiginosus*) Belted Kingfisher (*Megaceryle alcyon*) Hooded Merganser (*Lophodytes cucullatus*)
Reduced biomass of aquatic invertebrates	Littoral Zone of Lakes and Wetlands	Common Goldeneye (*Bucephala clangula*) Ring-necked Duck (*Aythya collaris*) American Black Duck (*Anas rubripes*) Virginia Rail (*Rallus limicola*)
Reduced biomass of aquatic invertebrates with adult stage terrestrial invertebrates	Riparian Wetlands	Spotted Sandpiper (*Actitus macularia*) Eastern Kingbird (*Tyrannus tyrannus*) Eastern Phoebe (*Sayornis phoebe*) Tree Swallow (*Tachycineta bicolor*) Barn Swallow (*Hirundo rustica*) Bank Swallow (*Riparia riparia*) Yellow-rumped Warbler (*Dendroica coronata*) Blackpoll Warbler (*Dendroica striata*) Palm Warbler (*Dendroica palmarum*) Common Yellowthroat (*Geothlypus trichas*)

Fish-eating species, such as Common Loon and Common Merganser (*Mergus merganser*), prefer large lakes and river systems but are equally at risk from the effects of acidification on fish prey (Kerekes *et al.* 1994, McNicol *et al.* 1995b,c). Other fish-eating species, such as kingfishers, herons and bitterns, as well as riparian species such as tree swallows (Blancher and McNicol 1986, 1988, 1991), are affected as a result of alterations to aquatic food webs (Table 2). Effects of acid rain on terrestrial ecosystems are reviewed by Longcore *et al.* (1993) with emphasis on the effects of maple dieback on forest birds (DesGranges *et al.* 1987, Darveau *et al.* 1992). However, this report focuses on research and monitoring of acid rain effects in aquatic ecosystems.

2.2 CWS Cause-and-Effect Research

Many approaches have been used to investigate the nature and severity of the acid rain problem to the chemistry and biology of sensitive surface waters in eastern North America. These included synoptic surveys and regional assessments (e.g. Pitblado *et al.* 1980), experimental acidification (e.g. Schindler *et al.* 1985), point-source effects (e.g. Keller *et al.* 1992a), laboratory studies (e.g. Freda and Dunson 1985), paleoecological reconstructions (e.g. Dixit *et al.* 1992) and mitigative measures (e.g. Keller *et al.* 1992b). However, much of the focus of acid rain research conducted in eastern Canada during the 1980s was on large, oligotrophic lakes or rivers suited for gamefish species (e.g. lake trout, *Salvelinus namaycush* or Atlantic salmon, *Salmo salar*).

The Canadian Wildlife Service has examined the effects of acidity on the biota of a broad range of habitats, including large lakes (McNicol *et al.* 1987b, DesGranges and Darveau 1985, Kerekes 1990). However, much of the research has focused on wetlands (bogs, fens, marshes, swamps; Blancher and McNicol 1987, 1988, Dale *et al.* 1984, Kerekes *et al.* 1986a) and small lakes (Bendell and McNicol 1987a, Schell and Kerekes 1989, McNicol and Mallory 1994). CWS research has shown that aquatic birds are adversely affected by acidity through a variety of ecological and ecotoxicological processes that occur at lower trophic levels. The probable pathway of effects of, and biological response to, the acidification of surface waters is depicted in Fig. 1. It emphasizes probable responses by birds to changing habitat quality arising from the acidification (or conversely the recovery) of aquatic ecosystems. Toxicological processes include the mobilization of trace metals in acidic waters and their bioaccumulation in fish and invertebrate prey (Spry and Wiener 1991, Wren and Stephenson 1991), which can cause impairment of avian reproduction (Scheuhammer 1991). Because it is less abundant in usable form in acidic lakes, concentrations of calcium (Ca) in invertebrate prey are lower and could lead to Ca stress for foraging species (Blancher and McNicol 1991).

Ecological processes include the loss of prey species that are sensitive to acidity (e.g. certain water striders, mayflies, leeches) and their replacement by species that are tolerant (Bendell 1988, Bendell and McNicol 1991), as well as changes in the abundance and diversity of prey communities (Bendell and McNicol 1987a,b, 1995a,b, McNicol and Wayland 1992, Mallory *et al.* 1994a). As lakes acidify, overall invertebrate abundance may remain the same or even increase, but species diversity and prey quality decline significantly (Schell and Kerekes 1989, Kerekes *et al.* 1990, McNicol *et al.* 1995a). Pristine acidic, organic waters are more productive in some respects than clear, less acidic waters lying on similar bedrock. Water bodies with coloured, organic waters also receive higher nutrient supply and maintain a higher overall biological productivity than that of less acidic, clear waters (Beauchamp and Kerekes 1989, Kerekes and Freedman 1989). Highly acidic waters ($pH < 4.0$) may remain highly productive for macrophytes, invertebrates and waterfowl in the presence of high external nutrient supply (Kerekes *et al.* 1984). 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, often arising from shifts in habitat selection and diet (Longcore *et al.* 1993).

◦ **Piscivorous Birds** - Fish species richness and abundance is adversely affected by increased acidity of wetlands and lakes (Matuszek and Beggs 1988, McNicol *et al.* 1995a). Several species of fish (e.g. yellow perch, *Perca flavescens*, and some cyprinids) have tolerances in the range of pH 5 - 6 (Bendell and McNicol 1987a), and thus are useful biological indicators. However, below pH 5, few fish survive, and often adults that do survive do not breed. By contrast, fish exhibit greater tolerance to pH in the highly organic waters in Kejimkujik. For example, yellow perch occur in lakes at pH 4.5 and tolerate autumn minimums of pH 4.1 (Kerekes 1982). At the same time, acidification can increase the trace metal content of fish and invertebrates, especially mercury (Hg) (Scheuhammer 1991, Spry and Wiener 1991, Wren and Stephenson 1991, McNicol *et al.* 1996e), which poses potential risks to wildlife preying on them (Scheuhammer and Blancher 1994). Evidence now exists linking increasing lake acidity, Hg loads in fish prey and blood Hg concentrations in Common Loons at levels sufficient to be of concern for loon reproduction (Atchison 1995, Meyer *et al.* 1995). A possible consequence is that the reproductive success of fish-eating species (e.g. Common Loon, Common Merganser) is lower on acidic lakes (McNicol *et al.* 1987b, 1990, 1995c, Kerekes *et al.* 1994). Consequently, in some areas piscivorous birds avoid acidic lakes, resulting in shifts in breeding densities or distributions (McNicol *et al.* 1987b, 1995b, DesGranges 1989).

