An Evaluation of the Environmental Risk Assessment of the Sudbury Soils Study

August 31, 2009

Prepared by Glen A. Fox

SUMMARY OF KEY FINDINGS

- The weight-of-evidence suggests terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the chemicals of concern (COC) in the soil and other factors such as soil erosion, low nutrient levels, lack of soil organic matter, and/or low soil pH.
    - The validity of that conclusion hinges on the results from the 3 reference sites. Ideally, one would like an equal number (18) or twice as many reference sites as test sites. Further selecting a number of reference sites in an area with similar geological, botanical, and climatic characteristics would have allowed the possibility of separating the localized impacts of the atmospheric deposition of metals from the confounding influences of declining levels of acid precipitation, climate change, and other non-metal stressors.
- Assessment endpoints explicitly define characteristics or attributes that are important to protect and which are potentially at risk. The chosen endpoint for terrestrial wildlife, population persistence, is inadequate as this may occur due to constant immigration. It is felt that the appropriate endpoint for terrestrial wildlife would have been adequate survival and reproduction to maintain a stable population.
- There are not accurate, real, or current measures for many of the variables required by the risk assessment model. Of the 25 dietary "items" used in the risk assessment, 80% were estimated. All the inter-individual and interspecific variation in metal content that results from an individual food organism's "taxonomy", physiology, ecology, and behavior is eliminated. This reduces the confidence in the model conclusions.
- It is felt that the approach applied to the exposure assessment, which is the only site- and VEC-specific component of the risk assessment, compromised the risk assessment, making it difficult to say anything about the likelihood of adverse effects of a COC on any valued ecosystem component (VEC).
- The efforts of assessors' to ground-truth conclusions using existing field information on reproductive success and population trends relied heavily on data that was anecdotal or qualitative. Quantitative data on ducks and loons suggest that numbers have responded positively to improved food resources and habitat quality that have accompanied reductions in acid deposition. However, whether or not adverse effects of metals pollution is limiting these increases in numbers and breeding success is unknown.

- The effect of the exposure to a "cocktail" of COC should be of concern. The cumulative impact of exposure to multiple chemicals and habitat quality plus potential frank or sublethal toxicity must be investigated.

- The problem formulation for a possible future detailed aquatic risk assessment highlights the lack of information on Sudbury-specific metal impacts on algae, macrophytes, invertebrates, additional species of fish, and amphibians. The marshes and wetlands have not been studied recently. It is therefore difficult to determine if metals are having a significant deleterious effect on these populations directly or through reductions in food or habitat quality.

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INTRODUCTION

BACKGROUND

For more than a century, the geological landscape and mixed boreal forest of the Greater Sudbury area have provided prosperity to the community through timber harvesting, and mineral and base metals extraction. These forestry, mining, and smelting operations have dramatically altered the landscape. Historical smelting operations have resulted in acidic, metal-containing atmospheric deposits which have denuded and altered the vegetation, and contaminated the soil, water, and biota. However, ecosystem recovery and transformation have been occurring since the mid-1970s due to emission reductions, wide-scale liming and fertilizing of damaged lands, and vegetation planting initiatives aimed at the "regreening" of the Sudbury landscape.

In 2001, the Sudbury urban and regional soils surveys collected approximately 8,400 soil samples from about 1,150 sites and analyzed them for 20 metals and metalloids. This was followed by a remote sensing analysis to examine changes in areas of vegetation impacted by emissions and by restoration efforts for the period 1976-2003. These two comprehensive landscape scale surveys provided the justification for the Environmental Risk Assessment (ERA) and informed the scientific approaches taken.

At the request of the Community Committee on the Sudbury Soils Study, Glen A. Fox provided this review of the Environmental Risk Assessment component of the Sudbury Soils Study. He was contracted by Environment Defence. This is his report.

ERA GOAL AND OBJECTIVES

The goal was "to characterize the current and future risks of chemicals of concern (COC) to terrestrial and aquatic ecosystem components from particulate emissions from Sudbury smelters and to provide information to support activities related to the recovery of regionally representative, self-sustaining ecosystems in areas of Sudbury affected by the COC." (SARA, Vol. III, ES2).

Further to this, the four objectives of the ERA are as follows:

1. Evaluate the extent to which the COC are preventing the recovery of regionally representative, self-sustaining terrestrial plant communities

2. Evaluate risks to terrestrial wildlife populations and communities due to the COC

3. Evaluate risks to individuals of threatened or endangered terrestrial species due to the COC

4. Conduct a comprehensive Problem Formulation for the aquatic and wetland environments in the Sudbury area to facilitate a more detailed risk assessment in aquatic/wetland ecosystems

GENERAL NOTES ON RISK ASSESSMENT

Risk assessment is a quantitative assessment of the probability of deleterious effects under given conditions. The four components of all risk assessments are stressor identification, exposure-response, exposure assessment, and risk characterization.

1. *Stressor identification* – identifies stressors, in this case a subset of metals (COC), present with known potential to cause biological impairment.

2. *Exposure-response* – characterizes the relationship between controlled exposure to the individual metal and biological responses such as toxicity under controlled conditions in laboratories and establishes a threshold exposure (dose) above which toxicity is likely to occur (the Toxicity Reference Value).

3. *Exposure assessment* – a site-specific characterization of the exposure of the individuals or population of a particular species of concern (VEC) to a specific metal through food, water, air, and soil.

4. *Risk Characterization* – an evaluation of the degree to which an individual's calculated exposure to a specific stressor exceeds the toxicity threshold. If probabilistic methods are used, a risk assessment can determine the likelihood that risks to an exposed individual will exceed a particular risk level of concern.

GENERAL NOTES ON PROBABILISTIC RISK ASSESSMENT

Probabilistic risk assessments (PRA) use probability models to represent the likelihood of different risk levels in a population (i.e., variability) or to characterize uncertainty in risk estimates. In the probabilistic approach, inputs to the risk equation are described as random variables (i.e., variables that can assume different values for different individuals in the population) that can be defined by a probability function. These probability functions describe the range of values that a variable may assume, and indicate the relative likelihood (i.e., probability) of each value occurring within that range for the exposed population. After determining the appropriate functions and parameter values for the selected variables, the set of probability functions are combined with the toxicity reference value in the exposure and risk equations to estimate a cumulative distribution of risks. In an ERA, risk distributions may reflect variability or uncertainty in exposure and/or toxicity.

The most common numerical technique for PRA is Monte Carlo simulation, where the computer selects a value for each variable at random from a specified probability distribution function and calculates the corresponding risk. This process is repeated 10,000 times, each time saving the set of input values and corresponding estimate of risk. Each iteration, in effect, represents a single individual and the collection of all iterations, a population.

In a PRA, distributions used as inputs to the risk equations can characterize the inter-individual variability inherent in each of the exposure assumptions. By characterizing variability with one or more input distributions, the output from the Monte Carlo simulation is a distribution of risks that could occur in that population.

An essential concept in PRA is the distinction between "variability" and "uncertainty". *Variability refers to true diversity or heterogeneity inherent within a population* due to individual or temporal differences in exposure and response. *Uncertainty occurs because of lack of knowledge*. Uncertainty can often be reduced by collecting more and better data, whereas variability can be better characterized but it cannot be reduced or eliminated.

GENERAL NOTES ON RISK ASSESSMENT UNCERTAINTY

Potential sources of uncertainty in risk assessment can be divided into one of three broad categories:

1. *Parameter uncertainty* – uncertainty in an estimate of an input variable in a model. Parameter uncertainty can occur in each step of the risk assessment process from data collection and evaluation, to the assessment of exposure and toxicity. Sources of parameter uncertainty may include systematic errors or bias in the data collection process, imprecision in the analytical measurements, inferences made from a limited database when that database may or may not be representative of the variable under study, and extrapolation or the use of surrogate measures to represent the parameter of interest.

2. *Model uncertainty* – uncertainty about the model structure (e.g. exposure equation) or intended use.

3. *Scenario uncertainty* – uncertainty regarding missing or incomplete information to fully define exposure.

THE ENVIRONMENTAL RISK ASSESSMENT

THE PROBLEM FORMULATION

The problem formulation for the ERA included a review of ecological information, the definition of the study area, selection of COC, the selection of valued ecosystem components (VECs), and the identification of assessment endpoints.

