ENVIRONMENTAL CONTAMINANTS IN CANADIAN RAPTORS, 1965 - 1989.

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RÉSUMÉ

Les résultats des analyses chimiques des oeufs et des tissus de rapaces recueillis par le Service canadien de la faune entre 1965 et 1988 sont compilés. On a rapporté des niveaux de résidus de DDE, de DDD, de DDT, de dieldrine, d'époxyde d'heptachlore, de HBC, de BPC, de bêta-HCH, d'oxychlordane, de myrex et de mercure dans vingt-quatre espèces canadiennes de rapaces. Seulement trois de ces échantillons de tissus contenaient des résidus (mercure ou DDE) indicateurs d'empoisonnement. Les valeurs critiques des effets toxiques du DDE, de la dieldrine, d'époxyde d'heptachlore et de mercure dans les oeufs sont déterminées à partir de documentation publiée et les proportions d'oeufs échantillonnés avec des résidus excédant ces niveaux sont rapportées. Plus de 50 % des oeufs de Pygargues à tête blanche, de Balbuzards, de Faucons émerillons, de Faucons des Prairies et de Faucons pèlerins (particulièrement ceux recueillis avant les années 1980) contiennent des DDE excédant les valeurs critiques spécifiques. Pour huit espèces, les données concernant les contaminants sont analysées en fonction des tendances temporelles. Le DDE diminue de façon significative chez les Faucons émerillons, les Faucons des Prairies, les Pygargues à tête blanche et les Faucons pèlerins; la dieldrine dans les Buses de Swainson et les Buses pattues, les Faucons émerillons, des Prairies et pèlerins; et l'époxyde d'heptachlore seulement chez les Faucons des prairies. On discute des résultats en fonction des modifications de statut des populations de rapaces au Canada. Il est possible d'utiliser les résidus chimiques dans les échantillons d'oeufs, de tissus et de sang des rapaces afin d'exercer un suivi de la contamination des écosystèmes terrestres.

SOMMAIRE

On sait que les polluants environnementaux tels que les pesticides organochlorés et les biphenyles polychlorés (BPC) sont persistants dans les écosystèmes aquatiques et terrestres. Les animaux prédateurs (tels que les oiseaux rapaces) sont souvent très contaminés en raison de la bioamplification par la chaîne alimentaire et de leur tendance à prendre des proies affaiblies et susceptibles d'être contaminées.

La disparition du Faucon pèlerin (falco peregrinus anatum) dans l'est de l'Amérique du nord dans les années 1960 a attiré l'attention des scientifiques sur les effets toxiques des pesticides largement utilisés tels que le DDT. En Europe, le taux de mortalité des rapaces à la suite d'un traitement aux grains enduits de fongicide de mercure a démontré l'effet mortel du mercure. Depuis le milieu des années 1960, le Service canadien de la faune (SCF) a fait des études sur les résidus chimiques dans les tissus et les oeufs des rapaces canadiens. Les résultats des analyses de la présence d'organochlorés et de mercure dans plus de 250 échantillons de tissus et plus de 1 400 oeufs de rapaces recueillis au Canada entre 1965 et 1988 sont résumés dans ce rapport.

Les pesticides organochlorés, incluant les DDT, la dieldrine, l'heptachlore et les HBC, ont été largement utilisés au Canada pour protéger les récoltes et les forêts jusqu'au début des années 1970; ils ont alors été remplacés en grande partie par des composés non persistants. Bien que des restrictions au États-Unis sur leur utilisation, à peu près en même temps qu'une réglementation canadienne, aient été mises en vigueur, l'emploi d'organochlorés en Amérique latine a continué d'augmenter au moins jusqu'aux années 1980. Malgré les restrictions sur plusieurs applications, des composés industriels tels que les BPC continuent de s'introduire dans l'environnement par les fuites des transformateurs, les effluents industriels, les déversements, les rejets et l'incinération. Les sources anthropogéniques existantes de métaux lourds tels que le mercure, le plomb et le cadmium comprennent les écoulements des mines métalurgiques, des fonderies et des usines fonctionnant au charbon et les infiltrations issues des sites d'enfouissement de déchets.

On a accumulé beaucoup de preuves sur les effets toxiques directs du DDE (le principal dérivé du DDT), de la dieldrine, du plomb et du mercure sur les rapaces. Bien que certains cas d'empoisonnement chez les rapaces aient été rapportés, nous connaissons moins les effets toxiques de l'oxyde d'heptachlore, de l'oxychlordane, des hexachlorocyclohexanes (HCH) isomères, du mirex, de

l'hexachlorobenzène (HCB) ou des biphényles polychlorés.

On a remarqué que plusieurs organochlorés et le mercure ont des effets presque mortels surtout sur la reproduction. Les coquilles d'oeufs des rapaces semblent être relativement vulnérables aux effets d'amincissement causés par le DDE. Il y a une grande variation spécifique dans la relation entre le contenu en DDE, l'épaisseur de la coquille des oeufs et la productivité chez les Faucons des Prairies et émerillons et les Pygargues à tête blanche et les Balbuzards qui sont parmi les plus sensibles à la diminution de productivité. Bien qu'il y ait eu peu de travaux expérimentaux sur les rapaces, des études portant sur d'autres oiseaux prouvent que la dieldrine, l'époxyde d'heptachlore, les BPC et le mercure réduisent aussi les chances de réussite lors de la reproduction. La diminution de l'éclosion d'oeufs pourrait mener à un déclin des populations.

Parmi les contaminants organochlorés détectés dans les rapaces canadiens, on trouve les DDT, DDD et DDE, la dieldrine, l'époxyde d'heptachlore, le mirex, l'oxychlordane, le cisnonachlore et le transnonachlore, le cischlordane et le transchlordane, les isomères HCH alpha, bêta et gamma, les dérivés chlorés du benzène (principalement des HCB) et les BPC. Les niveaux de résidus varient de non décelable à plus de 100 mg par kg dans le cas du DDE. Des améliorations dans la méthodologie analytique ont permis de détecter plus de composés dans les échantillons récents que chez ceux recueillis avant. En général, dans les oeufs, les niveaux démontrent les habitudes alimentaires; les oeufs des espèces se nourrissant de poissons et d'oiseaux contiennent plus de résidus.

Dans une très petite proportion de tissus analysés, on a trouvé des niveaux de résidus menant à un diagnostique d'empoisonnement aig@ : du mercure dans le foie d'un Pygargue à tête blanche et de plusieurs Urubus à tête rouge recueillis en Ontario en 1970, et du DDE dans le foie d'un Épervier brun recueilli en C.-B. au début des années 1980.

Les concentrations d'organochlorés dans plusieurs oeufs excédaient les niveaux seuils critiques minimum calculés à partir des publications sur la toxicologie. Il y avait des différences spécifiques considérables dans les valeurs critiques, le DDE affectant la productivité des Faucons des Prairies au niveau des oeufs avec plus de 1,2 mg par kg (poids net) tandis que la valeur critique des *accipiteri* semble être d'environ 10 mg par kg. Bien que le niveau critique de dieldrine n'ait pas été identifié, nous avons établi que les concentrations excédant 1,0 mg par kg étaient potentiellement dangereuses. Les valeurs critiques estimées de l'époxyde d'heptachlore et du mercure dans les oeufs étaient respectivement de 1,5 mg par kg et de 0,5 mg par kg.

Les oeufs de l'Épervier brun et de l'Épervier de Cooper étaient hautement contaminés par des niveaux de DDE et, dans un des cas, de dieldrine excédant souvent les valeurs critiques. Les *butei* étaient généralement moins contaminées au DDE que les *accipiteri*, mais une plus grande proportion des oeufs contenait des niveaux élevés de dieldrine et d'époxyde d'heptachlore. Une grande proportion des oeufs de Pygargues à tête blanche contenait des DDE excédant 6,0 mg par kg, avec des concentrations maximum atteignant 100 mg par kg. Plusieurs oeufs d'aigles étaient aussi très contaminés à la dieldrine, à l'époxyde d'heptachlore et au mercure. Seulement un oeuf d'Aigle royal contenait beaucoup de résidus chimiques (dieldrine), tandis que plusieurs oeufs de Balbuzards contenaient plus de 4,0 mg par kg de DDE, la valeur critique établi pour cette espèce.

Les oeufs de certains faucons étaient grandement contaminés. La plupart des quelques trois cent oeufs de Faucons émerillons analysés contenaient des DDE excédant la valeur critique, et plus de 10 % des oeufs contenaient aussi des concentrations élevées de dieldrine, d'époxyde d'heptachlore et de mercure. Les concentrations de DDE dans plus de 60 % des oeufs de Faucons des Prairies excédaient le niveau critique de cette espèce. La dieldrine, l'époxyde d'heptachlore et le mercure excédaient aussi les valeurs critiques dans plusieurs oeufs. Seulement un oeuf de Gerfaut et un oeuf de Crécerelle d'Amérique étaient considérablement contaminés (avec de la dieldrine dans le premier cas, et de l'époxyde d'heptachlore et de la dieldrine dans l'autre). Les oeufs de Faucons pèlerins étaient très contaminés, les concentrations de DDE excédant 10 mg par kg dans plus de 50 % des oeufs analysés. Près de 25 % des oeufs contenaient des concentrations élevées de résidus de dieldrine.

Il y avait peu d'oeufs de hibous sensiblement contaminés. Les niveaux de DDE étaient élevés dans deux oeufs de Grand-duc d'Amérique, et les niveaux d'époxyde d'heptachlore étaient élevés dans deux autres oeufs de cette espèce.

Les tendances temporelles des niveaux de résidus ont été déterminées pour plusieurs espèces. Dans les oeufs de Buses de Swainson et des Buses rouilleuses dans les Prairies, la dieldrine a diminué tandis que les concentrations de DDE et d'époxyde d'heptachlore n'ont pas changé de façon significative entre la fin des années 1960 et le milieu des années 1980. Dans les oeufs des Faucons émerillons recueillis dans les Prairies pendant la même période, les concentrations de dieldrine et de DDE ont sensiblement diminué mais l'époxyde d'heptachlore n'a pas montré de tendances précises. Chez les Faucons des Prairies, les concentrations des trois composés ont diminué.

Les niveaux de DDE dans les oeufs ont diminué considérablement chez les Faucons pèlerins dans la plupart de leurs habitats. Le niveau de dieldrine a aussi diminué légèrement, l'époxyde d'heptachlore a augmenté et les autres composés n'ont démontré aucune tendance. Chez les Pygargues à tête blanche du nord de l'Ontario, seules les concentrations de DDE ont diminué entre 1968 et le milieu des années 1980, et dans l'Arctique, la dieldrine dans les oeufs des Buses pattues a diminué.

Plusieurs populations canadiennes de rapaces ont connu des déclins au cours du dernier demi siècle qui peuvent être attribués aux pesticides. La population de l'est de Faucons pèlerins est disparue de l'est de l'Amérique du nord, et les Pygargues à tête blanche sont disparues des Grands Lacs inférieurs. Dans les deux cas, les oeufs étaient très contaminés au DDE, et la productivité a pratiquement été réduite à zéro. Bien que les preuves concernant d'autres espèces soient moins concluantes, il est possible que les populations de Balbuzards, de Faucons des Prairies, de Faucons émerillons et d'Éperviers de Cooper aient aussi connu des déclins avant les années 1980. En ce moment, plusieurs de ces espèces se rétablissent.

Plus récemment, quelques espèces, particulièrement les Buses rouilleuses, les Buses à épaulettes, les Effraies et les Chouettes des terriers ont subi des déclins de population. Les pesticides utilisés actuellement peuvent affecter les Chouettes des terriers; d'autres déclins ont été grandement attribués à la détérioration des habitats.

En raison de l'accumulation de composés organochlorés et de mercure, les rapaces peuvent être utilisés comme indicateurs de la contamination de l'environnement terrestre (ou aquatique dans certains cas). De plus, à cause de la vulnérabilité des rapaces aux effets toxiques, les répercussions sur leur santé peuvent être les premiers indices d'atteinte à l'écosystème. Les programmes de contrôle des contaminants sont susceptibles de comporter des échantillonnages : i) soit d'oeufs frais d'une espèce commune et répandue, ii) soit d'analyse de spécimens recueillis dans des centres de rétablissement d'oiseaux sauvages ou dans des musées, iii) soit de prises de sang effectuées à des stations de baguage de rapaces. Aussi, les spécimens jugés empoisonnés et soumis à une nécropsie au SCF, ainsi que les oeufs et les tissus recueillis selon le protocole de certains projets, continueront d'être analysés.

ABSTRACT

The results of chemical analyses of raptor eggs and tissues collected by the Canadian Wildlife Service between 1965 and 1988 are summarized. Residue levels are reported for DDE, DDD, DDT, dieldrin, heptachlor epoxide, HCB, PCBs, beta-HCH, oxychlordane, mirex and mercury in twenty-four species of Canadian raptors. Of these, only three tissue samples contain residues (mercury or DDE) indicative of acute poisoning. Critical toxic effect values for DDE, dieldrin, heptachlor epoxide and mercury in eggs are determined from the published literature, and the proportions of sampled eggs with residues in excess of those levels are reported. More than 50% of the eggs of Bald Eagles, Osprey, Merlins, Prairie Falcons and Peregrine Falcons (particularly those collected prior to the 1980s) contained DDE in excess of specific critical values. Contaminant data for eight species are analyzed for temporal trends. DDE declined significantly in Merlins, Prairie Falcons, Bald Eagles and Peregrine Falcons; dieldrin in Swainson's and Rough-legged Hawks, Merlins, Prairie and Peregrine Falcons; and heptachlor epoxide only in Prairie Falcons. Results are discussed with respect to changes in the status of raptor populations in Canada. It is feasible to use chemical residues in eggs, tissues or blood samples of raptors in order to monitor contamination of terrestrial ecosystems.

SUMMARY

Environmental pollutants such as organochlorine pesticides and polychlorinated biphenyls (PCBs) are known to persist in aquatic and terrestrial ecosystems. Predatory animals (such as raptorial birds) are often highly contaminated due to biomagnification via the food chain, and their tendency to take impaired and potentially contaminated prey.

The extirpation of the Peregrine Falcon (*Falco peregrinus anatum*) in eastern North America in the 1960s focused scientific attention on the toxic effects of widely used pesticides such as DDT. In Europe, mortality of raptors following treatment of seeds with mercurial fungicides demonstrated the deadly effects of mercury. Since the mid 1960s, the Canadian Wildlife Service (CWS) has carried out surveys of chemical residues in the tissues and eggs of Canadian raptors. The results of analyses for the presence of organochlorines and mercury in more than 250 tissue samples and more than 1400 eggs of raptors collected in Canada between 1965 and 1989, are summarized in this report.

Organochlorine pesticides, including DDT, dieldrin, heptachlor and BHC, were widely used in Canada for crop and forest protection until the early 1970s, when they were largely replaced by nonpersistent compounds. Although restrictions on use in the USA were implemented at about the same time as Canadian regulations, organochlorine use in Latin America continued to increase at least until the 1980s. Although many applications have been restricted, industrial compounds such as PCBs continue to enter the environment via leakage from transformers, industrial effluent, through spills, dumping and incineration. Current anthropogenic sources of heavy metals such as mercury, lead and cadmium include effluent from metal mines, smelters and coal-burning plants, and leaching from waste disposal sites.

Considerable evidence has been amassed on the direct toxic effects of DDE (the main derivative of DDT), dieldrin, lead and mercury on raptors. Although some raptor poisoning incidents have been reported, less is known of the toxic effects of heptachlor epoxide, oxychlordane, hexachlorocyclohexane (HCH) isomers, mirex, hexachlorobenzene (HCB) and polychlorinated biphenyls.

Many organochlorines and mercury have been found to have significant sublethal effects, particularly on reproduction. Raptors appear to be relatively susceptible to the eggshell thinning effects of DDE. There is considerable interspecific variation in the relationship between DDE content, eggshell

thickness and productivity, with Prairie Falcons, Merlins, Osprey and Bald Eagles among the most susceptible to decreased productivity. Although there has been little experimental work with raptors, there is evidence from studies on other birds that dieldrin, heptachlor epoxide, PCBs and mercury also reduce reproductive success. Reduced egg hatchability may result in population declines.

Organochlorine contaminants detected in Canadian raptors include DDT, DDD, DDE, dieldrin, heptachlor epoxide, mirex, oxychlordane, cis- and trans-nonachlor, cis- and trans-chlordane, alpha-, beta- and gamma-HCH isomers, chlorinated benzenes (mainly HCB) and PCBs. Residue levels range from undetectable to more than 100 mg/kg in the case of DDE. Improvements in analytical methodology allowed more compounds to be detected in recent samples than in those collected earlier. In general, levels in eggs reflect the diet, with highest residues in eggs of bird-eating and fish-eating species.

A very small proportion of tissues analysed were found to have residue levels diagnostic of acute poisoning; mercury in livers of a Bald Eagle and several Turkey Vultures collected in Ontario in 1970, and DDE in the liver of a Sharp-shinned Hawk collected in B.C. in the early 1980s.

Organochlorine concentrations in many eggs exceeded minimum critical threshold levels calculated from the toxicological literature. There were significant interspecific differences in critical values, with DDE affecting productivity in Prairie Falcons at egg levels greater than 1.2 mg/kg (wet weight) whereas the critical value for accipiters appears to be about 10 mg/kg. Although the critical level of dieldrin has not been established, we considered concentrations in excess of 1.0 mg/kg to be potentially hazardous. Estimated critical values for heptachlor epoxide and mercury in eggs were 1.5 mg/kg and 0.5 mg/kg, respectively.

Sharp-shinned and Cooper's Hawk eggs were highly contaminated, with DDE and (in one case) dieldrin levels often in excess of critical values. Buteos were generally less contaminated with DDE than accipiters, but a greater proportion of eggs contained elevated levels of dieldrin and heptachlor epoxide. A large proportion of Bald Eagle eggs contained DDE in excess of 6.0 mg/kg DDE, with maximum concentrations reaching 100 mg/kg. Many eagle eggs were also highly contaminated with dieldrin, heptachlor epoxide and mercury. Only one Golden Eagle egg contained significant chemical residues (of dieldrin), whereas many of the Osprey eggs contained more than 4.0 mg/kg DDE, the critical value calculated for that species.

Eggs of some falcons were highly contaminated. Most of more than three hundred Merlin eggs analyzed contained DDE in excess of the critical value, and more than 10% of eggs also contained elevated concentrations of dieldrin, heptachlor epoxide and mercury. Concentrations of DDE in more than 60% of Prairie Falcon eggs exceeded the critical level for that species. Dieldrin, heptachlor epoxide and mercury also exceeded critical values in a number of eggs. Only one Gyrfalcon and one American Kestrel egg were significantly contaminated (with dieldrin, and heptachlor epoxide and dieldrin, respectively). Peregrine Falcon eggs were highly contaminated with DDE in excess of 10 mg/kg in more than 50% of eggs analyzed. Almost 25% eggs contained elevated dieldrin residues.

Few owl eggs were markedly contaminated. DDE levels were high in two Great Horned Owl eggs, and heptachlor epoxide levels were elevated in two other eggs of that species.

Temporal trends in residue levels were determined for several species. In eggs of Swainson's and Ferruginous Hawks in the Prairies, dieldrin declined whereas DDE and heptachlor epoxide did not change significantly between the late 1960s and the mid 1980s. In Merlin eggs collected in the Prairies over the same time period, dieldrin and DDE declined significantly but heptachlor epoxide showed no consistent trend. In Prairie Falcons, all three compounds declined.

DDE egg levels have declined significantly in Peregrine Falcons over most of their range. Dieldrin also declined slightly, heptachlor epoxide increased, and other compounds showed no trend. In Bald Eagles from northern Ontario, only DDE declined between 1968 and the mid 1980s, and in the arctic, dieldrin in eggs of Rough-legged Hawks declined.

A number of populations of Canadian raptors have experienced declines over the past half century that may be attributed to pesticides. The eastern race of the Peregrine Falcon was extirpated from eastern North America, and Bald Eagles disappeared from the lower Great Lakes. In both cases, eggs were highly contaminated with DDE, and productivity had been reduced to virtually zero. Although the evidence for other species is less convincing, it is possible that Osprey, Prairie Falcons, Merlins and Cooper's Hawks also experienced population declines prior to the 1980s. Many of those species are presently recovering.

A few species, including Ferruginous Hawks, Red-shouldered Hawks, Barn Owls and Burrowing Owls, have exhibited population declines more recently. Current pesticide use may be affecting Burrowing Owls; other declines have been largely attributed to deterioration of habitat.

Because they accumulate organochlorine compounds and mercury, raptors can be used to monitor contamination of the terrestrial (and in some cases aquatic) environment. Moreover, because of their susceptibility to toxic effects, impaired health of raptors may be the first indication of chemical damage to ecosystems. Contaminant monitoring programs are likely to involve sampling of either: i) fresh eggs of a widely distributed common species, ii) analyses of specimens recovered from wild bird rehabilitation centres or museums, or iii) blood collection at raptor banding stations. In addition, specimens submitted to CWS for necropsy, which are suspected of being poisoned, and eggs or tissues collected as part of the protocol of specific projects, will continue to be analyzed.

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1.0 INTRODUCTION

High molecular weight organochlorine pesticides are highly persistent in soil, water, and biota (Beyer and Gish, 1980) and have been found to accumulate in the upper levels of food chains (Risebrough *et al.*, 1967; Newton, 1979).

The welfare of raptors, which are at the top of food chains, is cause for concern. The adverse effects of persistent contaminants on the survival and reproduction of raptors have been extensively documented. The reported effects include eggshell thinning (Ratcliffe, 1970; Cade *et al.*, 1971; Snyder *et al.*, 1973; Newton and Bogan, 1974; Grier, 1974), embryonic mortality (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975), abnormal parental behaviour (Fox, 1971; Hamerstrom, 1986) and increased adult mortality (Koeman *et al.*, 1969; Blus *et al.*, 1983; Stone and Okoniewski, 1983).

Increased adult mortality and/or reduced productivity may lead to population declines. In 1968, Hickey and Anderson were the first to report that many raptor populations in decline were experiencing eggshell thinning of at least 19%.

Public awareness of the impact of toxic substances in the environment, has given impetus to contaminant monitoring and research programs. Since 1965, in response to suspected reproductive problems in some Canadian raptors (Fox, 1971; Grier, 1974; Peakall, 1976), the Canadian Wildlife Service (CWS) has been monitoring contaminants in raptor eggs and tissues collected in Canada. Much of the data collected prior to 1976 has been published (Fox, 1971; Keith and Gruchy, 1972; Fimreite *et al.*, 1974; Fyfe *et al.*, 1976) but little has been reported since then.

Since the publication of the pre-1976 data, CWS has continued to collect and analyze tissues of Canadian raptors for their contaminant burden. Moreover, new analytical techniques have resulted in the detection of additional compounds, previously unidentifiable.

Most organochlorine pesticides such as DDT, dieldrin and heptachlor, have been heavily restricted in Canada since the early 1970s (Agriculture Canada, 1970, 1976a, 1976b, 1976c). However, although restrictions on organochlorine use in the USA and Europe were also implemented in the early 1970s, there continue to be reports of wildlife tissues with elevated levels of organochlorines, in those countries (Clark and Krynitsky, 1983; Burgers *et al.*, 1986; Hunt *et al.*, 1986; Blus *et al.*, 1987). The sources of this contamination have been variously attributed to:

i) illicit applications,

ii) use of residual stocks,

iii) uptake from persistent residues in soil (Clark and Krynitsky, 1983), and

iv) contamination of other chemical formulations (Blus *et al.*, 1987).

Another possible source is continued use in Latin America (Burton and Philogene, 1986; Inigo and Risebrough, 1989), where many Canadian raptors winter. Raptors may be exposed to organochlorines in prey obtained during the winter, or in migratory prey returning from Central and South America in the spring.

Atmospheric transport of organochlorines used outside North America is also a possibility. Organochlorines can vaporize and be carried to northern latitudes by prevailing air masses (Bidleman *et al.*, 1989). Long-range transport in the atmosphere is considered to be the major vector of organochlorine contamination in the Canadian Arctic (Norstrom *et al.*, 1988).

The main aim of this report is to present a summary of currently available CWS data, along with background information on pesticide use in Canada, acute and sublethal toxicities and some assessment of the status of Canadian raptor populations. It is not intended to be a comprehensive review of all compounds, the literature, nor a detailed analysis of the data.

1.1 Scope of report

Table 1 lists the numbers of egg and tissue samples analyzed for each species, in each year from 1965 to 1988. Raptors in this report include all members of the orders Falconiformes (vultures, hawks, eagles, ospreys, and harriers) and Strigiformes (owls) which breed in Canada and for which we have contaminant residue data. The paucity of data for many species indicates serious gaps in our knowledge of current or historical levels of environmental contaminants.

TABLE 1. Summary of raptor samples analyzed, 1965-1988.