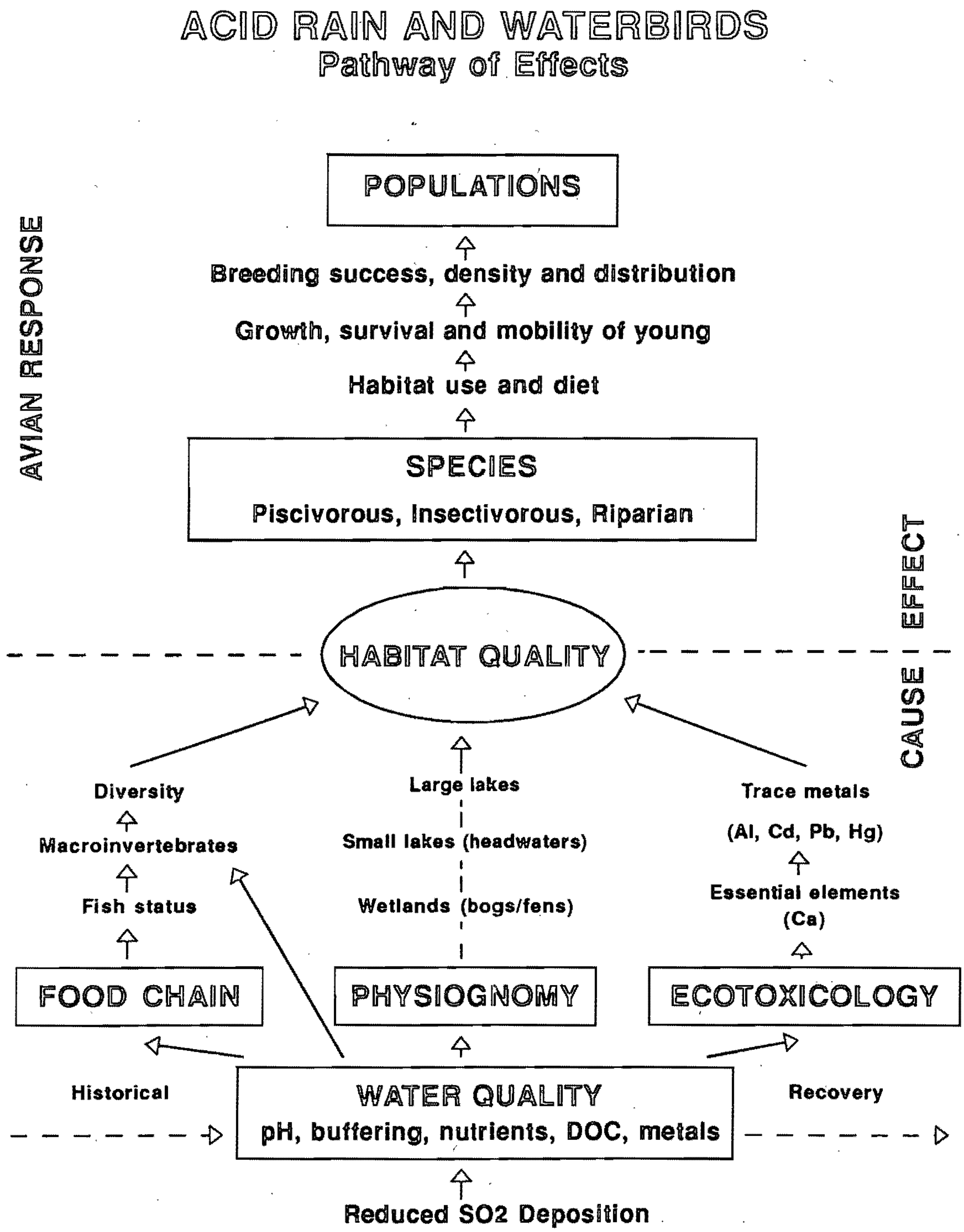

Figure 1. Diagram illustrating the probable pathway of effects of, and biological response to, the acidification or recovery of aquatic ecosystems, with emphasis on avian responses.

◦ **Insectivorous Birds** - Several species of invertebrates (e.g. certain dragonflies, caddisflies, mayflies, water striders, gastropods and leeches) have pH tolerances in the range of pH 5 - 6 (Bendell 1988, Bendell and McNicol 1991, 1993, McNicol *et al.* 1995a), and are useful biological indicators. In general, nektonic macroinvertebrates are strongly influenced by fish predation, while benthic assemblages are also influenced by acidity (Bendell and McNicol 1987a, 1995a, McNicol and Wayland 1992). Thus, the loss of fish from lakes usually results in decreased diversity but high abundance of acid-tolerant invertebrates (Bendell and McNicol 1987a, Mallory *et al.* 1994a). The net result is that some insectivorous waterfowl shift their diet (Bendell and McNicol 1995b), or alter their distribution (McNicol *et al.* 1995b), but generally are better able to adjust breeding habits in response to altered habitats than are piscivorous waterfowl. Insectivorous species utilize fishless, often acidic lakes with abundant macroinvertebrate fauna (e.g. Mallory *et al.* 1993, 1994b, Wayland and McNicol 1994), but prefer lakes with a greater diversity of fauna (higher pH lakes) and avoid lakes containing acid-tolerant fish competitors (McNicol *et al.* 1987b, 1990, McNicol and Wayland 1992). Waterfowl nesting and rearing broods on acidic, fishless lakes may increase their reproductive costs without producing more young, possibly because ducklings do not grow as well on acidic lakes (DesGranges and Rodrigue 1986, McAuley and Longcore 1988). Furthermore, young reared on lakes producing invertebrate prey containing lower Ca and elevated trace metals may experience chronic consequences for growth and reproduction (Scheuhammer 1991). Clear relationships now exist between Ca content in a variety of aquatic invertebrate prey, and subsequent risk of Ca deficiency for wildlife feeding in acid-stressed systems (Blancher and McNicol 1991), as reported in terrestrial systems (Graveland *et al.* 1994).

2.3 Waterfowl as Biological Indicators

Birds have long been used as biological indicators of environmental conditions, often acting as integrators of ecological responses to anthropogenic stressors. We selected waterfowl as indicators of the biological responses to reduced acidic deposition and chemical recovery due to their dependence on the immediate aquatic environment for nest sites, brood protection and food (McNicol *et al.* 1987a). Because of their reliance on suitable breeding habitat, changes in waterfowl distribution and production should reflect broad-scale changes in the habitats they rely upon, with the predominant habitat change being available food resources. Hence, individual trends in species distribution and breeding success should mirror changes in populations and distributions of the fish and invertebrates they rely upon, and thus should be suitable indicators for the aquatic ecosystems under consideration.

The Common Loon is perhaps the best indicator species because it is conspicuous, it is found across eastern Canada and its principal food source is fish. Research by Atlantic (Kerekes *et al.* 1994) and Ontario Regions (Wayland and McNicol 1990, McNicol *et al.* 1995c) has indicated a strong negative influence of lake acidity on loon reproductive success, with similar results suggested for the Common Merganser (McNicol *et al.* 1990, Kerekes *et al.* 1994). In contrast, the insectivorous Common Goldeneye can exploit acidified habitats (McNicol and Wayland 1992, Mallory *et al.* 1993, 1994b, Wayland and McNicol 1994) and is common in affected areas (McNicol *et al.* 1995b), although overall reproductive success may still be better for goldeneyes breeding on high pH lakes (McNicol *et al.* 1990).

3.0 CWS LRTAP BIOMONITORING PROGRAM

3.1 Ecological Monitoring

The CWS LRTAP Biomonitoring Program will collect long term ecological data in each of three regions in Ontario and one in Nova Scotia. Each region contains many highly sensitive lakes and wetlands that exhibit varying degrees of acidification, and are expected to respond differently to reductions in acidic deposition (Clair *et al.* 1995, McNicol *et al.* 1995d). To ascertain whether a trend of chemical and biological recovery is occurring in eastern Canada, it is essential that long term monitoring (temporal data) by repeated sampling of several areas (spatial data) be conducted (Schindler 1987, Brown and Roughgarden 1990). The value of monitoring of spatial and temporal reference sites is summarized below (adapted from Yan and Keller 1991).

Ecological monitoring can take many forms, from tracking the status of certain indicator species, to measuring absolute abundance of individual taxa, to measuring community structure (Cairns *et al.* 1993). Advantages and disadvantages are associated with each approach, however, the CWS LRTAP Biomonitoring Program has adopted a whole ecosystem approach to ecological monitoring which employs measurements of community structure as well as indicator species. Ecosystem monitoring is considered more appropriate than single-organism approaches in many situations because it minimizes the risk of false negative or false positive signals that are more likely to occur when too much reliance is placed on a single indicator or if a single indicator fails to sufficiently cover the breadth of effects that may occur (Cairns *et al.* 1993). The advantages of monitoring community structure are: 1) the information base gathered is much broader than monitoring one or a few indicator species; 2) some indicator species are included by default; 3) qualitative rather than quantitative sampling can be used and is reliable provided sampling methods are standardized; 4) the methods required are adapted to the habitat and fauna found at each sampling site; 5) the method is less susceptible to difficulties in locating or capturing a few "cosmopolitan" indicator species; and 6) interpretation of the data does not require prior knowledge of the acid sensitivity of each taxon. Yet, monitoring conspicuous indicator species, chosen for their ease of collection and sensitivity to acidification (e.g. leeches, loons), complements the community data but may be gathered over a much broader area.

