Evaluation of Wetland Biomonitors for the Great Lakes:

A Review of Contaminant Levels and Effects in Five Vertebrate Classes

Technical Report Series No. 182

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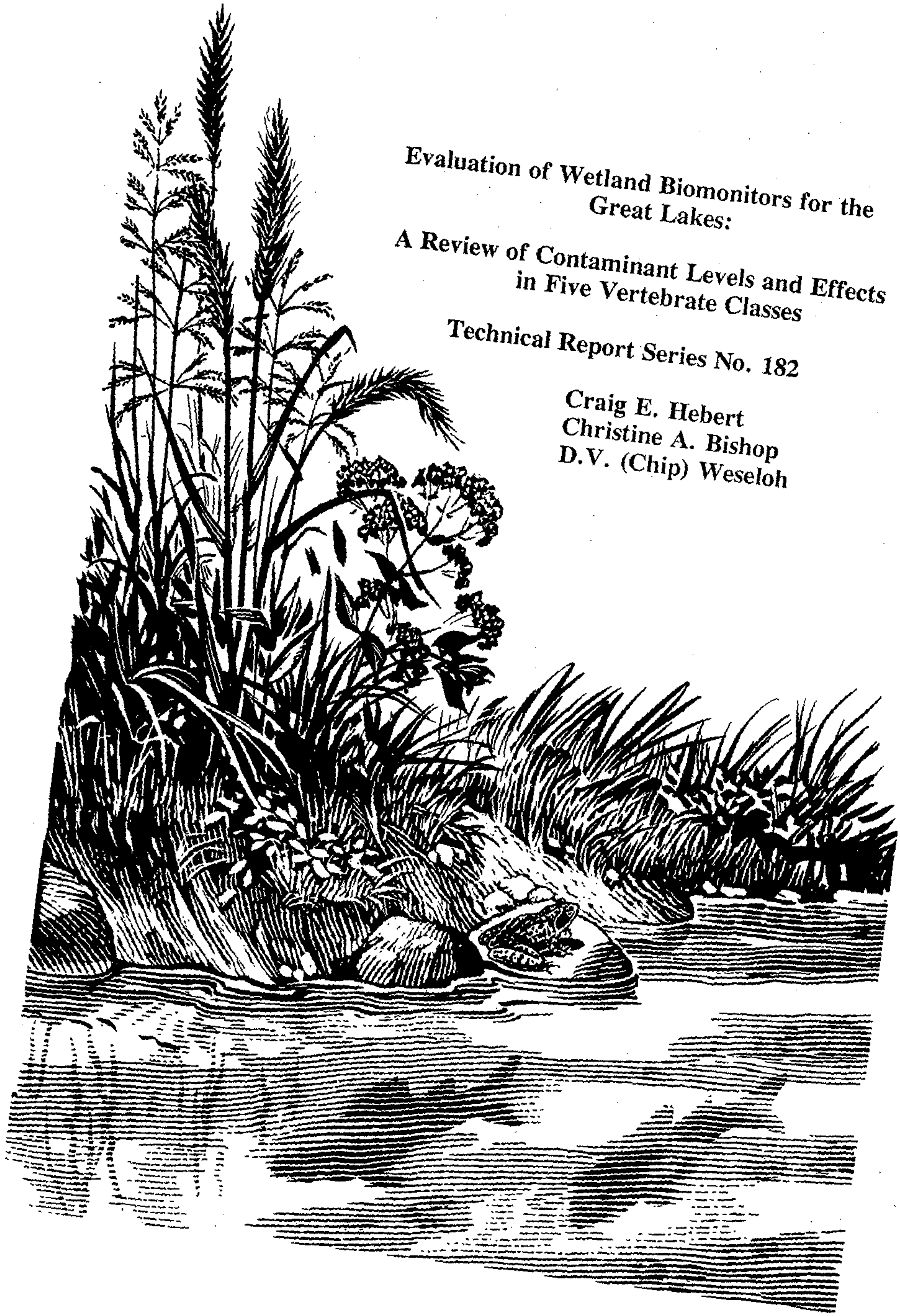

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SOMMAIRE

L'examen avait pour but d'indentifier les espèces qui pourraient servir d'indicateurs de la contamination des terres humides. À cette fin, cinq classes de vertébrés ont été retenues: les ostéichthyens ou *Osteichthyes* (poissons osseux), les amphibiens ou *Amphibia,* les reptiles ou *Reptilia,* les oiseaux ou *Aves* et les mammifères ou *Mammalia*. Des espèces de chaques classe ont été comparées à l'aide de sept critères, lesquels étaient fondés sur les caractéristiques des bio-indicateurs suggérées par le sous-comité des objectifs écosystémiques de la Commission mixte internationale. Les quatre premiers critères avaient pour but de comprendre la biologie des espèces. Aucun examen détaillé de la documentation n'a été effectué concerant ces critères; toutefois, espèces en tant que bio-indicateurs des terres humides. Les trois derniers critères ont servi à évaluer l'accessibilité de l'information relative aux niveaux de contaminants et à leurs effets sur les espèces vivant dans les terres humides. Le présent examen était centré sur la documentation publiée ayant trait à ces critères.

Une cote a été établie pour chaque espèce à l'aide des sept critères susmentionnés. Dans chaque classe, des tableaux ont été établis à l'aide des cotes des espèces et celles-ci ont été classées. Le classement a permis de déterminer la valeur relative de chacune des espèces en tant que bio-indicateurs des terres humides. Compte tenu des contraintes découlant des études sur place, par exemple, l'accessibilité des espèces locales, les espèces qui ont obtenu les cotes les plus élevées devraient être les plus utiles pour évaleur les niveaux de contaminants et leurs effets dans les terres humides. Les résultats sont résumés à la fin de chaque chapitre.

Les cotes peuvent être utilisées pour le choix d'espèces en vue d'évaluer la contamination des terres humides, mais on ne devrait pas s'y limiter. Il est peu probable qu'une seule espèces puisse répondre aux exigences de toutes les études en matière de données. Il incombe donc au chercheur de choisir les espèces qui permettront d'atteindre les objectifs de son étude. À titre d'exemple, si la recherche a pour but d'examiner l'étendue de la contamination des sédiments dans une terre humide, le chercheur devrait alors choisir les espèces associées au réseau trophique de la faune benthique, même si d'autres espèces ont obtenu des cotes plus élevées lors de l'examen. De la même manière, si l'étude a pour but d'examiner les répercussions de la contamination des terres humides sur les humians qui consomment du gibier, il serait alors plus approprié que le chercheur choisisse une espèce chassable. Comme ces considérations peuvent être illimitées, il

est donc préférable de ne pas suggérer une espèce comme étant la «plus appropriée» aux fins de la surveillance biologique des terres humides. L'examen devrait cependant nous fournir un cadre d'étude rationnel pour le choix des espèces devant servir de bio-indicateurs des terres humides et mettre en lumière une partie des travaux qui ont déjà été effectués.

EXECUTIVE SUMMARY

The purpose of this review was to identify species which could be used as indicators of wetland contamination. Five vertebrate classes; Osteichthyes (bony fishes), Amphibia (amphibians), Reptilia (reptiles), Aves (birds) and Mammalia (mammals) were included in the review. Within each class, species were compared using seven criteria. These criteria were based upon the characteristics for biomonitors suggested by the International Joint Commission's Ecosystem Objectives Subcommittee. The first four criteria examined our understanding of the biology of the species. No detailed literature review was conducted for these criteria. However, an attempt was made to evaluate them to provide an overall assessment of the species as wetland biomonitors. The remaining three criteria were used to evaluate the availability of information regarding contaminant levels and effects on wetland species. This review focused on the published literature pertinent to these three criteria.

A score was calculated for each species using the seven criteria. Within each class, the species scores were tabulated and the species were ranked. These rankings reflected the relative merits of the individual species as wetland biomonitors. Within the constraints imposed by field studies, ie. local species availability, the highest scoring species should be the most useful in evaluating contaminant levels and effects in wetlands. These results are summarized at the end of each chapter.

These scores can be used when selecting species to evaluate wetland contamination but they should not be used exclusively. It is unlikely that one species will be able to meet the data requirements of all studies. It is incumbent upon the researcher to choose those species best suited to accomplishing the goals of the study. For example, if the purpose of the research is to examine the extent of sediment contamination in a wetland, then those species associated with benthic food-webs should be selected, regardless of whether other species scored higher in this review. Alternatively, if the intent of the study is to examine the implications of wetland contamination to humans consuming wildlife, then selection of a game species might be warranted. These considerations are endless, thereby precluding any attempt to suggest one species as the "best" wetland biomonitoring species. It is anticipated, however, that this review will provide a rational framework for selecting species as wetland biomonitors and draw attention to some of the work which has already been completed.

GENERAL INTRODUCTION

This literature review was designed to document levels and effects of metals, organic contaminants and radionuclides in vertebrate species from wetlands in the Laurentian Great Lakes. Studies conducted outside the Great Lakes or in areas other than wetlands were included if their results were deemed relevant. A separate review was completed for each of five vertebrate classes: Osteichthyes (bony fishes), Amphibia (amphibians), Reptilia (reptiles), Aves (birds) and Mammalia (mammals). The amount of information available for each of these classes varied greatly.

The overall goal of this review was to assist in the selection of species from each class as indicators of ecosystem health in wetlands. The Lake Ontario Ecosystem Objectives Working Group has described a number of criteria which potential indicator species should possess (adapted from Ryder and Edwards, 1985). The selected species should:

1) have a broad distribution

2) have well documented and quantified niche dimensions expressed in terms of metabolic and behavioural responses

3) be easily collected

4) be suitable for laboratory investigation

5) have historical information pertaining to its abundance and other factors relevant to the state of the organism

6) respond to stresses in an identifiable and quantifiable manner

7) serve as a diagnostic tool for specific stresses of many sorts

8) exhibit a gradual response to human induced stresses

9) be indigenous and maintain itself through natural reproduction

10) interact directly with many components of its ecosystem

11) be recognized as important to humans

12) serve to indicate aspects of ecosystem quality other than those represented by presently accepted parameters

For the purposes of this review these criteria were modified to enhance their usefulness in selecting species as monitors of environmental contamination. Criteria #7 and #8 were combined, as were criterion #1 and part of criterion #9. Criteria #10, #11, #12 and part of #9 were omitted because it was felt that they contributed little to evaluating the relative scientific merits of potential biomonitoring species. The following seven criteria were applied in this review. The selected species should:

1) be commonly found in wetlands during all life-stages and have a broad distribution in the Great Lakes basin. Historical information pertaining to its abundance should also be available. Indigenous species preferred

2) have well documented and quantified niche dimensions. This requires that life history attributes, such as home range size, migratory behaviour, habitat/food selection and breeding biology are well understood

3) be easily collected

4) be suitable for laboratory investigation

5) have historical information pertaining to contaminant burdens

6) respond to stresses in an identifiable and quantifiable manner. These responses should then lead to the development of diagnostic tools

7) exhibit a dose-response relationship when exposed to human-induced stresses

No detailed literature review was conducted for criteria #1-#4. However, a preliminary attempt was made to evaluate these four criteria to provide an overall assessment of the suitability of the various species as Great Lakes wetland biomonitors. Total point scores for each criterion were determined by the number of components in that criterion. Each component was designed to be answered either yes (score = 1) or no (score = 0). The components constituting each criterion are described below along with the maximum possible score for each criterion.

Criterion #1 - a) Does the species inhabit wetlands? Species which did not meet this component were excluded from the review.
b) Is the species common?
c) Do all lifestages of the species reside in wetlands?
d) Does the species have a broad distribution?
e) Is there information regarding the historic abundance of the species?
f) Is the species indigenous?

Maximum score for criterion #1 = 6.

Criterion #2 - a) Does the species have a small home range during the period in which it inhabits the wetland?
b) Is there information regarding its food preferences?
c) Is there information regarding its habitat preferences?
d) Is the breeding biology of the species understood?
e) Is the migratory behaviour of the species understood?

Maximum score for criterion #2 = 5.

Criterion #3 - a) Are samples easily accessible?
b) Are samples widely available?

Maximum score for criterion #3 = 2.

Criterion #4 - a) Can the species be reared in captivity?
b) Can the species be bred in captivity?

Maximum score for criterion #4 = 2.

This evaluation was based upon information in general biological reviews (Appendix 1) and the authors' knowledge of each species. Species from each class were assigned scores for criteria #1-#4 by one of the three authors: Osteichthyes (C. Hebert), Amphibia and Reptilia (C. Bishop), Aves (D.V. Weseloh) and Mammalia (C. Hebert). Scores for an individual species were assigned only in relation to the other species in its class. Hence, species scores are not comparable among the five classes. A scoring rationale for each class can be found in Appendix 2.

An intensive literature review was only conducted for those criteria which were directly concerned with contaminants (Criteria #5-#7). Most of the studies cited in this review were published prior to 1992. Criteria #5-#7 were weighted equally and potential monitoring species were numerically scored for each criterion. The maximum possible score for each criterion was 3. For criteria #5-#7 scores were assigned according to the quantity and quality of information reported in the literature review and evaluated by the senior author. Scores were assigned as follows: excellent (3), good (2), poor (1), no information available (0). Obviously, the author's interpretation of these studies was an important factor in determining the species rankings. The maximum overall score possible for any one species was 24.

CLASS OSTEICHTHYES

Stephenson (1990) examined fish communities in five coastal marshes in Lake Ontario. She identified 17 species which were found in all five of the marshes examined and designated these species as comprising the "characteristic" coastal marsh fish assemblage. This assemblage consisted of the following species (ordered by family):

Cyprinidae	Bluntnose Minnow (Pimephales notatus), *Common Carp (Cyprinus carpio) [NI], *Creek Chub (Semotilus atromaculatus), *Emerald Shiner (Notropis atherinoides), *Fathead Minnow (Pimephales promelas), *Golden Shiner (Notemigonus crysoleucas), *Spottail Shiner (Notropis hudsonius)
Centrarchidae	Largemouth Bass (Micropterus salmoides), Pumpkinseed (Lepomis gibbosus)
Clupeidae	*Alewife (Alosa pseudoharengus) [NI], *Gizzard Shad (Dorosoma cepedianum) [NI]
Percichthyidae	White Bass (Morone chrysops) [NI], White Perch (Morone americana) [NI]
Catostomidae	*White Sucker (Catostomus commersoni)
Esocidae	*Northern Pike (Esox lucius)
Ictaluridae	Brown Bullhead (Ictalurus nebulosus)
Percidae	*Yellow Perch (Perca flavescens)

These species accounted for more than 90% of the total catch in the five Lake Ontario marshes.

Criteria #1-#4 were applied to these 17 species as a preliminary attempt to evaluate their relative usefulness as wetland biomonitors (Table 1). Although all of the species, except the White Bass and White Perch, are common and widely distributed, only 11 of the 17 species (asterisks) are found in all five of the Great Lakes (Scott and Crossman 1973, Hamilton 1987). Five of the species are not indigenous [NI]. Although all of the species are known to occur in wetlands, the Emerald Shiner, Alewife, Gizzard Shad and White Bass are most frequently found in the pelagic zone of lakes and rivers (Scott and Crossman 1973) and their home ranges are large. The other 13 species prefer shallow waters, although the Golden Shiner and the larger species, such as the White Sucker and Northern Pike, may migrate significant distances, particularly as they mature (Scott and Crossman 1973, Smith et al. 1991). Historic information regarding species abundance was only available for the game species and for species which had been introduced recently.

Aquaculture information could only be found for the Fathead Minnow and Yellow Perch. Appendix 2 gives further details regarding species scores for criteria #1-#4.

The following review concentrated on examining contaminant levels and effects in the 12 species which scored at least 12 or 75% (asterisks) with respect to criteria #1-#4. The 75% level was arbitrarily chosen by the author. Particular emphasis was placed on the Cyprinidae which contained the greatest number of species included in the marsh fish assemblage.