Species	Sample	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
		Year																							
Northern Goshawk	Eggs				1																		4		5
	Tissues				-																		-		-
Cooper's Hawk	Eggs		5	3	4	1	4		1		1			1						-	-	4	5	4	33
	Tissues		1	-	-	-	-		-		-			-						3	-	-	-	-	4
	Blood		-	-	-	-	-		-		-			-						-	-	3	1	1	5
Sharp-shinned Hawk	Eggs			1	-													-	3	-	-	3	3	3	13
	Tissues			-	1													1	1	4	1	-	-	-	8
	Blood			-	-													-	-	-	4	36	46	38	124
Red-tailed Hawk	Eggs		23	18	6	2																-			49
	Tissues		2^4	2^2	1	-																-			5
	Blood		-	-	-	-																3			3
Red-shouldered Hawk	Eggs								3																3
	Tissues								-																-
Swainson's Hawk	Eggs		6	9	2	-	-		1											3^{3p}	5^{5p}				18 + 8 pool
	Tissues		-	13^3	-	-	4^3	-	-											-	-				17
Ferruginous Hawk	Eggs			8	13	2	27													1^{1p}	1^{1p}				50 + 2 pool
	Tissues			-	1^2	-	10^2													-	-				11
Rough-legged Hawk	Eggs	2	8	1				2	1	-						4	2								20
	Tissues	-	4^2	-				-	2^3	1						-	-								7
Broad-winged Hawk	Eggs																					-			-
	Tissues																					-			-
	Blood																					2			2
Bald Eagle	Eggs			4	4	19	5	1		2								2							37
	Tissues			1^2	1^3	3^2	-	-		-								-							5

[a] includes 1965 data; x^{1-6} indicates max number of tissues analyzed per specimen (eg. 3^4 indicates three different specimens, each with up to four tissues analyzed); x^{yp} indicates number of pools included in data set (eg. 3^{2p} indicates three samples in data set, of which two are pools).

TABLE 1 continued. Summary of raptor samples analyzed, 1965-1988.

Species	Sample	Year																							
		66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
Golden Eagle	Eggs			2	4			3	6	5	2														22
	Tissues			-	-			-	2^{2}	-	-														2
Osprey	Eggs				2		10	1	2	1	1														17
	Tissues				1^{2}		1^{3}	-	-	-	-														2
Northern Harrier	Eggs		2	1	20																	-			23
	Tissues		-	4^{2}	-																	-			4
	Blood		-	-	-																	2			2
Merlin	Eggs			3	21	42	28	73	31	33	26	43	12	18								-	-	14	344
	Tissues			1^{2}	3^{2}	-	1^{2}	1^{4}	2^{3}-	-	-	1^{2}	-	-								-	-	-	9
	Blood			-	-	-	-	-		-	-	-	-	-								4	2	1	7
Prairie Falcon	Eggs		18	21	65	46	44	55	50	49	41	41	19	17		12							6^{2p}		482 + 2 pool
	Tissues		-	-	2^{5}	-	1	3^{4}	1^{3}	-	2^{2}	8^{3}	1^{3}	-		-							-		18
Gyrfalcon	Eggs				1		-		5	1	4					1	1		4						17
	Tissues				-		2^{4}		1^{2}	-	-					-	-		-						5
American Kestral	Eggs		6	3																			3^{3p}	2^{2p}	9 + 5 pool
	Tissues		-	2^{2}																			-	-	2
Peregrine Falcon	Eggs	8^{a}	15	8	12	2	2	9	11	7	8	6	4	6	7	16	16	8		7	3	8^{1p}	1^{p}		162 + 2 pool
	Tissues	4	9^{6}	-	7^{4}	-	1^{2}	1^{4}	1^{2}	2^{2}	-	-	-	-	-	-	1^{3}	-		-	-	1^{2}	-		29
Turkey Vulture	Eggs					-																			-
	Tissues					3^{2}																			3
Common Barn Owl	Eggs																			-					-
	Tissues																			8					8
Snowy Owl	Eggs								1																1
	Tissues								-																-

[a] includes 1965 data; x^{1-6} indicates max number of tissues analyzed per specimen (eg. 3^{4} indicates three different specimens, each with up to four tissues analyzed); $x^{?p}$ indicates number of pools included in data set (eg. 3^{2p} indicates three samples in data set, of which two are pools).

TABLE 1 continued. Summary of raptor samples analyzed, 1965-1988.

Species	Sample	Year																						
		66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	Total
Great Grey Owl	Eggs																			3					3
	Tissues																			-					-
Long-eared Owl	Eggs		2	3	4																				9
	Tissues		2	-	-																				1
Short-eared Owl	Eggs		-	-	6																				6
	Tissues		1^2	6^2	-																				7
Great Horned Owl	Eggs		15	9	7	2																			33
	Tissues		1^4	1	3	1																			6
Burrowing Owl	Eggs			1																					1
	Tissues			3^2																					3

[*] includes 1965 data; x^{1-6} indicates max number of tissues analyzed per specimen (eg. 3^4 indicates three different specimens, each with up to four tissues analyzed); x^{yp} indicates number of pools included in data set (eg. 3^{2p} indicates three samples in data set, of which two are pools).

Figure 1 Five collection regions of Canada

Eggs, the majority of samples analyzed, were collected fresh early in the season, or unhatched at the end of the season. Unless indicated as a pooled sample, analyses are of individual eggs. We did not determine clutch means in the few cases where more than one egg of a clutch was analyzed. Results of analyses of livers, brains, whole bodies, subcutaneous fat, breast muscle, ovaries, and blood plasma are also included.

Most of the data presented are of levels of organochlorines and mercury. The organochlorine contaminants included are: DDT, DDD, DDE, dieldrin, heptachlor epoxide (HE), mirex, beta-hexachlorocyclohexane (B-HCH), hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs) and oxychlordane (see Appendix 1). Occasionally, alpha-HCH, gamma-HCH, cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor are mentioned where residue levels were noteworthy.

No attempt has been made in this report to distinguish between different PCB congeners, although the toxic effects and pharmacodynamics differ markedly among the more than 200 possible congeners and isomers. Since 1987, PCB analyses of wildlife tissue have been congener-specific. There are some results of analyses for lead, but none for other industrial chemicals, other metals or radionuclides. Since the 1960s analytical methodology and technology have improved and some contaminants have only recently been detected. Although pre-1970 data were corrected for changes in techniques (see Methods), comparisons of these data with those reported elsewhere should be undertaken with caution.

Although the collection location was recorded to the nearest degree- minute block, most of the data are grouped in broad geographic regions for the spatial comparisons. These regions were considered sufficient because most raptors move within relatively large areas and many species disperse widely outside the breeding season. The five regions chosen were: i) the Atlantic provinces (Newfoundland, New Brunswick, Nova Scotia, and Prince Edward Island); ii) Quebec and Ontario; iii) the Prairie provinces (Manitoba, Saskatchewan, and Alberta); iv) British Columbia (B.C.); and v) Northern Canada (the Northwest Territories and Yukon Territory). These are delineated on the map of Canada in Figure 1.

Residue levels in eggs and tissues of Canadian raptors are compared mainly with data from other North American studies, although a few species (eg. Osprey, Peregrine Falcon and Barn Owl) are globally distributed.

1.2 Organization of report

Chapters 3 and 4 focus on the sources and pharmacodynamics of organochlorines and heavy metals in the terrestrial environment, and review their toxic effects in raptors. The results of the chemical analyses are summarized in Tables 3 to 9. We do not present the raw data, but provide the geometric means of seven major contaminants (DDE, dieldrin, heptachlor epoxide, oxychlordane, PCBs, HCB and mercury) for each period. These periods (1965-72, 1973-79, 1980-88) relate to organochlorine use, and were chosen to represent the i) pre-restriction, ii) immediately post restriction, and iii) the current situation, respectively.

We attempted to assess the toxic effects likely to result from the detected levels of contaminants in each species, based on the literature. We looked for any evidence that populations had declined, and whether this could be attributed to exposure to organochlorines or other contaminants.

We also looked for any changes in contaminant residue levels since the timing of restrictions. There has not been a standardized monitoring scheme for raptors in Canada and most tissues and eggs were obtained opportunistically. Therefore, no single species that can be used to determine temporal or spatial differences in contaminant levels. Nevertheless, because of the number of species involved, and the diversity of geographical locations sampled, we believe that some general patterns have emerged. The section of the text ends with an evaluation of the use of residue levels in raptors to monitor environmental contaminants.

Chapter 7 contains the species accounts, which discuss the contaminant residue levels detected in each species, their toxicological significance and any temporal trends. Residue levels were compared with data from other studies, and related to diet, migratory behaviour and population status. There is, unavoidably, some overlap between the last and previous sections of the report, but the more comprehensive species accounts allow the reader to focus on a species of particular interest.

In the appendices, we report mean levels of ten of the more commonly detected contaminants (DDE, DDT, DDD, dieldrin, heptachlor epoxide, oxychlordane, beta-HCH, HCB, PCBs and mercury) for each year of sampling. The appendices provide more detailed data for each species, and are organized by year of sampling, location, tissue and condition of tissue. In addition to the geometric mean, the sample size, maximum and minimum values for each category are given. In many cases, more specific information about the sample (eg. a bird found starved in the nest) or the location (eg. Wager Bay, N.W.T.) is included.

1.3 Disclaimer

Although this report has been reviewed, there may still be errors in the appendices due to the sheer volume of data presented. Persons wishing to use the data from the National Registry of Toxic Chemical Residues presented in the appendices should contact Laird Shutt at (819) 953-4098 or at the address from which copies of the report may be obtained.

2.0 METHODS

2.1 Sources of data

Data were retrieved by a search on selected species made on the CWS National Registry of Toxic Chemical Residues (Elliott *et al.*, 1987), a computerized repository for data on environmental contaminants in Canadian wildlife. Data files for each species were created, with details of: location; date of collection; type of tissue; percentage lipid; percentage water; type of chemical analysis; and concentrations of selected contaminants. Data were checked against original documents, field collection sheets, and laboratory notes to confirm the condition (fresh, addled, or rotten) of eggs and other tissues. Detected errors were corrected. Results of chemical analyses and collection information in CWS Internal Reports and Ontario Research Foundation Reports since 1981 were added to these databases, and also verified against the original collection sheets and lab notes.

2.2 Sample collection

In the 20 years covered by this report, field collection procedures varied with species, levels of investigation and reasons for collecting.

Most eggs were collected opportunistically near the end of the breeding season, and therefore constitute a potentially biased sample of unhatched eggs. The eggs were classified during tissue preparation as: i) fresh (no sign of embryo development); ii) addled (embryo unidentifiable); iii) rotten or infertile (no sign of embryo); or iv) unknown (unable to tell) or unreported. Eggs with detected embryo development were classified as nonviable, unless it was specified in the collection sheet data as a live embryo. It should be noted that an embryo may have died from causes other than embryotoxicity, such as abandonment, freezing, or mortality of one of the adults.

In some cases, eggs were collected early in the season in order to obtain samples more representative of the population. Unlike the eggs above, these should not be biased towards higher residues.

Tissues were obtained by a variety of methods, including shooting, but most were from adults found dead (usually of unknown causes). Nestlings were found dead in or below nests. Fat biopsies were taken from breeding birds; the technique is described in Enderson and Berger (1968).

The selection of tissues for analysis varied according to the reasons for collection. Livers are the major site of toxic substance metabolism and are the first organs exposed following absorption from the gastro-intestinal tract (Sundlof *et al.*, 1986). Breast muscle is the major portion of body mass, and therefore most closely represents whole body levels (Sundlof *et al.*, 1986), making it useful for estimating input from prey species. Brain concentrations of toxic substances have been correlated with clinical disease for the determination of lethal levels (Heinz *et al.*, 1979). Fat concentrations of organochlorines represent levels of contamination at the time the fat was laid down.

Egg contents and tissues were placed into acetone and hexane-rinsed glass jars with a chemically-cleaned foil liner between the lid and the jar, or wrapped in aluminum foil and stored frozen until analysis.

Carcasses of birds were wrapped in solvent-rinsed aluminum foil and/or placed into polyethylene bags and placed in frozen storage at the National

Wildlife Research Centre (N.W.R.C.).

Blood samples were obtained from migrating raptors at selected banding stations in the spring and fall. A 1 mL sample of blood was removed by syringe from the brachial vein, transferred to a heparinized tube, and stored on ice until centrifuged. Plasma samples were frozen -40° C, until analysis, as described by Smrek *et al.*, (1981).

2.3 Sample preparation

Tissues were dissected using instruments chemically-cleaned with acetone and hexane. Soft tissues including egg contents were homogenized in a Waring blender or Sorvall Omnimixer. Whole body samples were prepared by removal of the digestive tract, feathers, and hard body parts such as feet and beak, homogenized in a commercial meat-grinder, and further homogenized in a Waring blender as required.

2.4 Chemical analysis

Data included in this report dates from 1965. Prior to 1969, only DDE and dieldrin levels are presented. Although the presence of such compounds as DDT and DDD were confirmed in many samples, the quantitative information was unreliable because of interference from PCB congeners. A method for separating peaks of PCBs from those of other pesticides was developed on behalf of CWS in 1969 (Reynolds, 1969). Quantitative results for PCBs and other organochlorines are included subsequent to this date. A methodology review in 1979 revealed losses of DDD, DDT, HCB, and oxychlordane of up to 50% during vacuum oven drying. These losses were found to be reproducible and correction factors were added to the registry and applied to all pre-1978 data.

Prior to 1984, all analyses were carried out at the Ontario Research Foundation in Mississauga, Ontario, under contract to CWS. A strict quality control program has been maintained (Turle and Norstrom, 1987). Analytical procedures are described in Reynolds and Cooper (1975) and Norstrom *et al.* (1980). Since 1984, some samples have been analyzed at the N.W.R.C. using similar procedures (Peakall *et al.*, 1986).

PCBs were quantified by capillary gas chromatography, and are presented as a 1:1 mixture of Aroclors 1254 and 1260, or as Aroclor 1260, as is typical for presentation of residues in wildlife tissues (Reynolds, 1971; Norstrom *et al.*, 1978; Won and Norstrom, 1980). The 1:1 mixture can be determined since 14.643 pg of PCB 138 is equivalent to 200 pg of a 1:1 mixture of Aroclor 1254 and 1260. Aroclor 1260 has been determined from PCB 180 since 11.63 pg is equivalent to 100 pg of Aroclor 1260. However, due to differences in analytical methods, PCB levels prior to 1973 may not be comparable to those since 1973 (Turle *et al.*, 1988).

Since 1986, concentrations of 43 identifiable PCB congeners have been determined, but are not presented in this report. PCB congeners differ greatly in their toxicity and pharmacodynamics (Tanabe, 1988). Conversion factors are being developed which may permit estimation of the total sum of congeners from the 1:1 ratio (Turle, CWS, pers. comm.).

Total mercury was determined by wet digestion followed by flameless atomic absorption spectrophotometry (AAS) (Fimreite and Reynolds, 1973). Methodology for detection of lead involved freeze-drying followed by low temperature ashing and treatment with nitric acid/hydrogen peroxide. Concentrations were then determined by flame or flameless AAS. National Bureau of Standards bovine liver Standard Reference Material was used for quality assurance purposes.

2.5 Sample storage

The remains of most of the CWS specimens included in this report are retained in the CWS National Specimen Bank (Elliott, 1984). Samples were stored at about -25°C until 1981, at which time the collection was transferred to a -40°C storage facility. Some recent material is stored at -80°C.

2.6 Data analysis

Data in this report are presented on the basis of mg/kg, wet weight (w.w.). Reporting of residue levels on a wet weight basis is preferred for eggs because moisture content has been found to be less variable than lipid content during embryo development (Peakall and Gilman, 1979). Eggs which were dehydrated (i.e. the moisture content was less than 60%) were not included in the analyses of means. Residues in other tissues were also reported on a wet weight basis.

As residue concentrations are usually skewed but commonly exhibit a log normal distribution (Ohlendorf *et al.*, 1978), data are presented as geometric means. If a particular compound was not identifiable by techniques available at the time of analysis, those samples were not included in the calculations. When a chemical was analyzed for, but not detected, a value of one half the detection limit was entered (0.0005 mg/kg for most organochlorines). Geometric means were calculated from samples collected for the same species, tissue, years or groups of years, and general locations.

For most datasets, temporal or spatial differences could not be analyzed statistically because of the patchiness of sample collections. Where appropriate, statistical analyses were conducted using SAS and SPSS routines on a micro computer. We used ANOVA (with Student-Neuman-Keuls multiple comparisons) or Student t-test (Sokal and Rohlf, 1981) to test for differences in geometric means among years, or (rarely) among geographical regions. For a few species, the general linear model test was used to identify the direction of significant temporal trends.

2.7 Determining the status of raptor populations

Changes in the population status of raptors can be difficult to detect. Methods of censusing raptors were reviewed by Fuller and Mosher (1987). The main sources of data on population trends are counts along migration routes, Christmas Bird Counts, and regular monitoring of populations by a variety of techniques ranging from aerial surveys to detailed breeding studies. Counts of all raptors (except owls) are made annually during migration at a number of locations in

North America, where their movements are restricted by large bodies of water or mountain ranges (Heintzelman, 1986). Of the more than 100 such sites, Hawk Mountain, Pennsylvania, and Cape May, New Jersey, are among the best known. In the Great Lakes region, migrating raptors are monitored at Beamer and Hawk Cliff, Ontario, Derby Hill, New York, and Duluth and Whitefish Point, Michigan. Data from these counts can be used to determine trends if certain assumptions, such as no overall changes in migratory paths or height of flying, are met, and observer effort and weather data are standardized (Sattler and Bart, 1984).

Long-term population trends can also be estimated from Breeding Bird Surveys (BBS), a program of annual checks of the numbers of breeding birds recorded along selected transects in North America (Robbins *et al., 1986). Bald Eagles, Haliaeetus leucocephalus,* and Ospreys, *Pandion haliaetus*, which have large conspicuous nests, have been censused by aerial counts in many regions of Canada (Gerrard and Ingraham, 1985). However, nests of many of the woodland species, such as accipiters, can be difficult to locate, and less is known of the status of these species.

We would also like to point out that information on the population status of many Canadian raptors is scarce, and most status assessments are not conclusive. This highlights the need for more reliable methods of assessing the status of raptor populations.

2.8 Comments on interpretation of data

As noted previously, the absence of a particular chemical does not mean it was not present. The analytical techniques to separate a particular compound may not have been available, or the presence of an interfering substance may have masked its presence. Values close to the detection limits are the least reliable.

Differences among laboratories performing the CWS analyses also introduce a possible bias, although the quality assurance procedures should minimize this problem (Turle and Norstrom, 1987). This consideration is particularly important in comparing the residue values reported here with data reported in other publications. If eggs or other tissues were not prepared and stored using the methods described above, samples may have deteriorated to a point that chemical analyses would not be valid. Values are presented on a wet weight basis and most organochlorines are highly lipophilic. Therefore, the percentage fat is an important consideration in interpretation of results, particularly for tissue samples (see Appendices).

3.0 SOURCES OF ORGANOCHLORINES AND HEAVY METALS IN RAPTORS

3.1 Pesticide use in Canada

Organochlorine pesticides, including DDT, dieldrin, aldrin, heptachlor, and chlordane, were used extensively in Canada for control of agricultural and forest insect pests and in households. Pesticides that are applied to the soil may persist for many years (Beyer and Gish, 1980) contaminating local invertebrates and entering aquatic systems in run-off. Aerial application of chemicals (such as DDT) facilitates atmospheric transport and may result in contamination of the avifauna of much larger areas.

3.1.1 DDT and metabolites

More than seven million kg of DDT were used for spruce budworm control in Quebec and New Brunswick from the early 1950s until the late 1960s (Nigam, 1975). In Ontario, DDT was applied to tobacco, vegetable, and fruit crops in the control of cutworms and other insect pests. Other uses included control of biting flies on livestock, and around lakes in recreational areas. Nationwide restrictions on DDT use were first imposed in the late 1960s, with further restrictions in 1971 and 1975 (Agriculture Canada, 1976c). A few remaining minor uses of DDT in Ontario were finally revoked in 1988.

A potential source of DDE in raptors is Kelthane, which contains the active ingredient dicofol. An acaracide used mainly on fruit crops, Kelthane has been found to contain DDT impurities in the formulation, which may be metabolically converted to DDE (Risebrough et al., 1986). Although the permitted DDT content was significantly reduced by the end of 1988 (Schwarzbach *et al.*, 1988), Kelthane may be a contributing source of DDT and DDE detected in species such as American Kestrels, Falco sparverius, breeding in orchards in Southern Ontario.

3.1.2 Dieldrin

Dieldrin and its parent compound, aldrin, were also used extensively in Canada until the early 1970s, mainly as soil insecticides for vegetables and lawns in Ontario (Frank *et al.*, 1975) and for seed treatment and wireworm control in the Prairie provinces (Fyfe, 1973). It was also sprayed on many crops in the Prairies during the late 1950s to control grasshopper infestations (Fox, CWS, pers. comm.). Restrictions on use came into effect in 1970 in Southern Ontario (Agriculture Canada, 1976b), and in 1973-74 in the Prairies (Fyfe, 1973). By 1978 all uses except for control of subterranean termites and Japanese beetles had been suspended.

3.1.3 Heptachlor

Heptachlor was widely used on agricultural crops until 1970, when it was restricted to soil and seed treatment. In 1976 most uses of technical heptachlor were cancelled (Agriculture Canada, 1976a), although technical chlordane (which contains up to 8% heptachlor) continued to be used.

3.1.4 Chlordane

Technical chlordane became popular in the 1970s following restrictions on most other organochlorine insecticides. It was used in Canada primarily for control of soil pests such as Corn Rootworm and Strawberry Root Weevil (N.R.C.C., 1981). Although some uses were cancelled in 1978, it was widely available until

1986 as a household insecticide. It is still registered for subterranean termite control.

3.1.5 Mirex

Mirex has never been registered as a pesticide in Canada, but was found as a contaminant in industrial effluent entering Lake Ontario in the 1970s. Plants using mirex as a flame retardant in the manufacture of plastics, fabrics, and electrical components were apparently the source (Norstrom *et al.* 1980).

3.1.6 Hexachlorobenzene

Hexachlorobenzene (HCB) was used as a fungicidal seed treatment in Canada until 1970. It also occurs along with other chlorinated benzenes as a byproduct of pulp-bleaching and other industrial processes (Hallett *et al.*, 1982).

3.1.7 BHC and lindane

The insecticide BHC is a mixture of alpha- and beta-HCH isomers, and was widely used in Canada until 1970 when restrictions came into effect (Agriculture Canada, 1970). The original formulation has been replaced with lindane (which contains at least 99% gamma-HCH). Lindane is used mainly as an insecticidal seed treatment for wheat. It is also used on ornamentals, for log boring pests, to control lice, ticks and fleas on livestock, and as a household insecticide (Jessiman, 1989).

3.1.8 Endrin and toxaphene

Two other organochlorine pesticides have been found in Canadian wildlife. Endrin was used as a rodenticide in Alberta. Production was discontinued in 1989 and its use is currently restricted to controlling cutworms on cereal crops and potato pests (Agriculture Canada, 1990).

In Canada, toxaphene was used in fish eradication programs until the late 1960s, and to some extent as an insecticide on vegetable crops (Eisler and Jacknow, 1985). Agricultural applications were restricted first in 1970 and further in 1980. The standard analytical procedures carried out on most of the samples analyzed by CWS in the past did not allow quantification of this compound. However, recent findings of relatively high levels of toxaphene in eggs of Leach's Storm-petrels from both Canadian coasts (Elliott *et al.*, 1992a) suggest that significant amounts may be accumulated by some birds.

3.2 Pesticide use in the U.S.A.

Patterns of organochlorine pesticide use in the U.S.A. were similar to those in Canada, although the aggregate amounts used were about an order of magnitude higher.

DDT (which was used in forestry, agriculture, and in municipalities) was banned by the Environmental Protection Agency (EPA) in 1972 except for a few minor uses. Its use was occasionally permitted in special circumstances, as in the control of a Tussock moth outbreak in the northwestern states in 1974 (Henny, 1977). DDT was also manufactured in the U.S.A. although none of the factories are currently active. Water bodies adjacent to these sites are still contaminated above background levels (Fleming *et al.*, 1983), and may be a continuing source of contamination to wildlife. As in Canada, dicofol (Kelthane) containing DDT impurities (Brown *et al.*, 1986) was used on ornamentals and in orchards until recently.

Dieldrin, used mainly in the control of soil pests, was banned in the U.S.A. in 1975 (U.S. Environmental Protection Agency, 1979). Technical chlordane was used widely until 1980, when it was registered only for subterranean termite control. Use of technical heptachlor for seed treatment was permitted in many states until 1982 (Henny *et al.*, 1983).

Mirex was used as a pesticide in the control of fire ants, and industrially as a flame retardant in the manufacture of electrical components and plastics. In 1978, the E.P.A. banned all uses of mirex, but discharges from former factories were still contaminated in the early 1980s (Eisler, 1985).

Endrin is used mainly to control cutworms, potato beetles, and grasshoppers. It was banned east of the Mississippi in 1979, but was still registered for use on cereal crops in the western states until at least the early 1980s (Schladweiler and Weigand, 1983).

Toxaphene was used widely in the U.S.A. to control pests of cotton and vegetable crops. Most registered uses were cancelled by the U.S. E.P.A. in 1982 (Eisler and Jacknow, 1985).

3.3 Pesticide use in Latin America

Use of organochlorine pesticides in Central and South America has been suggested as a source of the continuing high levels of these compounds in migratory raptors or in their migratory prey (Enderson *et al.*, 1982; Henny *et al.*, 1982; Springer *et al.*, 1984; DeWeese *et al.*, 1986).

Many of the organochlorine pesticides (such as DDT, dieldrin, and heptachlor) were still in use in Latin America during the 1980s, although a few countries had introduced restrictions (Burton and Philogene, 1986). Of the persistent chlorinated pesticides discussed in this report, DDT, BHC, and toxaphene were used in the largest quantities. However, usage has declined more than 20% since 1978 as organophosphates and carbamates have replaced organochlorines.

Brazil is the primary user and manufactures more than 50% of the pesticides locally. Although DDT and BHC were used on a large scale, there have been attempts to replace these with synthetic pyrethroids. Mexico and Venezuela are the next largest users; but most organochlorine insecticides (DDT, aldrin, endrin, heptachlor, mirex, and chlordane) were restricted or cancelled in 1980 and 1984, respectively. Ecuador and Peru have also prohibited some uses of DDT and other organochlorines.