3.1.1 Spatial Reference Sites

Spatial reference datasets refer to collections of similar or identical data across a broad region to assess a particular question on a regional scale, and have many uses including:

◦ *Quantifying natural variation in structure and dynamics among non-impacted systems in a region*: without background data on waterfowl and food chain relationships in non-acidified habitats in eastern Canada, processes observed in lakes recovering from acidification could be misinterpreted.

◦ *Developing models to predict temporal changes by substituting spatial for temporal data*: CWS has developed a regional acidification model (Section 3.4.1) to estimate the extent of damage to waterfowl production and breeding habitat, the extent of recovery based on emission reduction scenarios applied to regions of eastern Canada, and the suitability of biomonitoring sites to detect change (McNicol *et al.* 1995d).

◦ *Assessing the status of ecosystems over broad geographic areas*: CWS LRTAP biomonitoring data are used to interpret long term trends in waterfowl and loon populations established in broad-scale synoptic surveys such as the North American Waterfowl Management Plan (NAWMP) and the Canadian Lakes Loon Survey (CLLS).

◦ *Identifying sites with particular attributes*: such sites would typify a region (e.g. low Ca lakes at Kejimkujik), or have desirable attributes, perhaps near atmospheric monitoring stations, part of other monitoring programs (Shaw *et al.* 1992), have historical data (Turkey Lakes and Kejimkujik Watersheds), or have elevated contaminant levels in prey.

◦ *Exploring ecological patterns at various spatial scales*: responses of waterfowl could be measured at provincial, ecoregional, watershed, territory (several adjacent lakes) or individual lake levels. Responses could be measured on selected waterfowl foods (fish/invertebrates) located in littoral habitats within a lake.

◦ *Separation of effects of interest from natural confounding covariates*: for example, fish species richness increases naturally with lake size (Matuszek *et al.* 1990, McNicol *et al.* 1995a) as does the likelihood that lakes will support nesting loons (McNicol *et al.* 1995c). The large CLLS database will allow analyses to correct for covariance of lake size with fish biomass, while demonstrating the effect of recovery on loon reproductive success.

3.1.2 Temporal Reference Sites

Temporal reference datasets refer to collections of similar or identical data over time in the same location to assess a particular question on a temporal scale. These datasets establish normal patterns of variability in a biological parameter through time, and have many uses including:

◦ *Detecting gradual or cyclic changes against a naturally noisy background*: because many factors (e.g. winter survival) other than those of direct interest (e.g. improving pH) affect biological organisms, high natural variation in a parameter may occur between years, and this must be considered when looking for trends attributable to the effect under observation.

◦ *Identifying causes of community alterations where effects are separated in time from their causes*: for example, chemical recovery may improve conditions for fish reproduction and lead to increased fish stocks capable of sustaining a nesting pair of loons; yet, an immediate response is unlikely due to philopatry (same pair return annually to same lake). Episodic acidic events may eliminate certain cohorts (one breeding season's production) of acid-sensitive fish or invertebrate prey from shallow, ephemeral habitats and influence waterfowl production that year. Long term records are required to understand what regulates long lived species.

◦ *Recognizing and assessing the impacts of unusual events, including perturbations not anticipated under the current design*: only against the background of a long term record can unusual circumstances be detected and explained. For example, record low temperatures coupled with high precipitation in the summer of 1992 contributed to the unusually poor fledging success of some ducks and tree swallows in northeastern Ontario.

◦ *Uses not anticipated under the current design*: many long term spatial or temporal reference datasets have been invaluable in assessing new questions. For example, the long term records of chemistry of Sudbury lakes may have their greatest value in the documentation of recovery from acidification (e.g. Gunn and Keller 1990, McNicol and Mallory 1994). Well designed, sustained surveillance programs may contribute to the detection and understanding of environmental perturbations unrelated to the original questions. For example, long term records will become increasingly important as the effects of climatic warming on lakes of the boreal forest become evident in the future (Schindler *et al.* 1990). As the prairie pothole region succumbs to increasing climatic stress, the boreal and mixed hardwood forests of eastern Canada may become a major source of recruitment to continental populations of many species.

3.2 Program Objectives

The primary objective of the CWS LRTAP Biomonitoring Program is to verify the rate, nature and extent of biological recovery of aquatic ecosystems in eastern Canada from the effects of acidification following the implementation of acid rain control programs in Canada and the U.S. The program monitors whole ecosystems, including higher trophic levels which rely on the integrity of various components of the aquatic food web. In addition, the program includes biological indicators (primarily acid-sensitive invertebrate and avian species identified in earlier cause-and-effect studies) that respond to ecological changes in the food web within the range of critical thresholds for most sensitive biota (pH 5-6), and are found across the types of surface waters at risk, including wetlands, small and large lakes. Furthermore, a modelling component predicts how emission reductions manifest themselves at the biotic community level. The monitoring and modelling components of the program are discussed below.

3.3 Monitoring

We measure the recovery of biotic communities in wetlands, small and large lakes by monitoring ecological responses of waterfowl and their foods to a changing acid deposition environment at several spatial and temporal scales. Inherent in this approach is the requirement for long term data collection on the production of waterfowl and the status of fish and invertebrate populations (that form the prey base for these waterfowl) as acid inputs to these water bodies change. This type of data collection permits the identification of sensitive aquatic biota whose recovery lags behind pH increases and the assessment of the ecological effects of the loss of these species on the biotic community. Concurrently, we can identify critical aquatic habitats that may require mitigative measures to recover. Continued monitoring will allow us to assess the risks of mercury and calcium to fish-eating and other birds in relation to changing lake acidity.

- Short term recovery of acidic and damaged lakes in the Sudbury area following reductions in local smelter emissions provides a natural experiment to study recovery of biotic communities following reversal of acidification at a much more accelerated rate than expected elsewhere (McNicol *et al.* 1995b). This work will allow refinement of methods used elsewhere and enhance our ability to predict and interpret results from other regions where recovery is anticipated to occur more slowly.

- Small lakes and wetlands are particularly vulnerable to acidification, and constitute the preferred breeding habitat for many waterfowl and wildlife species. To establish whether biological recovery occurs at the same rate and to the same degree in these ecosystems as in large lakes (e.g. Keller *et al.* 1992a), a stratified sample of highly sensitive lakes is being monitored in areas of Ontario east and north of the Great Lakes. Water bodies in these areas have similar physical characteristics, but differ in sensitivity and the extent of current acid rain damage, in current and predicted changes in SO_4 deposition, and in response to various emission reduction scenarios.

- An extensive assessment of the reproductive success of fish-eating birds, especially Common Loons, in relation to recovery of large lakes and improved fisheries production is being undertaken in eastern Canada (McNicol *et al.* 1995c). Much of the specific work on the relationship between lake chemistry, lake size and hydrology, fish production and loon reproductive success is conducted at the Kejimkujik watershed in Nova Scotia, where the distribution of lake size and chemistry in a small geographic area is conducive to detailed study (Kerekes 1990, Kerekes *et al.* 1994). A special concern exists in parts of Atlantic Canada that biological systems may not respond to reduced acidic deposition because of the extreme sensitivity of aquatic systems. Due to the effects of natural organic acidity, control measures aimed to maintain pH 6 or more in clear waters will not be sufficient to maintain this level in organic brown waters which are numerous in this region.