Table 1. The degree to which the 17 wetland fish species conformed with modified IJC criteria #1-#4 (see Appendix 2). Maximum possible total score was 15.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
*FATHEAD MINNOW	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
*YELLOW PERCH	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	14
*COMMON CARP	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	13
*CREEK CHUB	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	13
LARGEMOUTH BASS	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	13
*NORTHERN PIKE	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	13
*SPOTTAIL SHINER	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	13
BLUNTNOSE MINNOW	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	12
BROWN BULLHEAD	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	12
*GOLDEN SHINER	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	12
PUMPKINSEED	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0	12
*WHITE SUCKER	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	12
*ALEWIFE	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	11
*EMERALD SHINER	1	1	1	1	0	1	0	1	1	1	1	1	1	0	0	11
WHITE PERCH	1	1	1	0	0	0	1	1	1	1	1	1	0	1	0	10
*GIZZARD SHAD	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	10
WHITE BASS	1	1	1	0	0	0	0	1	1	1	1	1	0	1	0	9

* occurs in all five of the Great Lakes

Contaminant Levels

In Canada, the fish species which has been used most extensively to monitor contaminant levels in the Great Lakes is the Spottail Shiner. The Ontario Ministry of the Environment has utilized young-of-the-year of this species in its Great Lakes biomonitoring program since 1975 (Suns et al. 1981, 1985a, 1985b, 1991). The New York Department of Environmental Conservation recently initiated a similar program (Government of Canada 1991). Forage fish, such as the Spottail Shiner, have much smaller home ranges than game species. Young-of-the-year Spottail Shiners are thought to restrict their movements to an area of approximately two km^2 (Suns et al. 1985b). As a result, this species has been used to identify Areas of Concern in the Great Lakes and, because of its preference for nearshore habitat, has proven to be useful in compliance monitoring. Yearly Spottail Shiner collections have also provided information on temporal changes in contaminant levels in the Great Lakes (Suns et al. 1985b, Suns et al. 1991). Contaminant levels in Spottails collected at 129 Great Lakes locations from 1975-1988 have been summarized by Suns et al. (1991).

Hebert and Haffner (1991) examined interspecific differences in organochlorine levels in forage fish from the St. Clair and Detroit Rivers. Four species were examined: the Bluntnose Minnow, a benthivore; the Spottail Shiner, a facultative benthivore; the Emerald Shiner, a facultative surface feeder and the Brook Silverside (Labidesthes sicculus), a surface feeder. Interspecific differences were observed for contaminants with a log 1-octanol/water partition coefficient greater than 6.0. Levels were greatest in the Bluntnose Minnow followed by the Spottail Shiner, Emerald Shiner and Brook Silverside. These differences indicated that habitat partitioning is a major factor regulating contaminant levels in forage fish species. Leadley and Haffner (1993) confirmed dietary differences among these fish species.

Hebert (1990) found that organochlorine levels in the Bluntnose Minnow and the Spottail Shiner similarly reflected spatial changes in sediment contaminant levels in the marshes of the St. Clair River delta. These two species were much more reliable biomonitors of spatial changes in contaminant levels than another species, the Brook Silverside. This suggests that both these species have limited home ranges and are suitable indicators for examining local geographic differences in contaminant levels.

No studies have examined contaminant levels in feral populations of the Fathead Minnow or the Golden Shiner from the Great Lakes. However, Macdonald and Metcalf (1990) measured levels of nineteen PCB congeners in Golden Shiners, Yellow Perch and Bluntnose Minnows from four inland lakes in central Ontario. Levels in the Yellow Perch were greater than in the other two species.

In Ontario, the only other systematic program which has measured contaminant levels in any of the 13 wetland fish species is the Ontario Ministry of the Environment's sportfish testing program. It was established in 1977 to provide data for the development of fish consumption advisories. In 1990, it provided advice on consumption of sportfish from over 1700 locations in Ontario, 197 of which were located on the Great Lakes (OMOE 1990). However, caution must be exercised when utilizing these data to assess spatial and temporal differences in contaminant levels because the collection sites are not fixed and are sampled intermittently every one to five years. Nevertheless, contaminant levels have declined since the mid-1970s, in species such as the Common Carp, Largemouth Bass, Pumpkinseed, White Bass, White perch, White Sucker, Northern Pike, Brown Bullhead and Yellow Perch (OMOE 1991).

Temporal trends and geographic differences in organic contaminant and trace metal levels in freshwater fish have also been studied by the United States Fish and Wildlife Service. The National Contaminant Biomonitoring Program (formerly the National Pesticide Monitoring Program) was initiated in 1967 and has periodically sampled large fish species from approximately 110 stations in the United States. Fourteen of these stations are located on the Great Lakes: two each on Lakes Ontario, Erie and Huron; three each on Lakes Michigan and Superior; one on Lake St. Clair and one on the St. Lawrence River. Most contaminants have shown substantial declines since this program began (Henderson et al. 1969, 1971, 1972; Lowe et al. 1985, May and McKinney 1981, Schmitt et al. 1981, 1983, 1985; Walsh et al. 1977). Interspecific differences in contaminant levels were variable and depended upon factors such as the contaminant's physical/chemical properties and the organism's age, lipid content, degree of exposure and trophic position. However, benthivores and species occupying the top trophic positions generally exhibited the highest contaminant levels.

Hubert and Ricci (1981) found that time of collection, in addition to fish age, were important factors regulating concentrations of dieldrin and DDT in Carp from the Des Moines River, Iowa.

The Common Carp has been the subject of numerous biomonitoring studies in the Great Lakes. These investigations have shown the Carp to be a good indicator of geographic differences in contaminant levels. DeVault (1985) measured contaminant levels in Carp, Northern Pike, White Sucker and six other fish species collected from Great Lakes harbours and tributaries between 1980 and 1981. Spatial differences were observed in contaminant levels in both the Carp and the Northern Pike. This was not possible for the White Sucker because collections were only made at one location for this species. There were no consistent interspecific differences in contaminant levels. This was not unexpected in that fish size, age and lipid content were not controlled in this study.

Smith et al. (1985) collected Common Carp from the Detroit River in 1982. They measured levels of 72 PCB congeners, total PCBs and 14 other organochlorine contaminants. The five PCB congeners present in the greatest amounts were IUPAC #153, #180, #95, #138 and #170. This study concluded that the PCB composition of the Carp was determined by exposure to contaminated sediments.

Jaffe et al. (1985) collected Carp from Lakes Superior and Huron in 1983. Other species, such as the White Sucker and the Northern Pike, were sampled when Carp were unavailable. The Common Carp was chosen because it was thought to be relatively sedentary. Hence, contaminant levels in that species were expected to reflect the local bioavailability of contaminants. Spatial differences were observed in Carp contaminant levels. They found the highest concentration and variety of compounds in fish from the highly industrialized Saginaw Bay drainage basin. Lake Superior fish showed much lower contaminant concentrations.

In 1984, Jaffe and Hites (1986) collected Carp from the Niagara River and from the mouths of tributaries flowing into Lake Ontario. When Carp were not available, Goldfish (Carassius auratus) and White Sucker were analyzed instead. All of the species were chosen because they are benthic and thought to be relatively non-migratory. A variety of contaminants was found in the fish including fluorinated aromatics, brominated compounds and a variety of persistent pesticides and industrial chemicals. Spatial differences in fish contaminant levels were observed. Interspecific differences in contaminant levels were not examined.

Camanzo et al. (1987) measured contaminant residues in a variety of species, including Carp and Northern Pike, collected in 1983 from thirteen Lake Michigan tributaries and Grand Traverse Bay. Contaminant levels were greater in fish from areas with significant industrial and agricultural development. Wet weight concentrations of PCBs, toxaphene, DDT, DDE and other pesticides were greater in the bottom-feeding Carp than in the Northern Pike. Examination of the data indicates interspecific differences would have been reduced if the data had been lipid normalized.

Harlow and Hodson (1988) reviewed the extent of chemical contamination in Hamilton Harbour and found a variety of heavy metals and organic compounds in four fish species. Levels of mercury in Common Carp, Yellow Perch, White Perch and Alewife declined from 1974 to 1981. Levels of Cu, Ni, Zn, Pb, Cd, Mn, Cr, As, Fe, Al and Se were examined intermittently from 1976 to 1981 (Table 6). In 1980, mean geometric levels of lead in blood from Carp (127 ug/L), White Sucker (79 ug/L) and White Perch (51 ug/L) were lower than in Carp and White Sucker from other Lake Ontario harbours (maximum of 250 ug/L) (Hodson et al. 1984). A wide variety of organic contaminants were also found in muscle tissue taken from a number of fish species including Carp, Yellow Perch, Spottail Shiner and Northern Pike. Levels of most of the contaminants declined from 1972 to 1984.

Wong et al. (1988) examined alkyl lead concentrations in whole Carp, White Sucker and Brown Bullhead collected during the period 1981-87 from the St. Lawrence River near Maitland, Ontario. Levels declined in all three species. An unpublished study by the Ontario Ministry of the Environment in cooperation with the Ontario Ministry of Natural Resources showed a similar decline in total lead levels in whole White Sucker, Yellow Perch and Northern Pike collected at Maitland from 1983 to 1986 (Government of Canada 1991).

Niimi (1982) measured levels of 12 organochlorines and mercury in adult female fish and their eggs collected from Lake Ontario and Lake Erie. The five species examined included the White Sucker and the Yellow Perch. Although this study was not designed to examine interspecific differences in contaminant levels, whole body wet weight and lipid normalized contaminant levels were generally greater in the White Sucker. This study concluded that after spawning, the extent of change in organochlorine residue concentrations in adult females would vary with species. White Sucker concentrations would be expected to increase whereas levels in Yellow Perch would be expected to remain unchanged. These differences would be the result of variations in the relative concentrations between females and their eggs and the percent of body weight deposited as eggs.

Brown Bullhead, Yellow Perch, White Sucker, Northern Pike and three other fish species were collected from Port Hope Harbour in 1984/85 (Environment Canada 1991). Levels of six radionuclides were measured in these fish. The greatest overall radiation doses were observed in the Brown Bullhead followed by the Yellow Perch. Elevated levels were observed in these two species probably because they were long-term inhabitants of the area and they were feeding in contaminated sediments. The levels measured in Brown Bullhead and Yellow Perch at Port Hope were greater than those observed in the same species collected near Sarnia in 1986. The low levels observed in the White Sucker were unexpected as this species is a benthivore and has been considered to be relatively sedentary in other biomonitoring studies (Smith et al. 1991, Servos et al. 1991, Munkittrick et al. 1991).

<u>Contaminant Effects</u>

The chronic effects of persistent contaminants on Great Lakes fish physiology have been reviewed (Fitchko 1986). The most common physiological responses measured were survival, growth and reproductive success. Other responses examined were changes in oxygen consumption, breathing rate, coughing response, metabolism, enzyme activity, thyroid activity, heart rate, histopathology, morphology, immunology, locomotor activity, feeding, temperature selection and other behavioural traits. Many factors such as life stage, physiological state, pH, water hardness, temperature, disease and parasitism, diet, dissolved oxygen, chlorides and exposure to sunlight have been found to influence chemical toxicity (Fitchko 1986). Many of the studies reviewed by Fitchko were conducted on non-wetland species, however, general physiological responses may be similar among species. The following review focuses on studies which have examined effects in the wetland species listed previously.

Numerous laboratory investigations have examined the effects of contaminants on the Fathead Minnow (Devlin et al. 1985, Palmer and Klauda 1987, Schultz and Hermanutz 1990, Silberhorn et al. 1991, Ramey and Halverson 1991). This species is used in toxicity tests in Canada and the United States. However, studies documenting the toxic effects of contaminants on feral Great Lakes cyprinid populations are not available nor is an evaluation of the Fathead Minnow as a surrogate for other cyprinid species. In three non-cyprinid forage fish species, Slimy Sculpin (Cottus cognatus), Rainbow Smelt and Alewife, a relationship has been observed between organochlorine contaminant levels and the incidence of bilateral fin ray asymmetry (Whittle et al. 1987). Among the five wetland cyprinid species examined in this review, only the Common Carp has been the subject of intensive study regarding the impacts of contaminants on fish health. Elevated frequencies of gonadal tumours have been observed in Carp-Goldfish hybrids from the Great Lakes (Sonstegard 1977, Steele and Dickman 1979, Black et al. 1980). Elevated mixed-function oxidase (MFO) levels have also been observed in Carp exposed to contaminants, such as PCBs (Melancon et al. 1981, 1987). Inhibition of blood amino levulinic acid dehydratase (ALA-D) has been used to measure exposure to lead in Carp and White Suckers from the St. Lawrence River and Lake Ontario (Hodson et al. 1984). In this study, Hodson et al. (1984) demonstrated that nearshore benthic fish species, such as the Carp and White Sucker, were among the best species for monitoring health effects in fish.

The White Sucker has been used extensively to monitor the effects of chemical contaminants in the Great Lakes. Borgmann and Ralph (1986) found that sublethal concentrations of Cd reduced growth rates 67-100% in White Sucker larvae. The White Sucker has also been used successfully as an indicator of the carcinogenic potential of contaminated sediments (Cairns and Fitzsimmons 1988, Smith et al. 1989, Smith and Rokosh 1989, Hayes et al. 1990) and for biochemical investigations involving activation of the mixed-function oxidase (MFO) system (Kirby et al. 1989, 1990; Smith et al. 1991, Portt et al. 1991, Servos et al. 1991). Many chemicals have been shown to induce MFO activity including PAHs, PCBs and polychlorinated dibenzo-p-dioxins and dibenzo-furans (Kleinow et al. 1987, Stegeman and Kloepper-Sams 1987, Buhler and Williams

1989). Induced MFO levels have been associated with reduced reproduction in a White Sucker population located near a bleached kraft pulp and paper mill on Lake Superior (Munkittrick et al. 1991). The specific chemical or group of chemicals responsible for this effect could not be determined. The White Sucker has, however, been found to be more tolerant of pulp and paper mill effluent than the Yellow Perch (Kelso 1977). Elevated frequencies of lip papillomas and hepatocellular carcinomas have also been observed in White Sucker populations from contaminated areas (Cairns and Fitzsimmons 1988). Other studies have identified several questions which must be resolved to improve the utility of the White Sucker as a bioeffects monitor, including the degree to which they migrate (Hodson 1984, Smith et al. 1991, Servos et al. 1991).

Elevated frequencies of hepatocellular carcinomas have also been identified in Brown Bullhead populations from the Great Lakes (Black et al. 1980, Baumann et al. 1982, 1987; Black 1988). These tumours may have been caused by high levels of polynuclear aromatic hydrocarbons in the sediments (Baumann et al. 1982). Since 1982, Brown Bullheads have been utilized as an indicator of chemical carcinogenesis at 11 sites in the Great Lakes (Government of Canada 1991). Tumours have also been found in other fish species, including Northern Pike (Sonstegard 1975). A recent review has summarized the effects of environmental contaminants on fish at the molecular, cellular, individual and population levels (Government of Canada 1991).

Modified IJC Criteria

Based upon the studies described above, the 12 fish species were rated with respect to their abilities to fulfill all the criteria for biomonitors as defined in this report. The maximum score possible was 24. The Fathead Minnow scored highest in the comparison (Table 2). Other high scoring species were the Common Carp, Brown Bullhead, White Sucker, Spottail Shiner, Northern Pike Yellow Perch and Largemouth Bass. Each of these species has its limitations, ie. Fathead Minnow (limited field information), Common Carp (not indigenous), Brown Bullhead and Largemouth Bass (limited Great Lakes distribution), White Sucker, Northern Pike and Yellow Perch (possibly migrate) and Spottail Shiner (no studied bioeffects). However, future studies should resolve some of these questions thereby increasing the usefulness of these species as wetland biomonitors. In particular, more effort should be directed towards the examination of biological effects in species, such as the Spottail Shiner, for which spatial and temporal contaminant data already exist.

Table 2. The degree to which 12 wetland fish species conformed with the modified IJC criteria. Scoring for each criterion is described in the general introduction. The maximum total score possible for criteria #1-#7 was 24 (6+5+2+2+3+3+3).

SPECIES	MODIFIED IJC CRITERIA							
	1	2	3	4	5	6	7	TOTAL
FATHEAD MINNOW	5	5	2	2	1	2	2	19
COMMON CARP	5	5	2	1	2	2	1	18
BROWN BULLHEAD	4	5	2	1	2	2	1	17
WHITE SUCKER	5	4	2	1	2	2	1	17
NORTHERN PIKE	6	4	2	1	2	1	0	16
SPOTTAIL SHINER	5	5	2	1	3	0	0	16
YELLOW PERCH	6	4	2	2	2	0	0	16
LARGEMOUTH BASS	5	5	2	1	2	0	0	15
BLUNTNOSE MINNOW	4	5	2	1	1	0	0	13
CREEK CHUB	5	5	2	1	0	0	0	13
GOLDEN SHINER	5	4	2	1	1	0	0	13
PUMPKINSEED	4	5	2	1	1	0	0	13

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CLASS AMPHIBIA

Contaminant Levels

There is very little information regarding contaminant levels in this vertebrate class. Amphibians have never been routinely used as biomonitors and the studies which have documented contaminant levels in wild amphibians are somewhat out of date. Very little information is available specifically for the Great Lakes.