Some countries in Central America imposed restrictions on the use of organochlorines during the early 1980s. However, overall DDT use was comparable to that of Mexico or Brazil (Burton and Philogene, 1986).

3.4 Other pesticides

Although they are generally much less persistent, there have been some reports of raptor mortality due to currently used pesticides such as famphur (Franson *et al.*, 1985) and carbofuran (Balcomb, 1983). Secondary poisoning of raptors by acute rodenticides (1080, strychnine) have occurred frequently, but the newer anticoagulant rodenticides probably pose little risk to most raptors (Kaukeinen, 1982).

3.5 Contaminants originating from industrial processes

A wide variety of contaminants enter the environment through industrial effluent, combustion, equipment leakage, incineration, spills, and leaching from dump sites. Only PCBs and HCB are included in this report. Other compounds detected in raptors include chlorinated styrenes (Reichel *et al.*, 1974) and diphenyl ethers (Stafford, 1983) and fluoride (Bird *et al.*, 1989). Recently found in Bald Eagle eggs collected from nests near the Strait of Georgia, B.C. (Elliott, unpubl. data), dibenzo-p-dioxins and dibenzofurans have been detected in a number of fish-eating birds in Canada (Elliott *et al.*, 1987).

3.5.1 PCBs

PCBs are industrial chemicals with a wide range of uses, but appear primarily in closed-circuit electrical and heat transfer systems (Nisbet and Sarofim, 1972). The main American producer, Monsanto, reduced its output in 1970, and all manufacture of PCBs was banned in North America in 1977 (Canadian Council of Resource and Environment Ministers, 1986). Nevertheless, PCBs in existing transformers and from other sources continue to enter the environment. PCBs are particularly prevalent in marine and freshwater systems because they readily partition into water from air and undergo accumulation at each level of the marine food chain (Tanabe, 1988). HCB is another widespread industrial contaminant that occurs, along with other chlorinated benzenes, as a contaminant in industrial effluent.

3.6 Heavy metals

Metals are naturally occurring elements; however, human activities may increase environmental levels in some areas to concentrations toxic to biota. Only mercury and lead have been well studied with respect to their toxicity to raptors.

3.6.1 Mercury

Since the 1940s, mercurial seed dressings (fungicides) were used extensively, particularly in the Prairie provinces. Due to dangerously high levels detected in gamebirds and their predators in Canada and elsewhere, its registration for this use was discontinued in 1970 (Fimreite, 1974).

However, most mercury input to the environment comes from industrial and municipal discharges and atmospheric emissions. Prior to 1970, chlor-alkali plants released large amounts of mercury to rivers and coasts across Canada (Fimreite, 1974). Mercury discharge was reduced by more than 90% during the 1970s, as legislation was brought into effect. Other sources include coal-burning plants, smelters, mines, municipal wastewater treatment plants, and pulp and paper mills. Recently, mobilization of mercury in areas flooded by hydroelectric development has been shown to be a local source of high levels of mercury in fish (Bodaly *et al.*, 1984).

3.6.2 Lead

The main anthropogenic sources of lead to the environment include automobile emissions (now reduced), lead smelters, thermal power plants, base metal mines, and sewage sludges (Eaton *et al.*, 1986). Another major source of lead to raptors is lead shot in crippled or injured prey, particularly waterfowl (Pattee and Hennes, 1983).

3.6.3 Other metals

Other metals which are potentially toxic to raptors and which enter the environment from anthropogenic sources include aluminum, arsenic, cadmium, copper, chromium, molybdenum, nickel and selenium (Scheuhammer, 1987; Wiemeyer *et al.*, 1987).

4.0 TOXICITY OF ORGANOCHLORINES AND HEAVY METALS TO RAPTORS

Considerable evidence has been accumulated on the toxic effects of organochlorines and mercury on raptors, particularly fish and bird-eating species. Most of these studies have been done in the field, and show significant correlations between concentrations of residues found in tissues or eggs, and measures of reproductive performance, survivorship, or population trends.

Studies where sublethal effects were experimentally induced in raptors have generally been restricted to a few species easily bred in captivity (i.e. American Kestrels, Barn Owls, and Screech Owls). However, there have been exceptions. In one study with Prairie Falcons, dosing of wild birds was achieved by tethering contaminated prey species in their territories (Enderson and Wrege, 1973). In a study of Red-tailed Hawks, *Buteo jamaicensis*, and Golden Eagles, *Aquila chrysaetos*, by Seidensticker (1968), wild nestlings were dosed.

Toxicological studies using raptors are summarized by Peakall (1987). Furthermore, there is an extensive body of literature on the experimentally-induced toxicity of organochlorines and mercury to other bird species (primarily poultry, quail, Mallards, doves, blackbirds, starlings and cowbirds). These studies were used as a basis in interpretation of the potential risks of the detected residue levels of environmental contaminants to raptors.

4.1 Acute toxic effects

Raptors are usually at the top of terrestrial food chains, a position which is likely to expose them to high concentrations of bioaccumulative environmental contaminants in their prey. During the era of intensive pesticide use in industrialized countries, many raptors were found dead or dying with symptoms consistent with pesticide poisoning (Prestt *et al.*, 1968; Koeman *et al.*, 1969). Symptoms of poisoning include erratic behaviour, tremors, convulsions, and paralysis. Pathological signs include neurological damage, liver and skin lesions, enlarged livers, and severe emaciation.

The lethal or hazardous ranges of contaminants in brains (summarized in Table 2), have been established in laboratory studies with birds. As most raptors can be maintained for a short time in captivity, acute toxicity has been investigated in a wider variety of species. These include Red-tailed Hawks, Bald Eagles, Goshawks, and American Kestrels.

Cyclodiene insecticides are the most toxic. Dieldrin at brain residue levels greater than 4.0 mg/kg (Stickel *et al.*, 1969; Ohlendorf *et al.*, 1981); oxychlordane at brain levels between 1.1 and 5.0 mg/kg; and heptachlor epoxide at brain levels of 3.4 to 8.3 mg/kg, were lethal to captive birds (Stickel *et al.*, 1979). Blus *et al.* (1984) reported mortality of Canada Geese with brain levels of heptachlor epoxide greater than 8.0 mg/kg (w.w.). Cooke *et al.* (1982) considered 3 to 10 mg/kg (w.w.) cyclodienes in the livers of raptors to be lethal.

TABLE 2. Summary of critical levels (in mg/kg, wet weight) of major environmental contaminants in eggs, brains and livers of raptors.

Contaminant Level (mg/kg) diagnostic of:	1) acute toxicity		2) reproductive effects
	Brain	Liver	Eggs
Dieldrin	> 5.0 [a]	3 - 10 [b]	> 1.0 [c]
Oxychlordane	1.1 - 5.0 [d]	3 - 10 [b]	
Heptachlor epoxide	3.4 - 8.3 d	3 - 10 b	> 1.5 [e]
DDE	250 [f]	100 b	1.2 - 30 [g]
PCBs	500-3000 [h]		> 50 [i]
HCB			> 5.0 [j]
Mercury	> 50 [k]	20 - 45 k	> 0.5 [l]
Lead		> 10 [m]	

[a] Stickel et al, 1969
[b] Cooke et al, 1982
[c] Lockie et al, 1969; Wiemeyer et al, 1975
[d] Stickel et al, 1979
[e] Henny et al, 1983
[f] Stickel et al, 1984
[g] Fyfe et al, 1988; Lincer, 1975
[h] Heath et al, 1972
[i] Hoffman et al, 1987
[j] Boersma et al, 1986
[k] Scheuhammer, 1987
[l] Fimreite, 1971; Heinz, 1979
[m] Pattee et al, 1981

Dieldrin has been implicated in the mortality of many raptors in North America, including: Bald Eagles (Belisle *et al.*, 1972; Kaiser *et al.*, 1980); a Peregrine Falcon, *Falco peregrinus*, from North Carolina in 1973 (Reichel *et al.*, 1974); Red-shouldered Hawks ,*Buteo lineatus*, in Florida (Sundlof *et al.*, 1986); and a Cooper's Hawk *Accipiter cooperii*, a Great Horned Owl *Bubo virginianus*, a Screech Owl *Otus asio*, and a Barn Owl *Tyto alba* in New York (Stone and Okoniewski, 1988). Mortality was attributed to dieldrin where brain residues of this compound were greater than 4.0 mg/kg (w.w.), and where other contaminants were below levels associated with acute toxicity. However, brain levels of dieldrin as low as 1.0 mg/kg triggered fasting, which led to death in cowbirds (Heinz and Johnson, 1982).

Elevated levels of heptachlor epoxide (9.6 mg/kg) in the brain of a banded adult Merlin, *Falco columbarius*, from Alberta found dead in New Mexico in 1974 were considered responsible for its death (Henny *et al.*, 1976). DDE residues in the brain (178 mg/kg) were also high.

The first records of chlordane-related mortality of raptors were reported by Blus *et al.* (1983). Two Red-shouldered Hawks and one Great Horned Owl were found dead in the U.S.A. with lethal concentrations of oxychlordane and heptachlor epoxide in their brains. Of the other organochlorines detected, only dieldrin approached levels that may have contributed to mortality. In Oregon, the deaths of three Golden Eagles, an American Kestrel and a Rough-legged Hawk, *Buteo lagopus*, were attributed to heptachlor epoxide (Henny *et al.*, 1984). Either oxychlordane or heptachlor epoxide were considered to be principle agents in the deaths of Great Horned Owls, Cooper's Hawk, Sharp-shinned Hawk *Accipiter striatus*, Screech Owls and a Goshawk, *Accipiter gentilis*, in New York between 1982 and 1986 (Stone and Okoniewski, 1988).

The DDT compounds are less acutely toxic than the cyclodienes, with lethal brain values of 10 mg/kg for DDT, 50 mg/kg for DDD, and greater than 250 mg/kg for DDE, all wet weights (Stickel *et al.*, 1970). American Kestrels on a diet containing 2.8 mg/kg DDE died eventually with brain levels of 200 to 300 mg/kg DDE (Porter and Wiemeyer, 1972). Cooke and co-workers (1982) considered 100 mg/kg (w.w.) DDE to be the lethal threshold in the liver. Prouty and co-workers (1982) reported DDT poisoning in a Cooper's Hawk collected in Maryland in 1980. An American Kestrel found dead in New York had acutely toxic levels of both dieldrin and DDT (Stone, 1981). Two of 20 Great Horned Owls examined in New York were considered to have been poisoned by either DDE, dieldrin, or PCBs (Stone and Okoniewski, 1983).

In studies on laboratory species, Heath and Spann (1973) found mirex to be toxic at brain concentrations close to 200 mg/kg. There have been no reports of wild raptors dying due to mirex poisoning (Eisler, 1985).

Traditionally, PCB compounds were considered to be among the least acutely toxic of the organochlorines, with lethal ranges in the brain ranging from 500 to 3000 mg/kg (w.w.) (Heath *et al.*, 1972). This was later updated in a study by Stickel *et al.* (1984), which found brain levels greater than 280 mg/kg of Aroclor 1254 to be diagnostically lethal to passerines.

The above values are based on studies on commercial mixtures of PCBs such as Aroclors 1254 and 1260. Some coplanar PCB congeners, which have structures similar to the polychlorinated dioxins, are extremely toxic (Tanabe, 1988). Although these compounds are fortunately rare in commercial mixtures, their extreme toxicity makes even minuscule amounts a problem. A study of the relative toxicities of different PCB congeners showed that American Kestrels (Elliott *et al.*, 1991) were considerably less sensitive than Japanese Quail (Elliott *et al.*, 1990) to the effects of congener 124 (3,4,3',4',5'-PCB) on liver enzymes and induction of porphyria.

There is one report of PCB poisoning in a wild raptor. In 1981, Stone and Okoniewski (1983) found a dying Great Horned Owl in New York, which contained more than 300 mg/kg PCBs in its brain.

Mercury appears to be acutely toxic to birds of prey where brain concentrations exceed 15 to 20 mg/kg (w.w.), or liver concentrations exceed 20 to 50 mg/kg (w.w.) (Scheuhammer, 1987). Pathological symptoms include ataxia, weight loss, muscular atrophy, nerve cell degeneration, demyelination, and swelling of axons of myelinated nerves. Many European raptors died in the late 1960s due to ingestion of seed-eating prey heavily contaminated with mercury from seed-dressings (Borg *et al.*, 1969).

In experiments on Red-tailed Hawks, Fimreite and Karstad (1971) found that mercury levels in livers of birds that died averaged 20 mg/kg (w.w.). In American Kestrels, Koeman *et al.* (1971) found 45 mg/kg (w.w.) to be the lethal liver level. The fatal brain level of methylmercury in Goshawks was between 30 and 40 mg/kg (w.w.) (Borg *et al.*, 1970). In a recent study on Zebra Finches (Scheuhammer, 1988), neurological signs indicative of methylmercury intoxication did not develop until mercury concentrations of 15 mg/kg (w.w.) or greater had accumulated in the brain and at least 40 mg/kg (w.w.) in the liver and kidney. Although the lethal tissue levels are relatively similar among species, accumulation of methylmercury varies widely. Chickens and pheasants, for example, were found to tolerate much higher mercury concentrations in the diet than passerines (Finley *et al.*, 1979). Another factor is the amount of dietary selenium, which affords protection from the toxic effects of mercury in many birds (Scheuhammer, 1987).

Lead poisoning has been diagnosed in a number of raptors, including Bald Eagles (Kaiser *et al.*, 1980), a Prairie Falcon (Benson *et al.*, 1974), and Red-tailed Hawks and a Goshawk (Redig *et al.*, 1980). Pattee and co-workers (1981) found liver lead concentrations above the 10 mg/kg (w.w.) levels in Bald Eagles indicative of acute lead exposure, often associated with lead shot in the digestive tract. A recent study of blood ALA-d activity in Bald Eagles from B.C. showed a significant degree of lead poisoning in birds brought to veterinarians and rehabilitation centres (Elliott *et al.*, 1992b).

4.2 Influence of energetic demands on toxic effects

The levels of environmental contaminants in a bird are influenced by its physiological state. Organochlorines are lipophilic meaning they are concentrated in the fat component of tissues. Circumstances which increase the energetic needs of the bird may cause stored lipids to be metabolized, releasing the stored lipophilic contaminants into the bloodstream (VanVelzen *et al.*, 1972). The increased residues in the blood are transported throughout the body, including to the brain. This scenario has been used to explain the rapid rise in concentrations of toxins in the brain when birds are stressed, sick or starving (Barbehenn and Reichel, 1981).

Long-distance flight can be an energetically costly activity, and some raptors lose considerable weight during migration (Newton, 1979). Although migrating birds may initially be carrying low concentrations of organochlorines, metabolism of stored lipids may increase contaminant concentrations in other tissues to lethal levels. Extremely high levels of organochlorine contaminants in the brain of a Merlin banded in Canada and found dead in New Mexico, were thought to be the result of mobilization of stored lipids during migration (Henny *et al.*, 1976).

Other factors influencing contaminant levels through changes in lipid levels include the physiological demands of incubation and provisioning of nestlings, as well as stress caused by disease or injury.

4.3 Sublethal effects of environmental contaminants

The sublethal effects of organochlorines on raptors have been extensively documented, particularly in terms of effects on reproductive success.

4.3.1 DDE

DDE concentrations in eggs have shown a high correlation with eggshell thinning and reproductive failure in a number of raptors, including: Cooper's Hawks (Snyder *et al.*, 1973); European Sparrowhawks (Newton and Bogan, 1974); American Kestrels (Lincer, 1975); Merlins (Fox, 1971; Newton *et al.*, 1982); Peregrine Falcons (Cade *et al.*, 1971; Peakall and Kiff, 1979); Prairie Falcons (Enderson and Berger, 1970); California Condors (Kiff *et al.*, 1983); Harriers (Odsjo and Sondell, 1977); Bald Eagles (Wiemeyer *et al.*, 1984); and Ospreys (Wiemeyer *et al.*, 1988).

DDE in the female reduces eggshell thickness through interference with calcium pharmacodynamics during egg-formation (Peakall *et al.*, 1975). The exact mechanism has still not been established (Risebrough, 1989). Cooke (1973), in a comprehensive review of suggested mechanisms of eggshell thinning, concluded that: 1) the primary factors were reduced availability of calcium and carbonate ions; 2) many factors, including thyroid defects and calcium transport in blood could be involved; and 3) mechanisms probably differed among species, due to differences in eggshell structure. Enzyme inhibition was also suggested by Bird *et al.* (1983), who showed that DDE caused no change in blood calcium levels, but was associated with reduced levels of carbonic anhydrase and calcium ATPase, in American Kestrels.

Thin shelled eggs are less viable for a number of reasons, mainly related to reduced strength. Hairline cracks may result in loss of moisture, bacterial infection, or destruction of the egg by the parent detecting the abnormality. Not only thickness, but shell structure is affected. A number of studies (Fox, 1976; Cooke *et al.*, 1976; Springer, 1980) detected higher incidences of structural abnormalities in eggshells of eggs with elevated DDE levels. These microscopic structural defects affect the strength, porosity and therefore viability of the egg. High rates of breakage may be an indication that significant eggshell thinning is occurring.

The degree of eggshell thinning is determined by comparing the eggshell thickness of the sampled egg to that in eggshells obtained prior to 1947. Widespread use of DDT began in 1947, and abrupt decreases in eggshell thickness of many species occurred in that year (Newton, 1979). Many researchers use the Ratcliffe index (weight of shell/length x width), which is closely correlated with measured eggshell thickness. However, despite this correlation, exclusive use of the Ratcliffe index has been criticized by Moriarty *et al.* (1983), who claimed that it did not take into account changes in egg size or shape. These problems can be resolved to some extent to measuring the shell thickness directly, with a micrometer.

Furthermore, as thickness is influenced by a number of environmental and genetic factors (including the availability of calcium, natural variation in the population, the sequence of laying, and the size of the egg), large sample sizes are required.

Although DDE has been found to cause eggshell thinning in all raptors studied, the sensitivity to DDE-induced eggshell thinning varies among species. Fyfe *et al.* (1988) examined the relationships between DDE, eggshell thickness and productivity, within the genus *Falco*. As in other studies (Hickey and Anderson, 1968; Blus *et al.*, 1971; Snyder *et al.*, 1973; Lincer, 1975), they found a significant linear relationship between decreasing eggshell thickness and the logarithm of DDE concentrations in eggs. However, there were interspecific differences in the "threshold" level of DDE, below which there is little detectable change in eggshell thickness from the pre-1947 levels. Prairie Falcons and Merlins were the most sensitive, exhibiting decreases in eggshell thickness at DDE concentrations greater than 0.3 mg/kg (w.w.). American Kestrels were not affected until DDE levels in eggs attained at least 1.0 mg/kg (w.w.). The relationship between eggshell thickness and DDE residues in the egg varied somewhat among species of *Falco* (Fyfe *et al.*, 1988). Even at high DDE concentrations, however, Prairie Falcons and Merlins were more affected than either Peregrine Falcons or American Kestrels.

There are interspecific differences in the relationship between eggshell thinning and productivity. In spite of a similar response to DDE, the productivity of Prairie Falcons was more affected by eggshell thinning than that of Merlins (Fyfe *et al.*, 1988). Prairie Falcon productivity was affected by 8% eggshell thinning and no young were produced when eggshell thinning reached 14%. Application of the regression equation suggests that in Prairie Falcons, the minimum level of DDE in eggs likely to have an affect on productivity is 1.2 mg/kg (wet weight), and that virtually no young will be produced from eggs with more than 3.0 mg/kg DDE.

The threshold effect levels for Merlins and Peregrine Falcons were 15% and 20% eggshell thinning, respectively. Fyfe *et al.*'s (1988) study confirmed an earlier estimate by Peakall (1976) that in Peregrine Falcons, DDE levels in eggs between 15 and 20 mg/kg are likely to cause significant eggshell thinning and to reduce productivity.

Prairie Falcons appear to be one of the most susceptible raptors to the toxic effects of DDE, but few species outside the genus *Falco* have been investigated in detail. In 1975, Wiemeyer found that no Osprey eggs hatched from clutches where DDE levels in eggs were greater than 12 mg/kg. Further study showed that DDE levels greater than 4.0 mg/kg in Osprey eggs, were associated with 15% shell thinning and reduced productivity (Wiemeyer *et al.*, 1988).

In Bald Eagles, 10% shell thinning was associated with DDE egg levels of 5.6 mg/kg (Wiemeyer *et al.*, 1984). Total reproductive failure occurred where DDE levels in eggs exceeded 15 mg/kg.

Newton and co-workers (1986) found that 20% eggshell thinning in eggs of European Sparrowhawks, *Accipiter nisus*, was associated with DDE residues of 10.3 mg/kg in the eggs. DDE-induced egg-shell thinning has also been demonstrated in experimental studies with American Kestrels (Wiemeyer and Porter, 1970) and Screech Owls (McLane and Hall, 1972).

4.3.2 Other organochlorines

Dieldrin has been implicated in reproductive failure, not through eggshell thinning, but by embryotoxicity. Lockie *et al.* (1969) found that dieldrin levels greater than 0.9 mg/kg (w.w.) in eggs of Golden Eagles in Scotland were associated with significantly reduced productivity. Wiemeyer *et al.* (1975) reported that no Osprey eggs containing more than 1.0 mg/kg of dieldrin hatched. However, in a laboratory study of the effect of dieldrin on reproduction in Barn Owls (Mendenhall *et al.*, 1983), egg levels of 3 mg/kg were found to have no effect.

Heptachlor epoxide levels greater than 1.5 mg/kg (w.w.) in American Kestrel eggs were associated with a reduction in productivity (Henny *et al.*, 1983). There appears to be no data on the effects of oxychlordane, cis or trans chlordane, cis or trans-nonachlor, or any HCH isomers on avian reproduction.

There is no conclusive evidence that PCBs affect productivity in raptors, although Bird *et al.* (1983) demonstrated that dietary Aroclor 1254 reduced sperm production in kestrels. Wiemeyer and co-workers (1975) reported that no Osprey eggs containing in excess of 15 mg/kg PCB hatched, but PCB levels were highly correlated with those of other contaminants. Levels of 4 to 18 mg/kg PCBs in eggs of captive-dosed Screech Owls had no apparent effects on hatching or fledging rates (McLane and Hughes, 1980). However, in studies with Black-crowned Night-herons, *Nycticorax nycticorax*, a mean egg level of 4.1 mg/kg PCBs was correlated with lower embryonic weight (Hoffman *et al.*, 1986). A similar pattern was observed in Forster's Tern, *Sterna forsteri*, embryos from Green Bay, Wisconsin: hatching success and embryonic weight were reduced, and the incidence of congenital abnormalities was increased. This was in conjunction with increased levels of aryl hydrocarbon hydroxylase (AHH) inducers such as PCBs and polychlorinated dibenzo-dioxins (Hoffman *et al.*, 1987). Tern eggs at this colony contained a mean of 22 mg/kg PCBs. PCB levels from 3 to 16 mg/kg in eggs reduced hatchability in chickens (Cecil *et al.*, 1974) and Ringed Turtle-doves, *Streptopelia risoria*, (Peakall and Peakall, 1973). However, these species are apparently relatively sensitive to PCBs.

Mirex was also found to reduce sperm production in American Kestrels (Bird *et al.*, 1983), but the combination of mirex and Aroclor 1254 resulted in no difference from that of mirex alone.

4.3.3 Mercury

Although there have been no experimental studies on its effects on reproduction in raptors, mercury has been shown to reduce hatchability of pheasant eggs at levels between 0.5 and 1.5 mg/kg (w.w.) (Fimreite, 1971), and of Mallard eggs at levels of about 0.85 mg/kg (Heinz, 1979). Teratogenecity by methylmercury has also been reported in Mallards (Hoffman and Moore, 1979). There are some indications that embryos and newly hatched young are more susceptible to mercury intoxication than adults (Finley and Stendell, 1978).

4.4 Biochemical responses to contamination

Organochlorines and various halogenated industrial compounds have been shown to induce a suite of biochemical responses in birds. These include porphyria in Great Lakes Herring Gulls, *Larus argentatus* (Fox *et al.*, 1988), induction of AHH and other liver enzymes (Ellenton *et al.*, 1985; Boersma *et al.*, 1986), and chick-edema disease (Gilbertson, 1983). Although some of these responses are not directly lethal, they indicate pathological changes in the bird as a result of exposure to toxic substances.

4.5 Effects on behaviour

Abnormal parental behaviour attributed to elevated organochlorine body burdens has been reported in a number of species. Egg-eating was a phenomenon observed in Peregrine Falcons (Ratcliffe, 1980) and Grey Herons, *Ardea cinerea*

(Milstein *et al.*, 1970). Fox and Donald (1980) reported weakened nest defence in Merlins, and Hamerstrom (1986) reported "listlessness" and the cessation of the aerial courtship displays of Harriers. Other aberrant behaviours observed included desultory nest-building, abandonment of eggs, poor attendance at the nest, and deliberate egg-breaking (Milstein *et al.*, 1970; Snyder *et al.*, 1973).

Few lab studies on the effects of sublethal levels of organochlorines on behaviour have been attempted. Research on the predatory behaviour of kestrels under low-level exposure to DDE (Rudolph *et al.*, 1983) revealed that variance in response time was greater in exposed birds, although average response time and attack rates did not differ.

4.6 Effects on populations

Hickey and Anderson (1968) noted that 19% eggshell thinning was associated with population declines in raptors and fish-eating birds. Lincer (1975) and Newton (1979) calculated similar figures, of 16% and 18%, respectively.