THE STUDY AREA

The study area was defined by the area from which soil samples were collected for the Sudbury Regional Soils Project and encompasses approximately 40,000 km^2 of the Sudbury basin. For the wildlife ERA, the study area was subdivided into three zones whose boundaries were defined on the basis of metal concentrations in the soil, wildlife species foraging areas, and terrain. In addition, four communities of interest identified in the Human Health Risk Assessment were evaluated for some of the valued ecosystem components.

IDENTIFYING CHEMICALS OF CONCERN

COC are chemicals present in the study area that pose the greatest potential for exposure and risk to the components of the ecosystem. The Technical Committee established three criteria which must be satisfied in order to identify a metal as a Chemical of Concern:

1. Concentrations must equal or exceed criteria published in MOE's *Guidelines for Use at Contaminated Sites in Ontario* (1997);
2. Metal must be present across the study area; and
3. There must be scientific evidence that the metal originates from smelter operations.

Of the 20 metals measured in the Sudbury Soil samples, the Technical Committee identified arsenic, cobalt, copper, lead, nickel, and selenium as Chemicals of Concern. Cadmium, well known for its toxicity, did not meet these criteria or other more liberal criteria, and was eliminated as a COC by the Technical Committee. However, MOE requested that cadmium be considered a COC for the terrestrial ecological risk assessment (ERA).

Toxicity of these COC to Wildlife

Of greatest concern are nickel, cadmium, lead, and selenium which have been associated with significant toxicity to individuals or their habitat.

- **Nickel**. In their comprehensive literature review, Outridge and Scheuhammer (1993) suggested that there was potential for toxic effects in wildlife and alterations in diet quality due to alterations in aquatic macrophyte communities and food chains near the nickel smelters in Sudbury, based on concentrations measured in environmental media. In particular they suggested that young waterfowl and other waterbird species habitually feeding on aquatic macrophytes around Sudbury may have experienced potentially lethal levels of dietary nickel, at least in past decades. Macrophyte species richness was inversely correlated with nickel concentrations in lakes in the Sudbury region (Yan et al. 1985). Sublethal toxic effects of oral nickel exposure include growth inhibition, neuromuscular dysfunction, and reproductive impairment. Adverse effects due to nickel exposure should be suspected at concentrations >10 μg/g DW in the kidneys (Outridge and Scheuhammer 1993). Nickel levels in the kidneys of several muskrats from the Sudbury area measured by Parker (2004) were substantially above the range of 3 to 8 μg/g(DW) considered by Outridge and Scheuhammer (1993) to be the NOEL for most mammals.

- **Cadmium** is a nonessential metal that is released into the environment from metal smelting and the burning of coal. It is accumulated by most organisms throughout life. The highest concentrations accumulate in the kidney and it is here that damage is first observed or adverse functional changes occur. Studies of small mammals suggest that insectivores such as shrews and moles are likely to accumulate the highest concentrations and are therefore at greatest toxicological risk. Widespread kidney damage was observed in shrews from a polluted smelter site (Hunter et al. 1984). No toxic effects of cadmium have been reported in wild bird populations apart from kidney damage similar to that observed in dosed birds. Testicular damage has been found in birds at dietary concentrations that cause kidney damage. The critical concentration in kidneys of both birds and mammals is 100 μg/g WW (Cooke and Johnson 1996, Furness 1996).

- **Lead** is a nonessential, highly toxic metal and notorious enzyme poison. Lead affects the central nervous system, excretory system, hematopoietic system, cardiovascular system, and the gastrointestinal system. Mammals, chronically exposed to relatively low doses similar to conditions often encountered in environments with lead-polluted soils, may have significant sublethal effects. Chronic, low-level exposure during the prenatal and post natal stages in mammals may cause physical growth retardation and irreversibly disturb brain development resulting in neurobehavioral deficits. Although most cases of lead poisoning in wildlife result from lead ingestion from spent shot, bullet fragments, fishing sinkers or lead-based paints, toxic exposures can occur in birds occupying or feeding in an area near a point emission source, such as a lead mining area (Chupp and Dalke 1964, Beyer et al. 1985, Blus et al. 1991).

- **Selenium** is an essential component of several metalloenzymes that have very important physiological roles. It is also very toxic and has a very low margin between deficiency and excess. Within certain physiological limits, the body appears to have a homeostatic mechanism for retaining trace amounts and excreting the excess. Toxicity occurs when intake exceeds the excretory capacity. Base metal mining and smelting are important sources of anthropogenic selenium. In aquatic systems, selenium is readily taken up from solution by food-chain organisms and can quickly bioaccumulate (500 - 35,000x) to concentrations that are toxic to the fish and wildlife that consume them. Therefore >2 µg/L in water is considered highly hazardous to the health and long-term survival of fish and wildlife (Lemly 1996). Food chain organisms containing 3µg/g (DW) are potentially lethal to fish and wildlife that consume them. Selenium is efficiently transferred in eggs from parents to offspring where it is teratogenic and embryotoxic. Reproductive success is more sensitive to selenium toxicity than are growth and survival of juvenile and adults in both fish and birds. When livers of egg-laying female birds contain more than 3 µg/g (WW) selenium, reproductive impairment is possible (Heinz 1996). Aquatic herbivores or omnivores may ingest and accumulate more selenium than piscivores or insectivores.

IDENTIFYING VALUED ECOSYSTEM COMPONENTS

A VEC is a biological species, population or community that is ecologically significant, is important to people, has economic and/or social value and can be evaluated in a risk assessment. Several criteria, including trophic position and feeding guild, were used to select candidate VECs from a long list of plant and animal species present in the Sudbury area. Those selected were:

Plant and Invertebrate VECs:

- Terrestrial plant communities
- Blueberry
- Soil invertebrate communities

Wildlife VECs:

- American Robin
- Ruffed Grouse
- Peregrine Falcon
- Northern Short-tailed Shrew
- Meadow Vole
- Moose
- White-Tailed Deer
- Red Fox
- American Beaver

Aquatic/wetland VECs

- Common Loon
- Muskrat
- Mallard

Assessment: *The species chosen as valued ecosystem components to model are very appropriate and were selected through scientific review and extensive Stakeholder consultation. However, they represent very diverse diets and thereby complicate the risk assessment process.*

ASSESSMENT ENDPOINTS

Assessment endpoints are explicit expressions of what is to be protected, and defined by a species, population or community and a characteristic or attribute that is important to protect and which is potentially at risk. The assessment endpoints chosen were as follows:

- For plant communities, self-sustaining forest ecosystem
- For soil invertebrate communities, survival and reproduction of soil and litter biota, including earthworms
- For threatened/endangered wildlife, survival and reproduction of individual Peregrine Falcons in the city of Greater Sudbury and surrounding area
- For other terrestrial wildlife, population persistence in the city of Greater Sudbury and surrounding area

Assessment: *The assessment endpoint of population persistence for terrestrial wildlife implies that population persistence is adequate, even if it is persists only because of constant immigration. Adequate survival and reproduction to maintain a stable population would have been a more appropriate endpoint.*

EVALUATION OF THE ENVIRONMENTAL RISK ASSESSMENT

The following assessment is organized according to the objectives proposed within the ERA.

Objective 1. EVALUATE THE EXTENT TO WHICH THE COC ARE PREVENTING THE RECOVERY OF REGIONALLY REPRESENTATIVE, SELF-SUSTAINING TERRESTRIAL PLANT COMMUNITIES

The remote sensing analysis provided a synoptic and temporal view of the change in vegetation cover over the Greater Sudbury area. This “coarse scale” information was integrated into the planning of the ERA. This ERA clearly recognized that regionally representative, self-sustaining terrestrial plant communities are a fundamental requirement of any stable terrestrial ecosystem.

Several lines of investigation were undertaken to address Objective 1, which ranged from site-specific, detailed characterization of the plant community to the detailed examination of the abiotic and biotic characteristics of the supporting soils. Detailed chemical, physical, and biological data were gathered from 18 test sites, one historically-limed and regreened site, and 3 reference sites for a total of 22 field sites. Sites were selected on transects extending out from one of the three smelter locations and ranged from 1.8 to 41.3 km from the nearest smelter.

An experimental approach was also applied to assess the growth of test plant species in these soils under controlled conditions, and to determine the confounding role of soil pH in plant growth. Parallel experiments were conducted to assess the survival, reproduction, and growth of earthworms, a critical component of the soil biotic community in these soils. The rate of leaf litter decay was also experimentally assessed *in situ*.