Amphibians from a Lake Erie marsh were exposed to ^{36}Cl-DDT and their DDT levels were measured approximately one year after application (Meeks 1968). Mean levels in fat tissue from Northern Leopard frogs (Rana pipiens) and Bullfrogs (Rana catesbeiana) were 0.03 mg/Kg and 0.4 mg/Kg respectively.

As part of a study examining contaminant levels at the Times Beach confined disposal facility (CDF), located on Lake Erie near Buffalo, levels of six metals were measured in amphibians in 1985/86 (Stafford et al. 1991). Levels of Cd, Cr, Cu, Ni, Pb and Zn were measured in whole body, muscle, bone, liver and kidney samples from the American Toad (Bufo americanus) at the Times Beach CDF. Metal levels were also measured in amphibians collected, in 1986, from a relatively uncontaminated site on the Niagara River (Grand Island). At the Grand Island site, levels of the six metals were measured in muscle, bone and liver samples from frogs (Rana sp.) and in whole body and liver samples from salamander specimens (Plethodon sp.). Levels of Cd, Cr, Pb and Zn were greater in the salmander than in the frog species. Dry weight levels of most of the metals were greater in the Times Beach samples.

Bullfrogs were collected as part of a study examining metal levels in wildlife from Ontario (Ontario Ministry of Natural Resources, pers. comm.). Unfortunately, these samples have not been analyzed.

Other non-Great Lakes studies have documented the presence of contaminants in amphibians. Korschgen (1970) collected American Toads in 1967 from cornfields in Montana. Mean wet weight whole body total DDT residues were 0.1 mg/Kg in adult and juvenile toads. Mean wet weight whole body dieldrin levels were 1.4 mg/Kg in adult toads and 4.6 mg/Kg in juveniles.

Dimond et al. (1975) found that whole body wet weight DDT residues declined in frogs and toads collected over a 10 year period from forests in Maine. Total DDT levels in mixed-species pools of the Green Frog (Rana clamitans), Northern Leopard Frog, Pickerel Frog (Rana palustris) and Bullfrog declined from 0.61 mg/Kg to 0.15 mg/Kg, 10 years after a single DDT dose. Levels in American Toads declined from 2.39 mg/Kg to 0.33 mg/Kg seven years after a single DDT application. DDT residues were somewhat greater in tadpoles and toads than in frogs.

Punzo et al. (1979) measured DDE, dieldrin and heptachlor epoxide levels in viscera samples from American Toads and Northern Leopard Frogs collected in 1974 from an agricultural area in Iowa. Mean wet weight DDE levels were 19 ug/Kg (males) and non-detect (females). Mean wet weight dieldrin levels were 10 ug/Kg (males) and 8 ug/Kg (females). Heptachlor epoxide was not detected in toad samples. None of the contaminants were detected in the Leopard Frog samples.

Beyer et al. (1985) measured metal levels in frogs and toads collected from a site in Pennsylvania which was affected by smelter emissions. They found that Wood Frogs, American Toads, Woodhouse's Toads (Bufo woodhousei), Red-backed Salamanders (Plethodon cinereus) and Slimy Salamanders (Plethodon glutinosus) contained similar concentrations of Cd, Cu, Pb and Zn.

Southern Toads (Bufo terrestris) inhabiting a 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) contaminated site in Florida had whole body TCDD concentrations of 1.36 ug/Kg. This species was among the most contaminated species at the site. Interspecific differences in TCDD contamination were related to the degree to which the species were associated with contaminated soil. Southern Toads live underground and consume soil-borne insects (Young et al. 1987).

Organochlorine and metal levels have been measured in Mudpuppies (Necturus maculosus) from the St. Lawrence River (Bonin 1990). Spatial differences in contaminant levels were observed. Bonin concluded that this species could be a potentially useful biomonitor of contaminants in the environment.

Contaminant Effects

Few studies have examined the effects of organic contaminants on amphibian species native to the Great Lakes. Fitchko (1986) found that in studies conducted outside the Great Lakes the most common responses examined were survival, reproduction, growth, enzyme activity, morphological abnormalities and changes in behaviour. Historically, amphibians have been thought to be less sensitive to the effects of contaminants than fish and recent research seems to support this assumption for some compounds (Touart et al. 1991) whereas for metals, amphibians are often more sensitive than Rainbow Trout or Fathead Minnows (Birge 1992). Hall and Kolbe (1980) found that Bullfrog tadpoles accumulated organophosphate pesticides from water and were resistant to the toxic effects of these compounds. Mortality of Bullfrog and Green Frog tadpoles did not begin until parathion levels in water reached 5 mg/L (Hall 1990). Frog brain cholinesterase (AChE) has been shown to be extremely resistant to AChE inhibitors. Among six species tested from four vertebrate classes frog (Rana sp.) brain AChE showed the least sensitivity to inhibition by five organophosphates (Wang and Murphy 1982). For example, frog brain AChE was approximately 100 times as resistant to paraoxon, methyl paraoxon and diisopropyl fluorophosphate as chicken (Gallus domesticus) brain AChE (Wang and Murphy 1982). These interspecific differences in species sensitivity were the result of different binding affinities for the organophosphate inhibitors and differences in the rate at which AChE was phosphorylated (Wang and Murphy 1982).

Krauter (1993) examined hematological effects and the incidence of micronuclei formation in Bullfrog tadpoles exposed to two aromatic amines. Hematological effects were observed after exposure to both 2-acetylaminofluorene and 2-aminofluorene, although the latter was more toxic. The frequency of micronuclei in peripheral blood increased with increasing exposure to 2-acetylaminofluorene. The measurement of tadpole blood characteristics may provide a sensitive means of evaluating water quality for aquatic organisms.

Schuytema et al. (1991) documented the sensitivity of various life-stages of the Northern Leopard Frog and the Bullfrog to dieldrin. Tadpoles were more sensitive than adults. The responses of these two species were similar to that of the African Clawed Frog (Xenopus laevis), a species which is commonly used in laboratory toxicity studies. Schuytema et al. (1991) emphasized the usefulness of the African Clawed Frog in assessing contaminant hazards to amphibians.

The Frog Embryo Teratogenesis Assay: Xenopus (FETAX) is a 96 hour, whole embryo bioassay which utilizes embryos of the African Clawed Frog (Xenopus laevis). It has been widely used in the laboratory to evaluate the fetotoxicity, teratogenicity and effect on growth of single and complex mixtures of chemicals (Dawson and Schultz 1989, DeYoung et al. 1989, 1990; Fort et al. 1989, 1991; Dawson et al. 1990, Rayburn et al. 1990, 1991; Linder 1990). The degree to which results from this test can be related to effects in Great Lakes amphibian species should be examined.

The sensitivity of other amphibian species, not native to the Great Lakes, has been documented in laboratory studies examining the effects of organic and metal contamination (Anderson and Prahlad 1976, Hall and Swineford 1980, Marchal-Segault and Ramade 1981, Khangarot et al. 1984, 1985; Birge et al. 1985, Edwards et al. 1986, Schuytema et al. 1991, Westerman and Birge 1991). However, few studies have examined contaminant effects in the field. Cooke (1977) examined the effects of the herbicides diquat and dichlobenil on free-living newts (Triturus vulgarus) and on caged frog (Rana temporaria) and toad (Bufo bufo) tadpoles. Neither herbicide affected tadpole rate of development, level of activity or mortality. Cooke (1981) caged tadpoles (R. temporaria) in the field to document the effects of oxamyl, a carbamate pesticide. Mortality, growth, rate of metamorphosis and occurrence of deformities were measured at regular intervals. Mortality was elevated in the exposed tadpoles and their rates of development and growth were slower than in tadpoles not exposed to oxamyl. The incidence of deformities was also elevated in the exposed tadpoles. Cooke concluded that monitoring the incidence of deformities in tadpoles could be especially useful in examining the effects of contaminants on amphibian populations.

Very little information is available regarding the effect of contaminants on the mixed function oxidase system in amphibians. Observations in laboratory-reared Common Frogs (Rana temporaria) indicated that there was no significant difference in MFO activity in male and female frogs, except during breeding when MFO activity was higher in the male (Harri 1980). Rattner et al. (1989) indicated that the paucity of information on MFO levels in amphibians precluded conclusive statements regarding the use of MFO induction as a bioeffects monitor in amphibian populations.

Although acidic precipitation may not be of great concern in the wetland of the Great Lake, the effects of acidic water on amphibian populations has been intensively studied in North America and elsewhere (for reviews see Freda 1986, Clark 1991, Freda et al. 1991). Reproductive failure is the most important effect of acidic water on amphibians (Haines 1981). Reproductive failure occurs as a result of embryo and larval mortality and/or by the disruption of trophic relationships between amphibians and other organisms. The amphibian embryo was the most sensitive life-stage (Gosner and Black 1957, Pierce et al. 1984, Dale et al. 1985a) to the effects of acidic water. For example, the lethal pH levels for embryonic and larval Northern Leopard Frogs were 4.5 and 4.0 respectively (Freda and Dunson 1984, 1985). Similarly, the respective lethal pH levels for embryonic and larval Wood Frogs were 4.0 and 3.5 (Pierce et al. 1984). After hatching, acid tolerance increases throughout larval development (Pierce et al. 1984, Freda and Dunson 1985). Direct mortality of larval amphibians as a result of exposure to acidic water may not be a major contributor to overall mortality in amphibian populations because larval stages can withstand lower pHs than embryos (Freda 1986). Direct mortality of larvae may only occur after transient declines in pH such as those following rainfall or snowmelt (Gascon and Bider 1985). At this time, the major physiological effect which results in mortality of larval amphibians is the disruption of their internal Na and Cl balance (Freda and Dunson 1984, 1986, MacDonald et al. 1984).

Karns (1983) exposed eggs of the American Toad, Leopard Frog and Wood Frog (Rana sylvatica) to water with a pH of 4.2. The fertilization rate of these eggs was 100% indicating that the acidic water had no effect on fertilization. However, these embryos later died from developmental abnormalities caused by exposure to the acidic water. The physiological and toxicological responses of amphibian embryos to acidic water have been well characterized (Pough and Wilson 1977, Tome and Pough 1982, Freda and Dunson

1985). The primary response has been termed the "curling defect" and involves a curling of the embryo within the vitelline membrane (Tome and Pough 1982, Freda and Dunson 1985). Other responses included deformation of the posterior trunk, swelling of the thoracic region, retarded gill development and failure to retract the yolk plug (Pough and Wilson 1977, Karns 1983, Freda and Dunson 1986).

Interspecific differences in sensitivity to acidic water exist (Dale et al. 1986b). These differences generally reflected the acidity of the species' native habitat (Freda 1986). Freda (1986) compared the relative sensitivities of amphibian species to acidic water. He examined both the critical pH (pH at which hatching success declined below normal levels) and the lethal pH (pH at which 100% embryo mortality occurred) and found that the range between these two parameters for many of the species was only 0.2-0.5 pH units (Freda 1986). Of the 26 amphibian species which were compared in that study, 11 are found in the Great Lakes region. These included: the *Spring Peeper (<u>Hyla crucifer</u>), Gray Treefrog (<u>Hyla versicolor</u>), Western Chorus Frog (<u>Pseudacris triseriata</u>), *American Toad, Bullfrog, *Green Frog (<u>Rana clamitans</u>), Pickerel Frog (<u>Rana palustris</u>), *Northern Leopard Frog, *Wood Frog, *Blue Spotted Salamander (<u>Ambystoma laterale</u>) and Spotted Salamander (<u>Ambystoma maculatum</u>). Among these species only six (asterisks) are found around all of the Great Lakes. The lethal pH levels for each of the species indicated that the Northern Leopard Frog was most sensitive to decreasing pH and the Wood Frog was least sensitive. The salamanders (<u>Ambystoma</u> sp.) generally exhibited the highest critical pH (Freda 1986) although this information was not available for the Leopard Frog. Critical pH levels were lowest in the Wood Frog (Freda 1986).

Interspecific differences in breeding behaviour have been found to influence reproductive success (Freda 1986). Factors such as placement of egg masses, size of egg masses and time of oviposition were important in determining reproductive success (Karns 1983, Freda 1986).

Other factors which influenced the toxicity of pond water were temperature (Materna and Rabeni 1989), organic acid concentration in water (Freda et al. 1990) and the water concentrations of Ca (Dale et al. 1985a) and Al (Punzo 1983, Freda 1986). In acidic waters, the solubility of aluminum and other potentially toxic metals increased (Clark and Hall 1985, Freda and Dunson 1986). Exposure of Green Frog tadpoles to sublethal levels of lead adversely affected both acquisition learning and retention (Strickler Shaw et al. 1987). The physiological effects of Al have not been studied in amphibians but Al has been shown to enhance the severity of the "curling defect" (Clark and Lazerte 1985). The most sensitive Leopard Frog life stage to aluminum toxicity was not the embryo but prestage 25 tadpoles (Freda and MacDonald 1990). Threeweek old tadpoles were more tolerant of both acidity and Al than either embryos or prestage 25 tadpoles (Freda and MacDonald 1990).

The influence of Al on the toxicity of acidic water seems to be species specific. Al ameliorated the toxic effects of low pH in Spotted Salamander and Northern Leopard Frog (Clark and Lazerte 1987, Freda and MacDonald 1990). However, the hatching success of American Toad embryos, at a pH of 4.3, declined significantly from 72% to 11% when levels of inorganic monomeric Al were increased from 35 to 46 ug/L (Clark and Hall 1985). Studies using the Wood Frog also found that Al increased the toxicity of acidic water (Clark and Lazerte 1985, Freda et al. 1990).

Freda et al. (1991) have proposed a long term monitoring program to examine the effects of acidic precipitation on amphibian populations. Clark (1991) recommended that the Spotted Salamander be used in any long-term study examining the effects of acidic precipitation on amphibians.

Modified IJC Criteria

Eleven amphibian species were selected as potential wetland biomonitors. These species were chosen to coincide with the Great Lakes species discussed in the review by Freda (1986). Table 3 shows the scores for criteria #1-#4 (see Appendix 2). Overall scores are given in Table 4. The American Toad scored highest in the comparison followed by the Northern Leopard Frog. However, it is obvious that more work needs to be completed regarding the effects of persistent contaminants on Great Lakes amphibian species.

Table 3. The degree to which the 12 wetland amphibian species conformed with modified IJC criteria #1-#4 (see Appendix 2). Maximum possible total score was 15.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
AMERICAN TOAD	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	13
WOOD FROG	1	1	0	1	1	1	1	0	1	1	0	1	1	1	1	12
MOLE SALAMANDER COMPLEX	1	0	0	1	0	1	1	1	1	1	0	1	1	1	1	11
N. LEOPARD FROG	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	11
SPOTTED SALAMANDER	1	0	0	1	0	1	1	1	1	1	0	1	1	1	1	11
BULLFROG	1	0	1	0	1	1	1	0	1	1	0	1	1	1	0	10
GREEN FROG	1	1	1	0	1	1	1	0	0	1	0	1	1	1	0	10
SPRING PEEPER	1	1	0	1	1	1	1	0	1	1	0	0	0	1	0	9
CHORUS FROG	1	1	0	0	0	1	1	0	1	1	1	0	0	1	0	8
GRAY TREE FROG	1	1	0	0	0	1	1	0	1	1	1	0	0	1	0	8
MUDPUPPY	1	1	1	1	0	1	1	0	0	0	0	1	0	1	0	8
PICKEREL FROG	1	0	1	0	0	1	1	0	0	0	0	0	1	1	0	6

Table 4. The degree to which 11 Great Lakes amphibian species meet the modified IJC criteria for wetland biomonitors. Scoring for each criterion is described in the general introduction. The maximum total score possible for criteria #1-#7 was 24 (6+5+2+2+3+3+3).