Nevertheless, the considerable interspecific differences in the relationship between eggshell thinning and reproductive success reported by Fyfe *et al.* (1988) suggest that some species may be affected by even "minor" eggshell thinning.

The effects of contaminant-induced changes in breeding success on the status of the population are more difficult to gauge, and depend on the factors influencing survival and productivity. Some owls, for example, habitually lay large clutches. Only a few young survive to fledging, except in years of unusual prey abundance. A certain amount of egg-breakage may have little impact on those species. Additionally, a large clutch may allow the female to excrete a significant amount of her toxic burden through her eggs, as has been found for European Sparrowhawks (Newton and Bogan, 1978).

The effects of increased adult mortality also depend on the biology of the species. Some species may compensate for an increase in adult mortality by earlier recruitment to breeding, whereas long-lived species with low reproductive rates, such as the California Condor, may be severely affected. Shorter-lived species may also recover more quickly as exposure is reduced.

These problems were addressed by Newton (1988), who advocated the determination of the critical level of contamination that leads to a population decline for each species of interest. This would require considerable research on the relationships between levels of contaminants, measures of productivity and changes in population numbers.

5.0 RESULTS AND DISCUSSION

5.1 Contaminants detected in Canadian raptor eggs and tissues

Organochlorine contaminant concentrations in eggs and tissues of raptors varied widely from nondetectable to highly elevated. The contaminants detected included: DDT; DDE; DDD; dieldrin; heptachlor epoxide; mirex; oxychlordane; cis-chlordane; trans-chlordane; cis-nonachlor; trans-nonachlor; alpha-HCH; beta-HCH; gamma-HCH; chlorinated benzenes (mainly HCB); and polychlorinated biphenyls (PCBs). Discussion of the range of contamination found in each species is in Chapter 7.0.

Tables 3 to 7 summarize the levels of DDE, dieldrin, heptachlor epoxide, HCB, oxychlordane, PCBs, and mercury in the eggs of each species. A geometric mean, or result of a pooled analysis, is presented for three time periods in each of the five geographical regions (Figure 1) for which data are available.

The three time periods are derived from the date of implementation of restrictions on organochlorine use in North America, as follows: i) 1965-72 - period of extensive use before most restrictions were implemented; ii) 1973-79 - period when some restrictions on DDT, dieldrin, HCB, and heptachlor were first introduced; and iii) 1980-88 - period during which virtually all uses of the organochlorine pesticides discussed in this report were banned.

The geometric mean for each time period and geographical region is accompanied by the range of values, in parentheses. Where pooled samples were analyzed, they are presented separately. More detailed information is available in the Appendices, where the geometric means of egg levels for each year and within each province are listed, with the maximum and minimum values. We also noted the condition of the eggs, whether fresh, infertile, addled, or containing a dead embryo.

TABLE 3. Residue levels of environmental contaminants detected in eggs of accipiters in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Northern Goshawk (*Accipiter gentilis*):									
Atlantic	1965-72	1	3.9	0.049	0.019	-	-	-	-
Ontario	1980-88	4	0.99 (0.27-1.82)	0.089 (0.036-0.20)	0.41 (0.021-0.079)	0.064 (0.038-0.115)	0.004 (0.002-0.007)	0.56 (0.25-0.88)	-
Cooper's Hawk (*Accipiter cooperii*):									
Prairies	1965-72	17	3.84 (2.35-14.6)	0.17 (0.035-5.87)	0.096 (0.012-0.56)	-	0.009 (n=5) (0.006-0.010)	*0.33 (n=9) (0.057-1.5)	0.085 (n=7) (0.040-0.13)
Prairies	1973-79	3	5.06 (3.91-5.95)	0.24 (0.10-1.31)	0.076 (0.03-0.16)	0.060 (n=1)	0.032 (0.030-0.057)	2.2 (n=2) (0.64-7.98)	0.035 (n=2) (0.03-0.040)
Ontario	1980-88	13	4.61 (1.19-25.3)	0.03 (0.066-0.69)	0.16 (0.029-1.07)	0.23 (0.028-1.66)	0.009 (0.003-0.026)	1.97 (0.66-9.23)	-
Sharp-shinned Hawk (*Accipiter striatus*):									
Prairies	1965-72	1	7.0	0.12	0.057	-	-	-	0.12
Ontario	1980-88	9	8.25 (3.52-18.6)	0.27 (0.088-1.19)	0.19 (0.084-0.82)	0.20 (0.020-0.88)	0.021 (0.0095-0.057)	2.14 (1.51-3.68)	-
Atlantic	1980-88	3	7.03 (5.42-9.12)	0.53 (0.39-0.75)	0.34 (0.30-0.41)	0.76 (0.67-0.85)	0.041 (0.025-0.062)	4.24 (3.52-4.87)	-

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 4. **Residue levels of environmental contaminants detected in eggs of buteos in Canada.** (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Red-tailed Hawk (*Buteo jamaicensis*):									
Prairies	1965-72	46	1.222 (0.288-16.4)	0.365 (0.033-5.94)	0.092 (0.004-2.55)	-	-	*0.18 (n=5) (0.026-0.82)	0.099 (0.023-0.356)
Ontario	1965-72	2	0.487	0.170	0.018 (0.015-0.021)	-	0.038 (0.035-0.042)	*0.85 (n=2) (0.80-0.89)	0.089 (0.080-0.010)
B.C.	1965-72	1	4.720	0.262	0.110	-	-	*0.37	-
Swainson's Hawk (*Buteo swainsoni*):									
Prairies	1965-72	17	0.630 (0.092-5.92)	0.337 (0.021-1.25)	0.222 (0.063-4.08)	-	-	*0.029 (n=3) (0.09-0.029)	0.124 (n=8) (0.03-0.42)
Prairies	1973-79	1	0.660	0.080	0.030	-	0.019	*0.9	0.160
Prairies	1980-88	8 pools	0.397 (0.083-1.02)	0.050 (0.014-0.197)	0.120 (0.029-0.293)	0.025 (0.01-0.036)	0.021 (0.004-0.129)	0.154 (0.022-0.489)	-
Ferruginous Hawk (*Buteo regalis*):									
Prairies	1965-72	50	0.283 (0.030-13.1)	0.077 (0.0005-4.34)	0.140 (0.02-2.33)	-	0.0006 (n=29) (0.0005-0.010)	*0.001 (n=32) (0.0005-1.15)	0.035 (n=38) (0.010-0.249)
Prairies	1980-88	1 pool	0.053	0.047	0.085	0.024	0.003	0.210	-
Prairies	1980-88	1 pool	0.150	0.050	0.137	0.019	0.011	0.170	-

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 4 continued. Residue levels of environmental contaminants detected in eggs of buteos in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Red-shouldered Hawk (*Buteo lineatus*):									
Ontario	1973-79	3	2.427 (1.4-3.78)	0.182 (0.08-0.42)	0.046 (0.03-0.08)	-	0.015 (0.0095-0.019)	1.885 (1.05-3.11)	-
Rough-legged Hawk (*Buteo lagopus*):									
North	1965-72	14	0.439 (4.63-27.0)	0.020 (0.007-0.250)	0.0016 (n=12) (0.0005-0.074)	-	0.010 (n=2) (0.01-0.01)	*3.36 (n=2) (3.36-3.37)	0.149 (n=3) (0.045-0.320)
North	1973-79	1	0.460	0.050	0.030	-	0.019	*0.32	-
North	1980-88	6	0.329 (0.03-1.19)	0.032 (0.01-0.14)	0.216 (0.005-2.69)	0.040 (0.01-0.19)	0.042 (0.01-0.61)	1.323 (0.27-5.08)	0.053 (0.04-0.07)

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 5. Residue levels of environmental contaminants detected in eggs of eagles, ospreys and harriers in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Bald Eagle (*Haliaeetus leucocephalus*):									
Atlantic	1965-72	1	23.1	0.53	ND	-	0.020	*17.4	0.24
Atlantic	1980-88	2	2.31 (1.03-4.84)	-	-	-	0.025 (0.019-0.032)	8.11 (4.22-15.6)	-
Ontario	1965-72	19	35.3 (17.8-99.3)	1.42 (0.59-2.87)	0.122 (0.0005-0.69)	-	0.022 (n=5) (0.0005-0.16)	*26.5 (n=18) (9.35-202)	0.401 (n=18) (0.18-1.02)
Ontario	1973-79	2	33.9 (32.0-35.8)	0.85 (0.56-1.29)	0.052 (0.03-0.09)	0.108 (0.036-0.324)	0.293 (0.266-0.323)	18.8 (17.3-20.4)	0.24 (0.18-0.31)
Prairies	1965-72	13	4.11 (1.37-28.5)	0.215 (0.033-1.06)	0.0019 (0.0005-0.116)	-	0.011 (n=9) (0.004-0.030)	*3.0 (n=10) (1.05-8.5)	0.11 (n=9) (0.06-2.62)
Golden Eagle (*Aquila chrysaetos*):									
Prairies	1965-72	9	0.774 (0.29-2.81)	0.137 (0.06-0.56)	0.122 (0.02-0.86)	-	0.0031 (n=2) (0.0005-0.19)	*0.393 (n=7) (0.12-0.58)	0.014 (n=8) (0.0005-0.22)
Prairies	1973-79	12	0.824 (0.23-2.05)	0.123 (0.02-2.12)	0.081 (0.02-0.13)	-	0.0153 (0.0095-0.038)	1.01 (0.11-3.64)	0.038 (n=8) (0.005-0.22)
North	1973-79	1	0.8	0.010	0.010	-	ND	*0.33	ND

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 5 continued. **Residue levels of environmental contaminants detected in eggs of eagles, ospreys and harriers in Canada.** (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Osprey (*Pandion haliaetus*):									
Atlantic	1965-72	3	6.17 (5.67-7.15)	0.0014 (0.0005-0.01)	ND	-	0.0014 (0.0005-0.01)	*8.05 (6.9-9.8)	0.097 (0.07-0.13)
Ontario	1965-72	8	3.91 (1.71-9.61)	0.062 (0.01-0.31)	0.0009 (0.0005-0.05)	-	0.0018 (0.0005-0.02)	*3.38 (1.0-75)	0.103 (0.06-0.23)
Prairies	1973-79	2	4.6 (2.3-9.3)	0.10 (0.03-0.33)	0.035 (0.03-0.04)	-	0.019 (0.009-0.038)	0.94 (0.72-1.24)	0.063 (0.04-0.10)
British Columbia	1965-72	2	4.54 (3.37-6.11)	0.009 (0.005-0.017)	0.017 (0.014-0.020)	-	-	*0.34 (0.33-0.35)	-
Yukon	1973-79	2	17.9 (13.3-24.0)	0.039 (0.03-0.05)	0.063 (0.05-0.08)	-	0.027 (0.019-0.038)	*1.34 (0.87-2.08)	0.70 (0.62-0.79)
Northern Harrier (*Circus cyaneus*):									
Prairies	1965-72	22	1.411 (0.013-20.4)	0.272 (0.010-0.52)	0.087 (0.0005-1.56)	-	-	0.92 (n=8) (0.02-0.84)	0.044 (n=8) (0.018-0.28)
North	1965-72	1	14.5	0.99	0.069	-	ND	*3.0	0.09

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 6. Residue levels of environmental contaminants detected in eggs of falcons in Canada.
(Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Merlin (*Falco columbarius*):									
B.C.	1965-72	1	8.838	0.201	0.435	-	-	1.729	0.517
Prairies	1965-72	164	7.59 (1.13-135)	0.350 (0.029-3.24)	0.337 (0.04-5.4)	-	0.034 (n=143) (0.008-1.84)	*1.008 (n=161) (0.147-9.7)	0.163 (0.04-1.29)
Prairies	1973-79	158	9.78 (0.09-90.9)	0.225 (0.005-5.6)	0.491 (0.005-9.09)	0.184(n=60) (0.01-1.31)	0.053 (0.001-10.1)	1.404 (0.22-7.02)	0.049 (n=129) (0.0005-0.56)
Prairies	1980-88	14	2.95 (0.28-65.8)	0.042 (0.007-0.59)	0.30 (0.065-2.03)	0.080 (0.023-0.3)	0.014 (0.005-0.23)	0.240 (0.13-0.31)	-
N. Quebec	1965-72	1	33.2	0.23	0.082	-	0.003	*7.83	0.720
North	1973-79	4	16.5 (10.7-19.7)	0.95 (0.42-2.6)	0.29 (0.18-0.55)	-	0.089 (0.057-0.15)	1.30	0.073 (0.01-0.34)
Prairie Falcon (*Falco mexicanus*):									
Prairies	1965-72	247	1.86 (0.14-41.4)	0.129 (0.0008-8.94)	0.218 (0.022-30.2)	-	0.0178 (n=143) (0.0005-0.41)	*0.558 (n=222) (0.0005-9.28)	0.086 (n=227) (0.0005-1.71)
Prairies	1973-79	239	1.10 (0.08-33.4)	0.082 (0.005-7.2)	0.165 (0.005-0.243)	0.051 (n=47) (0.009-0.43)	0.0253 (0.0005-1.42)	0.542 (0.10-9.57)	0.019 (n=203) (0.0005-0.38)
Prairies	1980-88	16	0.687 (0.010-1.63)	0.061 (0.002-1.05)	0.084 (0.005-0.76)	0.023 (0.002-0.07)	0.049 (0.005-0.35)	0.250 (0.004-0.93)	0.018 (n=12) (0.010-0.060)
Prairies	1988	1 pool of 9 1 pool of 5	0.056 0.041	0.002 0.002	0.012 0.009	0.004 0.003	0.107 0.010	0.072 0.146	-

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 6 continued. Residue levels of environmental contaminants detected in eggs of falcons in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Gyrfalcon (*Falco rusticolus*):									
North	1965-72	1	9.020	0.167	0.057	-	0.020	*25.5	1.430
North	1973-79	10	0.334 (0.07-0.57)	0.016 (0.005-0.04)	0.016 (0.005-0.03)	-	0.014 (0.005-0.038)	0.597 (0.40-0.99)	0.009 (0.0005-0.03)
North	1980-88	6	0.124 (0.014-5.11)	0.018 (0.001-1.34)	0.028 (0.006-0.30)	0.031 (0.005-0.45)	0.069 (0.011-0.90)	0.475 (0.033-16.5)	2.20
American Kestrel (*Falco sparverius*):									
Atlantic	1965-72	1	12.4	0.44	ND	-	-	-	-
Prairies	1965-72	8	1.9 (0.60-11.9)	0.038 (0.002-1.25)	0.51 (0.034-4.8)	-	-	-	0.23(n=3) (0.16-0.29)
S. Ontario	1987	1 pool of 17	10.8	0.077	0.11	0.11	0.022	0.86	-
C. Ontario	1987	1 pool of 9	0.44	0.013	0.009	0.027	0.017	0.18	-
N. Ontario	1987	1 pool of 5	2.80	0.081	0.078	0.061	0.007	0.35	-
S. Ontario	1988	1 pool of 10	3.83	0.042	0.043	0.051	0.007	0.32	
C. Ontario	1988	1 pool of 9	0.43	0.066	0.039	0.038	0.005	0.17	-
Peregrine Falcon (*Falco peregrinus*):									
N. Quebec	1965-72	10	9.74 (4.63-27.0)	0.81 (0.27-1.91)	ND	-	-	-	-
N. Quebec	1973-79	4	11.8 (4.3-19.6)	0.99 (0.41-1.86)	0.21 (0.13-0.31)	-	0.033 (0.019-0.057)	13.6 (6.5-38.5)	0.29 (0.15-0.71)

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 6 continued. Residue levels of environmental contaminants detected in eggs of falcons in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Peregrine Falcon (*Falco peregrinus*) continued:									
N. Quebec	1980-88	10	5.68 (1.61-13.8)	0.574 (0.14-2.61)	0.423 (0.15-1.34)	0.174 (0.05-0.31)	0.043 (0.016-0.11)	10.84 (1.61-32.2)	-
Alberta	1965-72	5	36.5 (12.6-78.5)	1.25 (0.39-2.48)	0.269 (0.20-0.42)	-	0.061 (n=4) (0.040-0.070)	*11.37 (8.0-14.7)	0.360 (0.13-0.56)
Alberta	1973-79	20	10.6 (1.86-18.4)	0.43 (0.14-1.07)	0.26 (0.030-2.10)	0.116 (n=12) (0.070-0.19)	0.029 (0.009-0.150)	5.94 (2.34-11.1)	0.202 (n=7) (0.14-0.50)
Alberta	1980-88	14	9.35 (2.07-29.2)	0.396 (0.060-1.52)	0.401 (0.060-2.71)	0.106 (n=12) (0.030-0.20)	0.43 (0.011-1.06)	5.91 (2.61-13.2)	0.376 (n=11) (0.12-1.14)
NWT/Yukon	1965-72	29	5.16 (0.05-94.8)	0.286 (0.005-8.0)	0.081 (n=23) (0.0005-0.66)	-	0.0063 (n=6) (0.00050.020)	*7.97 (n=26) (0.15-68.1)	0.318 (n=26) (0.01-0.67)
NWT/Yukon	1973-79	25	11.56 (0.35-28.9)	0.66 (0.060-3.51)	0.257 (0.040-2.66)	0.072 (n=8) (0.006-0.14)	0.042 (0.005-0.36)	9.06 (n=12) (3.07-57.1)	0.228 (n=23) (0.0005-1.30)
NWT/Yukon	1980-88	27	9.86 (4.3-29.1)	0.46 (0.060-2.89)	0.33 (0.060-2.07)	0.10 (0.0005-0.30)	0.098 (0.018-1.10)	7.68 (2.95-30.7)	-
B.C.	1965-72	12	7.84 (0.57-29.3)	0.062 (0.01-0.164)	0.0034 (0.0005-0.049)	-	0.050 (0.008-0.23)	*7.62 (0.15-35.5)	0.869 (0.0005-5.00)
B.C.	1980-88	4	2.79 (0.79--6.57)	0.013 (0.003-0.036)	0.019 (0.005-0.043)	0.070 (0.021-0.17)	0.068 (0.024-0.19)	4.08 (1.11-9.79)	-

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 7. Residue levels of environmental contaminants detected in eggs of owls in Canada. (Geometric means, range and sample size, if different from N)

Region	Years	N	Residue concentrations (mg/kg, wet weight)						
			DDE	Dieldrin	HE	Oxychlordane	HCB	PCBs[a]	Mercury
Snowy Owl (*Nyctea scandiaca*):									
North	1973-79	1	3.27	0.14	0.15	-	0.11	*10.4	0.11
Great Grey Owl (*Strix nebulosa*):									
Michigan	1980-88	3	0.059 (0.04-0.10)	0.014 (0.01-0.02)	0.010 (0.01-0.01)	0.014 (0.01-0.03)	0.005 (0.004-0.007)	0.003 (0.0005-0.12)	-
Long-eared Owl (*Asio otus*):									
Prairies	1965-72	7	0.60 (0.078-3.06)	0.014 (0.005-0.16)	0.010 (0.005-0.018)	-	-	*0.058 (n=4) (0.013-0.35)	0.036 (n=3) (0.025-0.046)
Short-eared Owl (*Asio flammeus*):									
Prairies	1965-72	6	4.078 (2.14-7.64)	0.099 (0.025-0.945)	0.037 (0.016-0.108)	-	-	*0.10 (n=5) (0.029-0.32)	-
Great Horned Owl (*Bubo virginianus*):									
Prairies	1965-72	31	2.40 (0.073-21.4)	0.095 (0.011-0.76)	0.10 (0.0005-1.88)	-	0.017 (n=1)	*0.75 (n=8) (0.041-2.4)	0.034 (n=8) (0.0005-0.12)
Ontario	1965-72	1	8.85	0.22	-	-	-	-	-
North	1965-72	1	1.52	0.10	0.25	-	-	-	1.94
Burrowing Owl (*Athene cunicularia*):									
Prairies	1965-72	1	0.68	0.42	0.15	-	-	-	0.11

[a] PCBs are reported on the basis of a 1:1 ratio of Arochlors 1254 to 1260, unless preceded by an asterix indicating that PCBs are reported on the basis of Arochlor 1260 only.

TABLE 8. Concentrations of organochlorines in tissues of Canadian raptors between 1967 and 1985.

Species and year	Prov.	Tissue	N	Geometric means of residue concentrations (mg/kg, wet weight)					
				DDE	Dieldrin	HE	Oxychlordane	HCB	PCBS
Sharp-shinned Hawk									
1969	B.C.	Brain	1	0.349	0.043				
1982-85	B.C.	Livers	7	3.622	0.128	0.095	0.177	0.044	3.511
Cooper's Hawk									
1967	B.C.	Brain	1	0.580	0.013				
1984-85	B.C.	Livers	3	12.354	0.633	0.325	0.481	0.012	4.773
Red-tailed Hawk									
1967	Saskatchewan	Brain	2	0.068	0.075	0.016			
1968	Alberta	Brain	1	0.467	0.154	0.057			
1968	B.C.	Brain	1	0.395	0.013				
Swainson's Hawk									
1968	Saskatchewan	Brain	4	0.085	0.186	0.131			
1968-71	Alberta	Brain	5	0.058	0.041	0.048			
Ferruginous Hawk									
1969	Saskatchewan	Brain	1	0.116	0.013	0.852			
1971	Alberta	Whole body	2	0.050	0.027	0.077			
Rough-legged Hawk									
1973	Yukon	Brain	3	0.208	0.014	0.001		0.010	0.611
		Liver	3	0.074	0.007	0.002		0.007	0.212
1974	N.W.T.	Liver	1	0.130	0.020	0.010		0.020	1.130
Bald Eagle									
1970	N.B.	Brain	1	7.090	0.181	0.062		0.005	
1969	Manitoba	Brain	1	0.532	0.045	0.009			
		Liver	1	2.120	0.110	0.017			
1968	B.C.	Brain	1	6.220	0.100				

TABLE 8. (continued) Concentrations of organochlorines in tissues of Canadian raptors between 1967 and 1985.

Species and year	Prov.	Tissue	N	Geometric means of residue concentrations (mg/kg, wet weight)					
				DDE	Dieldrin	HE	Oxychlordane	HCB	PCBS
Golden Eagle									
1973	N.W.T.	Brain	2	0.212	0.010	0.002		0.007	0.568
		Liver	2	0.283	0.007	0.001		0.010	0.538
Osprey									
1969	Ontario	Brain	1	0.222	0.013			0.017	
		Liver	1	0.218	0.021			0.012	
1971	Ontario	Brain	1	0.100	0.020				
		Liver	1	0.540					
N. Harrier									
1968	Saskatchewan	Brain	3	0.039	0.007	0.030			
1968	B.C.	Brain	1	0.554	0.048				
Gyrfalcon									
1968	N.W.T.	Liver	1	0.040	0.001	0.001		0.005	0.140
1971	B.C.	Brain	1	0.580	0.000	0.000		0.030	
		Liver	1	0.800	0.010			0.014	
Merlin									
1969	Alberta	Brain	1	0.235	0.017	0.014			
1969	Alberta	Brain	1	0.294	0.068	0.181			
1972	Alberta	Brain	1	0.070	0.010				
		Liver	1	0.110	0.060	0.030			
1973	Alberta	Brain	2	1.092	0.035	0.010		0.010	1.874
		Liver	2	3.167	0.079	0.049		0.025	1.560
1968	B.C.	Brain	1	15.800	0.379	0.224			
American Kestrel									
1968	Alberta	Brain	1	0.260	0.017	0.062			
1968	Alberta	Brain	1	0.079	0.009	0.020			

TABLE 8. (continued) Concentrations of organochlorines in tissues of Canadian raptors between 1967 and 1985.

Species and year	Prov.	Tissue	N	Geometric means of residue concentrations (mg/kg, wet weight)					
				DDE	Dieldrin	HE	Oxychlordane	HCB	PCBS
Prairie Falcon									
1973	Alberta	Brain	1	0.360	0.020	0.020		0.010	0.750
		Liver	1	0.340	0.010	0.020		0.010	0.290
1969	Alberta	Brain	1	0.095	0.014	0.007			
1969	Alberta	Brain	1	0.374	0.033	0.182			
		Liver	1	0.285	0.056	0.426			
1972	Alberta	Brain	3	0.129	0.016	0.060		0.010	
		Liver	3	0.335	0.023	0.186		0.010	
1975	Alberta	Brain	1	1.970	0.080	0.110		0.020	0.310
		Liver	1	4.50	0.130	0.130		0.030	0.540
1975	Alberta	Brain	1	0.150	0.005	0.005		0.010	0.570
		Liver	1	0.030	0.001	0.001		0.005	0.180
1976	Alberta	Brain	1	0.420	0.040	0.090	0.010	0.005	0.440
		Liver	1	0.840	0.090	0.360	0.030	0.010	0.800
1976	Alberta	Brain	7	0.428	0.040	0.163	0.011	0.007	0.126
		Liver	7	1.582	0.116	0.547	0.069	0.030	0.742
1977	Alberta	Brain	1	0.730	0.020	0.060	0.001	0.020	0.350
		Liver	1	0.940	0.060	0.210		0.020	0.510
Peregrine Falcon (anatum)									
1969	NB	Brain	1	0.17	0.017	0.05			
		Liver	1	0.19	0.036	0.061			
1983	Ontario	Brain	1	1.31	0.049	0.10	0.085	0.006	0.92
		Liver	1	2.45	0.088	0.10	0.18	0.006	3.08
1986	Ontario	Brain	1	0.45	0.045	0.07	0.023	0.007	0.87
		Liver	1	2.40	0.25	0.68	0.061	0.010	5.10
1967	Alberta	Muscle	1	1.84	0.025				
1972	Alberta	Brain	1N	0.25	0.04		0.01		
		Liver	1N	0.54	0.09	0.01			
1973	Alberta	Brain	1N	2.26	0.06	0.01		0.01	1.76
		Liver	1N	3.46	0.07	0.02		0.01	1.74
1969	NWT	Brain	1N	6.51	0.086	0.021			

TABLE 8. (continued) Concentrations of organochlorines in tissues of Canadian raptors between 1967 and 1985.