The assessors concluded that terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the COC in the soil. Terrestrial plant communities are also impacted by other factors such as soil erosion, low nutrient levels, lack of soil organic matter, and/or low soil pH.

Objective 1 Assessment: *The techniques chosen, the execution, and the above conclusions based on the weight-of-evidence are appropriate. However, the strength of these conclusions hinges on the results from the reference sites. The investigators had difficulty finding reference sites and had to discard one with the net result of 3 reference sites for 18 test sites. Ideally, one would like an equal number or twice as many reference sites as test sites. The assessors recognized this problem, but it does weaken their conclusions.*

Assessor Recommendations: *The investigators should have gone further afield and selected a number of reference sites in an area with similar geological, botanical, and climatic characteristics. This would have allowed the possibility of separating the localized impacts of the atmospheric deposition of metals from the confounding influences of declining levels of acid precipitation, climate change, and other non-metal stressors.*

Objective 2. EVALUATE RISKS TO TERRESTRIAL WILDLIFE POPULATIONS AND COMMUNITIES DUE TO THE COC, and

Objective 3. EVALUATE RISKS TO INDIVIDUALS OF THREATENED OR ENDANGERED TERRESTRIAL SPECIES DUE TO THE COC

Terrestrial wildlife populations and communities are dynamic and diverse; the distributions of many species are changing in response to climate change and habitat fragmentation. This is particularly true for birds. The majority of the 300 bird species that are present in the Sudbury area are migratory, and are present for a few days or weeks in the spring and fall. The migratory bird species that actually breed in the Sudbury area only reside there for 4 to 6 months. It is currently believed that populations of migratory birds are greatly influenced by conditions they encounter the other 6 to 8 months of the year.

The assessors acknowledged the presence of some endangered species in the area. However, they concluded that it is unlikely that COC from the smelters are having a direct effect on these species. They did not consider sublethal effects.

For non-endangered terrestrial wildlife, it was concluded that "it is unlikely that metals in soil are exerting a significant direct toxic effect on VEC populations in the Sudbury area. However, previous effects of smelter emissions on habitat quality…may be having a continued influence on birds and mammals in the study area".

Overall, the likelihood of toxicity was addressed by application of a probabilistic risk assessment. Thus, it is here that an overall assessment of the ERA methodology is considered appropriate.

EXPOSURE ASSESSMENT

The purpose of the exposure assessment was to estimate the amount of each COC received by each VEC on a daily basis. *The exposure assessment is the most critical and the only site- and VEC- specific component of the risk assessment.* Exposures to COC from ingestion of food, soil, sediment, and water were estimated using a total daily intake (TDI) model. The model parameters included body weight, sediment/soil intake rate, water intake rate, food intake rate, proportions of individual dietary items consumed, and concentrations of COC in each item ingested, as well as the relative absorption factor for each COC. The various components of each wildlife VEC's diet were determined from the literature.

Estimates of COC concentrations for the components of the wildlife exposure model were derived in most cases from actual measured values in a variety of abiotic and biotic media from the Sudbury area, including surface water, sediment, soil, fish, plants, and invertebrates. COC concentrations in algae, aquatic plants, and benthic invertebrates had to be estimated using uptake factors and equations from the literature because Sudbury-specific data were not available. Literature-derived models were used to predict concentrations in benthic invertebrates, aquatic plants and vegetation, and small mammals.

According to the assessors, "some wildlife species have dietary preferences that can include a large number of different food items. For example, a herbivore (i.e., white-tailed deer) may consume forbs, grasses, twigs, buds, fruits, nuts and seeds throughout the year on a seasonal basis. In order to simplify this complexity, the exposure model only included dietary items that comprise at least 5% of the total diet of each species and divided the vegetation items into only two items – shoots or roots. This simplification was also necessary because measured or predictive models that could be used to estimate concentrations for each dietary item are unavailable in the scientific literature or on a site-specific basis." Additionally, "it is practically impossible to sample each dietary item that an animal consumes on a frequent basis and with sufficient coverage to fully characterize the chemical concentrations in every diet item across the entire Sudbury Study area. To compensate for this lack of information, the wildlife exposure model used surrogate models or best available and scientifically-defensible information to estimate the exposure that wildlife would receive on a chronic basis from food". Thus, of the 25 dietary "items" used in the risk assessment, 80% were estimated.

The origin of the metal concentration used for each food item as used in the exposure assessment, and an assessment of its validity, is summarized in the following table.

Diet Item	Measured or Estimated	Description of sample or base for derivation and source of equations used	Validity
Water	M	Single samples from 30 locations representing 80 (10%) of lakes. As, Se, and Pb below MDL	Represent 10% of lakes. No real values for As, Se, Pb
Sediment	M	Data from literature, many .10ys old. 8 to 81 samples from 6 -14 lakes	Very Questionable
Soil	M	100s of samples measured per site	High
Fish	M	73 fish of 5 species from 8 lakes	Represent 1% of lakes
Amphibians	E	Considered to be fish	Biologically Questionable
Small mammals	E	Soil using equations from literature	Highly Questionable
Birds	E	Considered to be small mammals	NONE
Benthic invertebrates	E	Sediments using equations from literature	Very Questionable
Worms	E	Soils using site-specific equations based on 17 earthworm-soil pairs	Only for earthworms
Terrestrial invertebrates	E	Soils using site-specific equations based on 17 grasshopper-soil pairs	Only for grasshoppers
Aquatic plants	E	Water using equations from literature	Biologically Questionable
Plant shoots	E	Soil using site-specific equations based on 17 soil-*Deschampsia* shoot pairs	Only for *Deschampsia shoots*
Plant roots and tubers	E	Soil using site-specific equations based on 15 soil-*Deschampsia* root pairs	Only for *Deschampsia roots*

As per this chart, all species of insects become a generic insect – a grasshopper; all birds and mammals become a generic terrestrial vertebrate - a small mammal; and all plants and plant parts become one of two parts of a generic plant based on a single plant species –

bunch grass (*Deschampsia* sp.) for the risk assessment. All the inter-individual and interspecific variation in metal content that results from an individual food organism's "taxonomy", physiology, ecology, and behavior is therefore eliminated. Because important data components for the model were so greatly over simplified, it is difficult to have confidence in the conclusions.

Evaluation: Given that the exposure assessment is the only site- and VEC-specific component of the risk assessment, it is felt that this approach compromises the assessment. To further illustrate, Parker and Hamr (2001) reported concentrations of cadmium, cobalt, copper, nickel, and lead in terminal twigs of Beaked Hazel, Red Maple, Red Oak, Trembling Aspen, White Birch, White Cedar and clippings of Deschampsia (representing species browsed by elk) from an area near Sudbury. This sample would be equivalent to "plant shoots" in this exposure assessment. Within that spectrum of 7 species and 2 locations, <u>mean</u> concentrations varied 9 -11x for cadmium, 2.4x for cobalt, 3.3x for copper, 4.5x for nickel, and 1.8x for lead. For this suite of metals in these tissues, concentrations ranked as follows Deschampsia<Red Oak<Red Maple<White Cedar<White Birch<Beaked Hazel<Trembling Aspen. Clearly Deschampsia is a poor surrogate for Trembling Aspen, let alone all species of plants. The roots and rhizomes of the Cattail have been documented as efficient accumulators of nickel and copper on Sudbury area marshes (Taylor and Crowder 1983). There is clearly a wide variation in the metal concentrations among species of plants, and likely variation among individuals of the same species depending on soil contamination, age, and physiological state. Some plant tissues would receive metals predominantly from absorption and translocation within the plant (roots, wood, shoots, leaves, seeds), while others like leaves and bark would also adsorb metals from the air, and in the case of roots, from the soil.

EFFECTS ASSESSMENT

The effects assessment for the ERA determined the levels of exposure to each COC that are not expected to result in adverse effects in each VEC. These chemical doses are the Toxicity Reference Values (TRVs).

The selection of chemical- and species-specific TRVs included a comprehensive search and review of the toxicological literature related to the COC and VECs; TRVs were then selected or derived according to the following order of preference; IC20, LOAEL, NOEL (NOEL only for the endangered Peregrine Falcon). TRVs were adopted from two recent US EPA sources which represent the most comprehensive review of toxicity data available.