SPECIES	MODIFIED IJC CRITERIA							
	1	2	3	4	5	6	7	TOTAL
AMERICAN TOAD	6	3	2	2	2	0	0	15
N.LEOPARD FROG	6	2	2	1	2	1	0	14
WOOD FROG	5	3	2	2	1	0	0	13
BULLFROG	4	3	2	1	1	1	0	12
MOLE SALAMANDER COMPLEX	3	4	2	2	1	0	0	12
SPOTTED SALAMANDER	3	4	2	2	1	0	0	12
GREEN FROG	5	2	2	1	1	0	0	11
MUDPUPPY	5	1	1	1	1	0	0	9
SPRING PEEPER	5	3	0	1	0	0	0	9
CHORUS FROG	3	4	0	1	0	0	0	8
GRAY TREEFROG	3	4	0	1	0	0	0	8
PICKEREL FROG	3	1	1	1	1	0	0	7

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CLASS REPTILIA

Contaminant Levels

A review by Hall (1980) compiled the results of 68 early studies which examined contaminant residues in reptiles. The ability of reptiles to accumulate contaminants was documented. Toxicokinetics and the distribution of contaminants among tissues were also discussed. Persistent, organic contaminants, such as DDT, were found to accumulate rapidly in reptiles (Owen and Wells 1976) with the greatest levels measured in fat tissue (Meeks 1968, Pearson et al. 1973) of carnivorous species. Reptile eggs were found to be an important vector of contaminant transfer from the adult female (Cully and Applegate 1967a, 1967b). Contaminant levels in eggs and adult turtles reflected temporal changes in environmental contaminant levels (Fleet and Plapp 1978, Holcomb and Parker 1979, Hall et al. 1979).

There are few recent studies which have examined contaminant levels in reptiles from the Great Lakes. Most of these have focussed on the Snapping Turtle (_Chelydra_ _serpentina_). This long-lived, omnivorous species is the largest turtle found in Ontario (Hammer 1969, Conant 1975, Lovisek 1982) and one of the most common (Weller and Oldham 1988). Most animals remain in the same home range in consecutive years (Obbard and Brooks 1981). Estimates of home-range size vary from 3-4 ha (Obbard and Brooks 1981) to 0.8-28.4 ha (Bishop et al. 1991a). It is consumed by humans (Lovisek 1982), hence, the potential for contaminant transfer to humans has been the focus of several studies.

Stone et al. (1980) found high levels of organochlorines, particularly PCBs, in Snapping Turtles from New York State. There were spatial differences in contaminant levels with the greatest residues observed in turtles from the Hudson River. Turtles from the Hudson River and some other locations were unfit for human consumption because of their high contaminant burdens. Stone et al. (1980) concluded that the analysis of Snapping Turtle fat tissue could facilitate the detection of extremely toxic chemicals present in trace amounts in the environment.

Other Great Lakes studies have also found extremely high concentrations of PCBs (Helwig and Hora 1983, Olafsson et al. 1983, Watson et al. 1985, Bryan et al. 1987a) and PCDDs and PCDFs (Ryan et al. 1986) in fat tissue taken from adult Snapping Turtles. Bryan et al. (1987a) found that tissue specific PCB deposition occurred in Snapping Turtles. Greatest PCB levels were measured in fat tissue followed by testes, brain, liver, heart, kidney, pancreas and lung.

Spatial differences in organochlorine levels were observed in adult Snapping Turtles collected from 16 locations in southern

Ontario during 1988-89 (Hebert et al. 1993). PCB levels were positively correlated with the age, mass and carapace length of the turtles. A significant relationship between types of contaminants occurring in adult female turtles and their eggs was also found.

Other studies have also measured contaminant levels in Snapping Turtle eggs. Struger et al. (1993) measured organochlorine levels in Great Lakes Snapping Turtle eggs collected from two locations in 1981 and eight locations in 1984. Spatial differences were found for PCBs, DDE, dieldrin, chlordane isomers, heptachlor epoxide, HCB, HCH and mirex. Levels were generally greatest in eggs collected from industrialized locations, such as Hamilton Harbour. The pattern of contaminant accumulation in Snapping Turtle eggs was similar to those exhibited by the Herring Gull and the Spottail Shiner.

Bishop et al. (1991b) measured levels of PCBs, PCDDs, PCDFs and organochlorine pesticides in Snapping Turtle eggs collected from four locations on the lower Great Lakes. Significant spatial differences in contaminant levels were observed.

Contaminant Effects

Hall (1980) reviewed the effects of contaminants on reptiles. Reptilian mortality resulting from exposure to pesticides was documented. Evidence suggested that pesticides may interfere with reproduction in oviparous snakes. Physiological studies suggested that enzymes involved in active transport may be inhibited by organochlorine contaminants. In addition, the activity of potential detoxifying enzymes was correlated with contaminant levels.

Few recent studies have examined the effects of contaminants on reptiles. In the Great Lakes, most of those studies have attempted to document the effects of contaminants on the Snapping Turtle. A number of studies have concluded that this species may be resistant to the effects of toxic contaminants (Stone et al. 1980, Olafsson et al. 1983, Albers et al. 1986, Ryan et al. 1986, Bryan et al. 1987a). However, these studies did not include detailed pathological examinations nor assessments of population health.

Bishop et al. (1991b) examined contaminant levels and reproductive success in Ontario Snapping Turtle populations. Eggs were collected from five locations in Ontario: three on Lake Ontario, one on Lake Erie and a control site in central Ontario. The incidence of unhatched eggs and deformites was significantly greater in eggs from the Lake Ontario wetlands. Eggs from two of the three Lake Ontario sites were more contaminated with PCBs, PCDDs and PCDFs than eggs from Lake Erie and the control site. Although a specific chemical could not be identified as the causative factor, PCBs were most strongly correlated with the biological effects, particularly 2,3,3',4,4'-pentachlorobiphenyl

(IUPAC #105).

Hebert et al. (1993) identified differences in contaminant composition in adult Snapping Turtles from sites in the Great Lakes where differences in reproductive success had been observed previously (Bishop 1989). It was postulated that the mono-ortho substituted congener, 2,3,3',4,4'-pentachlorobiphenyl may have been an important factor regulating inter-site differences in the frequency of biological effects.

Previous studies have identified the importance of mono-ortho substituted PCB congeners in contributing to a turtle's toxic burden. Bryan et al. (1987b) measured levels of individual PCB congeners in Snapping Turtle eggs from New York State. After calculating TCDD equivalents, two congeners, 2,3,3'4,4'-pentachlorobiphenyl (IUPAC #105) and 2,3,3'4,4',5-hexachlorobiphenyl (IUPAC #156) accounted for 99% of the toxicity. Olafsson et al. (1987) suggested that selective deposition of 2,3,4,3',4'-pentachlorobiphenyl (IUPAC #105) in the testes of adult male Snapping Turtles may affect the production of offspring.

Other studies have documented the effects of contaminants on reptiles outside the Great Lakes. Genetic damage has been observed in a South Carolina population of Slider Turtles (Trachemys scripta) exposed to low concentrations of the long-lived radionuclides ^{137}Cs and ^{90}Sr (Lamb et al. 1991). Assays involving red blood cell nuclei indicated that there was significantly greater variation in the DNA content of exposed turtles than in turtles from a non-radioactive site. Exposed turtles also exhibited other chromosomal anomalies.

Modified IJC Criteria

There is a paucity of information regarding contaminant levels and effects in reptiles. In the Great Lakes, comprehensive contaminant data sets are only available for the Snapping Turtle. Hence, at this time, this species is the only viable choice as a reptilian wetland biomonitor in the Great Lakes (see Appendix 2). However, other species of reptiles such as the Midland Painted Turtle and the Northern Water Snake are widely distributed in the Canadian Great Lakes and might prove useful in future studies.

Table 5. The degree to which three wetland reptile species conformed with modified IJC criteria #1-#4 (see Appendix 2). Maximum possible total score was 15.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
C. SNAPPING TURTLE	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	14
E. PAINTED TURTLE	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	14
N. WATER SNAKE	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	12

Table 6. The degree to which three Great Lakes reptile species meet the modified IJC criteria for wetland biomonitors. Scoring for each criterion is described in the general introduction. The maximum total score possible for criteria #1-#7 was 24 (6+5+2+2+3+3+3).

SPECIES	MODIFIED IJC CRITERIA							
	1	2	3	4	5	6	7	TOTAL
COMMON SNAPPING TURTLE	5	5	2	2	2	2	1	19
MIDLAND PAINTED TURTLE	6	4	2	2	0	0	0	14
NORTHERN WATER SNAKE	6	3	1	2	0	0	0	12

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CLASS AVES

Numerous studies have documented contaminant levels and effects in a variety of avian species (for reviews see, Conservation Foundation 1988, Government of Canada 1991). However, this review has attempted to focus on only those species which utilize wetlands for foraging and breeding and which have a broad breeding distribution in the Great Lakes. Information regarding habitat use and breeding distribution has been compiled for all of Ontario's bird species (Cadman et al. 1987, Ehrlich et al. 1988). Breeding distribution is important because eggs are a convenient sampling medium and their use minimizes the impact of collections on avian populations (Gilman et al. 1979). In addition, early life stages, such as eggs and chicks, may be most sensitive to the toxic effects of environmental contaminants (Meyers et al. 1991, Wolfe et al. 1990).

The IJC's Ecosystem Objectives Committee is considering a number of avian species as wetland biomonitors (Weseloh et al. 1992). These include: the Black-crowned Night-heron (*Nycticorax nycticorax*), Great-blue Heron (*Ardea herodias*), Black Tern (*Chlidonias niger*), Mallard Duck (*Anas platyrhynchos*), Northern Harrier (*Circus cyaneus*), Red-winged Blackbird (*Agelaius phoeniceus*) and Tree Swallow (*Iridoprocne bicolor*). These and 29 other bird species were considered in this review. The other 29 species were also examined because they are known to breed in Great Lakes wetlands. They included the following: the American Black Duck (*Anas rubripes*), Common Goldeneye (*Bucephala clangula*), Common Merganser (*Mergus merganser*), Canada Goose (*Branta canadensis*), Forster's Tern (*Sterna forsteri*), American Bittern (*Botaurus lentiginosus*), American Coot (*Fulica americana*), Belted Kingfisher (*Megaceryle alcyon*), Blue-winged Teal (*Anas discors*), Common Gallinule (*Gallinula chloropus*), Common Snipe (*Capella gallinago*), Common Yellowthroat (*Geothlypis trichas*), Eastern Kingbird (*Tyrannus tyrannus*), Gadwall (*Anas strepera*), Green Heron (*Butorides striatus*), Green-winged Teal (*Anas crecca*), Killdeer (*Charadrius vociferus*), Least Bittern (*Ixobrychus exilis*), Marsh Wren (*Cistothorus palustris*), Mute Swan (*Cygnus olor*), Pied-billed Grebe (*Podilymbus podiceps*), Sedge Wren (*Cistothorus platensis*), Sora (*Porzana carolina*), Spotted Sandpiper (*Actitis macularia*), Swamp Sparrow (*Melospiza georgiana*), Virgina Rail (*Rallus limicola*), Willow Flycatcher (*Empidonax traillii*), Wood Duck (*Aix sponsa*) and Yellow Warbler (*Dendroica petechia*). For many of the wetland species no information was available regarding contaminant accumulation. In some instances, information on species which do not breed in the Great Lakes was included because it provided general insights into contaminant dynamics and/or effects in avian species.

Contaminant Levels

Waterfowl

Organochlorine levels have been measured in Mallard and American Black Ducks since 1964. Heath and Prouty (1967) initiated a program measuring DDT, DDE, DDD and dieldrin in pooled samples of defeathered wings. This program was continued (Heath and Hill 1974, White and Heath 1976) and expanded to include PCBs, heptachlor epoxide, mirex, endrin, hexachlorobenzene and total chlordane isomers (White 1979, Cain 1981, Prouty and Bunck 1986). The percent occurrence of contaminants and range of contaminants has been found to be stratified by flyway and by species. The greatest contaminant levels have been observed in birds from the Atlantic flyway. Contaminant levels have generally declined through time.

A number of studies have examined contaminant levels in adult and juvenile waterfowl collected from sites in the Great Lakes (Baker et al. 1976, Kim et al. 1984, 1985; Smith et al. 1985, CWS 1986a unpublished, 1989 unpublished; OMNR 1989 unpublished, Hebert et al. 1990, Stafford et al. 1991).

Baker et al. (1976) measured levels of PCBs, As, Be, Cd, Hg and Pb in liver, muscle and brain tissue from waterfowl collected in New York state in 1972. The species included were the Canada Goose, American Black Duck, Mallard, Bufflehead (*Bucephala albeola*), Canvasback (*Aythya valisineria*, Greater Scaup (*Aythya marila*) and White-winged Scoter (*Melanitta deglandi*). Only the first three species breed extensively in the Great Lakes. Lowest contaminant levels were found in the Canada Goose which reflects its herbivorous diet. Highest PCB levels were observed in the diving duck species. Mercury was most frequently detected in liver samples from the Mallard and American Black Duck.

Mirex, PCB and DDE levels were measured in brain, breast muscle, liver and subcutaneous fat from 19 species of waterfowl including Mallards, Green-winged Teal, Blue-winged Teal and Common Mergansers collected in New York state from 1979-1980 (Kim et al. 1984). The waterfowl samples originated from different locations in New York state and the only birds that were collected from the Great Lakes were from the Niagara River. Among the species that were collected from the Niagara River, only the merganser species breed in the Great Lakes and even they do not regularly breed in the lower Great Lakes. However, interspecific comparisons in contaminant burdens indicated that the mergansers were the most contaminated species. Compared with the results from Baker et al. (1976) levels have declined in waterfowl from New York state.

Kim et al. (1985) examined PCB, DDE and mirex levels in breast muscle and subcutaneous fat from waterfowl collected from New York state in 1981-1982. Most of the birds were collected from the Hudson River. However, some of the Canada Goose and Mallard collections were completed on Lake Ontario. Results from this study corroborated those from Kim et al. (1984). Levels of PCBs and mirex in fat tissue continued to decline while mirex levels increased slightly.

Smith et al. (1985) measured levels of 14 organochlorines and 72 PCB congeners in eviscerated, defeathered carcasses of three species of diving ducks collected from the Detroit River during the winter of 1981. During the February to March period of fat mobilization total PCB levels were inversely correlated with percent lipid. Hepta- and octachlorobiphenyls were accumulated preferentially in all three waterfowl species. Waterfowl from the Detroit River were generally more contaminated than birds from New York state (Kim et al. 1984, 1985).

Levels of PCBs in Mallard and American Black Ducks collected from Lake Michigan in 1985-1986 ranged from 6.05-214 ppm (lipid weight) (WI DNR 1987).

The Canadian Wildlife Service examined organochlorine levels in pooled samples of liver and muscle tissue from Mallards, Common Goldeneyes and Common Mergansers collected from the St. Clair River in 1985/86 (CWS 1986a unpublished). Contaminant levels in Goldeneye and Common Mergansers increased with time reflecting their accumulation of locally bioavailable contaminants. Temporal trends in the Mallard were not as obvious. Contaminant levels were greatest in the Common Merganser.

The Canadian Wildlife Service (1989 unpublished) collected migratory waterfowl from Ontario in 1989/90. Breast muscle tissue was analyzed for the presence of organochlorines, metals, dioxins, furans and radionuclides. The relationship between contaminant levels in breast muscle and wing tissue is currently being examined. These collections were part of a nation-wide program to measure contaminant levels in waterfowl and assess the implications of those levels to the human consumer. Results are not yet available.

Foley et al. (1988) examined organochlorine levels in Common Goldeneye collected from the Niagara River during the winter of 1984-1985. Their results were similar to the above study (CWS 1986a unpublished). Levels of PCBs, dieldrin, HCB and heptachlor epoxide increased from the time of arrival on the wintering grounds until spring migration (45 to 135 days).

Organochlorine levels were quantified in 107 Mallard ducks collected from ten Great Lakes sites during July and August, 1988/89 (OMNR 1989 unpublished). Six of these sites were located in IJC Areas of Concern. Both adults and juveniles were collected. Liver and muscle tissue was analyzed. There were spatial differences in Mallard contaminant burdens. These differences reflected the local bioavailability of contaminants. For example, total PCB levels (wet weight) in liver tissue ranged from 38 ppb at Amherst Island, Lake Ontario to 2,087 ppb in Windermere Basin, Hamilton Harbour.

Hebert et al. (1990) measured organochlorine levels in liver and muscle tissue from resident and migratory waterfowl collected from the St. Clair River delta in 1986. For both Mallard and Redhead Ducks (Aythya americana), levels of pentachlorobenzene (QCB), hexachlorobenzene (HCB) and octachlorostyrene (OCS) were greater in resident breeding birds than in migratory individuals. There were no significant differences in contaminant levels between hens and their chicks, suggesting that the rate of contaminant accumulation in the chicks was rapid. Octachlorostyrene levels in hens and their chicks were correlated. However, there was a considerable amount of intra-brood variability in OCS levels. There were no significant differences in contaminant levels between resident Mallard and Redhead ducks.