3.3.1 Canadian Lakes Loon Survey (CLLS)

While boreal waterfowl are useful indicators of recovery on small lakes (< 20 ha), the Common Loon is an ideal biological indicator on larger lakes. The loon is a piscivorous bird that requires an abundant supply of fish for reproduction (Kerekes 1990), and thus has been negatively affected by acid-induced habitat degradation (Alvo *et al.* 1988). A major component of the CWS LRTAP Biomonitoring Program is the Canadian Lakes Loon Survey (CLLS). The CLLS is a volunteer-based survey program administered by the Long Point Bird Observatory (LPBO) that collects data on Common Loon reproduction in lakes across Canada. Through CWS staff surveys and the CLLS, the success of breeding loons on more than 1000 lakes in Ontario and Atlantic Canada is monitored annually. With support from CWS, LPBO initiated the survey in Ontario in 1981, and expanded it nationally in 1989 where it now focuses on the effects of human activity, acid precipitation and other lake chemistry variables on loon reproductive success across Canada. Over the years, a successful network of volunteer loon surveyors has been developed. For example, between 1987 and 1994, volunteers submitted 5083 reports for loons nesting on 1633 lakes in Ontario alone. McNicol *et al.* (1995c) discuss some advantages and disadvantages associated with using volunteers to survey loons, but conclude that the CLLS provides a reliable, cost-effective method of assessing the long term health of large, acid-sensitive lakes across eastern Canada. Results from Ontario surveys indicate that the dominant factor affecting loon reproduction is the size of the nesting lake, yet loons experience reduced productivity on more acidic lakes, probably because less food is available. These results have been confirmed by studies at Kejimkujik in Nova Scotia (Kerekes *et al.* 1994). Given the preference of loons for large lakes, it is clear that effective monitoring of this valuable indicator species is not possible without CLLS contributions.

3.4 Modelling

Modelling is an extremely important 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 utilize existing information to make predictions about the eventual status of ecological components of aquatic ecosystems in eastern Canada under various emission scenarios. With the aid of models, we can estimate responses of waterfowl, loons and their breeding habitats to predicted changes in acidic deposition following SO_2 emission reductions and report on the progress of recovery in aquatic ecosystems. 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.

3.4.1 Waterfowl Acidification Response Modelling System (WARMS)

The Waterfowl Acidification Response Modelling System (WARMS for WINDOWS™; hereafter WARMS) has been developed to evaluate effects of acid rain on waterfowl and their habitats in eastern Canada (Blancher *et al.* 1992, McNicol *et al.* 1995d). WARMS is a simple and flexible computer software program that facilitates the investigation of the effects of changes in lake acidity on waterfowl habitat suitability. WARMS is comprised of an existing acidification model (Marmorek *et al.* 1990) linked to fish and waterfowl models (Blancher *et al.* 1992). Information on breeding waterfowl, habitat and food chains gathered from acid-sensitive lakes in Ontario between 1980-1987 was used to develop the ecological aspects of the model (Blancher *et al.* 1992). The analysis process used in WARMS is illustrated in Fig. 2. WARMS uses lake characteristics and fish presence to estimate pre-acidification (hereafter "original"), present and eventual steady-state values for pH, fish presence and waterfowl breeding parameters under various emission scenarios. The underlying acidification model (ESSA/DFO; Marmorek *et al.* 1990) predicts eventual chemical status of lakes (alkalinity, pH, cations and SO_4) based on watershed morphometry and runoff, current lake chemistry (Neary *et al.* 1990), observed (assumed) levels of SO_4 deposition and assumed values of acid neutralization in watersheds (SO_4 reduction in lake, and background or original SO_4). Recent modifications to the model (Marmorek *et al.* 1996) better reflect the role of DOC in projections of alkalinity and pH, which is especially significant in water bodies used by waterfowl and in surface waters in Atlantic Canada (RMCC 1990). The

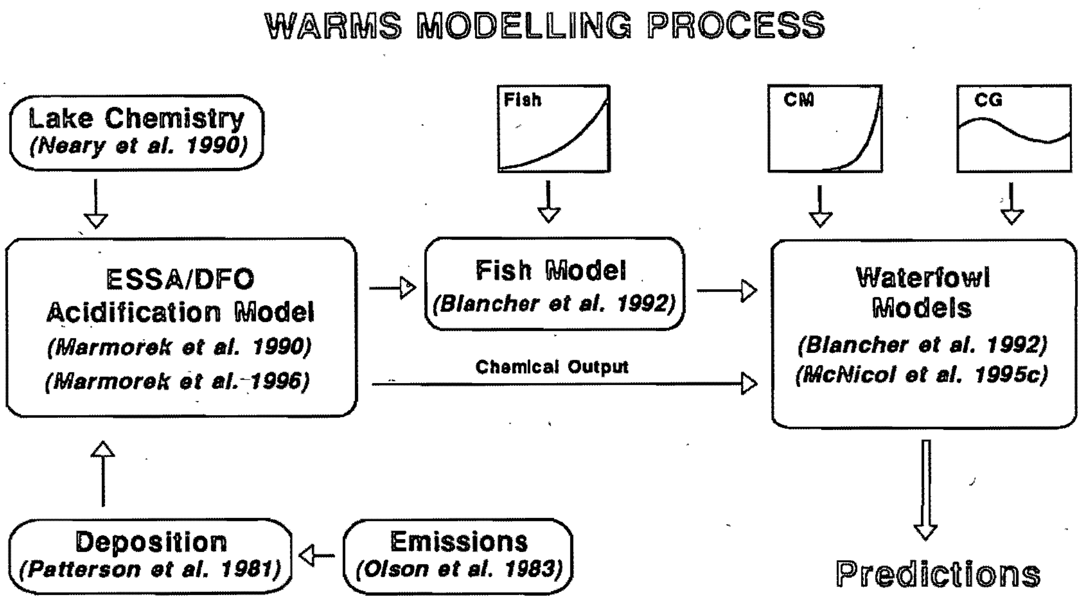

Figure 2. Diagram illustrating components of the WARMS modelling process.

WARMS software is continually being upgraded to improve functionality, flexibility and model validation capabilities (e.g. confidence limits, Monte Carlo simulations, added spaceholder variables). Biological relationships used in the model are updated regionally to provide better predictions of long term responses of biotic communities to recovery from acid rain (for example, recent logistic relationships developed specifically for fish-eating birds at Kejimkujik). Using logistic regression relationships derived independently for each waterfowl species in question, WARMS predicts the probability of observing pairs and broods of waterfowl under various emission scenarios (Blancher *et al.* 1992, McNicol *et al.* 1995d). WARMS will be used to assess current levels of damage to waterfowl populations, predict eventual benefits of various acid deposition scenarios to waterfowl production and assess the suitability of current CWS biomonitoring sites for long term spatial and temporal analyses.

In addition to increasing our general understanding of the ecology of individual species, 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 climatic change.

3.4.2 Integrated Assessment Model (IAM)

Over the past decade, a variety of mathematical models have been developed and applied successfully in Canada and elsewhere to simulate the long range transport, geochemical pathways and ecological impacts of acidifying pollutants (SO_2, NO_x). However, with the mandate to develop an acid rain strategy for the management of acidifying emissions in Canada post-2000, integration of these models across disciplines is required. An effort is currently underway to integrate the knowledge (data and models) from atmospheric, aquatic, terrestrial and ecological scientists, as well as socio-economists, so that 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.* 1996). A prototype of the Integrated Assessment Model (IAM) has been developed at the National Water Research Institute, based on the RAISON™ software for WINDOWS™, which links a source-deposition model to several geochemical and ecological models (including WARMS). The IAM can derive optimal emission reductions required to achieve SO_4 deposition critical loads at selected receptor sites for chosen source regions. Preliminary findings indicate that the attainment of critical loads for all receptor sites in Canada requires emission reductions and costs above and beyond those planned in existing emission reduction programs in some source regions (Lam *et al.* 1996).