Evaluation: Considerable effort was made to examine as many studies as possible to determine toxic concentrations, and to then characterize these values statistically to arrive at a conservative toxicity reference value.

RISK CHARACTERIZATION ASSESSMENT

The risk characterization determined the likelihood of adverse effects to wildlife populations occurring as a result of exposure to an individual COC in the study area by combining the results of the exposure assessment with those of the effects assessment. The predicted exposure ratio (ER) represents the potential risks to individuals within a population, or the probability of an individual receiving a particular exposure.

$$\textit{Exposure Ratio (ER)} = \frac{\textit{Predicted Exposure Estimates}}{\textit{Toxicity Reference Value}}$$

90% or greater probability of an ER less than or equal to 1.0: Signifies that most estimates of exposure are less than the TRV, indicating that adverse effects can be ruled out.

Greater than 10% probability of an ER greater than 1.0: Signifies that the potential for adverse effects is not ruled out; however, the significance of this potential must be judged according to the degree of uncertainty and degree of conservatism incorporated into the risk assessment, as well as site-specific information (ground truthing).

Evaluation: According to the assessors, variability was poorly characterized and uncertainty (lack of knowledge) high for 6 of 8 (75%) of the data elements used to estimate exposures including metal concentrations in environmental media and the various medium-to-biota uptake models. The variability is characterized poorly because sample numbers are low for the area of coverage, there were too few species or groups, and the study was performed only at one time period. Coverage is missing from many regions across the study area. The uncertainty suggests that collection of additional data is likely to improve our understanding of the existing data distributions. Site-specific conditions were significantly different (>10x) from assumptions and methodologies in literature.

Variability in dietary apportionment is required in the ERA model to account for individual, geographic, and seasonal differences in available food items and the wildlife species' preference. The thorough review of the literature should have characterized this well. However, the number of dietary items and the species they represent was low causing concern over biological relevance.

The validity, accuracy, or adequacy of the model cannot be assessed. However, it is important to note that as per the US EPA (2001)

> *All models are simplified, idealized representations of complicated physical and biological processes. Models can be very useful from a regulatory standpoint, as it is generally not possible to adequately monitor long-term exposure for populations at contaminated sites. However, models that are too simplified may not adequately represent all aspects of the phenomena they were intended to approximate or may not capture important relationships among input variables. Other sources of model uncertainty can occur when important variables are excluded, interactions between*

inputs are ignored, or surrogate variables that are different from the variable under study are used.

Objective 2 and 3 Assessment: *Conclusions associated with the result of the modeling are limited and overly simplistic, based on many estimated parameters, values obtained from unrelated studies, and too few species for reliable characterization of the metal content of food items and diets. Models have inherent limitations and the results they generate are only as good as the data used for the various parameters. The conclusion that the COC are unlikely to have a direct effect on threatened or endangered species is based entirely on distribution and not whether or not the COC are actually a problem. Additionally, long-term sublethal effects (e.g., behavioural and reproductive issues) were not addressed.*

Assessor Recommendations: *The most profitable lines of investigation would be the determination of whether (a) local exposure to any of the chemicals of concern is likely to result in toxicity, (b) breeding populations and/or species diversity are reduced on test sites relative to reference sites, and (c) measurements of metals in appropriate target tissues of valued ecosystem components approach or exceed concentrations associated with sublethal or lethal toxicity. Specifically in terms of endangered species, it is felt that the numbers and reproductive success of the Peregrine Falcons breeding in the Sudbury area should be followed on an ongoing basis.*

Objective 4. CONDUCT A COMPREHENSIVE PROBLEM FORMULATION FOR THE AQUATIC AND WETLAND ENVIRONMENTS IN THE SUDBURY AREA TO FACILITATE A MORE DETAILED RISK ASSESSMENT IN AQUATIC/WETLAND ECOSYSTEMS

An aquatic problem formulation was developed as an information gathering and interpretation stage to focus the approach for a possible future detailed aquatic risk assessment. It identified the common loon, mink, and mallard as VECs and used the same probabilistic exposure modeling methodology that was used to identify possible toxicity as was used for terrestrial wildlife for Objective 2.

Using that methodology, the assessors found no evidence of acceptable risks for arsenic, cobalt, copper, lead, or nickel in these species in any portion of the study area. However, unacceptable risks from selenium exposure were predicted for mink, loons, and/or mallards for all four areas in which they were assessed. The assessors had low confidence in the results of the modeling of exposure to selenium and therefore elected to ignore these findings. The potential risks to these species were related to sediment concentrations of selenium and the uptake of selenium into benthic invertebrates. The same water and sediment dataset was used for all four zones/areas, and included only a single selenium analysis for sediment from each of 8 lakes. It is presumed that one equation was used to model all benthic invertebrates from tiny snails to crayfish, the latter being important components of the diet of mink and loons.

The assessors concluded, however, that given the extensive aquatic research and monitoring studies that have been conducted in the study area during the past two decades, no detailed aquatic ecological risk assessment is planned at this time.

Objective 4 Assessment: *The ERA is incomplete without an assessment of possible effects in the aquatic ecosystem. The problem formulation further highlights the lack of information on Sudbury-specific metal impacts on algae, macrophytes, invertebrates, additional species of fish, and amphibians. As marshes and wetlands have not been studied recently, determining if metals are having a significant deleterious effect on these populations directly or through reductions in food or habitat quality is difficult. Aquatic ecosystems have the potential to receive smelter-derived metal contamination by direct atmospheric deposition and as leachate from soils that is transported in runoff.*

Assessor Recommendations: *It is felt that the following information would assist in the ERA process:*

- *Comprehensive water chemistry for each lake selected for study (would expand the Se data set)*
- *Comprehensive sediment chemistry for each lake selected for study (would update and expand the sediment data set and provide more data for Se)*
- *Sequential extraction of sediments to determine bioavailability (would provide real, local site-specific data for bioavailability)*
- *Chemical and biological data for marshes and wetlands (would update from the 1980s)*
- *More comprehensive data for fish*
- *Laboratory bioassays and measurements of uptake by benthic organisms from sediments using sediments from lakes of interest (would provide real, site-specific data on uptake by benthic organisms)*
- *Characterization of benthic community communities and use in bioassays*
- *Characterization of algal and macrophyte communities and use of algal bioassays*
- *Characterization of zooplankton communities and use in bioassays*
- *Evaluation of species diversity and populations of amphibians using call surveys*

It is further believed that collecting the above data would help clarify whether metals are having deleterious impacts in the aquatic ecosystems of the area, while providing a solid baseline against which to measure the results of any remedial measures.

A WAY FORWARD: MEASUREMENT OF METALS IN APPROPRIATE TARGET TISSUES OF VALUED ECOSYSTEM COMPONENTS

Conclusions associated with the modeling were based on many estimated parameters or values obtained from unrelated studies; too few species and individuals were used to characterize the metal content of food items and diets. Models have inherent limitations and the results they generate are only as good as the data used for the various parameters.

The assessors' "ground-truthed" their conclusions using existing field information on reproductive success and population trends; however, most of the data are anecdotal or qualitative. One quantitative dataset that was examined was the Christmas bird count. That analysis showed that wintering numbers of two year-round residents, the Black-capped Chickadee (Poecile atricapillus) and Downy Woodpecker (Picoides pubescens) have been increasing in the Sudbury area, but are doing so at a significantly lower rate than they are on nearby Manitoulin Island, which is not influenced by metal smelter emissions. This observation was not discussed.

The mallard is the most abundant duck species in the Sudbury area (McNicol et al. 1995). Extensive surveys of waterfowl pairs in the Sudbury region 1993-2002 found a significant increase of 9% in pair counts of dabbling ducks (includes mallards) on highly acidified lakes (pH<5.3), a 7% increase in lakes of pH 5.3-6.0, and a 1% decrease in lakes of pH >6.0 (Weeber et al. 2004). Breeding density of common loons in Sudbury correlated strongly with open water area and pH (McNicol et al. 1995). Persistently low pH and unsuitable nesting habitat in close proximity to Sudbury restricted the recruitment of loons to those areas. However, an increase in recruitment close to Sudbury was observed in the 1990s (McNicol et al. 1995). Between 1993 and 2002, Weber et al. (2004) reported an 11.7% annual increase in the pair counts of Common Loon and Common Mergansers in Sudbury lakes of pH <5.3. These duck and loon data suggest that numbers have responded positively to improved food resources and habitat quality that have accompanied reductions in acid deposition. However, whether adverse effects of metals pollution is limiting these increases in numbers and breeding success is unknown.