Stafford et al. (1991) examined levels of Cd, Cu, Hg and Zn in adult and juvenile Mallards from the Times Beach CDF located on Lake Erie. Levels of all of the metals, particularly Cd, were elevated in birds from the Times Beach site compared with a reference site. Metal levels were similar in both adults and juveniles, except for Cd, which was present in greater concentrations in the adult birds.

Other studies have introduced flightless domestic waterfowl into contaminated areas to measure their ability to accumulate contaminants (Brand and Rocke 1987, Miller et al. 1987, Dobos et al. 1991, Gebauer 1991, Rodrigue et al. 1991, Gebauer and Weseloh 1992, Weseloh et al. 1993). These studies have used domestic waterfowl as surrogates for wild birds to gain a better understanding of the processes which regulate contaminant levels in resident and migratory waterfowl. Heinz (1980) found that there were no differences between domestic and wild Mallards in their ability to accumulate methylmercury and concluded that domestic Mallards would be suitable substitutes for wild Mallards in toxicological studies. Brand and Rocke (1987) found that lead shot ingestion rates were similar in domestic and wild Mallards. During an outbreak of avian botulism, the mortality rates of domestic and wild Mallards were similar. This study concluded that domestic Mallards were sensitive and reliable indicators of contaminants and diseases in waterfowl.

Few studies have examined the rate at which contaminants are accumulated in waterfowl. This stems from the difficulty of accurately measuring the residence time of highly mobile wild birds at a particular site (Eberhardt and Cadwell 1985). It is important to understand the kinetics of contaminant accumulation in waterfowl so that the risk posed to birds utilizing contaminated areas, such as confined disposal facilities, can be assessed. Many North American wetlands may contain both excellent waterfowl habitat and high concentrations of persistent contaminants (Dobos et al. 1991, Gebauer 1991). A study by the Canadian Wildlife Service (Weseloh et al. 1993) found rapid rates of uptake for HCB, OCS, DDE, PCBs and lead in Pekin Ducks released into the lower St. Clair River and Hamilton Harbour's Windermere Basin. The ability of domestic Mallards to rapidly accumulate contaminants was also observed by Miller et al. (1987). Domestic Mallards released into a contaminated wetland accumulated DDE, PCBs, chlordane, arsenic, selenium and mercury. Significant accumulation of some of these contaminants occurred despite relatively low sediment contaminant levels. Similarly, PCBs, DDE and chlordane were rapidly accumulated in domestic Mallards and Call Ducks introduced into a confined disposal facility at Thunder Bay on Lake Superior (Dobos et al. 1991) and at two other contaminated areas in the Great Lakes (Gebauer 1991). Rodrigue et al. (1991) released adult Pekin Ducks at nine locations in the St. Lawrence River during the summers of 1987, 1988 and 1989. Exposure periods varied from 14 to 73 days. There was a rapid increase in liver contaminant concentations and the exposed birds were 10-1,000 times more contaminated than birds at a control site. Nebeker et al. (1991) found that dieldrin accumulation in juvenile Mallard Ducks was rapid. It is evident that areas which are utilized by waterfowl for even short periods of time, and are heavily contaminated, may be important in contributing to the birds' toxic burden.

Only one Great Lakes study has examined contaminant levels in waterfowl eggs. Haseltine et al. (1981) examined organochlorine (PCB Aroclor 1260, DDT, DDE, TDE, dieldrin, heptachlor epoxide, toxaphene, HCB, mirex, endrin, c-chlordane, o-chlordane, c-nonachlor, t-nonachlor), polybrominated biphenyl, polychlorinated styrene and metal (As, Cd, Cr, Cu, Hg, Pb, Se, Zn) levels in eggs from five species of waterfowl collected in Lake Michigan from 1977-78. The species examined in the study included the American Black Duck, the Mallard, the Gadwall and two piscivorous species, the Red-breasted Merganser (Mergus serrator) and the Common Merganser. The merganser species exhibited the highest contaminant levels. Dabbling ducks had much lower organochlorine and Hg residues than the mergansers. Geometric means of PCBs and DDT in dabbling duck eggs were below 2.0 and 1.0 ppm (wet weight), respectively. Levels of DDE and PCB Aroclor 1260 in the Red-breasted Merganser had declined since 1975 and eggshell thickness had increased to 2-3% below pre-1946 shells. Levels of the other compounds were low in all of the species.

The studies described above measured contaminant levels in tissue samples or eggs thereby requiring a large number of organisms to be sacrificed. Friend et al. (1979) found that DDE, dieldrin and PCB residues in the blood of Mallard Ducks adequately reflected fat concentrations and whole body burdens. Thus, non-lethal sampling techniques, such as the collection of blood samples, should be considered when planning biomonitoring studies.

Many studies have documented contaminant levels in adult and juvenile waterfowl from outside the Great Lakes (White and Finley 1978, Vermeer and Peakall 1979, White et al. 1979, Mayack et al. 1981, Di Giulio and Scanlon 1984a, Ohlendorf and Miller 1984, Mora et al. 1987, Hall et al. 1989, Ohlendorf et al. 1990, Merchant et al. 1991). Fewer studies have documented contaminant levels in waterfowl eggs (Ford and Hill 1990).

Waterbirds

Contaminant levels in colonial fish-eating birds such as the Herring Gull (Larus argentatus) (Gilbertson 1974, Gilman et al. 1977, Mineau et al. 1984, Struger et al. 1985, Weseloh et al. 1990), Double-crested Cormorant (Phalacrocorax auratus) (Weseloh et al. 1983), Common Tern (Sterna hirundo) (Weseloh et al. 1989) and Caspian Tern (Sterna caspia) (Struger and Weseloh 1985) have been measured extensively. However, these species do not usually breed in wetlands. For this reason, these species were not included in this report. Previous reviews have compiled information on contaminant levels and effects in these species (Conservation Foundation 1988, Government of Canada 1991).

Contaminant levels in waterbirds which inhabit Great Lakes wetlands have not been as thoroughly documented as the waterfowl species mentioned previously. Ohlendorf et al. (1981) measured organochlorine residues in herons from the United States. Organochlorine levels were measured in Great Blue Herons, Green Herons, Black-crowned Night-herons, Little Blue Herons, Louisiana Herons and Yellow-crowned Night-herons from 16 U.S. states, four of which were located on the Great Lakes. Levels were almost always greater in adult birds than in juveniles. Concentrations of many of the contaminants were greatest in birds from the Great Lakes. The most commonly detected contaminant was DDE followed by dieldrin. Mercury levels in Lake St. Clair Great Blue Herons were 23 and 175 ppm (wet weight) in carcass and liver samples, respectively.

Heinz et al. (1984) examined PCB, DDE and dieldrin levels in brain tissue, stomach contents and carcasses of four species collected on the Sheboygan River from 1976-1980. Wet weight PCB levels were greatest in Belted Kingfisher carcasses. Similar wet weight PCB levels were observed in Great Blue Heron, Spotted Sandpiper and Solitary Sandpiper (Tringa solitaria) carcasses. Examination of the data indicated that whole body, lipid normalized PCB levels were similar in the Belted Kingfisher and the Great Blue Heron. Lipid normalized levels were lower in the sandpipers.

Great Blue Herons have also been used to monitor contaminant levels in areas outside the Great Lakes, such as the Canadian prairie provinces (Vermeer and Reynolds 1970), British Columbia (Whitehead et al. 1991), eastern United States (Ohlendorf et al.

1979) and northwestern United States (Blus et al. 1980, 1985; Fitzner et al. 1988). Most of these studies examined contaminant residues in heron carcasses, however, other types of samples have been suggested, including excrement (Fitzner et al. 1982) and eggshells (Norman et al. 1989).

Another heron species, the Black-Crowned Night-Heron has also been used to monitor contaminant levels in Great Lakes wetlands. Gilbertson et al. (1976) examined PCB levels in heron eggs collected from Lakes Ontario and Erie in 1972-73. Eggs from Lake Ontario and Lake Erie contained total PCB levels of 304 ppm and 144 ppm (dry weight), respectively. Levels of PCBs, dioxins, furans and other organochlorines have been measured in Black-Crowned Night-Heron samples from Green Bay (WI DNR 1983, Heinz et al. 1985, Stalling et al. 1985) and Lake Michigan (Heinz et al. 1985). PCB and DDE levels were greater in Black-Crowned Night-Herons than in seven of eight other species (Heinz et al. 1985). Organochlorine levels in egg samples from the St. Clair River, the Niagara River and Middle Island in Lake Erie (CWS 1986a unpublished) had declined relative to levels observed in egg samples collected in 1982 (CWS 1982 unpublished). PCB levels in Niagara River eggs collected in 1985-86 were greater than those observed in heron eggs collected in 1979-81 from the Atlantic Coast (Custer et al. 1983) and the Tennessee Valley (Fleming et al. 1984). PCB levels in heron eggs from the St. Clair River and Lake Erie were similar to those observed in the eggs from the 1979-81 collections (CWS 1986a unpublished).

Other species which nest in wetlands are the Black Tern and Forster's Tern. Neither of these species is distributed widely in the Great Lakes, particularly the Forster's Tern. Very little information exists regarding contaminant levels in the Black Tern, and because of its rarity and threatened status in the Great Lakes basin, sampling for contaminant analysis may not be warranted. Black Tern eggs from Green Bay contained 0.5-2.2 ppm (wet weight) total PCBs (WI DNR et al. 1983). More information exists regarding contaminant levels in the Forster's Tern (Heinz et al. 1985, Stalling et al. 1985, CWS 1986b unpublished, Hoffman et al. 1987, Kubiak et al. 1989, King et al. 1991, Bishop et al. 1992). However, this species only nests in southwestern Ontario (Cadman et al. 1987).

Passerines

Few studies have examined contaminant residues in passerine species which inhabit wetlands. One of the species with the greatest potential as a wetland biomonitor is the Red-winged Blackbird. With an estimated population of almost 200 million, it may be the most abundant bird species in North America (Weatherhead and Bider 1979). Red-winged Blackbirds use a variety of habitats for nesting, feeding and roosting, including wetlands (Albers 1978, Case and Hewitt 1963). At the Times Beach CDF on Lake Erie, levels of Cd, Cr, Cu, Ni, Pb and Zn were measured in feathers and in liver, muscle and bone tissue from adult and immature Red-winged Blackbirds (Stafford et al. 1991). There were no consistent differences between adults and juveniles. Red-winged Blackbird eggs were also analyzed for the presence of metals (Stafford et al. 1991). Shell samples generally contained higher metal levels than did the yolk/albumen samples, except for Zn. Bishop et al. (1993) measured organochlorine levels in Red-winged Blackbird eggs from nine Ontario wetlands. Spatial differences in organochlorine burdens were detected, and a significant positive correlation with organochlorine residues in sediments were found. This study concluded that organochlorine levels in the Red-winged Blackbird reflected the local bioavailability of contaminants and that this species has potential as a wetland biomonitor.

Tree Swallow eggs have also been used to monitor contaminant levels in the environment (Shaw 1984, Jones and Giesy 1991, Beaver 1991, C.A. Bishop, pers comm.). Tree Swallow eggs are easily collected because breeding birds are readily attracted to artificial nestboxes. Shaw (1984) measured levels of organochlorine pesticides and PCBs in Tree Swallow eggs and nestlings from central Alberta. At two of the five locations studied, DDE and PCB levels were greater in nestlings than in eggs indicating that these contaminants were locally bioavailable. Beaver (1991) assessed the feasibility of using Tree Swallows as indicators of environmental contamination in Green Bay, Wisconsin and concluded that the Tree Swallow had potential as a biomonitor. Among the species nesting in the study area, Tree Swallow, Forster's Tern and Common Tern eggs contained similar concentrations of TCDD equivalents (Jones and Giesy 1991). TCDD-EQ concentrations in the Red-winged Blackbird were five to ten fold lower than those measured in the other three species and it was concluded that Red-wing Blackbirds accumulated TCDD-EQs very slowly. During the summer of 1991, Tree Swallow eggs and chicks were collected for organochlorine analysis from five sites in Ontario, three of which were located on the Great Lakes (C.A. Bishop, pers. comm.). Spatial differences in organochlorine levels were observed, and it appears that nestling swallows would be better local indicators of contaminants than their eggs.

Raptors

Limited data exist regarding contaminant levels in Northern Harriers. Organochlorine and mercury levels have been measured in various tissues of Northern Harriers from British Columbia, Saskatchewan and Quebec (Noble and Elliott 1990). No information is available regarding contaminant levels in Northern Harriers from the Canadian Great Lakes. Contaminant levels and effects in other raptor species, not specifically associated with wetlands, are documented elsewhere (Conservation Foundation 1988, Government of Canada 1991).

CONTAMINANT EFFECTS

In general, the most common physiological responses which have been measured in avian species to assess chronic exposure to contaminants have been changes in mortality, reproductive success, metabolism, morphology, enzyme activity, histopathology and behaviour (Fitchko 1986). The following review focuses on studies completed in the Great Lakes.

Waterfowl

No studies were found which documented the effects of organic contaminants on feral populations of Great Lakes waterfowl. Outside the Great Lakes, in Arkansas, the effects of polychlorinated dibenzo-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs) on Wood Duck reproduction has been documented (White and Hoffman 1991). Effects included a high incidence of lower bill deformities. The impact of agricultural chemicals on prairie waterfowl has been examined (Johnson 1986, Sheehan et al. 1987, Grue et al. 1988, Mineau et al. 1988). Avian mortality has been shown to result from the use of pesticides on turfgrass (Stone 1980).

Numerous laboratory studies have examined contaminant effects on waterfowl. The Mallard is the wetland species which has been most intensively studied (Hudson et al. 1984). A large amount of information is available regarding the acute and chronic toxicity of chemicals to the Mallard (Hudson et al. 1984, Smith 1987). A recent study has examined the relationship between contaminant exposure and monoxygenase activity in the Mallard (Melancon et al. 1991). Other studies have examined the mallard's sensitivity to organochlorines such as DDE and PCBs. The effect of DDE on eggshell thickness has been demonstrated experimentally with Mallards (Heath et al. 1969) and American Black Ducks (Longcore et al. 1971, Longcore and Stendell 1977). A recent study examining contaminant effects on Mallard eggshell quality concluded that the stage of embryonic development can affect the detection of contaminant effects (Bennett 1991).

Friend and Trainer (1970) found that PCBs were not toxic to Mallards when the birds were exposed for ten days at concentrations ranging from 25-100 ppm. However, when exposed to duck hepatitis virus the contaminant-exposed birds experienced greater mortality than the controls. Other studies have found that mallards are relatively insensitive to the toxic effects of PCB Aroclors 1254 (Heath et al. 1972, Custer and Heinz 1980) and 1242 (Haseltine and Prouty 1980) and to individual coplanar PCB congeners (Brunstrom 1988, Brunstrom and Lund 1988, Brunstrom 1989, Brunstrom et al. 1990). Other species, such as the Domestic Chicken (<u>Gallus domesticus</u>), are known to be much more sensitive to PCB exposure (Brunstrom et al. 1990).

Mallards have been shown to be more sensitive to the toxic effects of other organic contaminants. Brunstrom et al. (1990) assessed the embryotoxicity of 18 polycyclic aromatic hydrocarbons (PAHs) to four avian species including the Mallard, the Common Eider Duck (Somateria mollissima), the Domestic Chicken and the Turkey (Meleagris gallopavo). The sensitivity of the four species was similar. Bennett et al. (1990) examined the effects of dicofol on Mallard eggshell quality. Dicofol dietary concentrations were negatively correlated with eggshell strength, thickness and weight. The effects of crude oil ingestion on domestic Mallards (Pekin Ducks) have been documented (Miller et al. 1979). Petroleum contaminants have been implicated in impairing reproductive function in both male and female Mallards (Holmes and Cavanaugh 1990). Levels of reproductive hormones changed and the rate of nest abandonment increased in Mallards exposed to parathion (Bennett et al. 1987). In hens which abandoned their nests levels of prolactin were reduced and corticosterone concentrations were elevated. Exposure to methyl parathion was also found to alter loafing, foraging and escape behaviour in Mallard broods, potentially leading to a reduction in the number of young recruited into the population (Meyers et al. 1987). The effects of carbofuran on Mallard ducklings has been investigated (Martin et al. 1990). No direct mortality occurred during the experiment but behavioural changes were observed and brain cholinesterase levels were directly related to carbofuran exposure.