4.0 CHARACTERISTICS OF BIOMONITORING STUDY AREAS

There are presently four study areas in the CWS LRTAP Biomonitoring Program, three in Ontario (Algoma, Muskoka, Sudbury) and one in Nova Scotia (Kejimkujik) (Fig. 3). Study lakes span a range of physical and chemical characteristics, from wetlands to large, deep, oligotrophic basins (Table 3). These study areas also vary substantially in their current and historic levels of SO_4 deposition, as well as the predicted changes in lake water chemistry under proposed emission scenarios. A complete description of the location and physical, chemical and biological characteristics of biomonitoring study sites is presented in Part 3 of this series (McNicol *et al.* 1996a).

4.1 Study Area Descriptions

4.1.1 Algoma

The Algoma study area is located near the eastern shore of Lake Superior, and lies within the Canadian Shield (area centre at 47° 01' N, 83° 55' W). The region is underlain by precambrian granitic bedrock, covered by thin, widespread deposits of glacial ground moraine. Forest cover is comprised of mixed hardwoods of the Great Lakes-St. Lawrence Zone. SO_4 deposition over the study area varies with most areas receiving

Table 3. General characteristics of CWS LRTAP Biomonitoring study areas.

PARAMETER	KEJIMKUJIK	ALGOMA	MUSKOKA	SUDBURY
Location	SW NS	Cent Ont	East Cent Ont	NE Ont
Sensitivity	Extreme	Moderate	Broad	Broad
Number of Lakes	46	240	240	160
Lake Area (ha)	most > 20	most < 20	most < 20	most < 20
Typical Chemistry	pH 4.5-6.2 ↑ DOC, ↓ Ca	pH > 6	pH 5-6	pH < 5.5
Calibrated Basins	Kejimkujik	Turkey Lakes	Dorset	
SO_4 Deposition (kg/ha/yr)	Mod. 15-20	Mod. 15-25 TLW >30	High 25-30	Mod. - High 20-25
CWS Studies	1980	1980	1985	1983
Typical Waterbirds	Piscivore (LO + CM)	Insectivore (CG ↑, WD ↓)	(CG ↓, WD ↑)	All

>20 kg/ha/yr, but locally higher deposition occurs due to high annual precipitation (Shaw *et al.* 1992). Nine study plots measuring 5 x 5 km are located in the area, and contain roughly 240 lakes, many of which are naturally fishless. One plot overlaps the Turkey Lakes Watershed calibrated basin while two others in the Ranger Lake area contain lakes which have been studied by CWS since 1980. Some study lakes (N = 26) have historical chemical and biological data from provincial (Neary *et al.* 1990) and federal studies (Kelso and Jeffries 1988). Twenty lakes (minimum 2 per plot) form the Food Chain Monitoring Program (FCMP) study lakes.

4.1.2 Muskoka

The Muskoka study area is located in central Ontario (area centre at 45° 30' N, 79° 06' W), and includes portions of Algonquin Park, the Lesley Frost Centre, and the Haliburton Fish and Wild Life Reserve. It also lies within the Canadian Shield, and is underlain by granitic bedrock covered with shallow glacial till. Forest cover is comprised of mixed hardwoods of the Great Lakes-St. Lawrence Zone. SO_4 deposition at this site is highest of all study areas, currently averaging >30 kg/ha/yr. Seven 5 x 5 km plots located in the area contain roughly 240 lakes, many of which are fishless. Some study lakes (N = 60) have historical chemical data from provincial studies (Neary *et al.* 1990). Again, 20 lakes (minimum 2 per plot) form the FCMP study lakes.

4.1.3 Sudbury

The Sudbury study area (area centre 46° 54' N, 80° 41' W) has a heterogenous mixture of surface deposits that have produced lakes with a broad range of pHs (McNicol *et al.* 1995b). SO_4 deposition from long range sources is less than received in Muskoka, but deposition from local smelters is considered to be the highest in the province, and has affected lake chemistries over a broad area surrounding Sudbury (Neary *et al.* 1990). However, emission controls have been put in place which have effectively reduced local SO_2 emissions.

Research and monitoring of recovery from the effects of acidification continues in the Sudbury area today (Keller *et al.* 1992a, Gunn 1995). CWS has been active since 1983 (results summarized in McNicol *et al.* 1995b). The Wanapitei study area lies 50 km northeast of Sudbury, covers approximately 460 km^2, and contains roughly 378 small lakes and wetlands. Given the historical database and heterogenous nature of lake chemistries in a small area, Wanapitei is treated as one plot containing 160 lakes. Most lakes have recent water chemistry, fish and waterfowl data and nearly half have been equipped with duck boxes (McNicol *et al.* 1996d). Of these, 22 lakes form the FCMP study lakes.

4.1.4 Kejimkujik

The Atlantic Region CWS Biomonitoring Program is centred in Kejimkujik National Park in southwestern Nova Scotia, one of the major LRTAP study sites in Canada. Kejimkujik represents the most sensitive receptor system in Canada, and it is now widely recognized that such sensitive waters would remain acidified under proposed deposition levels of 12 kg/ha SO_4 per year. Forest cover is a complex mosaic of softwood, hardwood and mixedwood stands. A total of 46 lakes are found within the Park, many of which are coloured due to high concentrations of dissolved organic substances leached from boggy substrates on poorly drained soils. Therefore, the waters tend to be dilute with high DOC and very low calcium (<1 mg/L), and thus are naturally acidic, a unique feature that distinguishes this site from the other biomonitoring study areas (Table 3). While the pH of many lakes is below 5, only one lake is fishless.