To a wildlife biologist, ground-truthing would consist of some systematic census work, such as use of trapping and track boards for small mammals (the voles and shrews in particular) building on the work of Robitaille and Linley, breeding bird censuses, comparison of the two Ontario Breeding Bird Atlases for the periods 1981-85 and 2001-2205 to detect changes in distribution and abundance, waterfowl numbers, and productivity estimates. Waterfowl pair and brood counts could follow the methods of McNicol et al. (1995) and Weeber et al. (2004) and current data collected for those sites common to their study areas and the area encompassed by this ERA. Loon numbers and productivity could be estimated using the methodology of the Canadian Lakes Loon Survey.

Amphibian diversity and numbers could be assessed using the methodologies used by Ontario FrogWatch and Marsh Monitoring Programs.

To a wildlife toxicologist, appropriate ground-truthing would consist of collecting specific tissues from those species and locations for which the EC exceeded 1 and measuring the COC concentrations therein. Those concentrations could be compared to tissue residue guidelines and published reviews to see how close they are to concentrations where various forms of toxicity (both sublethal and lethal) are known to occur. Efforts should be made to obtain a sufficient number of matched kidneys and jaw bones of deer, moose, beaver, and muskrat to provide a good sample of older individuals in which to look at age-related bioaccumulation and the physiological significance of renal cadmium (Moose and deer) and nickel (muskrat) concentrations.

Recommendation: Overall, measuring metal concentrations in critical tissues of individuals would bypass modelling assumptions and provide a **r**eal measure of likely toxicity and the concentration of the toxic metal in the animal's tissues collected on the study site in question. Such current, real-world data would either support the conclusions of the risk assessment or suggest that hazards have been underestimated and identify specific wildlife issues. Population-level studies could also provide evidence of habitat-related effects. Systematically-collected data would also provide a baseline against which to evaluate the effectiveness of any remedial actions that are taken.

In the case of older individuals of long-lived species, real-world data would also provide a measure of the amount accumulated over the individual's life. This would be particularly informative for cadmium. An analysis of critical tissues (liver and kidneys) of the various VECs would be beneficial. Eight of 10 of the species for which tissue collection is recommended are harvested (hunted or trapped); however, for this sampling to be meaningful, a reasonably large sample of individuals from each site is required to assess variability. Collecting upper GI tract and crop contents might also be beneficial as these samples would provide a good idea of the metals content of the site-specific diet of those species. Particular attention must also be paid to year-round residents or those whose diets consists of metals-accumulating plants.

In the table below, the VECs (plus the muskrat); the period of the year which they are present in the Sudbury area;, their approximate life span; diet characteristics which might make them vulnerable to the toxicity of lead, cadmium, nickel, and selenium; and measurement timing which may best determine the likelihood of risks to these wildlife species and populations due to COC have been listed.

VEC	Present (months)	Life Span (years)	Diet components most likely to contain metals (COC)	Measure
Ruffed Grouse	12	<5	Aspen leaves, buds & apical tissues of	1(Fall)

			other trees and shrubs, insects	
Mallard	6-8	<5	Aquatic plants, aquatic invertebrates, snails	1 (Fall)
Common Loon	15 - 30	10 -15	Fish and crayfish	3
Peregrine Falcon	6 -12	10 -15	Birds of all types. Urban Peregrines feed primarily on Rock Doves	3
Robin	5 - 6	<4	Earthworms, large insects, snails	3
Meadow Vole	12	< 1.5	Grasses, shoots, insects	2 (Fall and Late Winter)
Beaver	12	10 -15	Bark of Aspens and Poplars	1(Fall and Winter)
Moose	12	15 - 20	Leaves, bark, twigs, shoots, water lilies	1 (Fall)
White-tailed Deer	12	3 - 12	Leaves, twigs, fruits of trees and shrubs and grasses	1 (Fall)
Mink	12	2 - 3	Crayfish, Fish, clams	1 (Fall and Winter)
Red Fox	12	6 - 10	Small mammals and birds	1 (Fall and Winter)
Short-tailed Shrew	12	6 - 10	Earthworms, insects, mice	2 (Fall and late Winter)
Muskrat	12	1 - 3	Root stalks and stems of cattails, other aquatic plants, clams	1 (Winter and spring)

Measures:
1 = harvested; collect tissues (Kidney, Liver), age individual, analyze for Se, Ni, Cd, Pb, (Hg)
2 = trap, collect tissues (Kidney, Liver), age individual, analyze for Se, Ni, Cd, Pb, (Hg)
3 = monitor breeding pairs and reproductive success

CONCLUSIONS

The Sudbury Area Soils Study is a very comprehensive project and assessment with great breadth, detail, and public involvement, as well as a comprehensive and open communications strategy. It sets the standard for investigations of the public's environmental and health concerns in terms of quality, depth, and transparency.

It is agreed that terrestrial plant communities in the Greater Sudbury area have been and continue to be impacted by the COC in the soil. It is also agreed that terrestrial plant communities are also impacted by other factors such as soil erosion, low nutrient levels, lack of soil organic matter, and/or low soil pH. This conclusion although weakened by the difficulty in finding assessment sits, is considered appropriate.

However**, there are points where methodology and/or conclusions are questioned.** Firstly, the assessment endpoint of population persistence for terrestrial wildlife implies that population persistence is adequate, even if it is persists only because of constant immigration. The appropriate endpoint would be adequate survival and reproduction to maintain a stable population. Secondly, the conclusions associated with modeling are limited and overly simplistic, based on many estimated parameters, values obtained from unrelated studies, and too few species for reliable characterization of the metal content of food items and diets. Given that the exposure assessment was the only site- and VEC-specific component of the risk assessment, this modelling makes it difficult to assess the actual likelihood of adverse effects of a COC on any VEC. Thirdly, there are limitations of chemical-by-chemical toxicity assessment such as this since the cumulative impact of multiple chemical exposure and habitat quality plus potential frank or sublethal toxicity is unknown. Fourthly, an assessment of possible effects in the aquatic ecosystem is needed to help clarify whether metals are having deleterious impacts in the aquatic ecosystems of the area. It would further provide necessary information to improve the risk assessment, and would provide a solid baseline against which to measure the results of any remedial measures.

Furthermore, while assessors' "ground-truthed" their conclusions using existing field information on reproductive success and population trends, most of the data are anecdotal or qualitative. Although there is evidence that numbers of dabbling ducks and loons are increasing in the Sudbury area, we cannot determine whether metal contamination is slowing this process. Terrestrial wildlife populations and communities are dynamic and diverse; the distributions of many species are changing in response to climate change and habitat fragmentation is known. Local, smelter-associated effects are superimposed over these more global effects and observational methods and do not allow us to separate local and global effects.

Measuring and analyzing the presence of metals in appropriate target tissues (liver and kidneys) of valued ecosystem components, is needed, even for the well-studied toxic metals cadmium, lead, and selenium. Doing so would bypass the assumptions and mathematical modelling, dietary sampling, etc. by providing a real measure of likely toxicity and the concentration of the toxic metal in the animal's tissues collected on the study site in question. In the case of older individuals of long-lived species, it also provides a measure of the amount accumulated over the individual's life and would be particularly informative for cadmium. Real-world investigations undertaken by G. Parker and students of Laurentian University have been quite revealing.

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Zoology (avian ecology and environmental physiology.)

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Biochemical Toxicology

Employment History:

Medical Laboratory technologist, Worked in hospitals and Veterinary Pathology Department at University of Saskatchewan.

Research Assistant, Dept. of Zoology, University of Guelph, 1969-1971. (Avian Ecology)

Technical Assistant to the Director, Alberta Provincial Laboratory of Public Health, Edmonton. 1973-1974.(Clinical Pathology)

Toxic Chemical Biologist, Canadian Wildlife Service, Edmonton and Ottawa, 1974-1975. (wildlife toxicology field studies)

Wildlife Toxicologist, Canadian Wildlife Service, National Wildlife Research Centre, Hull. 1976-1985. (Field and laboratory investigations on the effects of environmental contaminants on fish-eating birds in the Great Lakes and the development of biochemical and physiological techniques to detect effects). Position and program terminated while I was on educational leave at the University of Surrey, UK, studying Biochemical Toxicology.