Few studies have documented the effects of heavy metals on feral Great Lakes waterfowl. Lead concentrations in some highly industrialized areas, such as Hamilton Harbour, may be responsible for occasional waterfowl mortality (Weseloh et al. 1993). Lead shot ingestion may also be a major factor leading to waterfowl mortality (Anderson 1975, Sanderson and Bellrose 1986).

Field studies completed outside the Great Lakes have documented the effects of selenium on waterfowl. Mallards from California's Kesterton Reservoir had high Se levels and exhibited poor reproductive success, including a high incidence of teratogenesis (Hoffman et al. 1985, Ohlendorf et al. 1986).

For birds in general, the chronic toxicities of aluminum (Al), cadmium (Cd), mercury (Hg) and lead (Pb) have been reviewed (Scheuhammer 1987). This review, however, will examine in greater detail the effects on wetland species. The effects of heavy metals, such as Al, Cd, Hg, Pb and Se on Mallard and American Black Ducks have been documented in laboratory studies. Sparling (1990) found that dietary Al adversely affected bone formation in Mallard and American Black Ducks.

Cadmium induced effects have been observed in the testes and kidneys of Mallards (White et al. 1978, Cain et al. 1983). Cadmium has been shown to reduce packed cell volume and hemoglobin content in Mallard ducklings (Cain et al. 1983) but not in adults (White and Finley 1978). The effect of Cd on Mallard energy metabolism has also been studied (Di Giulio and Scanlon 1984b). Ducklings of American Black Ducks exposed to Cd displayed altered avoidance behaviour (Heinz and Haseltine 1983). Exposure to Cd, Pb and methylmercury resulted in increased metallothionein levels in exposed Mallards (Jordan and Bhatnagar 1990, Jordan et al. 1990).

Heinz (1979) found that female Mallards fed 0.5 ppm methylmercury laid more eggs outside their nests than did control birds. Exposed females also laid fewer eggs and raised fewer young. Ducklings of exposed hens were less responsive to maternal calls and were hyper-responsive to external stimuli.

The clinical signs of Pb poisoning in the Mallard have been documented (Roscoe and Nielsen 1979). Roscoe and Nielsen (1979) also showed that diet was a major factor influencing the toxicity of Pb. A similar relationship between diet and metal toxicity has been reported for other metals. When the amount of protein in the diet of Mallard ducklings was decreased their sensitivity to arsenate and selenium increased (Hoffman et al. 1992).

Domestic Mallards and American Black Ducks were less sensitive to Pb shot than wild Mallards and wild Black Ducks (Rattner et al. 1989). However, the stress of captivity may have played a role in the mortality of the wild birds. There was no difference in Pb sensitivity between domestic Mallards and domestic Black Ducks. One of the most sensitive biochemical indicators of Pb exposure is inhibition of the enzyme, delta-aminolevulinic acid dehydratase (ALAD). It has been used as an indicator of Pb exposure in waterfowl species, such as the Mallard (Finley et al. 1976, Dieter and Finley 1979) and the Canvasback (Aythya valisineria) (Dieter et al. 1976, Dieter 1979).

Exposure to Se has been shown to result in impaired reproduction (Heinz et al. 1987, 1989; Hoffman and Heinz 1988). Exposure to selenomethionine, a form of Se, resulted in a reduced immune response in Mallards (Fairbrother and Fowles 1990). Selenium had no effect on the ability of Mallard ducklings to respond to a fright stimulus (Heinz and Gold 1987).

The effects of acidic precipitation on avian trophic relationships and breeding success have been investigated (Blancher and McAuley 1987, Longcore et al. 1987, McNicol et al. 1987).

Waterbirds

The effects of contaminants on Great Lakes colonial waterbirds have been reviewed (Conservation Foundation 1988, Government of Canada 1991). For the purposes of this review, only three species, the Great Blue Heron, the Black-Crowned Night-Heron and the Forster's Tern are relevant. In all three species, contaminants are thought to be responsible for population declines, adverse effects on reproduction, congenital abnormalities and biochemical changes. Contaminants are also responsible for eggshell thinning in the Great Blue Heron and the Black-Crowned Night-Heron and for behavioural changes in the Forster's Tern. The relationship between monooxygenase activity and contaminant levels has been examined in pipping Black-Crowned Night-Herons from the Great Lakes (Rattner et al. 1991, Melancon et al. 1991).

Ohlendorf et al. (1981) found that more than 20 percent of herons found dead or moribund had lethal or hazardous concentrations of organochlorines in their brains. They concluded that dieldrin and DDT were probably responsible for most of the observed mortality. There is no recent information on contaminant induced effects in Great Lakes populations of Great Blue Herons. However, recent studies, completed in British Columbia, have found evidence of sublethal toxicity induced by tetrachloro-dibenzo-p-dioxin (TCDD) (Hart et al. 1989, Moul et al. 1989, Bellward et al. 1991). The effect of TCDD on the central nervous system of Great Blue Heron hatchlings has also been examined (Henshel et al. 1991).

Passerines

There is little information regarding the effects of contaminants on passerine species associated with Great Lakes wetlands. Koster (1991) assessed the impact of agricultural pesticides on Red-winged Blackbirds in the Holland Marsh. This area is removed from the Great Lakes but is intensively utilized for agricultural purposes. There was no difference in egg hatching success or AChE activity in blackbirds from exposure and control areas.

Laboratory studies have indicated that adult Red-winged Blackbirds may be more sensitive to some pesticides than other bird species for which comparative data exist (Schafer 1972, Schafer et al. 1983, Schafer and Brunton 1979, Wolfe et al. 1990). Wolfe et al. (1990) found that adult European Starlings were less sensitive than adult Red-winged Blackbirds to the organophosphate compounds diazinon and terbufos. However, the sensitivity of nestlings of the two species was similar (Wolfe et al. 1990). Nestling Red-winged Blackbirds were more sensitive to a single oral dose of dimethoate than European Starling nestlings (Meyers et al. 1991) but were less sensitive to chlorpyrifos. Red-winged Blackbird and European Starling nestlings were more sensitive than adult birds (Meyers et al. 1991, Wolfe et al. 1990).

The effects of cholinesterase inhibiting pesticides (organophosphates and carbamates) on brain cholinesterase activities in passerine birds from Montana and Oregon have been documented (Zinkl et al. 1979). The effects of methyl parathion on Red-winged Blackbirds dosed in the field has been studied (Meyers et al. 1990). Although methyl parathion caused ataxia, lethargy, lacrimation and a decrease in AChE activity there were no apparent adverse effects on reproduction or long-term survival.

The effects of organophosphate compounds on Tree Swallows and Eastern Bluebirds (Sailia sailis) was studied in southern Ontario apple orchards (Burgess et al. 1989). Tree Swallow hatching success was lower in the organophosphate sprayed orchards than in the unsprayed orchards.

The effects of lake acidification on reproductive success and trace metal induced biochemical responses in the Tree Swallow have been examined (V. St. Louis, pers comm.). This study also included an examination of the effects of lake acidification on Tree Swallow foraging behaviour (St. Louis and Breebaart 1991, St. Louis et al. 1990). It concluded that the reproductive success of Tree Swallows nesting near lakes was at risk if prey and/or calcium availability declined as a result of acidification.

Modified IJC Criteria

Thirty-six avian species were evaluated as potential wetland biomonitors. Table 7 shows the scores for criteria #1-#4 (see Appendix 2). Overall scores are given in Table 8. The Mallard scored highest in the comparison followed by the Red-winged Blackbird. The limitations of these species as biomonitors should be considered when interpreting results. For the Mallard, these weaknesses include its relative lack of sensitivity to contaminant effects and its relatively poor ability to accumulate persistent contaminants because of its herbivorous diet.

There were species which were not included in the review that have been the subject of intensive toxicological study. As such, they might also have potential as wetland biomonitors. For example, the American Kestrel (Falco sparverius) and the European Starling (Sturnus vulgaris) will nest in artifical nestboxes, hence, they could probably be enticed to breed in nestboxes located in wetlands. However, further research would be necessary to examine the degree to which these species, which are normally found in uplands, would feed in the wetland.

Table 7. The degree to which 36 wetland avian species conformed with modified IJC criteria #1-#4 (see Appendix 2). Maximum possible total score was 15.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
AMERICAN BLACK DUCK	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	13
KILLDEER	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	13
MALLARD	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	13
SPOTTED SANDPIPER	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	13
BLUE-WINGED TEAL	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	12
CANADA GOOSE	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
RED-WINGED BLACKBIRD	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	12
TREE SWALLOW	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	12
EASTERN KINGBIRD	1	1	0	1	0	1	1	1	1	1	1	1	1	0	0	11
GREEN-WINGED TEAL	1	0	0	1	0	1	1	1	1	1	1	1	0	1	1	11
WOOD DUCK	1	1	0	1	0	1	0	1	1	1	1	1	0	1	1	11
YELLOW WARBLER	1	1	0	1	0	1	1	1	1	1	0	1	1	1	0	11
BLACK TERN	1	1	0	0	1	1	0	1	1	1	0	1	1	1	0	10
COMMON YELLOWTHROAT	1	1	0	1	0	1	1	1	1	1	0	1	1	0	0	10
GADWALL	1	0	0	1	0	1	1	0	1	1	1	1	0	1	1	10
PIED-BILLED GREBE	1	1	0	1	0	1	1	1	1	1	0	1	1	0	0	10
SWAMP SPARROW	1	1	0	1	0	1	1	1	1	1	0	1	1	0	0	10
AMERICAN BITTERN	1	1	0	1	0	1	1	1	1	1	0	1	0	0	0	9

Table 7. cont'd.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
AMERICAN COOT	1	0	0	1	0	1	1	1	1	1	0	1	0	1	0	9
COMMON GALLINULE	1	1	0	0	0	1	1	1	1	1	0	1	0	1	0	9
COMMON GOLDENEYE	0	0	0	1	0	1	0	1	1	1	1	1	1	1	0	9
GREAT BLUE HERON	0	1	0	1	1	1	0	1	1	1	1	0	1	0	0	9
MARSH WREN	1	1	0	0	0	1	1	1	1	1	0	1	1	0	0	9
BELTED KINGFISHER	1	1	0	1	0	1	0	1	1	0	0	1	0	1	0	8
B-C NIGHT HERON	1	0	0	0	1	1	0	1	1	1	1	0	0	1	0	8
NORTHERN HARRIER	1	0	0	1	0	1	0	1	1	1	0	1	0	1	0	8
WILLOW FLYCATCHER	1	1	0	0	0	1	1	1	1	1	0	1	0	0	0	8
COMMON MERGANSER	0	0	0	1	0	1	0	1	1	1	1	0	0	1	0	7
COMMON SNIPE	1	1	0	1	0	1	1	0	1	0	0	1	0	0	0	7
SORA	1	0	0	1	0	1	1	0	1	1	0	1	0	0	0	7
VIRGINIA RAIL	1	0	0	1	0	1	1	0	1	1	0	1	0	0	0	7
FORSTER'S TERN	0	0	0	1	0	1	0	1	1	1	0	1	0	0	0	6
GREEN HERON	0	1	0	0	0	1	0	1	1	0	0	1	0	1	0	6
MUTE SWAN	1	0	0	0	1	0	1	0	0	0	0	1	0	1	1	6
SEDGE WREN	1	0	0	1	0	1	1	0	1	0	0	1	0	0	0	6
LEAST BITTERN	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	5

Table 8. The degree to which 36 Great Lakes avian species meet the modified IJC criteria for wetland biomonitors. Scoring for each criterion is described in the general introduction. The maximum total score possible for criteria #1-#7 was 24 (6+5+2+2+3+3+3).

SPECIES	MODIFIED IJC CRITERIA							TOTAL
	1	2	3	4	5	6	7	
MALLARD	5	5	1	2	3	3	2	21
RED-WINGED BLACKBIRD	5	5	2	1	1	2	2	18
B-C NIGHT-HERON	3	4	0	2	3	2	2	16
CANADA GOOSE	5	5	2	2	1	0	0	15
AMERICAN BLACK DUCK	4	5	0	2	3	0	0	14
KILLDEER	4	5	2	2	1	0	0	14
SPOTTED SANDPIPER	4	5	2	2	1	0	0	14
BLUE-WINGED TEAL	4	5	1	2	1	0	0	13
GREAT BLUE HERON	4	4	1	0	1	2	1	13
TREE SWALLOW	5	4	2	0	1	1	0	13
WOOD DUCK	4	4	1	2	1	1	0	13
FORSTER'S TERN	2	3	1	0	2	2	2	12
GREEN-WINGED TEAL	3	5	1	2	1	0	0	12
COMMON GOLDENEYE	2	4	2	1	2	0	0	11
EASTERN KINGBIRD	4	5	2	0	0	0	0	11
GADWALL	3	4	1	2	1	0	0	11
YELLOW WARBLER	4	4	2	1	0	0	0	11
COMMON YELLOWTHROAT	4	4	2	0	0	0	0	10
PIED-BILLED GREBE	4	4	2	0	0	0	0	10
SWAMP SPARROW	4	4	2	0	0	0	0	10
AMERICAN BITTERN	4	4	1	0	0	0	0	9
AMERICAN COOT	3	4	1	1	0	0	0	9
BELTED KINGFISHER	4	2	1	1	1	0	0	9
BLACK TERN	4	2	2	0	1	0	0	9
COMMON GALLINULE	3	4	1	1	0	0	0	9
COMMON MERGANSER	2	4	0	1	2	0	0	9

Table 8. cont'd.

SPECIES	MODIFIED IJC CRITERIA							TOTAL
	1	2	3	4	5	6	7	
MARSH WREN	3	4	2	0	0	0	0	9
NORTHERN HARRIER	4	4	0	0	1	0	0	9
WILLOW FLYCATCHER	3	4	1	0	0	0	0	8
COMMON SNIPE	4	2	1	0	0	0	0	7
GREEN HERON	2	2	1	1	1	0	0	7
SORA	3	3	1	0	0	0	0	7
VIRGINIA RAIL	3	3	1	0	0	0	0	7
MUTE SWAN	2	1	1	2	0	0	0	6
SEDGE WREN	3	2	1	0	0	0	0	6
LEAST BITTERN	2	2	1	0	0	0	0	5

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CLASS MAMMALIA

Only mammalian species which inhabit wetlands were included in this literature review.

Contaminant Levels

A number of studies have documented contaminant levels in Mink (Mustela vison) and River Otter (Lutra canadensis) from the Great Lakes and elsewhere (Franson et al. 1974, Frank et al. 1979, Henny et al. 1981, O'Shea et al. 1981, Hill and Dent 1985, Proulx et al. 1987, Foley et al. 1988, Stuht 1988, Glooschenko et al. 1990; 1991, Mason 1992). Several reviews have compiled the available information (Conservation Foundation 1988, Government of Canada 1991, IJC 1991). The International Joint Commission's Biological Effects Subcommittee has evaluated the usefulness of Mink and River Otter as indicators of water quality in the Great Lakes (IJC 1991). More information is available regarding contaminant levels and effects in the Mink than the Otter. The report concluded by stating, "In the absence of biotic and other abiotic limiting factors, thriving populations of Mink and Otter could serve as biological indicators of the health of shoreline wetlands of the Great Lakes basin". However, the report also stated that before biomonitoring programs involving Mink or Otter are initiated a number of questions must be resolved (see IJC 1991).

A recent Ontario study documented lower Mink harvests in townships adjacent to Lakes Erie and Ontario than in inland townships (Glooschenko et al. 1990). Smaller populations of Mink along these lakes may be the result of elevated PCB levels. However, further research must examine the availability of Mink habitat in coastal areas of the lower Great Lakes before this hypothesis can be accepted. Wren (1991) and Welch (1992) have pointed out the limitations of using harvest data as a surrogate for population status. Glooschenko et al. (1991) examined levels of individual PCB congeners in Mink from 14 townships in Ontario. The congeners examined included three non-ortho substituted types (IUPAC #77, #126, #169). They concluded that the PCB levels observed in Mink bordering the Great Lakes were sufficiently elevated to affect Mink health.

The usefulness of small mammals as indicators of environmental contamination has been reviewed (Talmage and Walton 1991a). Levels of heavy metals, radionuclides and organic contaminants were documented in 35 species of small mammals. The most commonly studied species were the White-footed Mouse (Peromyscus leucopus), the Meadow Vole (Microtus pennsylvanicus) and the Short-tailed Shrew (Blarina brevicauda). In these species, exposure to contaminants was determined from tissue analyses, biochemical assays and cytogenetic assays. Carnivorous species (shrews) exhibited the greatest contaminant levels followed by omnivores (mice) and herbivores (voles). However, shrews were much more difficult to maintain in the laboratory than mice or voles.