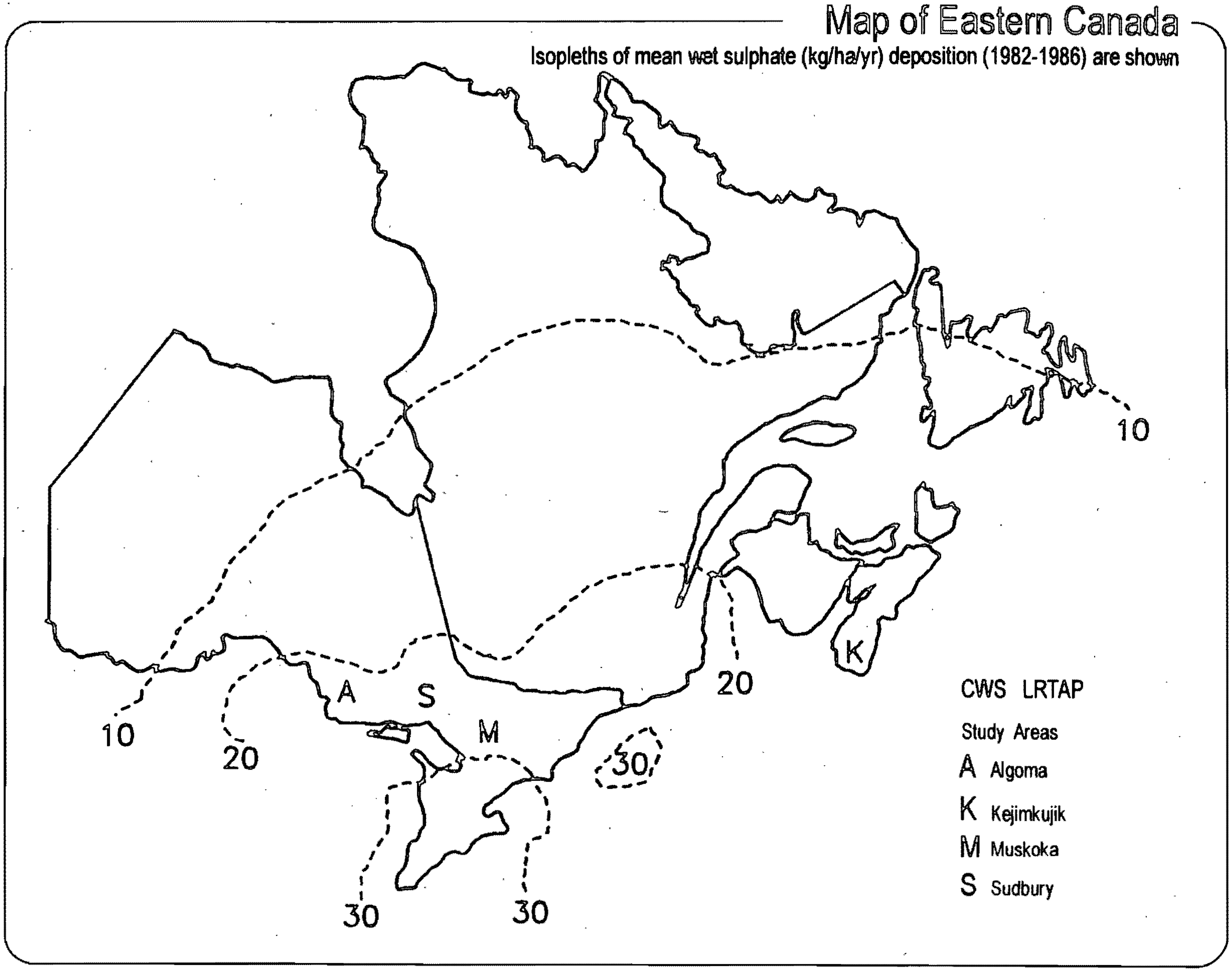

Figure 3. Map of eastern Canada showing location of CWS LRTAP Biomonitoring study areas in relation to isopleths of mean wet sulphate (kg/ha/yr) deposition (1982 - 1986).

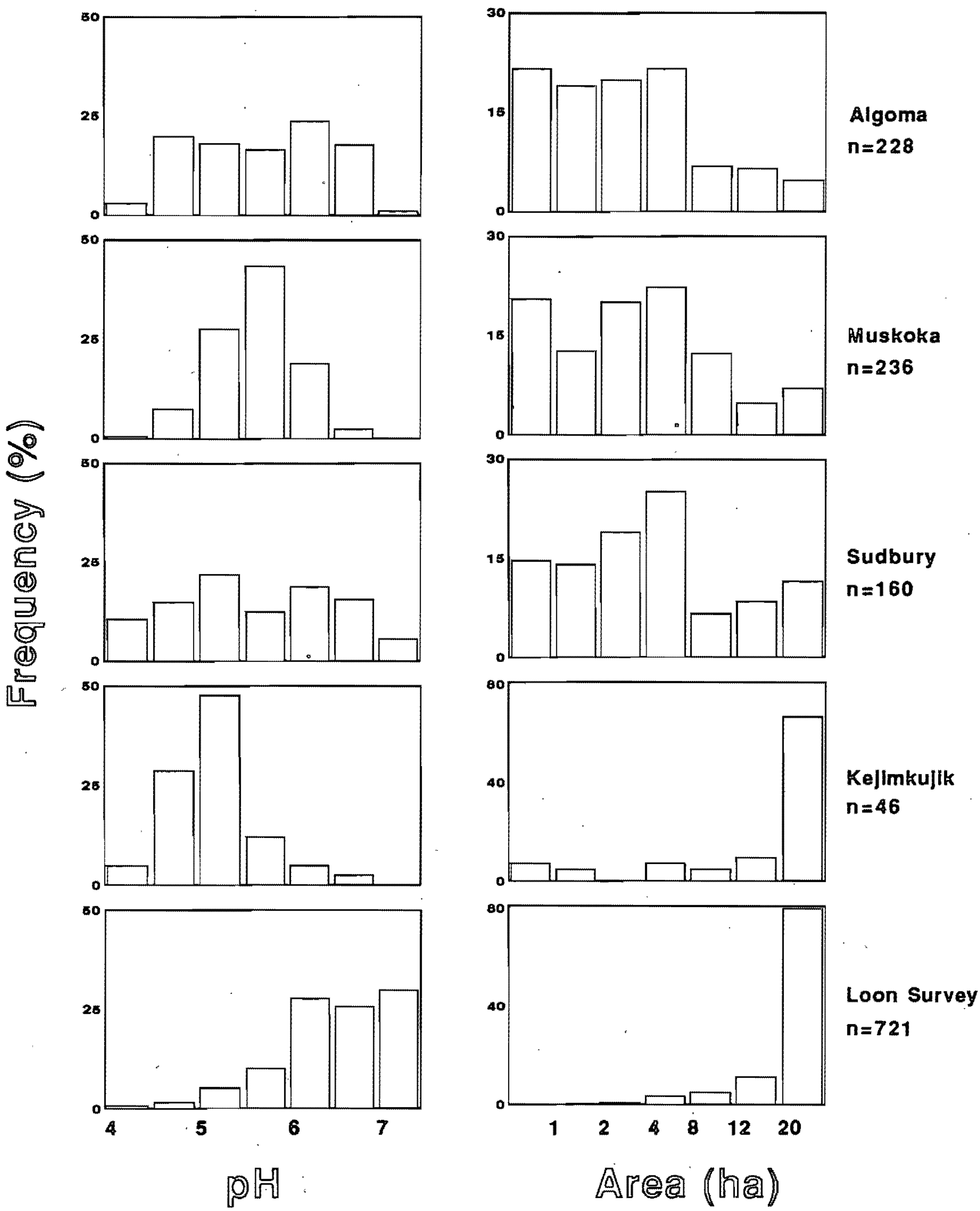

Figure 4. Distribution of pH and area (ha) for lakes in CWS LRTAP Biomonitoring study areas.

4.2 Modelling Impacts of SO_2 Emission Reductions

Under current deposition scenarios (mean 1982-1986; Fig. 3), Kejimkujik receives the lowest wet SO_4 deposition, with Algoma receiving slightly more and Muskoka receiving the highest annual deposition (RMCC 1990, Minns *et al.* 1992). Sudbury receives similar deposition loadings from long range sources as Algoma, but has also received relatively high deposition from local sources; combined local and long range sources contribute to slightly lower deposition levels at Sudbury than at Muskoka (Table 3). Existing atmospheric deposition models predict that the greatest reductions in SO_4 deposition will occur at Muskoka and Sudbury, with substantially less change predicted for Algoma and Kejimkujik. Canadian emission reductions (50%) have the greatest impact at Muskoka and Sudbury, whereas U.S. reductions are required to manifest a proportionally greater impact at Algoma and Kejimkujik.

We have used WARMS to estimate chemical and biotic responses to various emission scenarios simulated for watersheds in the three biomonitoring study areas in Ontario (McNicol *et al.* 1995d). Under each scenario, heavily damaged Sudbury lakes would improve in response to lower deposition inputs than experienced historically. Canadian reductions (50%) would have relatively little impact in Algoma since most of its deposition originates in the U.S. (RMCC 1990). Combined Canada plus U.S. reductions would result in clear improvements in Algoma but may be required to maintain current conditions at Muskoka. However, proposed emission reductions do not return lakes to conditions predicted prior to industrialization. Predicted responses by waterfowl to emission reductions are achieved primarily through changes in the fish status of lakes. Fish-eating species suffer when fish are reduced, while insectivores often benefit in the absence of fish but suffer under low pH due to the progressive reduction in the diversity of invertebrate prey as pH declines. Further species-specific waterfowl and fish relationships will be validated on watersheds elsewhere in eastern Canada (including Kejimkujik) prior to undertaking regional assessments of waterfowl responses to predicted emission reductions.

5.0 BIOMONITORING DATA COLLECTIONS

The CWS LRTAP Biomonitoring Program monitors both indicator species and biotic communities, and involves an extensive series of survey/sampling procedures and data collections described in Part 4 of this series (McNicol *et al.* 1996c). A summary of biomonitoring data collections is provided in Table 4 according to physical, chemical, biological and waterfowl study components.