Environmental Contaminants and Pesticides Evaluator, Canadian Wildlife Service, National Wildlife Research Centre, Hull. 1986-1989. (Contaminant and pesticide regulation and field studies of impacts)

Contaminants Evaluation Officer, Canadian Wildlife Service, National Wildlife Research Centre, Hull. 1989-1992. (Contaminant evaluation under CEPA and bioeffects research and biomarker development in Great Lakes)

Most Recent Position:
Contaminant Effects Specialist, Canadian Wildlife Service, National Wildlife Research Centre, Hull/Ottawa. 1993-2005 (Plan, conduct and coordinate laboratory and field research on the effects of environmental contaminants on wildlife and their habitat, and provide advice and leadership to the CWS Contaminants Program and the broader scientific and regulatory community. (Reclassified from biologist to research Scientist in 1992). Retired March 31, 2005. Held as an Emeritus Scientist, 2005-2007.

ACHIEVEMENTS
Publications as of March 2006: 104 (primary author on 40) plus 9 prior to joining CWS
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- 18 books chapters or conference proceedings
- 12 government departmental or other reports

Literature Citations: as of 1999, there were 479 citations for 29 first-authored publications, and 632 citations for 38 citeable co-authored publications. A total of 14 publications were cited 25 or more times.

Poster and platform presentations, lectures etc.: 89

International Service:
Appointed to the Science Advisory Board to the International Joint Commission on the Great Lakes for two successive 3-year terms and served two terms as Canadian co-chair for the SAB's Workgroup on Ecosystem Health

Areas of Expertise:
Wildlife health assessment and biological effects monitoring
Wildlife toxicology, particularly in the Great Lakes region
Environmental endocrine disruption
Ecoepidemiology and application of the Precautionary Principle

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Fox, G.A. Platform presentation: The effects of DDE on the nesting ecology of the Merlin on the Canadian Prairies*. Annual Meeting of the American Ornithologists Union, 1978, Madison, WI.*

Fox, G.A. Effects of environmental contaminants on reproduction of non-human vertebrates. *Preventive Medicine Symposium, University of Ottawa. 1981*. Invited platform presentation

Fox, G.A. and A.P. Gilman. Unsatisfactory reproduction in gulls feeding in a highly contaminated food chain. Platform presentation*, Annual meeting of the American Public Health Association, Nov. 1981, Los Angeles, CA.*

Fox, G.A. Congenital anomolies in colonial fish-eating birds: a monitor for environmental teratogens. Platform presentation: *Annual meeting of the American Public Health Association, 14-18 Nov. 1982, Montreal.*

Fox, G.A. Pollutant-induced endocrine dysfunction in Great Lakes Herring Gulls. Invited platform presentation**:**Roundtable on Environment and Nutrition, *3rd International Symposium on Avian Endocrinology, 25-28 June 1984, New Brunswick, NJ.*

Fox, G.A. and D.V. Weseloh. Colonial waterbirds as indicators of environmental contamination in the Great Lakes. Platform presentation: "Birds as Bioindicators of Environmental Conditions*", 19th I.C.B.P. World Conference, 1986, Kingston, ON.*

Fox, G.A. Fish-eating birds as sensors of toxic levels of environmental contaminants in the Great Lakes. Platform presentation: *30th conference of the International Association for Great Lakes Research, 11-14 May 1987, Ann Arbor, MI.*

Houston, C.S., R.D. Crawford, L.D. Oliphant and **G.A. Fox**. Addled eggs in Swainson's Hawk nests in Saskatchewan. Poster presentation: *Annual Meeting of the Raptor Research Foundation, 1987, Boise, ID.*

Fox, G.A. and P.C. James. Impact of grasshopper sprays on Burrowing Owls in Saskatchewan. Poster presentation: *3rd Annual Meeting of Society Environmental Toxicology and Chemistry, 9-12 Nov. 1987, Pensacola, FL.*

Kennedy, S.W., **G.A. Fox** and R.J. Norstrom. Polyhalogenated aromatic hydrocarbon-induced porphyria in Great Lakes Herring Gulls. Poster Presentation: *3rd Annual meeting of Society of Environmental Toxicology and Chemistry, 9-12 Nov. 1987, Pensacola, FL*.

James, P.C., T.J. Ethier, **G.A. Fox** and N. Todd. New aspects of Burrowing Owl biology.
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Fox, G.A., B. Collins, T.J. Kubiak, J.P. Ludwig, D.V. Weseloh and T.C. Erdman. Incidence and prevalence of bill defects in Double-crested cormorants from Green Bay, Michigan. Platform presentation: *32nd conference of International Association of Great Lakes Research, 30 May-2 June, 1989, Madison, WI.*

G.A. Fox. Temporal and spatial variation in a battery of biomarkers in Great Lakes fish-eating birds in relation to known patterns of chemical contamination. Invited platform presentation**:** *32nd conference of International Association of Great Lakes Research, 30 May-2 June, 1989, Madison, WI.*

Fox, G.A. Practical causal inference - a lesson in applied epidemiology. Invited platform presentation***:*** *32nd conference of International Association of Great Lakes Research, 30 May-2 June, 1989, Madison, WI*

Fox, G.A., S.W. Kennedy and S. Trudeau. Temporal and spatial variation in a battery of biomarkers in Great Lakes fish-eating birds in relation to known patterns of chemical contamination. Poster presentation: *5th International Congress of Toxicology, 16-21 July, 1989 Brighton, UK.*

Fox, G.A. Temporal and spatial variation in a battery of biomarkers in Great Lakes fish-eating birds in relation to known patterns of chemical contamination. Platform presentation:*10th annual meeting of the Society of Environmental Toxicology and Chemistry, 28 Oct.- 2 Nov, 1989, Toronto, ON.*

Jessiman, B., M. Wong, **G.A. Fox**. Environmental risk from the current use patterns of Lindane. Poster presentation:*10th annual meeting of the Society of Environmental Toxicology and Chemistry, 28 Oct.- 2 Nov, 1989, Toronto, ON.*

Fox, G.A., S.W. Kennedy and S. Trudeau. Temporal and spatial variation in a battery of biomarkers in Great Lakes fish-eating birds in relation to known patterns of chemical contamination. Poster presentation: *6th International Symposium on Responses of Marine Organisms to Pollutants, Woods Hole, MA. 24-26 April. 1991*

Fox, G.A. Contaminant levels and effects in Great Lakes wildlife. Invited platform presentation*: Environmental Health Effects Workshop, Walpole Island First Nation. 28-29 August., 1991*

Fox, G.A. Biomarkers: what are they and what have they told us about the effects of contaminants on the health of Great Lakes wildlife? Invited platform presentation**:** *Cause-Effect Linkages II Symposium, Traverse City, MI. 27-28 November, 1991.*

Fox, G.A. Fish and wildlife studies. Invited platform presentation*: "Our Community, Our Health - A Dialog Between Science and Community" an IJC-sponsored Ecosystem Health workshop, 14-15 Sept., 1992 Ann Arbor, MI.*

Fox, G.A., K.L. Williams, D.A. Jeffrey and K.A. Grasman. Retinol homeostasis, a sensitive and relevant biomarker for PHAHs in fish-eating birds. Invited platform presentation**:** *Annual meeting of the Society of Environmental Toxicology and Chemistry, 8 - 12 Nov., 1992, Cincinnati, OH.*

K.A. Grasman, P.F. Scanlon and **G.A. Fox**. Preliminary analysis of hematological and immunological parameters in fish-eating birds in the Great Lakes. Invited platform presentation:*13th annual meeting of the Society of Environmental Toxicology and Chemistry, 8-12 Nov., 1992, Cincinnati, OH.*

Fox, G.A. Temporal trends in biomarker responses of adult herring gulls from seven Great Lakes colonies, 1974-1991. Platform presentation: *36^{th} Conference of the International Association for Great Lakes Research,4-10 June, 1993, De Pere, WI.*