Species and year	Prov.	Tissue	N	Geometric means of residue concentrations (mg/kg, wet weight)					
				DDE	Dieldrin	HE	Oxychlordane	HCB	PCBS
Peregrine Falcon (tundrius)									
1966	NWT	Brain	2	0.43	0.10				
		Liver	2	1.57	0.46				
1967	North Quebec	Fat	8	285	8.60				
1969	NWT	Brain	2N	0.35	0.04	0.055			
1974	NWT	Brain	2N	1.36	0.15	0.069		0.005	2.07
		Liver	2N	9.54	0.92	0.55		0.02	6.96
1981	NWT	Brain	1	13.9	2.03	2.08	1.10	0.10	59.0
		Liver	1	84.2	2.97	2.98	1.41	0.17	208
Peregrine Falcon (pealei)									
1966	BC	Brain	1	0.25	0.009				
		Muscle	1	1.65	0.033				
1969	BC	Brain	2	2.16	0.0039				
		Liver	2	4.99	0.019	0.0069			
1971	BC	Brain	1N	0.53					
		Liver	1N	0.94	0.01			0.02	
Barn Owl									
1984-85	BC	Liver	8	0.553	0.033	0.037	0.057	0.006	0.482
Great Horned Owl									
1969	N.B.	Brain	2	0.184	0.003				
1967	Saskatchewan	Brain	1	0.212	0.023	0.010			
1969	Saskatchewan	Brain	1	0.039	0.003	0.006			
1970	Saskatchewan	Liver	1	0.743	0.097	0.167			
1984	Alberta	Liver	2	14.882	0.322	0.795	0.389	0.305	12.520
Burrowing Owl									
1968	Alta.-Sask.	Brain	3	1.078	0.019	0.092			
Long-eared Owl									
1967	Saskatchewan	Brain	1	0.145	0.022				
Short-eared Owl									
1968	B.C.	Brain	3	0.060	0.004				

TABLE 9. Mercury concentrations (mg/kg, wet weight) in livers of raptors collected in Canada between 1968 and 1976.

Species	Years	Province/Territory	No.	Geometric mean
Swainson's Hawk	1968	Saskatchewan	7	0.36
	1968-71	Alberta	10	0.16
Red-tailed Hawk	1968	Alberta	1	0.48
Ferruginous Hawk	1969	Saskatchewan	1	0.18
	1971	Alberta	8	0.020
Rough-legged Hawk	1974	N.W.T.	1	0.030
Bald Eagle	1970	Ontario	2	30.6
Osprey	1969	Ontario	1	3.1
	1971	Ontario	1 N	0.68
Northern Harrier	1968	Saskatchewan	3	0.057
Turkey Vulture	1970	Ontario	2	30.8
Merlin	1969	Alberta	1	0.084
	1971	Alberta	2	0.050
	1972	Alberta	1	0.040
Prairie Falcon	1969	Alberta	1 N	0.15
	1969	Alberta	1	1.26
	1972	Alberta	2 N	0.024
	1975	Alberta	1	0.11
	1975	Alberta	1	0.020
	1976	Alberta	1	0.42
	1976	Alberta	3	0.022
Peregrine Falcon	1969	N.W.T.	1N	0.44
	1969	N.W.T.	2N	0.28
	1971	BC	1N	0.61
	1972	Alberta	1N	0.76
	1974	N.W.T.	2N	0.48
	1981	N.W.T.	1	1.85
Gyrfalcon	1971	B.C.	1	0.68
American Kestrel	1968	Alberta	1	0.74
	1968	Alberta	1	0.46
Great Horned Owl	1968	Ontario	1	1.44
Burrowing Owl	1968	Saskatchewan	3	1.77
Short-eared Owl	1968	Alberta	3	3.47

N = nestling

The levels of organochlorines detected in tissues of raptors collected between 1967 and 1988 are listed in Table 8. The levels of mercury found in livers of raptors are summarized in Table 9. More detailed information about the sampling location, the condition of the bird when collected, and levels of contaminants in other tissues are reported in the Appendices.

5.2 Incidences of raptor mortality due to pesticides

A very small proportion of the tissue samples of raptors collected during the period 1965 to 1988 contained contaminants at levels diagnostic of acute toxicity (see Table 2).

In 1970, the liver of a Bald Eagle from Northern Ontario was found to contain mercury residues of 42 mg/kg (w.w.). Livers of three Turkey Vultures, *Cathartes aura*, from the same year also contained high levels of mercury, one as high as 60 mg/kg (w.w.). In the early 1980s, the liver of one Sharp-shinned Hawk, *Accipiter striatus*, found dead in B.C. contained more than 100 mg/kg (w.w.) of DDE. According to Cooke *et al.* (1982), residues of this magnitude can be lethal.

As there is no system in place to retrieve and analyze raptors found dead, we cannot accurately assess the incidence of raptor mortality from pesticides during the era of extensive North American use of organochlorines (i.e. prior to the 1970s). The infrastructure to test wildlife specimens for poisoning by contaminants of agricultural or industrial origin was developed further by the 1980s. However, as poisoned birds are seldom recovered in the wild (Mineau and Collins, 1988), the actual incidence of poisoned birds may have been higher than is suggested by these results.

Agencies in Canada have also reported incidences of elevated tissue levels. At least two (a Bald Eagle and a Screech Owl) of twenty-one raptors collected by the Ontario Ministry of Natural Resources in the Great Lakes Basin between 1972 and 1988, were found to have lethal levels of dieldrin and chlordane, respectively, in their brains (Frank and Braun, 1990). Although not diagnostic of acute toxicity, dieldrin levels greater than 2.0 mg/kg and heptachlor epoxide levels greater than 1.0 mg/kg were measured in the brains of two kestrels found dead in Southern Ontario in 1987 (Baker, unpubl. data).

These findings, as well as numerous reports of dead birds with potentially lethal levels of contaminants in their tissues found in the U.S.A. (Chapter 4.1) indicate that almost 20 years after being restricted by legislation, the persistent organochlorine chemicals still pose a threat to raptors.

5.3 Levels in eggs and significance to reproductive success

Many eggs contained contaminants at levels associated with reproductive effects. The critical levels considered to have effects on reproduction are summarized in Table 2. For DDE, we used 10 mg/kg as the minimum value likely to affect productivity in most raptors (Note that this is not based on the same criteria as the 15 mg/kg DDE considered to result in population declines of Peregrine Falcons). For four species known to be particularly sensitive to DDE, we calculated critical values from the literature; 1.2 mg/kg for Prairie Falcons (Fyfe *et al.*, 1988), 4.0 mg/kg for Osprey (Wiemeyer *et al.*, 1988), 5.0 mg/kg for Merlins (Fyfe *et al.*, 1988) and 6.0 mg/kg for Bald Eagles (Wiemeyer *et al.*, 1984). Critical threshold levels of dieldrin, heptachlor epoxide and mercury were 1.0, 1.5 and 0.5 mg/kg, respectively.

Because so little is known of interspecific differences in the effects of those compounds, we used the same critical threshold values for all species. Table 10 summarizes the proportions of eggs exceeding the critical values for DDE, dieldrin, heptachlor epoxide and mercury. Interspecific differences in critical values are discussed in the detailed species accounts.

Concerning accipiters, during the period 1980-1988, three of 13 Cooper's Hawk eggs and five of nine Sharp-shinned Hawk eggs (all from different nests) from Southern Ontario contained DDE in excess of 10 mg/kg (Table 10). During the same period, dieldrin was detected at levels greater than 1.0 mg/kg in one Sharp-shinned Hawk egg. The high levels encountered in Sharp-shinned Hawks may be related to the predominance of birds, particularly migratory insectivores, in their diet (Sherrod, 1978). Comparisons of the organochlorine residues in the eggs of all three accipiters collected in Southern Ontario during the mid 1980s (Figure 2) are consistent with that hypothesis.

TABLE 10. Proportion of eggs with threshold critical levels of DDE, dieldrin, heptachlor epoxide or mercury, likely to affect productivity. The critical values are 10 mg/kg DDE (except where indicated), 1 mg/kg dieldrin, 1.5 mg/kg heptachlor epoxide and 0.5 mg/kg total mercury. No pooled samples are included.

REGION	YEARS	DDE	DIELDRIN	HE	MERCURY
Northern Goshawk					
Atlantic	1965-72	0/1	0/1	0/1	-
Ontario	1980-88	0/4	0/4	0/4	-
Cooper's Hawk					
Ontario	1980-88	3/13	0/13	0/13	-
Prairies	1965-72	1/17	1/17	0/17	0/7
	1973-79	0/3	1/3	0/3	0/1
Sharp-shinned Hawk					
Atlantic	1980-88	0/3	0/3	0/3	-
Ontario	1980-88	5/9	1/9	0/9	-
Prairies	1965-72	0/1	0/1	0/1	0/1
Red-tailed Hawk					
Ontario	1965-72	0/1	0/1	0/2	0/2
Prairies	1965-72	4/46	5/46	1/42	1/14
B.C.	1965-72	0/1	0/1	0/1	-
Red-shouldered Hawk					
Ontario	1973-79	0/3	0/3	0/3	-
Swainson's Hawk					
Prairies	1965-72	0/18	2/17	1/17	-
	1973-79	0/1	0/1	0/1	0/1
Ferruginous Hawk					
Prairies	1965-72	1/50	2/49	1/50	-
Rough-legged Hawk					
North	1965-72	0/13	0/13	0/3	0/3
	1973-79	0/1	0/1	0/1	-
	1980-88	0/6	0/6	1/6	0/2
Bald Eagle [1]					
Atlantic	1965-72	1/1	0/1	-	0/1
	1980-88	0/2	-	-	-
Ontario	1965-72	16/16	10/16	0/14	5/15
	1973-79	2/2	1/2	0/2	0/2
Prairies	1965-72	4/13	2/13	0/5	1/10

TABLE 10. (continued) Proportion of eggs with threshold critical levels of DDE, dieldrin, heptachlor epoxide or mercury, likely to affect productivity.

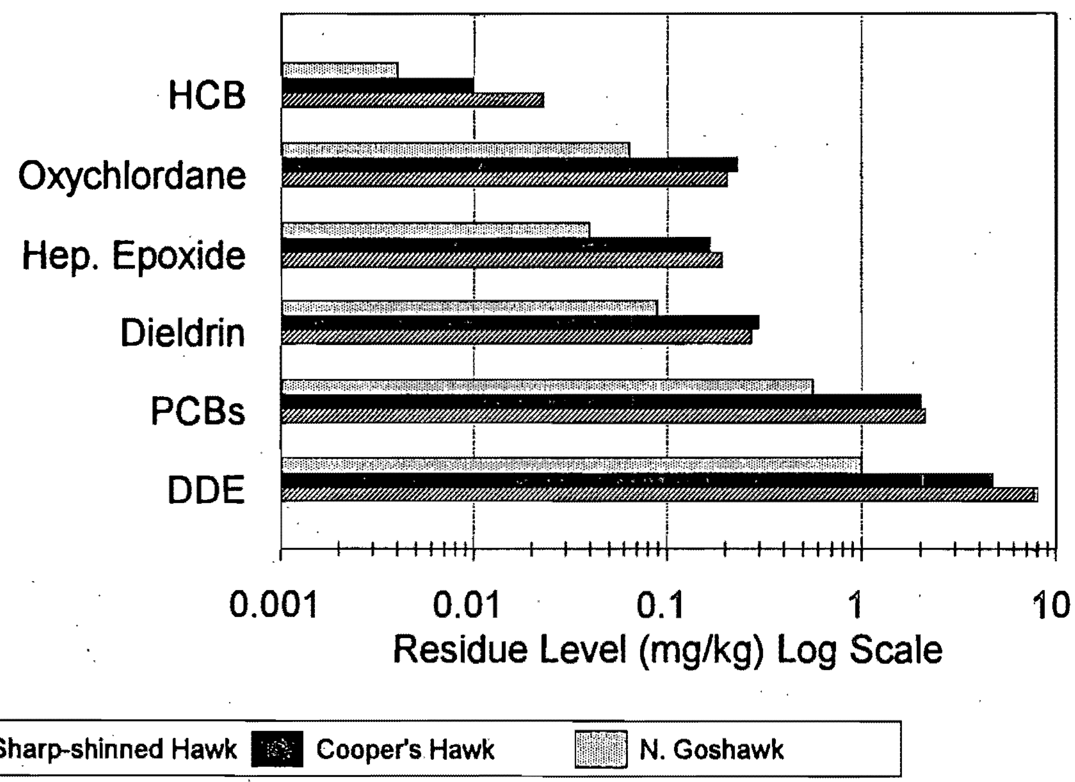
REGION		YEARS	DDE	DIELDRIN	HE	MERCURY
Golden Eagle						
	Prairies	1965-72	0/9	0/9	0/9	0/6
		1973-79	0/12	1/12	0/12	0/12
	North	1973-79	0/1	0/1	-	-
Osprey [2]						
	Atlantic	1965-72	3/3	0/1	-	0/3
	Ontario	1965-72	4/8	0/8	0/1	0/8
	Prairies	1973-79	1/2	0/2	0/2	1/2
	B.C.	1965-72	1/2	0/2	0/2	-
	North	1973-79	2/2	0/2	0/2	0/2
Northern Harrier						
	Quebec	1965-72	1/1	0/1	0/1	0/1
	Prairies	1965-72	3/22	3/22	1/22	0/8
Merlin [3]						
	N. Quebec	1965-72	1/1	0/1	0/1	1/1
	Prairies	1965-72	88/165	32/165	13/165	8/93
		1973-79	129/159	19/159	23/159	1/141
		1980-88	5/14	0/14	3/14	-
	B.C.	1965-72	1/1	0/1	0/1	3/3
	North	1973-79	4/4	2/4	0/4	0/4
Prairie Falcon [4]						
	Prairies	1965-72	154/249	17/249	9/249	17/229
		1973-79	132/216	12/216	16/216	0/180
		1980-88	3/16	6/16	0/16	0/12
Peregrine Falcon (anatum)						
	Atlantic	1965-72	1/1	0/1	0/1	0/1
	S. Que/Ont	1980-88	4/7	3/7	0/7	-
	Prairies	1965-72	5/5	3/5	0/5	1/5
		1973-79	12/20	2/20	0/20	1/5
		1980-88	8/14	3/14	3/14	3/11
	NWT/Yukon	1965-72	6/6	1/6	0/6	0/6
		1973-79	4/4	2/4	0/4	1/3
		1980-88	6/9	1/9	1/9	-
Peregrine Falcon (tundrius)						
	North Quebec	1965-72	4/10	4/10	-	-
		1973-79	3/4	3/4	0/4	1/4
		1980-88	2/10	2/10	0/10	-
	NWT	1965-72	7/23	8/22	0/15	5/23
		1973-79	13/20	4/20	3/20	0/19
		1980-88	5/19	4/19	3/19	0/8

TABLE 10. (continued) Proportion of eggs with threshold critical levels of DDE, dieldrin, heptachlor epoxide or mercury, likely to affect productivity.

REGION	YEARS	DDE	DIELDRIN	HE	MERCURY
Peregrine Falcon (pealei)					
B.C.	1965-72	7/12	0/12	0/6	7/10
	1980-88	0/4	0/4	0/4	-
Gyrfalcon					
North	1965-72	0/1	0/1	0/1	1/1
	1973-79	0/10	0/10	0/10	0/4
	1980-88	0/6	1/6	0/6	1/1
American Kestrel					
Atlantic	1965-72	0/1	0/1	-	-
Prairies	1965-72	1/8	1/8	1/8	0/3
Great Horned Owl					
Ontario	1965-72	0/1	0/1	-	-
Prairies	1965-72	6/30	0/30	2/29	0/7
North	1965-72	0/1	0/1	0/1	1/1
Snowy Owl					
North	1973-79	0/1	0/1	0/1	-
Burrowing Owl					
Prairies	1965-72	0/1	0/1	0/1	0/1
Great Grey Owl					
Minnesota	1980-88	0/3	0/3	0/3	-
Long-eared Owl					
Praires	1965-72	0/7	0/7	0/7	0/3
Short-eared Owl					
Prairies	1965-72	0/6	0//6	0/6	-

1 Bald Eagle: critical value of DDE = 6 mg/kg
2 Osprey: critical value of DDE = 4 mg/kg
3 Merlin: critical value of DDE = 5 mg/kg
4 Prairie Falcon: critical value of DDE = 1.2 mg/kg

Figure 2. Geometric Mean Residue Levels In Accipiter Eggs Collected In Ontario, 1986-1988



Overall, the buteos were considerably less contaminated than the accipiters. Four eggs of Red-tailed Hawks collected in 1968 were the only eggs to contain DDE in excess of 10 mg/kg (Table 10). Dieldrin concentrations exceeded 1.0 mg/kg in five Red-tailed Hawk eggs, two Swainson's Hawk, *Buteo swainsoni*, eggs, and two Ferruginous Hawk, *Buteo regalis*, eggs collected during the late 1960s (Table 10). Heptachlor epoxide levels exceeded the critical value of 1.5 mg/kg (Henny *et al.*, 1983) in one Red-tailed Hawk egg, one Swainson's Hawk egg, one Ferruginous Hawk egg, and one Rough-legged Hawk egg. One Red-tailed Hawk egg also contained 1.6 mg/kg mercury, slightly above the critical value reported to cause detrimental effects on reproduction (Fimreite, 1971; Heinz, 1979).

Bald Eagles, which feed on fish, birds, and carrion, exhibited high levels of contamination in their eggs. This agrees with observations of declines in many populations, particularly along the Great Lakes (Brownell and Oldham, 1980). Twenty-three of 34 eggs contained DDE residues in excess of 6 mg/kg (Table 10), twenty-one of them were greater than 15 mg/kg. DDE attained maximum values of 100 mg/kg in areas of Northern Ontario where reproductive failures were common (Grier, 1982).

Thirteen Bald Eagle eggs contained more than 1.0 mg/kg dieldrin. Six eggs contained more than 2.0 mg/kg, more than twice the critical value associated with reduced reproductive success in some raptors. Heptachlor epoxide and other organochlorines were relatively low in all eggs. Mercury exceeded the critical value of 0.5 mg/kg in six out of twenty-eight eggs.

In eggs of Golden Eagles, a species which feeds almost entirely on mammals (Sherrod, 1978), only dieldrin at 2.12 mg/kg in one egg from Alberta (Table 10) was found to exceed concentrations associated with reduced productivity in this species.

Only two Osprey eggs from the Prairies were found to contain more than 12 mg/kg DDE, the critical value determined by Wiemeyer *et al.*, 1975. However, 11 of the 17 eggs collected between 1968 and 1973 contained more than 4 mg/kg, levels high enough to reduce productivity (Wiemeyer *et al.*, 1988). None of the other organochlorines or mercury detected in Ospreys exceeded the critical values (Table 10).

Northern Harriers, *Circus cyaneus*, may have been affected by organochlorines in the past. Four eggs from the Prairie region contained more than 10 mg/kg DDE, three eggs exceeded the critical value for dieldrin and one egg exceeded the critical value for heptachlor epoxide (Table 10). The most contaminated egg contained 5.0 mg/kg dieldrin. There have been no analyses of eggs of this species since 1971.

Falcons, some of which are very susceptible to organochlorines (Fyfe *et al.*, 1988), tended to be highly contaminated. More than two hundred of the Merlin eggs collected in the Prairies during the late 1960s and early 1970s contained DDE, dieldrin, and heptachlor epoxide in excess of critical values (Table 10). During the mid 1970s , dieldrin levels were as high as 5.6 mg/kg and heptachlor epoxide levels reached 9.1 mg/kg. During the same period, concentrations of HCB greater than 5.0 mg/kg and oxychlordane greater than 1.0 mg/kg in a few eggs were also potentially hazardous. By 1988, there were no eggs with elevated dieldrin levels, but five of 14 eggs contained more than 5.0 mg/kg DDE, and three eggs contained more than 1.5 mg/kg heptachlor epoxide (Table 10).

A number of Prairie Falcon eggs collected between 1966 and 1988 in the same areas as the Merlins also exhibited high levels of DDE, dieldrin, heptachlor epoxide, and mercury (Table 10). This species is the most susceptible to DDE-induced eggshell thinning, with effects on reproductive success probably evident at DDE levels greater than 1.2 mg/kg (Fyfe *et al.*, 1988).

DDE in all eggs of Gyrfalcons, *Falco rusticolus*, was less than 10 mg/kg, but one egg contained more than 1.0 mg/kg dieldrin (Table 10). All American Kestrel eggs analyzed prior to 1972 contained less than 10 mg/kg DDE, but one egg contained 1.25 mg/kg dieldrin and 4.8 mg/kg heptachlor epoxide. Eggs of American Kestrels from Ontario collected in 1987 and 1988 contained low levels of most contaminants. DDE levels in those pools, however, varied from 0.44 to 10.8 mg/kg, suggesting that some individuals had been exposed to this chemical. As this species is apparently not particularly susceptible to DDE-induced shell thinning (Fyfe and Peakall, 1988), the DDE levels detected probably had little effect on populations.

Many eggs of Peregrine Falcons contained DDE in excess of 10 mg/kg (Table 10). Furthermore, DDE in many eggs exceeded 15 mg/kg, the critical value considered to be associated with population declines in this species (Peakall *et al.*, 1990).

Owls were relatively uncontaminated, but there is little recent data. Only eggs of the Great Horned Owl were found to contain potentially hazardous levels of organochlorines. DDE concentrations up to 16 mg/kg in eggs of this species from the Prairies may have caused some eggshell thinning. Two eggs contained heptachlor epoxide in excess of 1.5 mg/kg.

None of the eggs of other owl species (Snowy Owl, Great Grey Owl, Long-eared Owl, Short-eared Owl, or Burrowing Owl) were found to have significant amounts of any contaminants (Table 10). This is probably related to their predominantly mammalian diet (Godfrey, 1986), a food source usually low in organochlorines (Lincer and Sherburne, 1974).

5.4 Levels of contaminants in relation to diet

As expected, diet appeared to be the most important influence on differences in contaminant levels among raptor species. We assigned species to one of five groups, based on their principal prey during the breeding season (i.e. birds, mammals, fish, invertebrates or omnivorous). References for the diet assignments are listed in the species accounts (Chapter 7.0).

Figures 3 to 6 show that levels of contaminants detected in Canadian raptors collected in the 1980s appeared to roughly reflect their diet. DDE residues exceeded 3 mg/kg only in eggs of bird-eating species, such as Peregrine Falcons, Merlins, Sharp-shinned Hawks and Cooper's Hawks, and in American Kestrels, which feed extensively on insects during the breeding season (Figure 3). The low DDE level in the single Bald Eagle egg collected during this time was unexpected, considering that its main diet of fish or birds are usually relatively contaminated (Frenzel and Anthony, 1989). Dieldrin (Figure 4) and heptachlor epoxide (Figure 5) residues were highest in eggs of bird-eating species.

Figure 3 Mean DDE residues in eggs of Canadian raptors, 1980-1988.

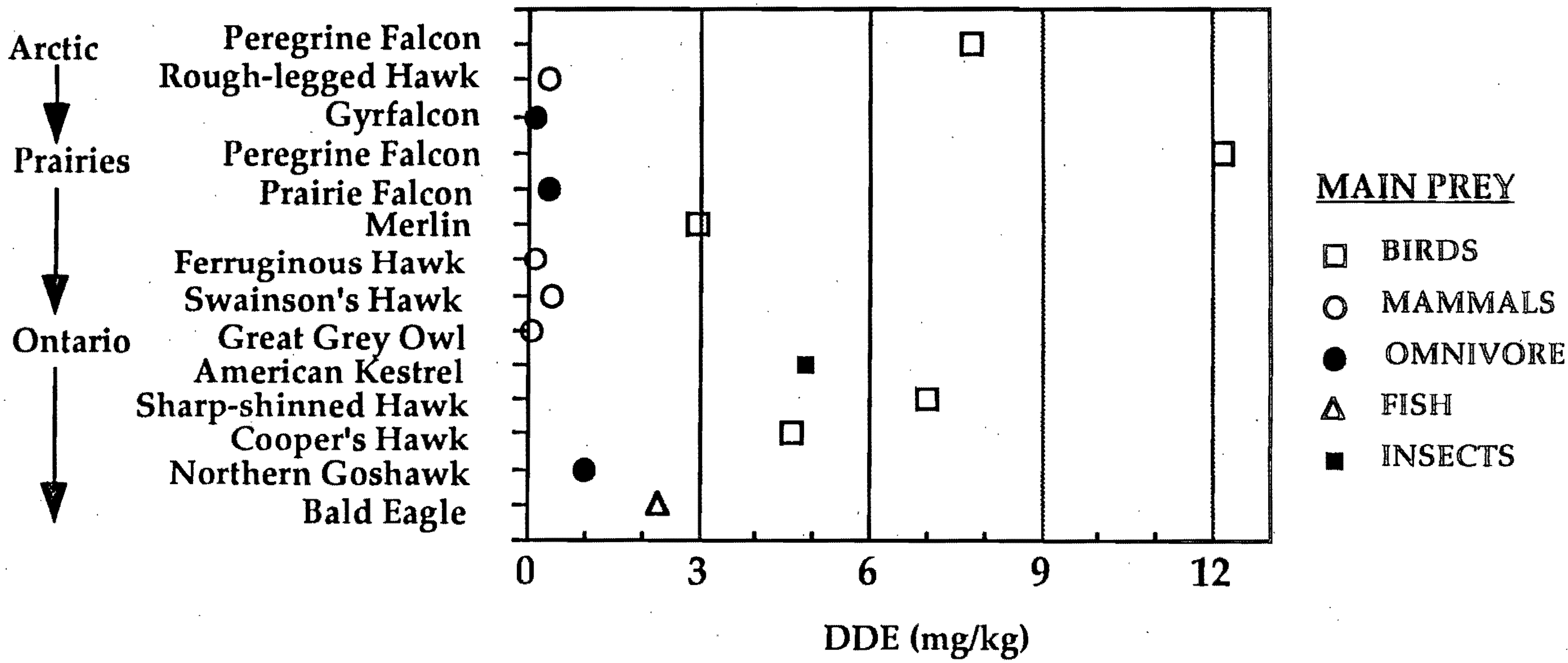


Figure 4 Mean dieldrin residues in eggs of Canadian raptors, 1980-1988.