5.1 Physical Data

Habitat characterization of all study plots and lakes has been completed. In Ontario, a mapping system (SPatial Analysis System - SPANS) was used to characterize forest cover, surficial geology, riparian habitat cover, lake and wetland size, position, configuration and connectivity. Using SPANS, we can analyse relationships between spatial and temporal ecological variables with chemical and physical data, and how these relate to fish, invertebrate and waterfowl data and their changes over time.

5.2 Chemical Data

Lakes are sampled regularly at all four study areas (Table 4). Additional chemical data are available for many lakes from other sources. However, cuts to provincial and other federal agencies mean that we remain one of the few programs collecting chemical data on a regional scale and over the long term in Canada, and the only program collecting data on small lake and wetland systems preferred by breeding waterfowl. Among the chemical parameters measured from water samples collected during fall turnover in Ontario are: pH, alkalinity,

Table 4. Timing of CWS LRTAP Biomonitoring data collections (year).

COMPONENT	ALGOMA	MUSKOKA	SUDBURY	KEJIMKUJIK
Chemical	88, 92, 94, 95	90, 91, 93, 95	87, 90-95	every year
Landscape		- once because constant -		
Fish		- once because constant -		
FCMP	88, 89, 90, 92	91	87, 88, 89, 94	N/A
Waterfowl	88, 92, 94, 95	89, 93, 95	93, 94, 95	88-90, 92-95

conductivity, cations (Ca, Mg, Na, K), anions (SO_4, Cl, SiO_2), nutrients (TP, TKN, NO_2&NO_3, NH_3), DOC, water colour and trace metals (Al, Fe, Mn; Sudbury lakes are also monitored for Ni and Cu). Results from Sudbury lakes (N = 161) sampled between 1983-1995 indicate that only a small proportion show signs of chemical improvement (16 % with increasing pH), despite local emission cuts and continued declines in SO_4 levels (47 % of lakes), and evidence of chemical recovery in larger lakes elsewhere in the region (Keller *et al.* 1992a). However, there is clear evidence that precipitation (drought and wet cycles) has markedly altered small lake chemistries near Sudbury in the short term (McNicol and Mallory 1994).

5.3 Biological Data

Examining biological recovery at lower trophic levels (fish and invertebrates) provides the basis for interpreting patterns of waterfowl and loon population change, and whether certain organisms lag behind other species in recovery (i.e. taxa-specific rates of recovery). CWS regularly samples several components of the trophic web. Fish species composition has been assessed at all sites both because fish are preferred prey for piscivorous species (such as loons and common mergansers) and because fish compete with insectivores for common macroinvertebrate prey. Complete characterization of invertebrate communities is impractical; fortunately, invertebrate communities can to some extent be predicted from the structure of fish communities (McNicol and Wayland 1992, Mallory *et al.* 1994a). Because fewer invertebrates are found where fish are prevalent, fish presence can be used to infer invertebrate availability.

5.3.1 Food Chain Monitoring Program (FCMP)

The Food Chain Monitoring Program (FCMP) is undertaken on a subset of core study lakes in each of the three study areas in Ontario, and is described in Part 2 of this series (McNicol *et al.* 1996b). Monitoring of aquatic invertebrates, amphibians and fish is conducted on a rotating basis for 62 lakes (20 each in Algoma and Muskoka, 22 in Sudbury) chosen to represent the range of pH and fish status in small lakes (< 20 ha) that are typical breeding habitat for waterfowl species of these regions. Collections are designed to sample specific components of the littoral macroinvertebrate community that comprise principal waterfowl foods or are acid-sensitive indicator species (e.g. leeches, water striders) (Table 5; see also Bendell and McNicol 1995a,b, McNicol *et al.* 1995a).

∘ **Fish** - Fish and amphibians are among the best known biological indicators of acid rain damage, and thus the return of acid-sensitive species to lakes where they had been lost is an important index of biological recovery. Fish and amphibian tadpoles (collections also include leeches, crayfish, newts and assorted macroinvertebrates) are sampled regularly in food chain lakes, with other study lakes sampled at longer intervals. The primary focus of fish collections is on the small, minnow-type species that are prey for

Table 5. Sampling methods, intensity and target organisms of the Food Chain Monitoring Program conducted in Ontario lakes (from McNicol *et al.* 1996b).

	COLLECTION METHOD				
	SWEEP	HOOP	BENTHIC	FUNNEL	MINNOW
Target group	Hemiptera	Trichoptera	Anisoptera, Ephemeroptera, Gastropoda	Hirudinea	Nekton, Fish, Amphibians
Location	Open Water < 5m to shore	Shoreline < 0.5m deep	On Bottom < 1m deep	On Bottom < 1m deep	Near Shore < 1m deep
Samples / lake	10	10	10	5	6
Collection approach	10 Dipnet Passes	Visual Search $0.31m^2$	Sediment Drag $0.14\ m^2$	Bottle Trap 24 hr	Wire Trap 24 hr

piscivorous waterfowl and loons, as well as the medium-sized fish (e.g. perch) that compete with insectivorous waterfowl for invertebrate prey. Because many fish feed on invertebrates, fishless lakes tend to have high abundance of certain invertebrates. For lakes with fish, invertebrate abundance is also high in sites that include fish with small mouth gapes (e.g. northern redbelly dace, *Phoxinus eos*) because these species do not eat larger invertebrates. In contrast, few invertebrates are typically found where fish have large gapes (e.g. yellow perch). To date, more than 10,000 fish have been captured from 638 lakes, representing 25 species (16 in Muskoka, 15 in Algoma, 22 in Sudbury). Small, non-game species predominate, including Cyprinidae (13 spp.), yellow perch and white sucker (*Catostomus commersoni*).

◦ **Aquatic Invertebrates** - Aquatic invertebrates are important prey for fish, waterfowl and riparian birds. Diversity of these organisms increases rapidly as pH improves, and certain invertebrate species are key indicators of acid-stress (e.g. leeches, water striders, mayflies). Moreover, these organisms can disperse quickly, and are numerically and taxonomically abundant, so they should be among the first indicators of biological recovery. The invertebrate component of the FCMP was designed to detect changes in the occurrence, composition and abundance of target groups (Table 6), many of which are important waterfowl foods. To date, more than 25,000 macroinvertebrates representing 159 taxa (genera or species) have been collected from the 62 core lakes (113 spp. in Muskoka 1991, 114 in Algoma 1992, 102 in Sudbury 1994).

Major taxonomic groups recorded were: Coleoptera (34 spp.), Odonata (27), Hemiptera (25), Trichoptera (23), Hirudinea (12), Gastropoda (12) and Ephemeroptera (9). In addition, work in Ontario includes continued monitoring of indicator species (leeches and water striders) in Sudbury area lakes where chemical change is expected to be most dramatic and biological recovery should occur most rapidly. As yet, there is no evidence of improvements in the distribution of leeches in small, acid-stressed lakes near Sudbury sampled in 1987, 1992 and 1994.

Using results of sampling conducted in Ontario food chain lakes, we predicted macroinvertebrate and fish responses at critical points along the pH gradient (McNicol *et al.* 1995a). In all regions, the number of acid-sensitive taxa per lake is related to pH, and should increase as lakes recover from acidification. However, predicting macroinvertebrate responses to recovery must consider concurrent effects of fish, as they are a dominant factor structuring these communities.

5.4 Waterbird Monitoring

Waterfowl populations, breeding success and productivity are monitored to determine whether chemical improvements attributable to reduced acid-causing emissions are resulting in improvements in waterfowl populations and ecology in affected areas. In Ontario, waterfowl breeding distribution and productivity surveys are conducted by helicopter for indicated pairs and broods, with some validation by ground surveys (Ross and McNicol 1996). Timing of surveys is based on the breeding chronology of focal species to maximize the amount of usable information (Sinden 1995). Pair and brood data can be analysed separately or in combination to compare habitat requirements (Shutler *et al.* 1995).