Fox, G.A. Scientific Principles. Invited platform presentation:Workshop on Weight of Evidence, 1993 *Biennial Meeting on Great Lakes Water Quality, 22-24 Oct, 1993, Windsor, ON.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox**. Poster presentation. Environmental contamination and immune function in Great Lakes colonial waterbirds. *21st Conference of the International Union of Game Biologists, 15-20 Aug., 1993, Halifax, NS.*

Fox, G.A. and K.A. Grasman. Temporal trends in PCB and DDE burdens and biomarker responses of adult herring gulls from eight Great Lakes colonies and a maritime reference colony, 1974-1993. Invited platform presentation: *Wingspread Worksession on Environmentally Induced Alterations in Development: A Focus on Wildlife. 10-12 Dec., 1993, Racine, WI.*

Grasman, K.A., **G.A. Fox**, and P.F. Scanlon. Immunological biomarkers and environmental pollutants in Great Lakes fish-eating birds. Invited platform presentation: *Wingspread Work Session on Environmentally Induced Alterations in Development: A focus on Wildlife. 10-12 Dec., 1993. Racine, WI.*

Fox, G.A., and K.A. Grasman. Evidence of altered sexual development, endocrine and immune function in fish-eating birds of the Great Lakes. Invited platform presentation*: Special symposium on Environmental Endocrine Disruptors, Annual Meeting of American Society of Zoologists, 5-8 Jan., 1994, St. Louis, MO.*

Norstrom R.J., T.P. Clark, **G.A. Fox** and C.E. Hebert. Bioaccumulation of PCBs in Herring Gulls: QSAR and modelling approaches. Platform presentation: *Annual meeting of the Society of Environmental Toxicology and Chemistry, 30 Oct-3 Nov, 1994, Denver, CO.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox.** Immunological biomarkers and environmental contaminants in fish-eating birds of the Great Lakes. Poster presentation: *Annual meeting of the Society of Environmental Toxicology and Chemistry, 30 Oct.-3 Nov., 1994, Denver, CO.*

Fox, G.A. Killing the messenger: chemicals that interfere with the body's "information highway".
Invited seminar: Organismal Biology Series, *Dept. of Biology, McGill U., Montreal, PQ., 1995*

Grasman, K.A., P.F. Scanlon and **G.A.Fox**. Immunological biomarkers and environmental contaminants of fish-eating birds of the Great Lakes. Invited platform presentation: *Annual conference of the International Association for Great Lakes Research, 28 May-1 June,1995, East Lansing, MI.*

Norstrom R.J., C.E. Hebert, **G.A. Fox**, S. Kennedy and D.V. Weseloh. The Herring Gull as a biomonitor of trends in levels and effects of halogenated contaminants in Lake Ontario: A 25-year case history. Platform presentation: *Annual conference of International Association for Great Lakes Research, 28 May-1 June, 1995, East Lansing, MI.*

Grasman, K.A., P.F. Scanlon, and **G.A. Fox**. Developmental immunotoxicicity of environmental contaminants in fish-eating birds of the Great Lakes. Invited platform presentation: *Wingspread Work Session on Chemically- Induced Alterations in the Developing Immune System: The Wildlife/Human Connection, 10 - 12 Feb.,1995, Racine, WI.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox**. Organochlorine-induced immunosuppression in fish-eating birds of the Great Lakes. Poster presentation: *Annual meeting of the Society of Environmental Toxicology and Chemistry, 5 - 9 Nov, 1995,Vancouver, BC.*

Fox, G.A. and K.A. Grasman. Evidence, past and present, of endocrine disruption in fish-eating birds in the Great Lakes. Poster presentation: *6th International Symposium on Avian Endocrinology, 31 March - 5 April, 1996, Lake Louise, AB*

Fox, G.A. and K.A. Grasman. Evidence, past and present, of endocrine disruption in fish-eating birds in the Great Lakes. Platform presentation: *Annual conference of the International Association for Great Lakes Research, 26 - 30 May, 1996, Mississauga, ON.*

Kennedy, S.W., **G.A. Fox**, S. Trudeau, L.J. Bastien and S.P. Jones. Highly carboxylated porphyrins: biochemical markers of PCB exposure in Herring Gulls. Platform presentation: *Annual meeting of the Society of Environmental Toxicology and Chemistry, 17 - 21 Nov,1996. Washington, DC.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox**. Immunological biomarkers and environmental contaminants in fish-eating birds of the Great Lakes. Invited platform presentation: *Symposium on Immunotoxicology, Annual meeting of the Society of Environmental Toxicology and Chemistry, 17 - 21 Nov., 1996, Washington, DC.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox.** Immunological biomarkers and environmental contaminants in fish-eating birds of the Great Lakes. Invited platform presentation: Symposium on Aquatic Pollution-induced Immunotoxicity in Wildlife Species. *Annual meeting of the Society of Toxicology, 10 - 19 March, 1996, Anaheim, CA.*

Grasman, K.A. and **G.A. Fox**. Trends in biochemical markers in Great Lakes birds. Invited platform presentation: Workshop on Environmental Results: Monitoring and Trends of Effects Caused by Persistent Toxic Substances, *Biennial meeting of the International Joint Commission, 12-13 Sept, 1996, Windsor, ON.*

Grasman, K.A., P.F. Scanlon and **G.A. Fox**. Organochlorine-induced immunosuppression in fish-eating birds of the Great Lakes. Platform presentation: *Annual conference of the Wildlife Society, 1 - 5 Oct., 1996, Cincinnati, OH.*

Fox, G.A. Killing the messenger: chemicals that interfere with the body's "information highway". Invited lecture: Ecotoxicology course, *Department of Biology, University of Ottawa,* 1997.

G.A. Fox and K.A. Grasman. Evidence, Past and Present of Endocrine Disruption in Fish-eating Birds in the Great Lakes. Poster presentation. *Health Conference '97 - Great Lakes/St. Lawrence, May 12-15, 1997, Montreal*

G.A. Fox, S.W. Kennedy, S. Trudeau, C.A. Bishop, and M. Wayland. Hepatic Porphyrin Patterns in Birds as a Promising Measure of Effect and Bioavialability of PCBs and Other HAHs in Water and

Sediments. Platform presentation. *17th Symposium on Chlorinated Dioxins and Related Compounds, Aug. 25-29, 1997, Indianapolis, IN.*

K.A. Grasman, D.L. Hammersley, P.F. Scanlon, and **G.A. Fox** . Blood Plasma Proteins as Biomarkers of Contaminants in Fish-eating Birds of the Great Lakes. Poster presentation. *SETAC Annual Conference, Nov. 16-20, 1997, San Francisco, CA.*

G.A. **Fox**. Organized and chaired a plenary session entitled "Observed and Potential Impacts of Endocrine Disruption on Wildlife". *Gordon Research Conference on Endocrine Disruption, July 12-17, 1998, Plymouth NH,*

G.A. Fox. Biomarkers: What are they and what can they tell us about the effects of contaminants?". *1998 Conference of the Wildlife Society, Sept 22-26, Buffalo NY.*

G.A. Fox. Perturbations in Terrestrial Vertebrate Populations; Contaminants as a Cause. Invited plenary presentation. *Environmental Contaminants and Terrestrial Vertebrates. Effects on Populations, Communities, and Ecosystems, Oct 19-21, 1998, College Park, MA*. (SETAC-TWS-PWRC-sponsored symposium).

K.A. Grasman and **G.A. Fox**. Biomarkers for contaminant-associated immunosuppression in colonial waterbirds of the Great Lakes. *SETAC, Nov. 1998, Charlotte NC,*

K.A. Grasman, P.F. Scanlon, and **G.A. Fox**. An examination of the health of herring gulls (*Larus argentatus*) in the Great Lakes basin in the early 1990s: Association between hematological biomarkers and organochlorine contaminants. Poster presentation.
SETAC, 14-18 November, 1999, in Philadelphia, PA

M.E. Kelly, K.A. Grasman, and **G.A. Fox**. Gonadal histology of Great Lakes herring gulls. Poster presentation. *SETAC, 14-18 November, 1999, in Philadelphia, PA*

R.W. Jeffery, S.W. Kennedy and **G.A. Fox**. Cytochrome P4501A1 induction in avian hepatocyte cultures by PAHs: might Greater Scaup be at risk from embryotoxic effects of PAHs?
CWS Wildlife Toxicology Program Science Meeting, 4-6 October 1999, Ottawa.