The three species named above have been used in monitoring studies around the Great Lakes (MacLaren 1984, Dobos et al. 1991, Great Lakes Institute 1991, Stafford et al. 1991, Hebert et al. 1993) and elsewhere (Dimond and Sherburne 1969, Williamson and Evans 1972, Scanlon 1979, Forsyth and Peterle 1984, Beyer et al. 1985, Scanlon 1987, Tice et al. 1987, Sawicka-Kapusta et al. 1990). Forsyth and Peterle (1984) examined how age affected DDT levels in Meadow Voles, Short-tailed Shrews and Masked Shrews (Sorex cinerus). They found that in all three species DDT levels were similar in embryos and breeding adults. The greatest concentrations were observed in five to six day old nestlings. Peak levels began to decline with weaning and continued to decline with increasing body weight. Beardsley et al. (1978) assessed the usefulness of the Field Vole (Microtus agrestis) as a biomonitor. They found it to be an insensitive indicator of environmental metal contamination. Haschek et al. (1979) measured Pb levels in Meadow Voles, White-footed Mice and Pine Voles (Pitymys pinetorum) collected from apple orchards in New York state. Lead levels were greatest in Pine Voles followed by Meadow Voles and White-footed Mice. Interspecific differences were correlated with the degree of subsurface feeding and movement.

Contaminant levels were generally low in mice and voles. Concentrations in the carnivorous shrew were much greater (Dimond and Sherburne, Scanlon 1987, Dobos et al. 1991). Shrews may also have an enhanced ability to bioaccumulate contaminants (Forsyth and Peterle 1984, Talmage and Walton 1991b).

Much less work has been directed towards measuring contaminant levels in other Great Lakes mammalian species. Organochlorine levels in Muskrat (Ondatra zibethicus) from the St. Clair River delta were measured in 1986 (GLI 1987). Levels of hexachlorobenzene (HCB), octachlorostyrene (OCS) and PCB Aroclors 1242, 1254 and 1260 were low. Munney et al. (1991) found that Muskrats accumulated metals but their tissue concentrations were not correlated with forage plant concentrations. In addition, Muskrats did not accumulate PCBs when exposed to PCB contaminated sediments.

Studies have examined cadmium levels in Moose (Alces alces) from Ontario and Quebec (Glooschenko et al. 1988, Pare et al. 1989). These studies were primarily concerned with human consumption of contaminated Moose tissue. Obviously, use of this species as a wetland biomonitor would be restricted to northern Ontario. In addition, because of its herbivorous diet this species would not be expected to accumulate persistent contaminants to high levels.

CONTAMINANT EFFECTS

Fitchko (1986) reviewed the most common physiological responses measured in studies examining the chronic effects of contaminants on mammals. These included changes in survival, growth, reproductive success, histopathology, metabolism, morphology, neurological function, immune function and behaviour.

Numerous laboratory studies have documented the adverse effects of Hg, PCBs and other contaminants on the Mink. It has been shown to be extremely sensitive to PCB contamination. However, there is a paucity of data linking contaminant levels and effects in wild Mink populations. The difficulty of studying reproduction of mink in a field situation has likely been an important contributing factor to this lack of information. Less is known regarding the effects of contaminants on the Otter although it may respond in a similar fashion (Wren 1991, Mason 1992). Several reports have reviewed the relevant literature (Conservation Foundation 1988, Government of Canada, Wren 1991, IJC 1991). Recent studies have documented the Mink's sensitivity to heptachlor (Aulerich et al. 1990) and have strengthened the association between PCB contamination and reproductive failure in Great Lakes Mink populations (Heaton et al. 1991). Female Mink, exposed to PCBs through their diet, exhibited a dose-dependent increase in liver, spleen and lung weight expressed as a percentage of brain weight. Hepatic PCB concentrations also increased in a dose-dependent manner (Heaton et al. 1991).

The effects of contaminants on small mammals have been documented in a variety of studies (Talmage and Walton 1991a). Hachek et al. (1979) found intranuclear inclusion bodies, which are diagnostic of lead poisoning, in renal epithelial cells of the proximal convoluted tubules in voles from contaminated orchards. They also found inclusion bodies in hepatocytes, astrocytes and endothelial cells of the outer cerebral cortex in some voles. There was also evidence of arrested osteocystic osteolysis in the long bones. In a laboratory study, Finlay et al. (1979) examined the effects of cadmium on reproduction and fetal-health in the White-footed Mouse. There was a reduction in fertility in mice exposed to 1 ppm cadmium in drinking water. Birth weights and fetal survival were unaffected by exposure to cadmium. Linzey (1987) found that reproductive success was impaired in a White-footed Mice population chronically exposed to PCBs. She concluded that exposure to PCB contaminated food could contribute to declines in populations of White-footed Mice by reducing the number of young entering the breeding population. Tice et al. (1987) detected the presence of genotoxic and cytotoxic chemicals in a population of White-footed Mice inhabiting a contaminated site. The extent of genetic and cytologic damage varied seasonally. Yocum et al. (1987) found that cadmium and lead acted synergistically to reduce reproductive success in a population of White-footed Mice. Batty et al. (1990) found that reproduction was inhibited in a population of White-

Footed Mice inhabiting an area contaminated with PCBs and heavy metals. Changes were also observed in the structure and function of the liver, spleen, adrenal glands and testes. Charters et al. (1991) examined the effects of contaminants on the demographics of three Meadow Vole populations near the Love Canal Superfund site. There were significant differences among populations with respect to mean population age, population density and age at maturity. This study illustrated the advantages of using small mammal demographic studies to assess hazardous waste sites.

Other studies have not detected contaminant-induced effects. Jett et al. (1986) found that exposure to the organophosphate insecticide, Orthene, had no affect on the health of a wild Meadow Vole population. White-footed Mice inhabiting a site contaminated with Aroclor 1254 showed no significant difference in the number of chromosomal aberrations than individuals from an uncontaminated site (Shaw-Allen 1990).

Modified IJC Criteria

Eight mammalian species were selected as potential wetland biomonitors. These species were chosen based upon the results of the contaminant literature review. Scores for criteria #1-#4 are shown in Table 7 (see Appendix 2). Overall scores are shown in Table 8. The Mink scored highest in the comparison. However, there are deficiencies in our understanding of Mink biology. Continuing research into its habitat requirements, prey selection and population status should improve the Mink's utility as a wetland bioindicator (IJC 1991).

Table 9. The degree to which the 8 wetland mammalian species conformed with modified IJC criteria #1-#4 (see Appendix 2). Maximum possible total score was 15.

CRITERIA	#1						#2					#3		#4		TOTAL
SPECIES	a	b	c	d	e	f	a	b	c	d	e	a	b	a	b	
DEER MOUSE	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
MEADOW VOLE	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
MINK	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	14
WHITE-FOOTED MOUSE	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
MUSKRAT	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13
SHORT-TAILED SHREW	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	13
MOOSE	1	0	1	0	1	1	0	1	1	1	1	0	0	0	0	8
RIVER OTTER	1	0	1	0	1	1	0	1	1	1	1	0	0	0	0	8

Table 10. The degree to which eight Great Lakes mammalian species meet the modified IJC criteria for wetland biomonitors. Scoring for each criterion is described in the general introduction. The maximum total score possible for criteria #1-#7 was 24 (6+5+2+2+3+3+3).

SPECIES	MODIFIED IJC CRITERIA							TOTAL
	1	2	3	4	5	6	7	
MINK	6	5	1	2	2	2	2	20
MEADOW VOLE	5	5	2	2	2	1	0	17
WHITE-FOOTED MOUSE	5	5	2	2	2	1	0	17
DEER MOUSE	5	5	2	2	1	0	0	15
SHORT-TAILED SHREW	5	5	2	1	2	0	0	15
MUSKRAT	6	5	2	0	1	0	0	14
RIVER OTTER	4	5	0	0	1	1	0	11
MOOSE	4	4	0	0	1	0	0	9

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APPENDIX 1 - General biological reviews used to evaluate criteria #1-#4

Osteichthyes

Hamilton, J.G. 1987. Survey of critical fish habitat within International Joint Commission designated Areas of Concern August - November, 1986. Prepared for the Ontario Ministry of Natural Resources by B.A.R. Environmental, Toronto, Ontario. pp. 119.

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Amphibia

Conant, R. 1975. A field guide to reptiles and amphibians of eastern and central North America. Houghton Mifflin Co., Boston, MA, U.S.A. pp. 429.

Weller, W.F. and M.S. Oldham. 1988. Ontario Herpetofaunal Summary. Publ. Ont. Field Herpetologists, Ontario, Canada. pp. 221.

Reptilia

Conant, R. 1975. A field guide to reptiles and amphibians of eastern and central North America. Houghton Mifflin Co., Boston, MA, U.S.A. pp. 429.

Weller, W.F. and M.S. Oldham. 1988. Ontario Herpetofaunal Summary. Publ. Ont. Field Herpetologists, Ontario, Canada. pp. 221.

Aves

Cadman, M.D., P.F.J. Eagles, F.M. Helleiner. 1987. Atlas of the breeding birds of Ontario. University of Waterloo Press. pp. 617.

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Mammalia

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APPENDIX 2 - Criteria #1-#4 scoring rationale

Scores were given YES=1 or NO=0. Species scores are only comparable within each class.

Osteichthyes - C. E. Hebert

General Notes

1a. Found in wetlands
All of the fish species examined in this review are found in wetlands.
1b. Species is common
Based on information presented in Scott and Crossman. All of the species examined in this review were considered to be common in their home ranges. Home range size was not considered during scoring. For example, the White Perch is only found in the lower Great Lakes where it is locally abundant, eg. Bay of Quinte in Lake Ontario. Therefore, even though its range is limited it is still scored as common because of its local abundance.
1c. Resident in wetlands during all life stages
All of the species in this review were considered to be resident in wetlands during all life-stages. However, for species in which the adults are pelagic (Emerald Shiner, Alewife, Gizzard Shad and White Bass), it should be remembered that only a small portion of their lives may be spent in wetlands, primarily during breeding.
1d. Broad distribution
Must occur along all of the Canadian Great Lakes shoreline. Although six of the species scored 0 under this criterion, four of those were found in all the Great Lakes except Lake Superior. Only the White Bass and White Perch have very limited distributions. These two species are primarily found in the lower Great Lakes.
1e. Historic abundance
More information regarding historic abundance is generally available for the game species and species which have been recently introduced.
1f. Endemic
Self-explanatory. Five of the species are not endemic to the Great Lakes (Common Carp, Alewife, Gizzard Shad, White Bass and White Perch).

2a. Small home range during period in which they inhabit wetlands
Small non-pelagic species generally have small home ranges. Although the Golden Shiner is not a pelagic species it is known to move over large distances. The game species examined in this review are also thought to be relatively sedentary. Although this is generally accepted, more work must examine the degree to which species such as the Northern Pike and White Sucker migrate.

2b. Food selection well-documented

Food preferences are generally known for all of the species. It should be remembered when selecting biomonitors that benthic species and species which occupy high trophic levels generally accumulate the highest levels of persistent contaminants. These interspecific differences in contaminant exposure were considered to some extent under criterion #5.

2c. Habitat selection well-documented

Generally known for all of the species. More information is available for the economically important species.

2d. Breeding biology well-documented

Breeding information is often not available specifically for Canadian populations, however, there is usually information on breeding behaviour and timing from studies completed in the United States. This has obvious implications when estimating time of breeding in Canadian waters.

2e. Migration behaviour well-documented

Migratory behaviour, particularly, in the non-pelagic small species is generally thought to be limited. Benthic species are generally thought to be relatively sedentary. More information is needed for some of the game species (White Sucker, Northern Pike and Yellow Perch).

3a. Sample accessibility

Sample accessability is good for all of the species. Scores were based upon ease of capture. A variety of techniques are available which can be tailored to species specific collections.

3b. Sample availability

Scores for this criterion were based upon the distribution of the species and their relative abundance.

4a. Captive rearing possible and well understood

Most of the species can survive in the laboratory. However, pelagic species (Emerald Shiner, Alewife and Gizzard Shad) may be more difficult to maintain. Some species, such as the Emerald Shiner, may also be sensitive to capture and exhibit high mortality during field collections. Large specimens of some species, such as the Northern Pike, would also be more difficult to maintain in captivity.

4b. Captive breeding possible and well understood

Few of the species have been bred in captivity. Culture information exists for the Fathead Minnow and the Yellow Perch. Other species, particularly the near-shore cyprinid species (Bluntnose Minnow and Spottail Shiner), may also be amenable to laboratory culture.

Amphibia - C. A. Bishop

General Notes

1a. Found in wetlands
If it was found in wetlands at any stage of its life cycle it scored YES.
1b. Species is common
Based on number of locations reported by Oldham and Weller for Great Lakes shoreline locations and relative to other amphibian species being scored here.
1c. Resident in wetlands during all life stages
Self-explanatory.
1d. Broad distribution
Must occur along all of the Canadian Great Lakes shoreline.
1e. Historic abundance
Very few extensive historical records have been kept on density and presence or absence of species scored here for the Great Lakes. Therefore, any species in which there is likely to be, according to the opinion of this author, any information on presence or absence of a species along all or half of the Great Lakes shoreline was scored YES. Historic, accurate, density estimates are lacking for all of the species.
1f. Endemic
Self-explanatory.

2a. Small home range during period in which they inhabit wetlands
All of the species scored here probably have home ranges of less than one acre during the period in which they inhabit Great Lakes wetlands.
2b. Food selection well-documented
All adult amphibians are mainly carnivorous. There is a wide range in the amount of information available for each species.
2c. Habitat selection well-documented
This is not well understood for most of the species considered here.
2d. Breeding biology well-documented
For wild populations in Ontario, the time of year for breeding, number of eggs laid/female, and period of metamorphosis is well known for most of the species considered here.
2e. Migration behaviour well-documented
Poorly studied for most species during the period after breeding.

3a. Sample accessibility
Many wetlands of the Great Lakes suffer poor water clarity either due to wind re-suspension of sediments, or sediment loading from erosion within the upstream watershed. Adult and larval amphibians, and especially egg masses will be more difficult to see and catch when turbidity is high in a wetland. Scores given to each species consider only the biology of each species in relation to accessibility. However, one must remember that where that water clarity is a problem most amphibian species would be less

accessible.

3b. Sample availability

This criteria applies to how much time it would take to get a sample of the life stage of interest relative to other species.

4a. Captive rearing possible and well understood

Hatching eggs and rearing tadpoles to adulthood has been performed in the past for most species. However, it is often not well studied.

4b. Captive breeding possible and well understood

Techniques for breeding most of the amphibians discussed here have not been well studied but could be easily developed for specific species of interest.

Species Information

SPRING PEEPER

1a. Found in wetlands

Yes.

1b. Species is common

Yes.

Species commonly breeds in most wetlands around the Great Lakes although its geographic range extends north of Lake Superior. Adults forage by sitting in bushes and small trees around wetlands therefore they are not commonly in contact with water and sediment of wetlands although they probably eat some emergent, aerial insects from the wetland.

1c. Resident in wetlands during all life stages

No.

Eggs and tadpoles develop in wetlands but adults do not forage in wetlands.

1d. Broad distribution

See 1b.

1e. Historic abundance

Yes.

Moderate amount of information on historical abundance exists.

1f. Endemic

Yes.

2a. Small home range during period in which they inhabit wetlands.

Yes.

Tadpoles probably forage within less than .25 acres.

2b. Food selection well-documented

No.

2c. Habitat selection well-documented

Yes, for adults. Little known about tadpoles.

2d. Breeding biology well-documented

Yes.

Moderate amount of information available.

2e. Migration behaviour well-documented
No.
Moderate amount of information available. Time period in which they migrate to breeding sites well-known. Distance which they travel to and from breeding sites not well documented.

3a. Sample accessibility
No.
Eggs are small, cryptic, and laid singly. Therefore not easily sampled. Adults are difficult to locate even when calling during breeding season and almost impossible to reliably find them after breeding. Adults are usually found by accident!
3b. Sample availability
No.
Eggs and adults are cryptic.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

GRAY TREE FROG

1a. Found in wetlands
Yes.
Breeds in wetlands.
1b. Species is common
Yes.
In wetlands surrounded by woodlots, it is a common breeding species. However, this is not always the case at wetlands throughout the Great Lakes. Does not occur on Lake Superior shoreline.
1c. Resident in wetlands during all life stages
No.
Once it has metamorphosed to adulthood it will forage in trees. Adults are common in wetlands during breeding.
1d. Broad distribution
No. See 1b.
1e. Historic abundance
No.
Known for local areas. Nothing known of breeding success and density estimates would be very crude.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.