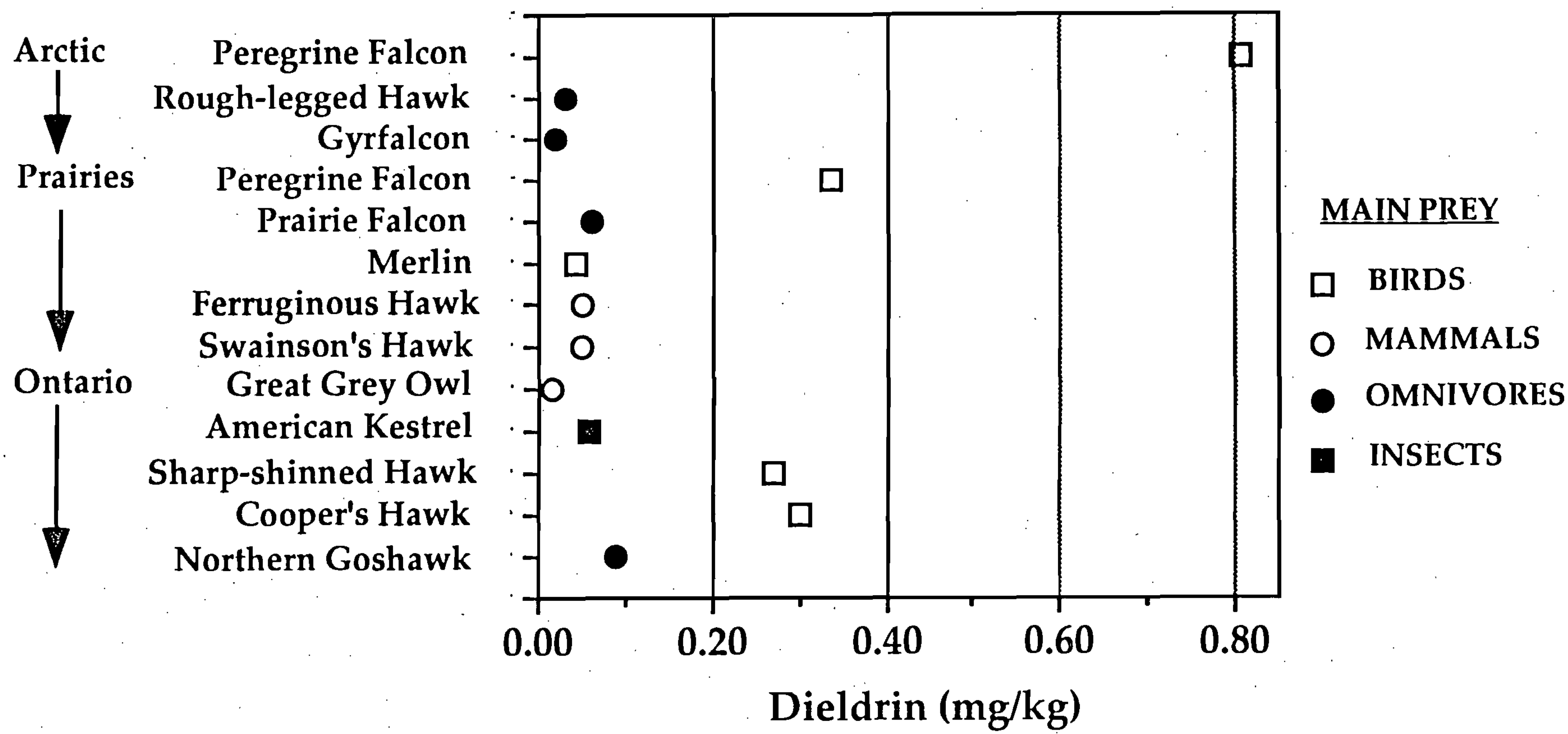


Figure 5 Mean heptachlor epoxide residues in eggs of Canadian raptors, 1980-1988.

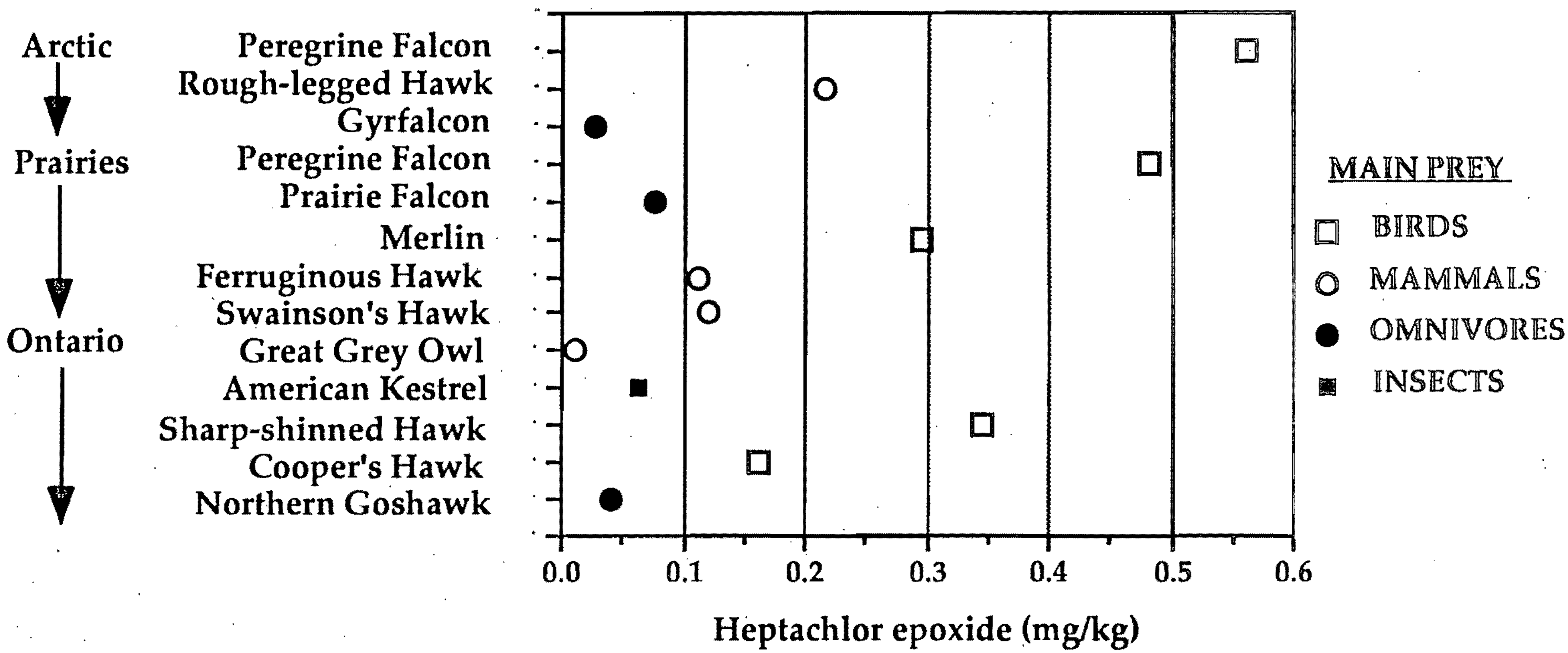
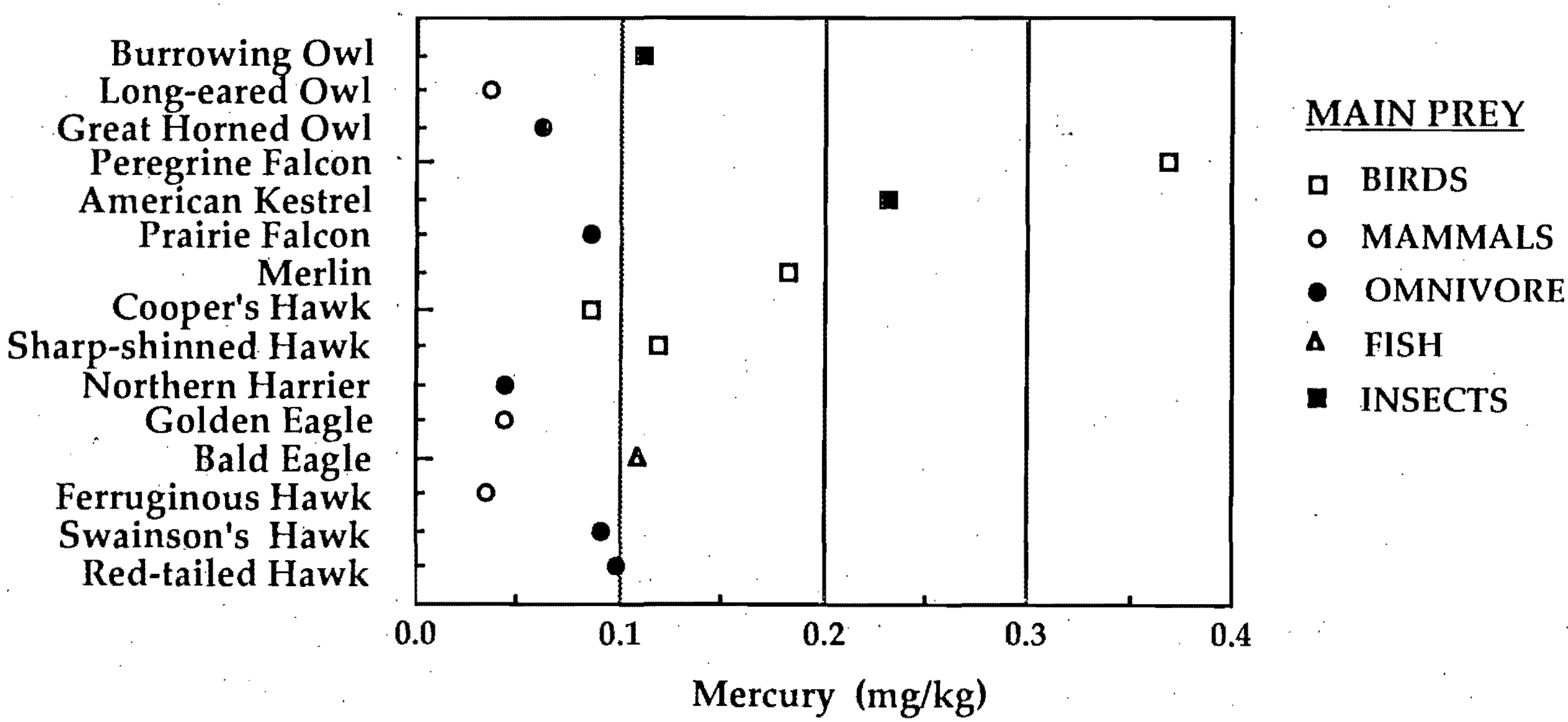


Figure 6 Mean mercury residues in eggs of raptors from the Prairie Provinces, 1965-72.



Mercury residues, however, in eggs of raptors collected in the Prairie provinces between 1965 and 1972 showed no particular trend with diet (Figure 6). Peregrine Falcons were the most contaminated. The analyses of liver samples from Canadian raptors collected between 1968 and 1976 include more species (Table 9). Bald Eagles and Turkey Vultures were the most contaminated, with some livers containing more than 30 mg/kg mercury. Ospreys, Short-eared Owls *Asio flammeus*, Great Horned Owls and Burrowing Owls also had significant levels of mercury in their livers. These data suggest that exposure to mercury is mainly through aquatic systems, or by eating carrion.

The raptor eggs included in Figures 3 to 6 were collected from three regions of Canada; there appeared to be little effect of region on contaminant levels. This was true for most of the data. Few species were sampled in more than one location during the same years so it was not usually possible to analyze the data for geographical differences. Moreover, raptors inhabiting different regions of Canada also tend to differ in diet and in migratory habits, further confounding the interpretation of geographical variation. Geographical variation in contamination of Peregrine Falcon eggs is discussed in Chapter 7.18.

Generally, similar relationships between diet and contaminant levels were found in other data sets. Among raptors breeding in the Prairie provinces between 1965 and 1972, DDE was highest in Northern Harriers, with Sharp-shinned Hawks and Cooper's Hawks and the piscivorous Bald Eagles containing only moderate amounts. Other species which prey mainly on small mammals, such as the buteos and Golden Eagles, contained very little DDE.

Figure 7 depicts mean levels of DDE, dieldrin and heptachlor epoxide in seven raptor species collected in the Western Arctic (mainly the Yukon) in 1972 and 1973. DDE was highest in Merlins and Peregrine Falcons (which feed mainly on migratory birds) and Ospreys. However, Osprey eggs contained very little dieldrin or heptachlor epoxide. The single Snowy Owl, *Nyctea scandiaca*, egg contained more heptachlor epoxide than most other raptors sampled. In contrast, mercury was highest in the Osprey, and low in all other species (Figure 8).

Figure 7 Levels of organochlorine contaminants in eggs of raptors collected in the western Arctic in 1972 and 1973.

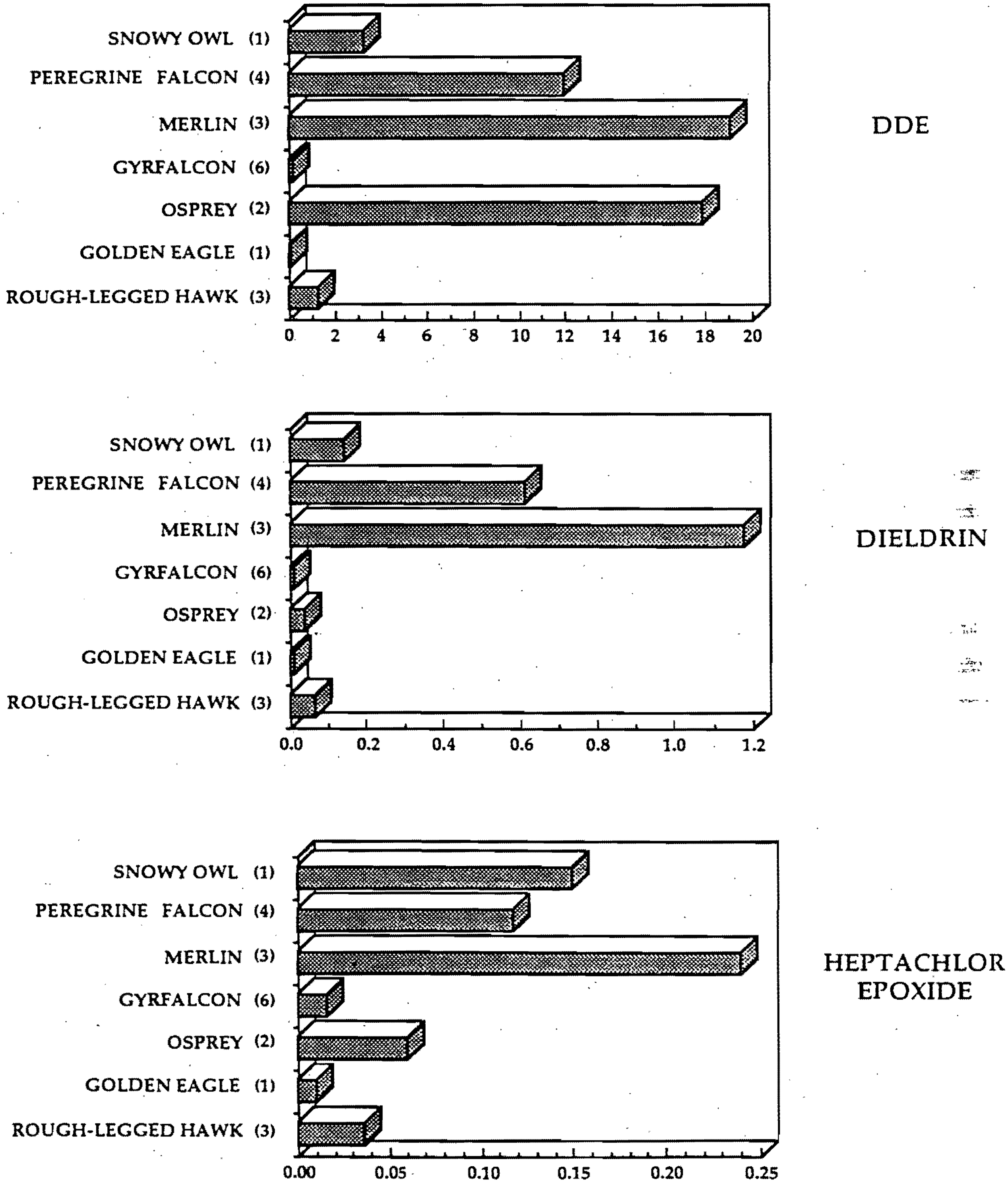
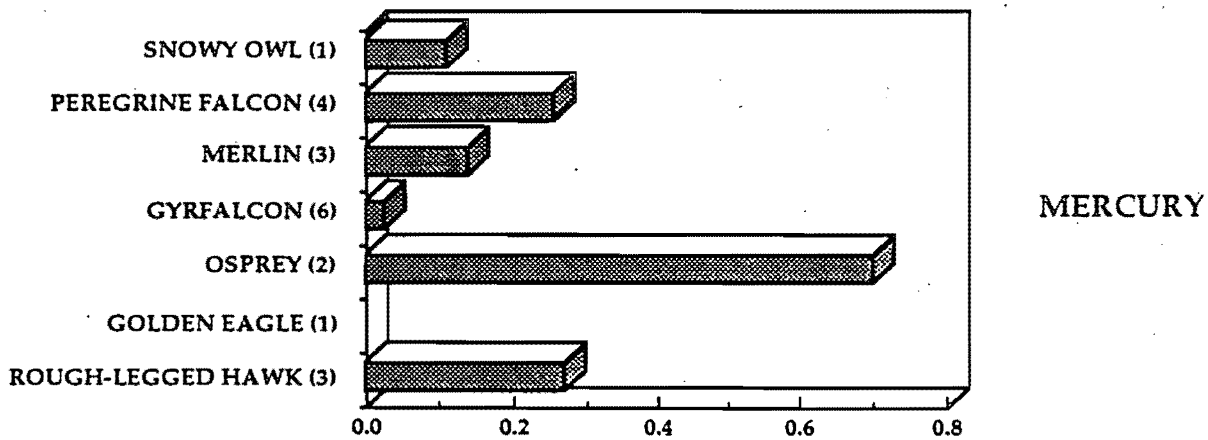


Figure 8 Levels of mercury in eggs of raptors collected in the western Arctic in 1972 and 1973.



Similar patterns of contamination in relation to diet have been documented elsewhere. Prey selection appeared to account for most of the differences in contaminant levels in concurrently-sampled arctic raptors (Cade *et al.*, 1971), accipiters (Snyder *et al.*, 1973), and raptors found dead in Florida (Sundlof *et al.*, 1986). Among the criteria for elevated residues in raptors appear to be prey species that are either i) migratory and insectivorous (Enderson *et al.*, 1982), ii) aquatic (Baril *et al.*, 1989), or iii) ground-feeding (Johnston, 1975).

5.5 Temporal changes in contaminant levels

Data permitting the evaluation of temporal changes in contaminant residues are limited. Only eggs, which are representative of contamination at the beginning of the breeding season and which tend to be uniform in fat and water content, provide a standardized sample to compare among years. Unfortunately, in most cases, the number of eggs collected at a particular location (often one or two collected opportunistically) was insufficient to detect statistical differences. We have, therefore, pooled eggs from different regions and years, based on the timing of pesticide restrictions in Canada. Nevertheless, the extreme variability in contaminant levels in eggs meant that few trends were significant.

In the Prairies, contaminant residues in the eggs of four species were examined for temporal trends. Since it was not possible to quantitatively measure PCBs, chlordane metabolites, HCH, or chlorinated benzenes, in earlier analyses, long term trends are available only for DDE, dieldrin, and heptachlor epoxide.

In eggs of Swainson's Hawks from Saskatchewan and Alberta, dieldrin levels after 1968 were significantly lower (t-test, Table 11) than prior to 1968, whereas DDE and heptachlor epoxide did not show this pattern. In eggs of Ferruginous Hawks, annual geometric means of DDE, dieldrin and heptachlor epoxide exhibited the same pattern as in Swainson's Hawks, although there were no significant differences in mean concentrations between the two time periods (t-test, Table 11).

Table 11. Significance and direction of changes in residue levels with time.

Species and time periods compared:	DDE	Dieldrin	Heptachlor epoxide
PRAIRIE REGION:			
Swainson's Hawk 1968-71: 1984-85	N.S.	DECLINE **	N.S.
Ferruginous Hawk 1968-72: 1984-85	N.S.	N.S.	N.S.
Merlin 1965-72: 1973-78	INCREASE **	N.S.	INCREASE **
1973-78: 1980-88	DECLINE **	DECLINE **	DECLINE *
1965-73: 1980-88	DECLINE *	DECLINE **	N.S.
ARCTIC REGION			
Rough-legged Hawk 1966-72: 1980-81	N.S.	N.S.	N.S.
Gyrfalcon 1973-75: 1980-81	N.S.	N.S.	N.S.

* $0.01 < p < 0.05$
** $p < 0.01$

Although temporal trends were not statistically analyzed, Prairie Falcon eggs collected in Saskatchewan and Alberta, showed declines in dieldrin, heptachlor epoxide, oxychlordane, and PCBs between 1968 and 1988. HCB levels in eggs increased during the same period.

DDE and dieldrin concentrations in Merlin eggs from Saskatchewan and Alberta declined between 1968 and 1988 (Figure 9) but, unlike Prairie Falcons, heptachlor epoxide egg levels increased. Scheffe's multiple range comparisons of residue levels in viable eggs showed that both DDE and heptachlor epoxide, but not dieldrin, increased significantly between the earliest time period and the mid to late 1970s (Table 11). By the mid 1980s, DDE, dieldrin, and heptachlor epoxide had declined to significantly lower levels, although heptachlor epoxide levels did not differ significantly from those detected in the earliest collections.

Very little long-term data were available from outside the Prairies. If analyses reported by Grier (1982) are included, it is possible to track changes in contaminant levels in eggs of Bald Eagles (Figure 10). Grier, using some of the data reported here, found that DDE, but not dieldrin or mercury, declined in Bald Eagle eggs from Northern Ontario between 1970 and 1982. There was no evidence of a decline in PCB levels, but because PCB data from 1970 may be an underestimate (Turle *et al.*, 1988), we must be cautious in our interpretation.

Two arctic species were sampled at enough locations to permit some analysis of temporal trends. In eggs of Rough-legged Hawks, only dieldrin residues showed a significant downward trend, while heptachlor epoxide levels appeared to increase. Comparisons of geometric means between the earliest collections and the 1980s, revealed no significant differences in DDE, dieldrin, or heptachlor epoxide (t-test, Table 11). In the relatively small samples of Gyrfalcon eggs, no consistent trends in any contaminants could be detected (Figure 11).

There were insufficient data from either Atlantic Canada or British Columbia to permit statistical analyses of temporal trends of contaminant concentrations in any raptor.

Figure 9 Changes in residue levels in eggs of Merlins collected in the Prairie Provinces.