◦ **Population Studies** - Systematic surveys in the Sudbury area are conducted to detect changes in local populations in response to dramatically reduced emissions from Sudbury smelters. The Sudbury area offers the best opportunity to conclusively link waterfowl population changes to chemical improvements because water quality improvements should occur at an accelerated rate compared to other regions. This study area covers approximately 17,000 km^2, generally corresponding to the area southwest and northeast of Sudbury which has been influenced by past sulphur emissions from Sudbury smelters (McNicol *et al.* 1995b). Spring surveys of breeding populations were undertaken in 4 km^2 plots located throughout this area between 1985 and 1995. These surveys suggest that certain populations are responding to chemical improvements in breeding habitats. Local populations of piscivorous species, especially Common Loons and Hooded Mergansers, have increased through 1985-1995 in areas where average lake pHs exceed 5.5. Given the apparent lag time between chemical improvements and biological responses, monitoring will continue in order to track recovery following the final stage of local emission reductions implemented in 1994.

◦ **Production Studies** - Surveys of waterfowl and loon breeding pairs and corresponding brood production are undertaken at all four biomonitoring study areas. When analysed in relation to corresponding chemical, physical and biological data, estimates of the production of young per breeding attempt can be used to assess the suitability of various types of lakes to support breeding waterfowl in each area.

◦ **Nest Box Studies** - In 74 Sudbury lakes, and all food chain lakes, use of nest-boxes by cavity-nesting waterfowl (Common Goldeneye, Hooded Merganser, Wood Duck, Common Merganser) are monitored. Data have been collected on nest-box use at Sudbury since 1987. No change in cavity-nesting duck densities has been observed as yet, although a steady reduction in the proportion of nesting attempts on fishless lakes has been observed (McNicol *et al.* 1996d). Shifts in the proportion of boxes occupied, clutch size or hatching success by insectivorous or piscivorous species augments data from population surveys and will indicate trends in biological recovery.

5.5 Waterfowl Habitat Suitability Modelling in Ontario

Using the unique dataset gathered in Ontario (Table 4), Shutler *et al.* (1995) examined habitat associations for waterfowl breeding in the northern Great Lakes - St. Lawrence and southern Boreal Ecoregions. This dataset spans several years and contains information on waterfowl and loon distributions and production, water chemistry, landscape features and relationships of birds to their foods (fish and macroinvertebrates) on over 600 water bodies, including large oligotrophic lakes, small headwater lakes, wetlands and chico swamps. Using over 1500 lake-years of data from the three study areas, Shutler *et al.* (1995) developed habitat models for eight species (Table 6), and ran an intensive set of validations to test the generality of habitat associations identified in time and space. Habitat associations were mostly landscape-related for piscivores (size and depth of water bodies with a preference for large lakes with fish) and mostly chemically-related for divers (preference for low cation concentrations and fishless lakes). Few habitat associations were identified for

Table 6. Habitat requirements for eight waterfowl species which commonly breed in central and northern Ontario (modified from McNicol *et al.* 1995b).

SPECIES	DIET	HABITAT	
		NESTING	BROOD-REARING
Common Loon	Small to medium-sized fish	Ground near water	Medium to large oligotrophic lakes
Common Merganser	Small to medium-sized fish	Tree cavity	Rivers and medium to large lakes
Hooded Merganser	Small fish and invertebrates	Tree cavity	Small meso- to oligotrophic lakes
Ring-necked Duck	Invertebrates and plant matter	Ground near water	Small productive wetlands
Common Goldeneye	Invertebrates	Tree cavity	Small to medium oligotrophic lakes
Mallard	Invertebrates and plant matter	Ground	Small productive wetlands
American Black Duck	Invertebrates and plant matter	Ground	Small productive wetlands
Wood Duck	Invertebrates and plant matter	Tree cavity	Small productive wetlands

dabblers (mostly generalists). However, models varied substantially in their capacity for being generalized, indicating that it is often inappropriate to use models developed in different times and spaces. The appropriate scale to use in building habitat suitability models varies according to the mobility of the focal species and other factors. The models developed here provided important baseline information on these species in central and northern Ontario, and suggest species towards which continued monitoring efforts should be directed.

5.6 Studies at Kejimkujik

The biomonitoring study at Kejimkujik collects data on a discrete number of piscivorous birds (i.e. whole population study). This type of data is ideal to establish the stability of populations, the normal annual variability in population numbers and breeding success and the effects of annual environmental factors (e.g. water levels) on success. Since 1988, an average of 39 (range 38-42) pairs of loons have used the 46 study lakes, suggesting that the breeding density is remaining stable and that most available, suitable habitat is occupied. However, the number of large young produced per pair ($\bar{x} = 0.28$) is very low in comparison to the number produced in Ontario ($\bar{x} = 0.76$; McNicol *et al.* 1995c). Successful breeding of fish-eating birds, both loons and Common Mergansers, at Kejimkujik is controlled by a number of factors including pH. The amount of fish available in a lake, which influences reproductive success of these species, is controlled by the nutrient supply (phosphorus) (Kerekes 1990). At least 20 ha of lake surface area is required to provide enough fish to support a resident pair of loons; $\geq$ 40 ha is needed to support the breeding of either loons or mergansers; and $\geq$ 80 ha is necessary to support two or more of either of these two species or their combinations (Kerekes *et al.* 1994). Much annual variability in breeding success is due to climatic factors, particularly water levels.

The CWS LRTAP Program initiated in Kejimkujik National Park in 1978 (Kerekes 1977) generated a large amount of environmental knowledge and technical expertise (Kerekes 1989b, Stacier *et al.* 1994). This has led to the establishment of the Kejimkujik Ecological Research and Monitoring Centre, the first such Centre in Environment Canada's nationwide Ecological Monitoring and Assessment Network (EMAN).

5.7 Partnerships

CWS established cooperative linkages with several federal and provincial agencies, universities, non-governmental organizations and consultants which contribute to the CWS LRTAP Biomonitoring Program.

Table 7. Major partners involved with the CWS LRTAP Biomonitoring Program.

FEDERAL GOVERNMENT		
Environment Canada	Atmospheric Environment Service (AES)	
	National Water Research Institute (NWRI)	
	Environmental Protection - Air Issues Branch (EP-AIB)	
	North American Waterfowl Management Plan (CWS, BDJV & EHJV)	
Fisheries and Oceans	Great Lakes Laboratory for Fisheries and Aquatic Sciences (GLLFAS)	
	Freshwater Institute - Experimental Lakes Area (ELA)	
	Bedford Institute of Oceanography (BIO)	
Natural Resources Canada	Canadian Forestry Service - Great Lakes Forestry Centre (GLFC)	
PROVINCIAL GOVERNMENTS		
Ontario	Ministry of Environment and Energy (OMEE)	
	Ministry of Natural Resources (OMNR)	
Québec	Ministère de l'Environnement du Québec	
Nova Scotia		
New Brunswick		
UNIVERSITIES		
	Carleton University	University of Guelph
	Dalhousie University	McMaster University
	Laurentian University	Université du Québec
	Trent University	McGill University
	University of Toronto	Queen's University
	University of Wales at Cardiff	
NON-GOVERNMENT ORGANIZATIONS		
	Long Point Bird Observatory (LPBO)	
	Haliburton Forest and Wild Life Reserve Ltd.	
	World Wildlife Fund - Wildlife Toxicology Fund	
	Wildlife Habitat Canada	
ENVIRONMENTAL CONSULTANTS		
	ESSA Technologies Ltd.	
	Monenco AGRA Inc.	
	Geomatics International Inc.	
	Institut national de la recherche scientifique (INRS-Eau)	

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