G.A. Fox. From Wingspread to EDSTAC: What fell through the cracks? Opening plenary presentation. *5-NR EDS Working Group's workshop "Establishing a National Agenda on the Scientific Assessment of Endocrine Disrupting Substances", 13-17 Feb, 2000, Grandview Inn, ON*

G.A. Fox. Endocrine disruption in Canadian wildlife. *5-NR EDS Working Group's workshop "Establishing a National Agenda on the Scientific Assessment of Endocrine Disrupting Substances", 13-17 Feb, 2000, Grandview Inn, ON*

G.A. Fox. The weight-of-evidence problem: Approaches to decision making in the face of uncertainty. *5-NR EDS Working Group's workshop "Establishing a National Agenda on the Scientific Assessment of Endocrine Disrupting Substances", 13-17 Feb, 2000, Grandview Inn, ON*

Norstrom, R.J., K.D. Drouillard, A.P. Gilman, and **G.A. Fox**. 2000. Toxicokinetics of PCBs in the herring gull (*Larus argentatus*) embryo. Assessing the impact of lipid metabolism on exposure and risk of hydrophobic chemicals of maternal origin. Paper, *IAGLR '00 Conference, Cornwall, Ontario, IAGLR.*

Grasman K.A., **Fox G.A.**, Burgess N.M., Kuzic Z.A., Jeffrey D. Effects of polychlorinated biphenyls on the immune system of Black Guillemots from Labrador. *SETAC-2000, Nashville TN.*

Kelly M.E., Grasman K.A., Burgess N.M., Kuzyk Z.A., **Fox G.A**.. Altered reproductive development in PCB-exposed Black Guillemot chicks. *SETAC-2000, Nashville, TN*.

Kelly, M.E., K.A. Grasman, and **G.A. Fox**. 2000. Gonadal histology of Great Lakes pipping embryos and 28-day herring gull chicks. *SETAC-2000, Nashville, TN,*

McNabb, F.M.A., L.A. Fowler, C.M. Parsons, K.A. Grasman, and **G.A. Fox.** Thyroid function in herring gulls from PCB-contaminated Great Lakes sites. *Society for Integrative and Comparative Biology, Jan 2001, Chicago, IL*

Norstrom R.J., Drouillard K.G., Gilman A.P., **Fox GA**. 2000. Toxicokinetics of PCBs in the Herring Gull (*Larus argentatus*) embryo. Assessing the impact of lipid metabolism on exposure and risk of hydrophobic chemicals of maternal origin. *IAGLR-2000, Cornwall, ON.*

Servos M, Delorme P, **Fox G**, Sutcliffe R, Wade M. 2000. A Canadian perspective on endocrine disrupting substances in the environment. *27th Aquatic Toxicity Workshop, St. John's, NFLD.*

Fox, G.A. Invited platform presentation: Wildlife as sentinels of human health effects in the Great Lakes-St. Lawrence Basin. 2001 Workshop on "Methodologies for Community Health Assessment in Areas of Concern, IJC, Windsor, ON

G.A. Fox. Ecotoxicology. Invited presentation. *The Application of Ecological Research to Conservation: East meets West", August 2001, Simon Fraser University, Vancouver, BC*

Kelly M, Grasman K, **Fox G**. Persistence of gonadal abnormalities in young herring gulls from the Great Lakes (1997-2000). Poster, *SETAC 2001, Baltimore MD.*

Kelly M, Grasman K, **Fox G**. Gonadal histology of Great Lakes herring gull embryos (1997-2000). Poster, *SETAC 2001, Baltimore MD.*

McNabb FMA, Fowler LA, Parsons CM, Grasman KA, **Fox GA**. Herring gulls from PCB-contaminated Great Lakes sites have altered thyroid function. Poster, *SETAC 2001, Baltimore MD.*

Fernie KJ, **Fox GA**, Shutt LJ, Trudeau S, Shugart LR. Polyaromatic hydrocarbons: effects of NDA and Hepatic biomarkers in herring gulls. Poster, *SETAC 2001, Baltimore MD.*

G.A. Fox. Wildlife as sentinels of human health effects. Invited presentation, *2002 Carolinas SETAC Annual Meeting, NCSU, Raleigh NC* .

FMA McNabb, **GA Fox**, KA Grasman. Comparison of variables for evaluating pollutant effects on thyroid function in birds. Platform presentation *SETAC-2002, Salt Lake City, Utah*.

RD Maher, KA Grasman, **GA Fox**, FMA McNabb. The effects of polychlorinated biphenyls on free thyroxine (FT4) concentrations in herring gull plasma. Platform presentation *SETAC-2002, Salt Lake City, Utah.*

KA Grasman, **GA Fox**, D Bennie, Nonylphenol in livers of herring gull chicks from the Great Lakes and the Bay of Fundy. Poster presentation *SETAC-2002, Salt Lake City, Utah*.

KJ Fernie, DA Jeffrey, **GA Fox**. Snapping turtles in selected Canadian Areas of Concern: Clinical chemistry results for adult males. Poster presentation *SETAC-2002, Salt Lake City, Utah*.

G.A. Fox and A. McNabb. Do chemicals cause thyroid abnormalities in Great Lakes herring gulls. *Director General's Science Forum 2003*, *Ottawa*

G.Fox, L. Shutt, K. Fernie, S. Brown, A. McNabb and K. Grasman. Endocrine disruption in wildlife of the Great Lakes of North America, Past and present. Invited platform presentation: *International Symposium on Environmental Endocrine Disrupters 2003, in Sendai, Japan*

ET Lavoie, KA Grasman, **GA Fox**. Contaminant-associated alteration in lymphocyte proliferation in Herring Gulls, Caspian Terns, and Black-crowned Night Herons from the Great Lakes., Poster presentation, *SETAC-03, Austin, TX*

M.E. Reeves, K.A. Grasman, and **G.A. Fox**. Effects of persistent organic contaminants on the developing reproductive organs of fish-eating birds. Platform presentation*. VIIIth International Symposium on Avian Endocrinology, June 6-11, 2004, Scottsdale, AZ*

F.M.A. McNabb and **G.A. Fox**. Thyroid disruption in Herring Gulls from the Great Lakes: Then and now. Platform presentation. *VIIIth International Symposium on Avian Endocrinology*, *June 6-11, 2004, Scottsdale, AZ*

G.A. Fox, D.A. Jeffrey, F.M.A. McNabb, and K.A. Grasman. Health of adult herring gulls in the Lake Huron-Detroit River-Lake Erie Corridor in 2001. Platform presentation. *Central Canadian Symposium on Water Quality Research, February 14-15, 2005, Burlington, ON.*

K.J. Fernie, R.J. Letcher, **G.A. Fox** and D.A. Jeffrey. Changes in systemic and organ function of adult snapping turtles in Canadian Areas of Concern in the lower Great Lakes. Platform presentation.
Central Canadian Symposium on Water Quality Research, February 14-15, 2005, Burlington, ON.

G.A. Fox, L. Shutt, C. Hebert, K. Fernie, P. Martin, S. Brown, J. Sherry, M. McMaster, A. McNabb, K. Grasman, and W. Bowerman. Health of Wildlife of the Great Lakes, Past and Present. Invited platform presentation, Workgroup on Ecosystem Health's Conference: *Chemical Exposure and Effects in the Great Lakes Today, March 29-31, 2005, Chicago, IL,*

K. J. Fernie, R.J. Letcher, D.A. Jeffrey, S. de Solla, and G.A. Fox. Changes in organ function of snapping turtles associated with hydroxylated- and parent persistent organic pollutants. Invited platform presentation,
SETAC-05, Baltimore, MD

G.A. Fox, L. Shutt, C. Hebert, K. Fernie, P. Martin, S. Brown, J. Sherry, M. McMaster, A. McNabb, K. Grasman, W. Bowerman, and M. Lind. Health of Wildlife of the Great Lakes, Past and Present. Invited Expert Panelist. *Wingspread '97 Revisited – ATSDR's Great Lakes Human Health Effects Research Program Expert Panel Meeting, February 9-11, 2006, Atlanta, GA*

R. Lundberg, **G.A. Fox,** and P.M. Lind. Do EDCs Effect Bone Tissue in Great Lakes Herring Gulls? *Poster presentation, Annual meeting of Society of Toxicology, March 2006, San Diego, CA.*