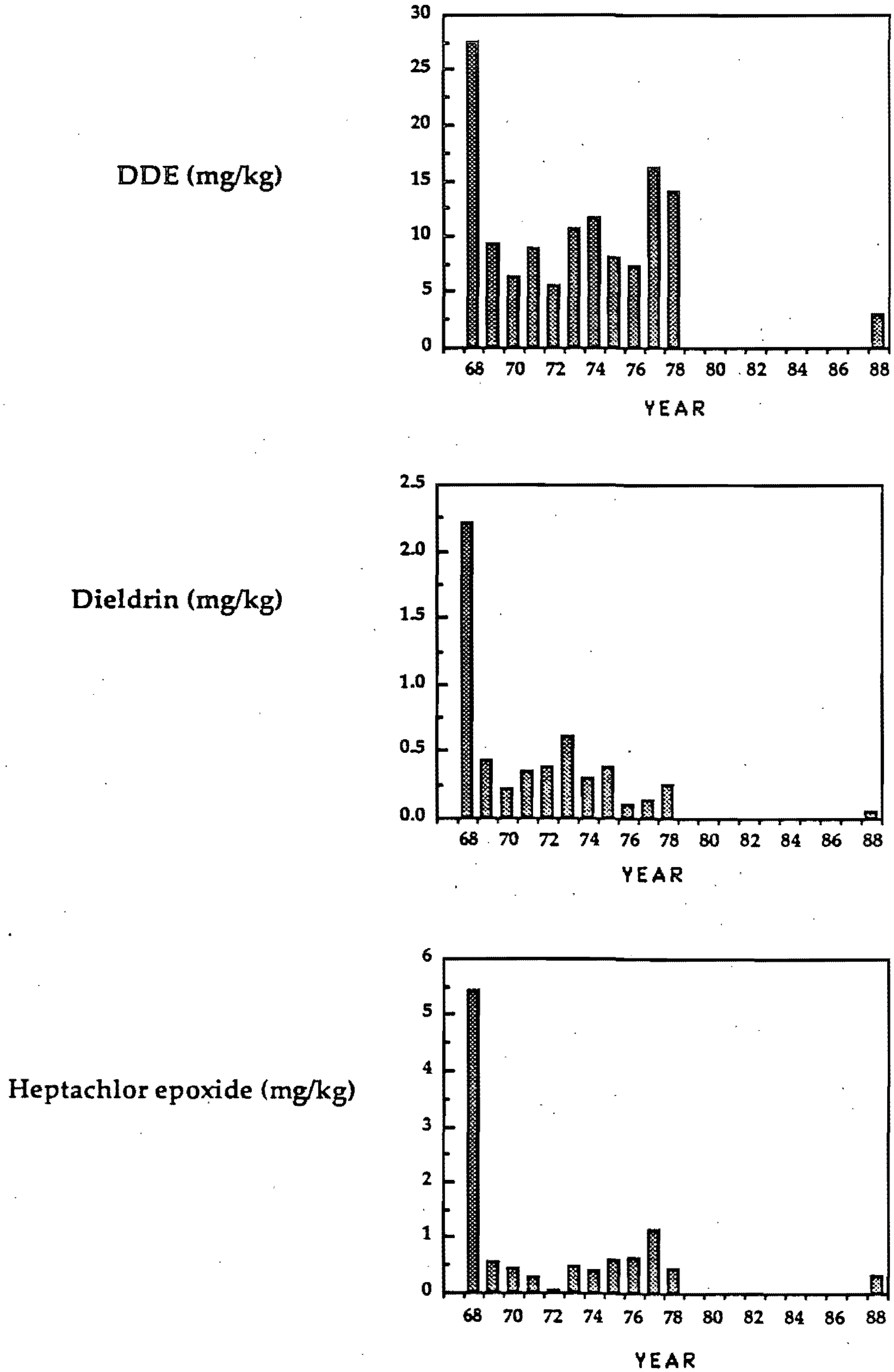


Figure 10 Changes in residue levels in eggs of Bald Eagles from northwestern Ontario.

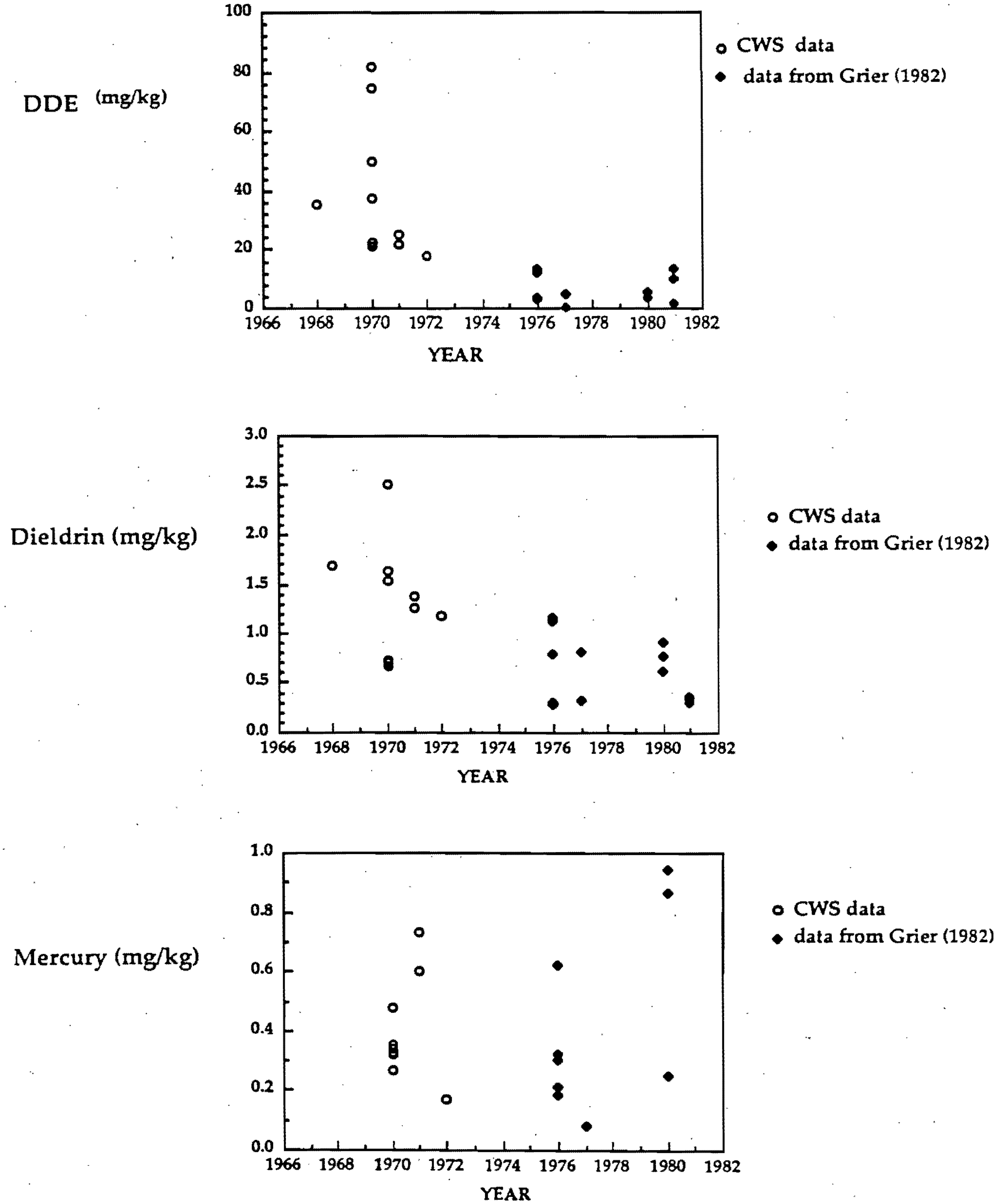
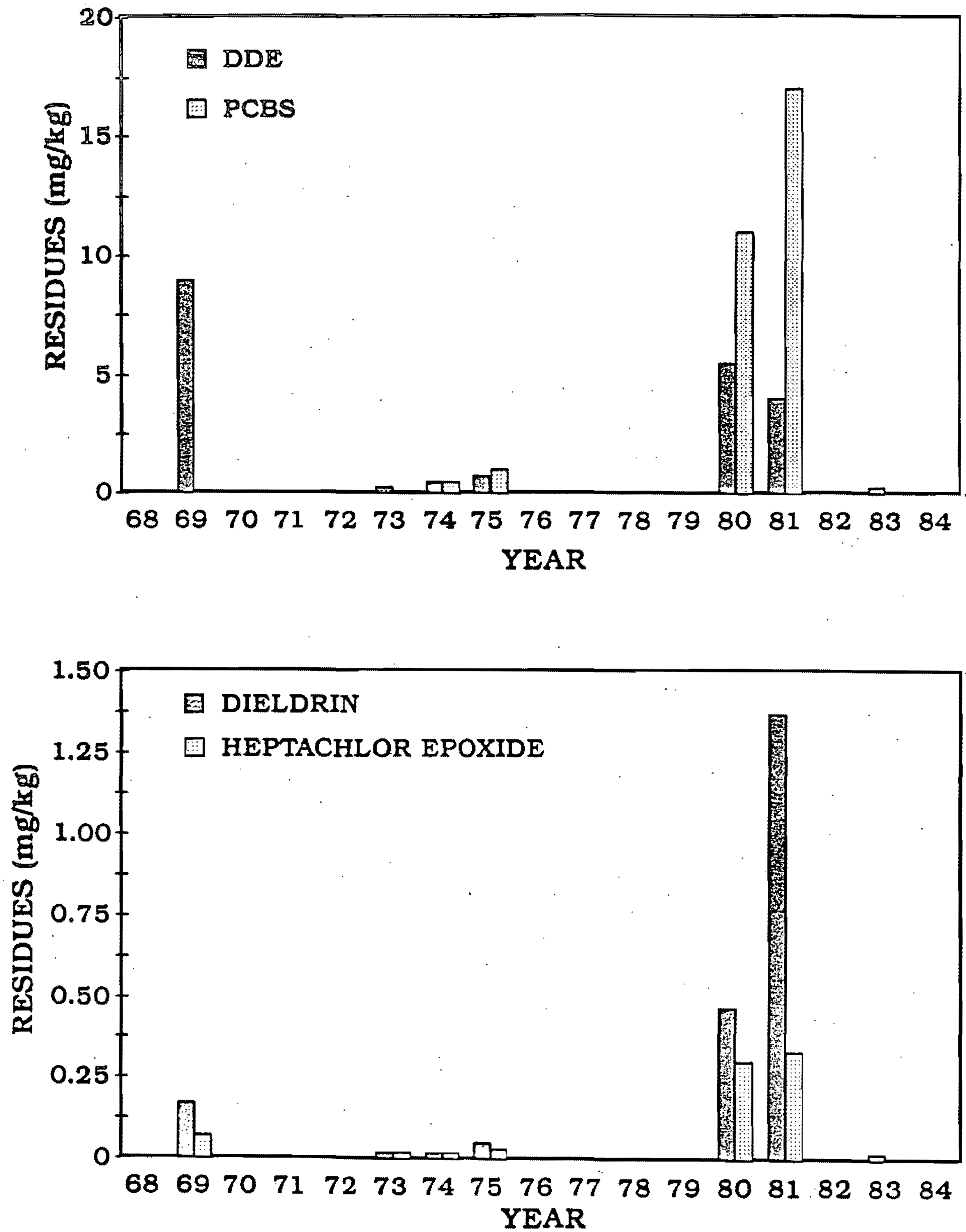


Figure 11 Changes in residue levels of organochlorine contaminants in eggs of Gyrfalcons in Northern Canada



Raptors have been used to monitor changes in environmental levels of persistent contaminants in the U.S.A. (Sundlof *et al.*, 1986) and Europe (Cooke *et al.*, 1982; Froslie *et al.*, 1986; Newton *et al.*, 1986). In most cases, these were much larger data sets than are reported here. The extreme variability in both egg and tissue levels due to geographic and individual differences in diet and migratory behaviour in Canada make it difficult to discern many trends. From the sparse temporal data for Canadian raptors, we can conclude only that dieldrin and probably DDE currently occur at lower levels in the Prairies than during the early 1970s, and that heptachlor epoxide levels appear to be stable.

5.6 Status of raptor populations in Canada

The status of raptor populations in Canada are not well known, despite increasing interest in their conservation. All estimates are subject to biases, and require cautious interpretation, as discussed by Fuller and Mosher (1987).

Table 12 summarizes reports of the status of North American raptor populations, based on a number of sources. Blue lists are subjectively based on "expert" opinions of the relative abundance of a particular species in their area. Counts at hawk migration stations, during Breeding Bird Surveys and Christmas Bird Counts are influenced by a number of factors. The effects of such variables as weather and observer effort bias are likely to differ with the method, hence we have assumed that the estimates from the various sources are independent. Some assessments of population status were determined by modelling. Henny (1972) used banding and reproductive data to estimate survival and recruitment rates. The biases inherent in the methods used to obtain the estimates differ considerably with the method. Therefore, we consider that a consistent status assessment for any given species constitutes evidence for that assessment.

The sources cited in Table 12 tend to be broad surveys of the status of raptor populations, differing in the periods considered. We used those surveys in conjunction with the available literature on the status of particular species or populations in Canada (see Chapter 7.0), in order to assign each raptor to one of four categories (Table 13).

TABLE 12. Status of North American raptor populations based on different sources.

Source:	Henny, 1972	Fyfe,1976	Robbins et al,1982	Heintzelman,1986	Blue List
Time period:	1946-68	1975	1965-79	1961-84	1980s
Sharp-shinned Hawk		stable decline in Ont	stable	increase(1977-84)	declining?
Cooper's Hawk	declining	stable decline in Ont.	stable	increase(1975-84)	stable
Northern Goshawk		cyclic		cyclic	
Red-tailed Hawk	stable	stable	increasing	stable	
Red-shouldered Hawk	declining	declining	stable	declining?	declining
Broad-winged Hawk		stable	stable	stable	
Rough-legged Hawk		fluct.		cyclic	
Ferruginous Hawk		stable			declining?
Swainson's Hawk		declining			stable?
Bald Eagle		stable declining in Ont.		increase(1975-84)	
Golden Eagle		stable		declining	stable
Osprey	declining	stable	increase(east) declining(west)	stable	increase
Northern Harrier		fluct. decline in Alta	declining	stable	
Turkey Vulture			stable		

TABLE 12. (continued) Status of North American raptor populations based on different sources.

Source:	Henny, 1972	Fyfe,1976	Robbins et al,1982	Heintzelman,1986	Blue List
Time period:	1946-68	1975	1965-79	1961-84	1980's
Peregrine Falcon		**declining**		**declining(1972-84)**	
Prairie Falcon		**stable in Prairies** **decline in B.C.**			
Merlin		**stable** **decline in Ont.**		**declining**	
American Kestrel	**declining(1960-70)**	**stable** **increase in B.C.**		**cyclic**	
Gyrfalcon		**stable**			
Great Horned Owl		**stable** **increase in Ont.**	**stable**		
Short-eared Owl		**fluct.**			**declining**
Long-eared Owl		**fluct.**			
Barn Owl	**stable?**				**declining?**
Burrowing Owl		**stable**	**declining**		**declining?**
Great Grey Owl		**fluct.**			
Snowy Owl		**fluct.**			
Saw-whet Owl		**stable**			

Table 13. **Status of North American raptor populations in relation to organochlorine pesticide use in North America.**

Category 1: Populations that declined during peak years of organochlorine pesticide use in North America	
∘Bald Eagle (Eastern Canada)	∘Peregrine Falcon (most of North America)
∘Osprey (Eastern North America)	∘Prairie Falcon (Prairies)
∘Merlin (Eastern North America and Prairies)	∘Cooper's Hawk
Category 2: Populations that declined since restrictions on the use of organochlorine pesticides were implemented in the early 1970s	
•Red-shouldered Hawk	•Short-eared Owl
•Ferruginous Hawk (Prairies)	•Burrowing Owl (Prairies)
•Barn Owl	
Category 3: Populations which appear to have been stable or increasing	
•Red-tailed Hawk	•Great Horned Owl
•American Kestrel	•Turkey Vulture
Category 4: Insufficient information to determine the status of population in North America	
•Golden Eagle	•Gyrfalcon
•Northern Goshawk	•Northern Harrier *
•Sharp-shinned Hawk *	•Snowy Owl
•Rough-legged Hawk	•Great Grey Owl
•Swainson's Hawk	•Long-eared Owl
•Broad-winged Hawk	

* declines have been suggested by some authors

The first group includes all species for which significant population declines were reported during the era of heavy pesticide use. It includes: i) Bald Eagle populations in Ontario and the Maritimes (Postupalsky, 1972; Stocek and Pearce, 1978; Grier, 1982), ii) Merlins, particularly in the Prairies (Fox, 1971; DeSmet, 1982) but see Oliphant and Thompson (1978), iii) Prairie Falcons (Fyfe *et al.*, 1969), iv) Osprey (Postupalsky, 1972), v) Cooper's Hawks (Penak, 1983) and vi) Peregrine Falcons (Peakall, 1976).

Some of those species are currently showing evidence of recovery; other populations are still reduced. Bald Eagle populations are now considered stable or increasing throughout most of Canada, except in the Great Lakes region (Gerrard and Ingraham, 1985). Peregrine Falcons are also starting to return to historical sites, aided in many cases by intensive reintroduction programs.

For some species, there is little information on the status of Canadian populations, so we have extrapolated from population trends in the USA. Osprey populations in Canada apparently did not experience the dramatic declines noted in the U.S.A. (Fyfe, 1976), but there is some evidence that current productivity in Nova Scotia has increased since the mid-1970s (Fleming, pers. comm.). Although opinions differ as to the extent of population declines of Merlins during the 1950s and 1960s, particularly in the Prairies (DeSmet, 1982), productivity is currently high and numbers appear to be stable.

Determining the status of Cooper's Hawks in Canada was also problematic. Sharp declines in numbers and reduced productivity of Cooper's Hawks were reported in the U.S. (Henny and Wight, 1972; Snyder *et al.*, 1973), but not everywhere (Table 12). Extensive shooting of this species during the 1950s and 1960s might be one complicating factor (Penak, 1983). An ability to compensate for declining numbers by high productivity early in life might be another.

The second category is comprised of species which are currently declining in numbers, whether or not they were known to be declining in the past. Canadian raptors in this category include: i) Red-shouldered Hawks (Risley, 1983), ii) Ferruginous Hawks in the Prairies (Schmutz and Schmutz, 1980), iii) Barn Owls (Campbell and Campbell, 1983; Colvin, 1985), iv) Short-eared Owls, and v) Burrowing Owls (Wedgewood, 1978).

The third category is comprised of species whose overall populations have always been stable or which appear to be increasing. These include: i) Red-tailed Hawks, ii) American Kestrels, iii) Turkey Vultures and iv) Great Horned Owls.

The final category is comprised of species for which there is no consistent evidence of either declines or increases (Table 12). These include most of the boreal forest owls, Golden Eagles, Gyrfalcons (Martin, 1978), Northern Goshawk, Rough-legged, Swainson's, and Broad-winged Hawks *Buteo platypterus*, Sharp-shinned Hawks (Flood and Bortolotti, 1986) and Northern Harriers.

There are many possible causes of raptor declines, not the least of which is direct mortality due to shooting, an activity that was very prevalent as late as the 1960s. Other factors include loss of nesting habitat, reductions in prey numbers, disturbance to breeding areas, competition from more successful species, and poisoning by currently used insecticides, rodenticides or other compounds.

Examination of the species in each category reveals some common denominators. The species in Category 1, which exhibited the most dramatic declines in the 1950s and 1960s (the DDT-era), feed primarily on birds or fish. We stated earlier that eggs of bird-eating raptors contained the highest levels of DDE and other organochlorines. Livers of piscivorous species such as Bald Eagles and Osprey had the highest concentrations of mercury. Since legislation restricting the use of organochlorines and mercurials was introduced in the late 1960s and early 1970s, species such as the Bald Eagle have shown evidence of increased reproductive success and increased numbers (Grier, 1982).

Although some of the species in the second category also feed on birds, most are species with specialized habitat requirements. The decline of Red-shouldered Hawks in Ontario has been attributed mainly to loss of riparian deciduous forests (Risley, 1983). In Western Canada, the deterioration and loss of natural prairie and its replacement with agricultural crops, has undoubtedly contributed to declines in raptors such as the Ferruginous Hawk (Schmutz and Schmutz, 1980) and the Burrowing Owl (Wedgewood, 1978).

Species in the third category tend to adapt well to human activities, profiting from new sources of food. Although American Kestrels are likely to be exposed to potentially hazardous agricultural chemicals, numbers may have increased due the increase in suitable open habitat and the availability of nest boxes. Red-tailed Hawks may have benefited from the reduced numbers of some of their competitors (Runyan, 1987).

The fourth category includes most of the arctic species, for which few population data are available, and which have probably not been affected by habitat changes. It also includes species with cyclic fluctuations in numbers. Numbers of Northern Harrier, Gyrfalcon, and Rough-legged Hawk tend to correspond to the density of their primary prey species: voles, ptarmigan, and lemmings, respectively (Martin, 1978; Duncan, 1986; Godfrey, 1986). Finally, this category includes such abundant species as the Sharp-shinned Hawk, whose population trends have never been established (Flood and Bortolotti, 1986). This species is still blue-listed in some areas of North America (Tate and Tate, 1982; Tate, 1986), but other populations appear to be healthy.

6.0 USE OF RAPTORS AS MONITORS OF ENVIRONMENTAL CONTAMINATION

The catastrophic declines in certain populations of raptors in Western Europe and in Eastern North America during the 1960s focused attention on the deadly effects of persistent insecticides and mercury. The widespread occurrence of poisoned raptors was a dramatic and obvious indication that the environment was severely contaminated. Since those events, raptors have been used as *ad hoc* indicators of the magnitude of environmental contamination.

The purpose of this chapter is to describe and evaluate the use of raptors as monitors of environmental contamination in Canada.

6.1 Rationale

The bioaccumulation of many contaminants in organisms results in magnification of residue levels at each rung of the terrestrial food chain (Lincer and Sherburne, 1974; Beyer and Gish, 1980). Raptors are often at the top of food chains, and therefore tend to accumulate high concentrations of lipophilic contaminants (such as organochlorines), as well as some heavy metals and radionuclides.

We assume that the main objective of a monitoring program is to detect changes in contamination over time. Levels of contaminants in raptors should reflect those in their prey and other components of the ecosystem therefor changes in overall contamination can be detected by monitoring levels in raptors. It may also be possible to compare contaminant levels in different areas. The main criteria for selection of an appropriate monitor species are: i) the ability to accumulate high levels, ii) a broad distribution, iii) abundance and accessibility, and iv) knowledge of its biology, particularly diet and seasonal movements (Gilbertson *et al.*, 1986).

6.2 History of surveys for contaminants in Canadian raptors

In Canada, analyses of raptor eggs for contaminant content were initiated in the late 1960s. Tissue samples from raptors found dead were chemically analyzed by CWS in order to help determine the cause of death. A few individuals were collected in order to provide control levels of contaminants in random samples of the population.

The main aim of these initial surveys was to establish contaminant levels in raptors and to identify the cause of population declines. Because so many contaminants were discovered in the eggs and tissues, it was difficult to determine which contaminant, if any, was responsible for the problems in raptors. Until experimental studies were completed, the evidence for toxic effects of organochlorines and mercury was purely correlative (Chapter 4.0).

The Canadian Wildlife Service continued to analyze eggs and tissues of raptors throughout the 1970s and 1980s (Table 1). Although there has been no official long-term monitoring program of any Canadian raptor, large data sets exist for a few species. These include the results of analyzing more than 340 Merlin eggs and more than 490 Prairie Falcon eggs, between 1967 and 1988. More than forty eggs of Bald Eagles nesting in Northern Ontario were collected by W.Grier between 1968 and 1981 in collaboration with CWS (Grier, 1982).

Apart from the studies above, little long-term data on contaminants in Canadian raptors exist. For most species, the data consists of analyses of unhatched eggs from several locations, as well as analyses of livers, brains, muscle or fat of nestlings found dead in the nest or adults found dead or shot. In a few cases, eggs were sampled in the 1980s in order to compare contaminant levels with those found in eggs collected earlier.

Current projects include: 1) surveys of contaminant levels in eggs of accipiters in Southern Ontario; 2) monitoring of blood levels in several raptor species at hawk migration points along the Great Lakes; and 3) analyses of eggs of prairie raptors, collected to compare residue levels with those in the 1970s.

6.3 Use of raptors as monitors outside Canada

Outside Canada, raptors have often been used to monitor environmental levels of contaminants in terrestrial ecosystems and their biota. Since 1963, the Nature Conservancy in England has analyzed tissues of raptors submitted to them by the public (Cooke *et al.*, 1982). Specimens in the "trauma category" (where the obvious cause of death was unrelated to pesticides) were considered to be representative of the population, and were used to monitor changes in contaminant levels over time. In Holland, birds of prey found dead between 1965 and 1968 were analyzed for organochlorine content in order to determine whether the bans on seed-dressings were successful in reducing levels (Fuchs *et al.*, 1972). In Norway, Froslie *et al.* (1986) reported the levels of mercury and organochlorines in livers of hawks and owls collected between 1965 and 1983. There were no significant declines of any compounds in the livers of six species, but DDE and PCBs declined in the eggs of Sparrow Hawks and Eagle Owls. In Spain, Hernandez *et al.* (1986) found that DDE had declined but PCB levels had remained about the same in eggs of raptors collected in 1980-83 compared to those from 1972-76. In Sweden, there were no significant changes in levels of PCBs, DDE, or mercury in the eggs of White-tailed Eagles between 1965 and 1978 (Helander *et al.*, 1982).

6.4 Evaluation of possible monitoring programs using raptors

6.4.1 Raptor specimens found dead

Some raptors found dead, including nestlings, are submitted to the Canadian Wildlife Service for necropsy and analysis of organochlorine and heavy metal content. These constitute a valuable source of specimens that are either: i) obvious accidental deaths, or ii) possible cases of poisoning. The proportion of specimens with potentially lethal (or elevated) contaminant levels in their tissues could be used as an index of mortality due to a particular contaminant. A more difficult question is whether specimens obtained randomly, such as obvious accidental deaths could be used to assess the mean residue levels in the population. There may be a bias because of the tendency of contaminated birds to become impaired.

In the U.S.A., lethal levels of contaminants in the brains of raptors have been used to estimate the incidence of pesticide-related mortality. Tissues of 75 dead or moribund raptors collected in Florida were reported by Sundlof *et al.* (1986), who detected lethal concentrations of dieldrin in three individuals. In Illinois, Havera and Duzan (1986) reported that five of 57 birds of prey found dead or disabled between 1966 and 1981 had lethal levels of dieldrin in their brains. Since the early 1970s, tissues of Bald Eagles (Kaiser *et al.*, 1980) and Osprey (Wiemeyer *et al.* 1987) found dead across the U.S. have been analyzed for organochlorine and heavy metal content.

It should be remembered that all analyses of tissues, differences in diet, age, and sex among individuals sampled introduce considerable variance.