2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
Yes.

3a. Sample accessibility
No.
Eggs and tadpoles are cryptic.
3b. Sample availability
No.
Not reliably available due to the cryptic nature of all life stages.

4a. Captive rearing possible and well understood
Yes.
Rearing possible.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

CHORUS FROG (two species occur in Ontario, Western Chorus Frog (Pseudacris triseriata triseriata), Boreal Chorus Frog (Pseudacris triseriata maculata))

1a. Found in wetlands
Yes.
Breeds in wetlands.
1b. Species is common
Yes.
In wetlands surrounded by woodlots, it is a common breeding species. However, the presence of woodlots is is not always the case at wetlands throughout the Great Lakes. If geographic distribution of both species are combined, they are sparse between Georgian Bay and Thunder Bay.
1c. Resident in wetlands during all life stages
No.
Once it has metamorphosed to adulthood it will forage in trees. Adults are common in wetlands during breeding.
1d. Broad distribution
No.
1e. Historic abundance
No.
Known for local areas. Nothing known of breeding success and density estimates would be very crude.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.

2b. Food selection well-documented
No.
2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
Yes.

3a. Sample accessibility
No.
Eggs and tadpoles are cryptic.
3b. Sample availability
No.
Not reliably available due to the cryptic nature of all life stages.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

AMERICAN TOAD

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
Extremely common. Geographic range extends to Hudson Bay.
1c. Resident in wetlands during all life stages
Yes.
However, can be found foraging in fields and woodlots as well.
1d. Broad distribution
Yes.
See 1b.
1e. Historic abundance
Yes.
Local abundance records probably available in most wetlands but no density estimates.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.
However, information is more extensive than for most amphibians.
2c. Habitat selection well-documented
Yes.

Information is more extensive than for most amphibians.
2d. Breeding biology well-documented
Yes.
Information is more extensive than for most amphibians.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
Egg masses are relatively large, tadpoles easy to find and identify, adults common enough to collect fairly reliably.
3b. Sample availability
Yes. As described in 3a. the samples are available, however, in Great Lakes wetlands where high sediment loading and Carp are a problem the clarity of the water decreases the chance of seeing the eggs and tadpoles for collection.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
Information better than for most amphibians.
4b. Captive breeding possible and well understood
Yes.
Breeding probably possible but not well studied. Information is more extensive than for most frogs and toads considered here.

BULLFROG

1a. Found in wetlands
Yes.
1b. Species is common
No.
In some areas it is abundant but it is not common in all wetlands surrounding the Great Lakes. This is probably due to overhunting. Geographic range extends to southern Lake Superior.
1c. Resident in wetlands during all life stages
Yes.
1d. Broad distribution
No.
Geographic distribution extends to Lake Superior.
1e. Historic abundance
Yes.
Better documented than most amphibians.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.
However, information is more extensive than for most amphibians.

2c. Habitat selection well-documented
Yes.
Information is more extensive than for most amphibians.
2d. Breeding biology well-documented
Yes.
Information is more extensive than for most amphibians.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
Adults and larvae are reasonably easy to catch when common in a wetland. Even if water is turbid adults can be caught. Egg masses obvious.
3b. Sample availability
Yes.
As 3a.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood. Information better than for most amphibians.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

GREEN FROG

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
Not as common as American Toad and Leopard Frog. Geographic range extends to Lake Superior.
1c. Resident in wetlands during all life stages
Yes.
1d. Broad distribution
No.
1e. Historic abundance
Yes.
Local abundance, without density estimates, are probably available.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands.
Yes.
2b. Food selection well-documented
No.
2c. Habitat selection well-documented
No.
However, better than some amphibians especially breeding location

preferences.
2d. Breeding biology well-documented
Yes.
Better information than for some amphibians.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
Both adults and young are easily caught.
3b. Sample availability
Yes.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

PICKEREL FROG

1a. Found in wetlands
Yes.
1b. Species is common
No.
1c. Resident in wetlands during all life stages
Yes.
Although adults will also forage in upland areas as well.
1d. Broad distribution
No.
Occurs in Southern Ontario only.
Much less common than Leopard Frog or American Toad. It occurs along southern Great Lakes shoreline except absent in south western Lake Erie.
1e. Historic abundance
No.
Not well documented.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.
2c. Habitat selection well-documented
No.
2d. Breeding biology well-documented
No.
Less information than for most other amphibians.
2e. Migration behaviour well-documented

No.

3a. Sample accessibility
No.
For the novice, it is possible to mistake this species for the much more common Leopard Frog. This species is much less common than all the other ranid species in Ontario.
3b. Sample availability
Yes.
Adults, and egg masses easily collected when visible in water. Tadpoles difficult to distinguish from other species, especially for novices.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well understood.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

NORTHERN LEOPARD FROG

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
Very common.
1c. Resident in wetlands during all life stages
Yes.
However, they will forage in upland areas as well.
1d. Broad distribution
Yes.
Common around all Great Lakes north to Hudson's Bay.
1e. Historic abundance
Yes.
Presence/absence data available but not density estimates in most areas.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.
2c. Habitat selection well-documented
No.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.
However, information is better than for most amphibians.

3a. Sample accessibility
Yes.
Adults, egg masses and tadpoles are easy to catch and identify.
3b. Sample availability
Yes.
Adults, and egg masses easily collected when visible in water.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well understood.
4b. Captive breeding possible and well understood.
No.
Breeding probably possible but not well studied.

WOOD FROG

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
1c. Resident in wetlands during all life stages
No.
Adults tend to forage in upland areas but can commonly be found near wetlands.
1d. Broad distribution
Yes.
Range extends to and includes Lake Superior shoreline, but does not occur in Essex and western Kent county in southwestern Ontario.
1e. Historic abundance
Yes.
Information on presence/absence available but not density estimates.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
No.
2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
Adults, and eggs are easily found during breeding season. Tadpoles not difficult to distinguish from other species. Adults more cryptic in summer.

3b. Sample availability
Yes.
Because the species is common and is an "explosive" breeder, it is simple to catch many adults and young in a small area.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
4b. Captive breeding possible and well understood
Yes.
Breeding probably possible but not well studied.

MOLE SALAMANDER COMPLEX

1a. Found in wetlands
Yes.
1b. Species is common
No.
Prefers ephemeral pools for breeding. Not common around Great Lakes although geographic range extends to Thunder Bay.
1c. Resident in wetlands during all life stages
No.
Adults forage in upland habitats.
1d. Broad distribution
Yes.
Range extends to areas around Lake Superior.
1e. Historic abundance
No.
Poorly documented.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
Yes.
2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
3b. Sample availability
Yes.
Adults, larvae and eggs are relatively easy to catch.

4a. Captive rearing possible and well understood
Yes.

4b. Captive breeding possible and well understood.
Yes.

SPOTTED SALAMANDER

1a. Found in wetlands
Yes.
1b. Species is common
No.
Locally common, not abundant in all wetlands. Prefer ephemeral pools for breeding therefore Great Lakes wetlands are not preferred breeding habitat.
1c. Resident in wetlands during all life stages
No.
Adults forage in upland habitats.
1d. Broad distribution
Yes.
Range extends to areas around Lake Superior.
1e. Historic abundance
No.
Poorly documented but better than Mole Salamander complex.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
Yes.
2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.
When water is not turbid, adults, larvae and egg masses are accessible. Egg masses easier to locate than mole salamander egg masses because Spotted Salamander egg masses are approximately four times as large.
3b. Sample availability
Yes.
Adults, larvae and eggs are relatively easy to catch.

4a. Captive rearing possible and well understood
Yes.
4b. Captive breeding possible and well understood.
Yes.

MUDPUPPY

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
Species commonly lives in many wetlands around the Great Lakes.
1c. Resident in wetlands during all life stages
Yes.
1d. Broad distribution
Yes.
See 1b.
1e. Historic abundance
No.
Poorly documented.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands.
Yes.
Not well studied but suspected to have small home range.
2b. Food selection well-documented
No.
2c. Habitat selection well-documented
No.
2d. Breeding biology well-documented
No.
2e. Migration behaviour well-documented
No.

3a.Sample accessiblity
Yes.
3b. Sample availability
No.
Only available where commercial or sport fishing occurs.

4a. Captive rearing possible and well understood
Yes.
Rearing possible but not well-understood.
4b. Captive breeding possible and well understood
No.
Breeding probably possible but not well studied.

Reptilia - C. A. Bishop

COMMON SNAPPING TURTLE

1a. Found in wetlands
Yes.
1b. Species is common

Yes.
<u>1c. Resident in wetlands during all life stages</u>
Yes.
<u>1d. Broad distribution</u>
No.
Very common throughout Great Lakes wetlands up to Georgian Bay and uncommon or not occuring on north shore of Lake Superior.
<u>1e. Historic abundance</u>
Yes.
Information from trapping records in some areas and local historic information on common biota in wetlands.
<u>1f. Endemic</u>
Yes.

<u>2a. Small home range during period in which they inhabit wetlands</u>
Yes.
<u>2b. Food selection well-documented</u>
Yes.
<u>2c. Habitat selection well-documented</u>
Yes.
<u>2d. Breeding biology well-documented</u>
Yes.
<u>2e. Migration behaviour well-documented</u>
Yes.

<u>3a. Sample accessibility</u>
Yes.
<u>3b. Sample availability</u>
Yes.

<u>4a. Captive rearing possible and well understood</u>
Yes.
<u>4b. Captive breeding possible and well understood</u>
Yes.

<u>NORTHERN WATER SNAKE</u>

<u>1a. Found in wetlands</u>
Yes.
<u>1b. Species is common</u>
Yes.
<u>1c. Resident in wetlands during all life stages</u>
Yes.
<u>1d. Broad distribution</u>
Yes.
<u>1e. Historic abundance</u>
Yes.
Local records only and much of it anecdotal.
<u>1f. Endemic</u>
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
Yes.
2c. Habitat selection well-documented
No.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
No.
3b. Sample availability
Yes.

4a. Captive rearing possible and well understood
Yes.
4b. Captive breeding possible and well understood
Yes but not well studied.

EASTERN PAINTED TURTLE

1a. Found in wetlands
Yes.
1b. Species is common
Yes.
1c. Resident in wetlands during all life stages
Yes.
1d. Broad distribution
Yes.
Most common species of turtle throughout the Great Lakes wetlands.
1e. Historic abundance
Yes.
Local records from many areas but mainly ancedotal information.
1f. Endemic
Yes.

2a. Small home range during period in which they inhabit wetlands
Yes.
2b. Food selection well-documented
Yes.
2c. Habitat selection well-documented
Yes.
2d. Breeding biology well-documented
Yes.
2e. Migration behaviour well-documented
No.

3a. Sample accessibility
Yes.

3b. Sample availability
Yes.

4a. Captive rearing possible and well understood
Yes.
Not well studied but possible.
4b. Captive breeding possible and well understood
Yes.
Possible but not well studied.

Aves - D. V. Weseloh

General Notes

1a. Found in wetlands
All species considered in this review either breed in wetlands or spend much of their time in wetlands while breeding nearby.
1b. Species is common
Species judged to be of "Common" abundance or greater are indicated with a 1. Within this category, one should remember that some species will be only "Common" while some will be "Abundant". Those species whose numerical status was felt to be less than "Common" are indicated with 0.
1c. Resident in wetlands during all life stages
No bird species fit this category because wetlands freeze in winter and all the birds migrate. However, by restricting our choices to birds as per 1a, we assure ourselves of considering species whose residence in wetlands is maximized.
1d. Broad distribution
The Atlas of the Breeding Birds of Ontario was used as the sole reference source. Probable or confirmed nesting records had to exist for the given species on all four Great Lakes which border Ontario to score a 1.
1e. Historic abundance
There are several accounts of the historic distribution of birds in many regions of Ontario. Most of these accounts make some subjective comment about the historic abundance in that region, eg. common, rare, abundant, etc. However, very few make any kind of quantitative assessment. I have indicated the species for which there might be quantitative numbers because of either the tendency to nest in groups/colonies (ie. Black Tern) or their conspicuousness (ie. Mute Swan).
1f. Endemic
Only two species which are considered here, the Mute Swan and the European Starling, are not endemic to the Great Lakes.

2a. Small home range during period in which they inhabit wetlands
For this category I mainly considered whether the species would range outside of the wetland to forage while it was breeding or raising its young. If not, I scored it 1, if so, I scored it 0.
2b. Food selection well-documented
Literature sources for all of the species listed here were not examined. However, the general biology of most birds has been studied. Nevertheless, for those species which are relatively secretive or which have just established themselves as nesters in Ontario, I assumed it was less likely that their diet would have been well documented.
2c. Habitat selection well-documented
I judged habitat factors to be well known for all species except the Mute Swan, a fairly recent introduced species which breeds in Ontario.
2d. Breeding biology well-documented

Breeding biology studies are generally available for species which are hunted and for the more common or economically important non-game species. Again, very secretive species tend to be less well studied than non-secretive species.

2e. Migration behaviour well-documented

The success or existence of migration studies depend upon individuals being resighted or captured after they have been banded. This means that the more common or commerically important species will have more data upon which to base such studies. The migration of ducks will be very well known; the migration of rails and wrens will not.

3a. Sample accessibility

Scores were assigned on the ease of getting to the nesting habitat.

3b. Sample availability

Scores were assigned based on the availability or likelihood of finding the nest once you get to the correct habitat.

4a. Captive rearing possible and well understood

Given the food and habitat requirements, would it be easy or difficult to keep this bird in captivity? Birds having specialized or seasonal food requirements (insects) might be more difficult than others.

4b. Captive breeding possible and well understood

Same type of considerations as for the previous question.

Mammalia - C. E. Hebert

General Notes

1a. Found in wetlands
All of the species are found in wetlands. It should be remembered that the small mammal species included in this review are terrestrial. As such, they would probably be poor integrators of contamination in the aquatic environment.
1b. Species is common
All of the species were deemed to be common except for the River Otter and the Moose. Obviously, the most common group would be the small mammals, particularly the mice and voles.
1c. Resident in wetlands during all life stages
Self-explanatory.
1d. Broad distribution
Must occur along all of the Canadian Great Lakes shoreline. Only the River Otter and the Moose are not found around all the Great Lakes.
1e. Historic abundance
More information regarding historic abundance is generally available for species of economic importance (Mink, River Otter, Muskrat and Moose).
1f. Endemic
All of the species are endemic.

2a. Small home range during period in which they inhabit wetlands
Most of the species have limited home ranges except for the Moose. Insufficient information exists regarding home range size in the River Otter hence it scores 0 in this category. The average home range of mink has been estimated to be approximately 2.0 km along a length of stream (Gerell 1970, Birks and Linn 1982). Males (1.0-5.0 km) generally have larger home ranges than females (1.0-2.8 km) and juvenile males (1.05-1.4 km). Although the home range of the mink is much larger than those of the small mammal species it is still sufficiently limited to provide an indication of local contaminant bioavailability.
2b. Food selection well-documented
Dietary preferences are reasonably well known for all of the species. More information regarding the diet of the Mink would be useful.
2c. Habitat selection well-documented
Habitat requirements are reasonably well known for all of the species.
2d. Breeding biology well-documented
Breeding information is available for all of the species.
2e. Migration behaviour well-documented
None of the species exhibits migratory behaviour.

3a. Sample accessibility
Scores were assigned based upon ease of sample collection. Differences in scores largely reflected the behaviour of the

species. Secretive species such as the Mink, River Otter and Moose would likely be much more difficult to sample than the other species.

3b. Sample availability

Scores for this criterion were based upon the distribution of the species and their relative abundance. Although the mink scored 1 in this category it is much less abundant than the four small mammal species or the muskrat.

4a. Captive rearing possible and well understood

Captive rearing of the Mink is commonplace. All of the small mammal species could probably be maintained in the laboratory, although shrews would likely pose more difficulties than either mice or voles. The other aquatic species would be much more difficult. The Muskrat scored 0 because there was no information available regarding its behaviour in captivity.

4b. Captive breeding possible and well understood

Captive breeding of the Mink and most of the small mammal species has been demonstrated. Breeding of the carnivorous shrew is likely to be more difficult. The other aquatic species would be very difficult.