Although raptors found dead or sick are more likely to be reported than many other wildlife species (because of relatively high interest in their welfare), the number of samples submitted to the Canadian Wildlife Service is currently small. For a monitoring program dependent on submitted samples to succeed in Canada, it should be carried out in conjunction with veterinarians and/or rehabilitation centres, with considerable efforts made to increase reporting of casualties. Species inhabiting remote or inaccessible areas could probably not be sampled this way. Regular collections of some of the more common species is another option, but one that might not be favoured by all those concerned with the welfare of raptors.

6.4.2 Egg collections

Regular collection of fresh eggs from a particular area appears to be the best way to monitor changes in contamination of raptors. Randomly collected eggs, which vary little in lipid content (Peakall and Gilman, 1979), provide a means of obtaining a standard sample, representative of the population. A disadvantage of egg collections for estimating exposure in a population is that only females are being sampled. Males and females may utilize separate prey bases in sexually size-dimorphic species.

Another criticism of collecting fresh eggs is that sampling will reduce productivity. There is also the possibility that visits to nest sites early in the season will unduly disturb the breeding birds and cause desertion. Therefore, collection of fresh eggs may not be desirable for rare species or those prone to desertion.

Alternatively, it is possible to collect unhatched eggs remaining in the nest at the end of the season. These constitute a biased sample of the eggs most likely to exhibit high residue levels. Contaminant concentrations in nonviable eggs can be compared to those in fresh eggs in order to assess the effects on hatchability.

Eggs may be difficult to collect. Many species breed in remote areas, or in inaccessible sites such as cliffs or the tops of dead trees. Raptors are generally solitary breeders, and the nests of some species are difficult to find.

6.4.3 Blood samples

Levels of contaminants in blood of migrating raptors have been used to investigate the possibility that contaminants are acquired on the wintering grounds rather than in the breeding areas (Henny *et al.*, 1982; Elliott and Shutt, 1993). Although blood levels may be influenced by the physiological state of the individual, blood sampling of raptors at raptor banding stations should be able to be used to i) monitor blood levels directly, or ii) predict egg residues. Henny and Meeker (1981) found the blood plasma - egg relationship to be species-independent. We feel that monitoring organochlorines in the blood of migrating raptors should be pursued as a viable supplement to egg collections.

6.4.4 Feathers

We have no data on levels of environmental contaminants in feathers of Canadian raptors, but feathers have been used by a number of authors (Appelquist *et al.*, 1984; Furness *et al.*, 1986) to monitor levels of mercury in the environment. Because most of the body burden of mercury is contained in the feathers, the mercury content of a particular feather is influenced by the moult sequence. Furness *et al.* (1986) noted that the mercury content of feathers does not reflect dietary levels of mercury at the time of feather growth, but the amount of mercury stored in body tissues.

6.5 Use of raptors as bioindicators

There is considerable evidence that raptors are relatively susceptible to contaminants. Egg-shell thinning associated with elevated DDE levels, and the toxic effects of dieldrin, heptachlor epoxide, and mercury have been well established in both experimental and field studies (Chapter 4.0). Concern about the additional stress of environmental contaminants on raptors already under siege from other factors provided the impetus for many of the early studies. The Peregrine Falcon is now probably the best known symbol of the deadly effects of DDT. However, whether the effects in raptors (such as eggshell thinning or population declines) can be used to quantitatively assess contamination of the environment is a complex subject that will not be discussed in detail here.

7.0 DETAILED SPECIES ACCOUNTS

7.1 Northern Goshawk *Accipiter gentilis*

The breeding distribution of the Goshawk extends across Canada below the treeline south to Mexico (Palmer, 1988). Although found to breed in many habitats, this species prefers edges of both coniferous and mixed forests. The wintering range extends slightly further south than the breeding range (Godfrey, 1986).

The diet of the Goshawk, particularly the female, includes more mammals than that of other accipiters (Storer, 1966), and because of its larger size, a wider variety of prey can be taken. Major prey items include gamebirds, hares, rabbits and squirrels (Palmer, 1988). In the eastern U.S.A., mammals such as chipmunks and squirrels accounted for 40 to 60% of its diet, while birds (mainly grouse, crows, jays, flickers and doves) accounted for the remainder (Sherrod, 1978).

7.1.1 Analyses

One fresh egg from a nest in New Brunswick was collected in 1969 and four fresh eggs were collected in 1987 from southern Ontario.

7.1.2 Levels and toxic effects

Levels of DDE, DDD, DDT, dieldrin, and heptachlor epoxide in eggs (Table 3) were below levels associated with reduced reproductive success in other accipiters (Snyder *et al.*, 1973; Newton *et al.*, 1986).

Snyder *et al.* (1973) found Goshawk eggs to have the lowest residues of DDE among accipiters, and related this to the prevalence of mammals and resident birds in their diet compared with other accipiters. Nevertheless, exposure to pesticide spraying may result in elevated tissue levels. Residues of DDT and metabolites in blood plasma of Goshawks were 2.6 times those found in American Kestrels in an area sprayed with DDT (Henny, 1977). There have been no reports of egg breakage attributed to contaminants in this species.

7.1.3 Status and conclusions

There are no reports of population declines of Northern Goshawks in Canada or the U.S.A. Population trends are difficult to assess because of the periodicity of its population cycle, which track the cyclic eruptions of its primary prey, snowshoe hares and grouse (Heintzelman, 1986). This species is less dependent on migratory birds than other accipiters and does not appear to be as readily exposed to organochlorine contaminants. In Europe, it has been suggested as a good monitor of heavy metal levels (particularly lead and cadmium) because it is usually resident rather than migratory, widely distributed, and prey remains can be identified near the nest site (Ellenberg *et al.*, 1985).

7.2 Cooper's Hawk *Accipiter cooperii*

The Cooper's Hawk has a breeding distribution in Canada extending from southern B.C. to southern Quebec. Although some individuals winter in southern Ontario, others may migrate as far south as Costa Rica or Guatemala (Palmer, 1988). It breeds in both deciduous and coniferous forests, with a preference for riparian habitat (Penak, 1983).

Cooper's Hawks have a preference for birds, which constitute from about 60% of its diet in the western U.S.A.(Snyder *et al.*, 1973; Reynolds and Meslow, 1984) to 85% in the northeastern U.S.A. (Sherrod, 1978). Birds taken are primarily medium-sized songbirds (Blue Jays, woodpeckers, starlings, Robins), as well as doves, bobwhite, pheasants and other gallinaceous birds (Palmer, 1988). About 15 to 30% of the diet are mammals, mainly chipmunks and squirrels. Invertebrates and amphibians are also occasionally consumed (Duncan, 1966).

7.2.1 Analyses

Twenty fresh or addled Cooper's Hawk eggs were collected in the Prairie provinces between 1967 and 1978, most between 1967 and 1971. In B.C., the brain of one specimen collected in 1967 and three livers of birds collected in 1984 were analyzed for organochlorine content.

Thirteen eggs were sampled from southern Ontario between 1986 and 1988. In 1986-1988, blood samples were obtained from spring migrants at Whitefish Point, Michigan. All samples were analyzed for organochlorines, and in some cases mercury.

7.2.2 Levels and toxic effects

Only four eggs, all from different clutches, contained organochlorines at levels high enough to be associated with toxic effects. DDE was detected at 14.6 mg/kg in one addled egg from Manitoba, collected in 1967. Three of 13 eggs from Ontario collected between 1986 and 1988 contained DDE at levels greater than 10.0 mg/kg. Two eggs were very contaminated, with DDE levels of about 25 mg/kg.

In studies on the effects of DDE on Cooper's Hawks in Arizona and New Mexico, eggshell thinning was significantly correlated with DDE content of eggs (Snyder *et al.*, 1973). DDE levels ranged from 1.0 to over 8.0 mg/kg, and were significantly higher in unsuccessful nests. Differences in DDE content between fertile, infertile, deserted, addled, and broken eggs suggested that DDE was not involved in infertility or embryonic death, but was implicated in desertions and egg breakage. Egg breakage occurred in at least 11 out of 60 cases, and several instances of abnormal parental behaviour were observed in that study.

In extensive studies of the European Sparrowhawk in Britain (Newton *et al.*, 1986), a logarithmic relationship between DDE content of eggs and eggshell thinning was found. Converted to wet weights, a value of 10.3 mg/kg DDE was likely to cause significant (20%) eggshell thinning. Newton and co-workers' studies also demonstrated that the effects on nesting success were almost entirely through eggshell thinning, not other factors.

Lincer and Clark (1978) reported 19% eggshell thinning in New York where DDE in two Cooper's Hawk eggs averaged 13 mg/kg (w.w.) in 1971. Pattee and co-workers (1985) examined organochlorine content of Cooper's Hawk eggs in the eastern U.S.A. in 1980 and found very little evidence of eggshell thinning. DDE levels in eggs were all less than the 4 mg/kg suggested by Snyder *et al.* (1973) to be associated with reproductive failure.

Dieldrin in one egg was 5.9 mg/kg. Although dieldrin, heptachlor epoxide, and PCBs in the remainder of the eggs were below levels associated with reproductive effects (Chapter 4.0), two of the four eggs collected in 1988 were contaminated with heptachlor epoxide at levels close to 1.0 mg/kg. One of those eggs also contained elevated levels of oxychlordane - 1.66 mg/kg.

Liver tissue collected in B.C. in 1984 contained DDE at concentrations up to 38 mg/kg (w.w.). Although elevated, these are below levels that might have detrimental effects (Cooke *et al.*, 1982). A few instances of pesticide poisoning in this species have been reported in the U.S.A. In 1980, in Colorado, a Cooper's Hawk was found in convulsions, with 200 mg/kg DDE, 46 mg/kg DDT, and 16 mg/kg DDD in the brain, all wet weights (Prouty *et al.*, 1982). This bird apparently died of DDT poisoning, perhaps obtained on its wintering grounds in Mexico. No other organochlorines were at detectable levels in the brain.

Henny (1977) reported highly elevated residues of DDT and metabolites in the blood plasma of Cooper's Hawks sampled in an area in Oregon sprayed with DDT.

7.2.3 Temporal trends

There are no indications of any obvious temporal trends in levels of contaminants in this species. Although data from Ontario in the 1980s is not strictly comparable to data from the Prairies in the early 1970s, the levels - except for a slight and insignificant increase in heptachlor epoxide - were quite similar.

7.2.4 Geographic comparisons

The levels of organochlorines in Cooper's Hawk eggs from western Canada were much lower than egg levels found in New York by Lincer and Clark (1978) but similar to those found in Arizona and New York by Snyder *et al.* (1973) during the early 1970s. These authors noted that DDE levels were generally somewhat higher in the eastern States than in the western States. Although DDE levels in most eggs of this species in Ontario were similar to those recorded by Pattee *et al.* (1985) in New York, two eggs from Ontario containing 25.0 mg/kg DDE were significantly more contaminated.

7.2.5 Status and conclusions

This species is considered rare in Ontario. The reduction of populations is attributed mainly to pesticide contamination, habitat destruction, and shooting (Penak, 1983). Its breeding status east of Ontario remains uncertain, whereas populations in the west are now considered stable. Henny (1972) estimated a 25% annual decline in North American numbers during the late 1960s, probably attributable to pesticides and shooting, and concluded that Cooper's Hawks were in serious trouble. Tate (1986) noted that although this species has been "blue-listed" since 1972, most contributors considered populations to be healthy in the early 1980s. There are some indications of recovery in both Canada and the U.S.A. (Pattee *et al.*, 1985), and there are vast tracts of suitable habitat yet to be surveyed.

This species preys to a larger extent on mammals than the Sharp-shinned Hawk, and probably on a higher percentage of resident gallinaceous birds (Sherrod, 1978). The females, which are almost double the weight of males, tend to take much larger prey (Newton, 1979) and hence may be exposed to a different suite of contaminants. Snyder *et al.* (1973) showed a significant correlation between percentage of birds in the diet at individual nests (range of 25 to 70%) and the DDE content of eggs. Residue levels in eggs of accipiters collected in Ontario, between 1986 and 1988, which show the Cooper's Hawk as intermediate in contaminant levels, conform with this pattern (Figure 2).

Although most of the contaminant levels in eggs and tissues of this species in Canada were found to be below levels associated with adverse reproductive effects, the safety margin is small and there are no indications that organochlorine residues (DDE, dieldrin, and heptachlor epoxide) are declining. Where migratory songbirds constitute a major proportion of the prey of this species, organochlorines may still be affecting reproduction.

7.3 Sharp-shinned Hawk *Accipiter striatus*

Sharp-shinned Hawks breed in woodland habitat south of the treeline from coast to coast in Canada . The wintering area extends from southern Canada to

Costa Rica (Godfrey, 1986). The smallest of the accipiters, Sharp-shinned Hawks feed almost exclusively on birds, mainly forest passerines during the breeding season, and on migrants along the coast and in more open areas outside the breeding season (Sherrod, 1978; Palmer, 1988).

Storer (1966) estimated 97% of the prey to be birds, with robins, thrushes, warblers, swallows, and sparrows predominating.

7.3.1 Analyses

Until recently, only one addled egg from Saskatchewan, collected in 1968, had been analyzed. In 1983, three unhatched eggs from New Brunswick were collected for organochlorine analyses. A further nine eggs from southern Ontario were collected between 1986 and 1988. The brain of a Sharp-shinned Hawk found dead in B.C. in 1969, livers of seven birds collected in B.C. between 1982 and 1985, and blood samples taken between 1985 and 1988 from over one hundred migrants in Ontario and Michigan were also analyzed for organochlorines.

7.3.2 Levels and toxic effects

Five of the 12 eggs collected in the 1980s, all from Ontario, contained DDE concentrations greater than 10 mg/kg (w.w.), with a maximum of 18.6 mg/kg. British studies on the ecologically similar European Sparrowhawk demonstrated a logarithmic relationship between DDE content of eggs and eggshell thinning (Newton *et al.*, 1986). DDE levels of 10.3 mg/kg (w.w.) were associated with serious (20%) eggshell thinning in that species.

Dieldrin in one Sharp-shinned Hawk egg from Ontario collected in 1986 exceeded 1.0 mg/kg, the critical level considered to have detrimental effects on reproduction in some raptors (Table 2). Heptachlor epoxide, HCB, PCBs, and HCH isomers were at levels below those associated with effects in other studies.

One of the livers of birds collected in B.C. contained DDE residues greater than 100 mg/kg, DDD residues greater than 2.7 mg/kg, and oxychlordane residues greater than 2.5 mg/kg. These are very close to the lethal ranges in livers proposed by Cooke *et al.* (1982), and suggest that the bird could have died of pesticide poisoning. Levels of dieldrin and heptachlor in that sample were low.

Blood samples are more difficult to assess. We used the following equations developed by Henny and Meeker (1981) to convert plasma DDE levels to egg levels:

1) Total DDT in eggs = 6.243 x (Total DDT in blood plasma)$^{1.033}$ in the post-laying period; and
2) Total DDT in eggs = 3.079 x (Total DDT in blood plasma) in the pre-laying period).

Application of Formula 1 suggests that the mean total DDT in eggs that were previously laid by adult migrants flying south in the fall of 1985 through Hawk Cliff, Ontario, would have been 0.36 mg/kg (w.w.), with a maximum value of about 3.0 mg/kg. These values are much lower than those observed in any recently analyzed eggs of this species. This formula is inapplicable for juveniles flying south for the first time.

Application of the second formula to the spring migrants going through Whitefish Point, Michigan, suggests that the mean value of total DDT in eggs would be 0.68 mg/kg (w.w.), with a maximum value of about 17 mg/kg. These values are somewhat lower than the means of egg levels found in southern Ontario. This may be due to differences in the populations sampled, and suggests that Henny and Meeker's formula be applied with caution.

Most organochlorine (DDE, dieldrin, heptachlor epoxide, and HCB) concentrations were greater in spring migrants returning from their first winter than in juveniles sampled in the fall, suggesting that exposure in their wintering areas (including Central America) was influencing levels in Canadian breeding birds. There were no differences between spring and fall migrants in birds greater than one year old.

The egg from Saskatchewan in 1968 was analyzed for mercury. It was found to contain 0.12 mg/kg (w.w.).

7.3.3 Temporal trends

There is a lack of historical data on levels of organochlorines in eggs of this species (see Table 3). We could not analyze statistically for temporal trends. DDE in the single egg collected in 1968 was similar to values in Ontario in the 1980s, whereas levels of dieldrin and heptachlor epoxide were lower.

7.3.4 Spatial trends

Levels of organochlorines in Sharp-shinned Hawk eggs in the 1980s are generally lower than in eggs of this species collected in the western U.S.A. during the 1970s (Snyder *et al.*, 1973). Those investigators found Sharp-shinned Hawk eggs to contain the highest levels of DDE among accipiters in Arizona, New Mexico, and Oregon between 1969 and 1971. The eggs from Oregon which contained up to 100 mg/kg DDE were extremely thin-shelled and many eggs in those clutches were broken.

7.3.5 Status and conclusions

DDE concentrations in some of the eggs were high enough to cause significant eggshell thinning and reduce reproductive success. Dieldrin may also have reduced productivity in some areas of Ontario.

Although there is little evidence of declines in numbers of Sharp-shinned Hawks in Canada, there were some indications of declines in the northeastern U.S.A. (Snyder *et al.*, 1973). Despite the lack of data, most authors agree that this species was adversely affected in the 1960s and 1970s by organochlorine contaminants and shooting. Flood and Bortolotti (1986) considered the North American population to be currently stable, and Heintzelman (1986) reported increases in numbers migrating through Hawk Mountain. Numbers of birds seen during fall migration at Holiday Beach, Ontario, did not change significantly between 1976 and 1981 (Duncan, 1982).

Further blood sampling may elucidate current trends in levels of organochlorines in this species, and help to determine the main source of the contaminants. This species preys almost exclusively on migratory birds and may be particularly susceptible. Studies on the reproductive success of this species in areas where the eggs were relatively contaminated seem warranted.

7.4 Red-tailed Hawk *Buteo jamaicensis*

The Red-tailed Hawk breeds over most of forested Canada. Although many individuals migrate south to wintering areas in the southern U.S.A., others are resident in Canada year round (Godfrey, 1986).

This species feeds on a variety of prey species, although mammals predominate (75%) over birds (25%), according to Sherrod (1978). McInvaille and Keith (1974) found ground squirrels and hares to be the dominant prey in Alberta, although grouse and waterfowl were also taken.

7.4.1 Analyses

Forty-nine eggs were collected from Ontario, Manitoba, Saskatchewan, Alberta, and B.C. between 1967 and 1970, and analyzed for organochlorine and mercury content. Four tissues of two specimens from Saskatchewan in 1967, liver and brain from an Alberta specimen from 1968, brain and breast muscle from an adult collected in British Columbia in 1968, and brain tissue from a nestling found dead in a nest in British Columbia in 1969, were also analyzed. The only recent data consists of blood samples from three migrants at Hawk Cliff in 1986.

7.4.2 Levels and toxic effects

DDE levels in eggs were generally low, exceeding 15 mg/kg (w.w.) in only two eggs from Alberta in 1968, and greater than 10 mg/kg in a total of four eggs (Table 4). DDD plus DDT amounted to greater than 2.0 mg/kg in one egg from Saskatchewan. Although this is suggestive of recent exposure, there are no known reproductive effects at those levels.

Springer (1980) found significant differences in residue levels of DDE between viable and addled eggs of this species in Oregon during the 1970s. Seidensticker and Reynolds (1971) reported 11% eggshell thinning in eggs of Red-tailed Hawks collected in Montana in 1967, where DDE ranged from 0.25 to 10.3

mg/kg (w.w.).

Dieldrin levels were very high (3.2 mg/kg) in one addled egg from Manitoba in 1967, and in one egg from Saskatchewan in 1969 (5.9 mg/kg). Altogether, five (19%) of the eggs collected in the Prairies contained dieldrin residues in excess of 1.0 mg/kg. Concentrations of dieldrin greater than 1.0 mg/kg (w.w.) have been associated with reduced hatchability in Ospreys (Wiemeyer *et al.*, 1975).

One egg from Alberta contained heptachlor epoxide at 2.5 mg/kg, a value associated with reduced breeding success in American Kestrels (Henny *et al.*, 1983). All other eggs contained less than 1.0 mg/kg of heptachlor epoxide. In the egg mentioned above, mercury was also present at a potentially hazardous level of 1.6 mg/kg (w.w.).

None of the levels of DDT, DDD, DDE, heptachlor epoxide, or dieldrin found in tissues were high enough to be associated with acute toxic effects. Residue levels in blood samples were also very low in comparison to those in accipiters and falcons.

7.4.3 Geographic comparisons

Frank and co-workers (1975) reported similar levels of DDT compounds and dieldrin in 11 eggs collected from the Niagara Peninsula, Ontario, in 1971. However, the maximum concentrations were higher in the data presented here for western Canada than in those found in Ontario by Frank.

Springer (1980) found little DDE, levels of heptachlor epoxide and PCBs similar to those reported here, and greater amounts of dieldrin in eggs of Red-tailed Hawks collected in Ohio in 1976 and 1977.

7.4.4 Status and conclusions

The Red-tailed Hawk was an abundant resident, and appeared to be increasing in some parts of its range in the 1970s (Henny and Wight, 1972). Even during the era of high pesticide use in Canada, levels of organochlorines in this species were relatively low.

Despite their proximity to agricultural areas, 11 eggs of this species collected in the Niagara region of southern Ontario in 1971 contained lower levels of DDT compounds (mean of 2.47 mg/kg, wet weight), dieldrin, PCBs, and mercury than in aquatic fish-eating birds collected concurrently (Frank *et al.*, 1975). Its predominantly mammalian diet and its tendency to winter in the breeding area result in low exposure. The few cases of high dieldrin or heptachlor epoxide levels are probably due to localized use in the foraging range (breeding or wintering) of that individual.

The lack of analyses since 1970 means that the effects of currently or more recently used organochlorines cannot be assessed. Nevertheless, there appear to be no evidence of declines of this species anywhere in Canada.

7.5 Red-shouldered Hawk *Buteo lineatus*

The Red-shouldered Hawk has a restricted breeding distribution in Canada, which includes southern Ontario, southwestern Quebec, and southern New Brunswick (Godfrey, 1986). It winters mainly south of Canada in the southern part of its breeding range south to Florida.

This species prefers wet river-bottom habitat, but will also breed in close proximity to farmland (Risley, 1983). The diet is mainly mammals, reptiles, and amphibians, with occasional birds and invertebrates. Portnoy and Dodge (1979) found that 99% of the stomachs examined contained small mammals (mainly chipmunks), 23% reptiles (mainly snakes) and only 3% birds. Risley (1983) cited two studies on the diet in Ontario: Hanna (1973) who found the diet to be 80% mammals and 10% birds; and Snyder (1949) who reported only 20% mammals, 10% birds and 50% reptiles and amphibians by composition.

7.5.1 Analyses

Data on contaminants in this species is limited to analyses of three fresh eggs, collected in southern Ontario in 1973.

7.5.2 Levels and toxic effects

Levels of DDT compounds were relatively low, except for 1.1 mg/kg of DDT (the parent compound of DDE) in one egg. The low DDE:DDT ratio suggested recent exposure to DDT, but not enough to affect reproduction. All other compounds detected were at low levels (Table 4) and were unlikely to have any effect on viability.

In Maryland, Henny *et al.* (1973), reported 9% eggshell thinning, where DDE egg levels ranged from 0.79 to 2.4 mg/kg (w.w.).

7.5.3 Geographic comparisons

The concentrations of DDT, dieldrin, and PCBs reported here are similar to levels found in Red-shouldered Hawk eggs collected from southern Ontario in 1971 and 1973 (Frank *et al.*, 1975; Risley, 1983).

7.5.4 Status and conclusions

The Red-shouldered Hawk has declined in numbers over much of its range, including southern Ontario, since the 1960s (Risley, 1983). This is attributed largely to the loss of suitable habitat from swamp drainage and conversion to farmland, and to competition from Great Horned Owls and Red-tailed Hawks, which prefer the drier habitat.

Its diet consists mainly of mammals, organochlorine contaminants in eggs are usually low, and there have been no reports of significant eggshell thinning or reduced productivity. Nevertheless, some individuals are occasionally exposed to lethal levels of dieldrin, heptachlor, or chlordane. Two Red-shouldered Hawks were found dead in the eastern U.S.A. in 1978 and 1981, with hazardous levels of oxychlordane (1.9 and 5.2 mg/kg) and heptachlor epoxide (3.4 and 4.0 mg/kg) in their brains (Blus *et al.*, 1983). Dieldrin concentrations were also close to lethal levels, greater than 4.0 mg/kg (w.w.) in the brain. Two Red-shouldered Hawks found dead in Florida during the mid- 1970s were thought to have died of dieldrin poisoning, with up to 11 mg/kg (w.w.) of dieldrin detected in the brains (Sundlof *et al.*, 1986). Those compounds were probably acquired during movement through areas of local use, reaching hazardous levels in the brain as lipid stores were metabolized during migration. Elevated levels in amphibians or reptiles associated with contaminated aquatic systems are also a possibility.

7.6 Swainson's Hawk *Buteo swainsoni*

The Swainson's Hawk breeds mainly in the southern parts of the three prairie provinces, with small populations in British Columbia and the Northwest Territories. This species is highly migratory, wintering mainly in Argentina (Godfrey, 1986).

It prefers open arid country in the prairies, foothills and the tundra of the low arctic. Like other buteos, the diet consists mainly of small mammals. Dunkle (1977) found that mammals, including ground squirrels, rabbits, and gophers, accounted for almost 70% of their diet in Wyoming. Birds, including blackbirds and waterfowl, comprised 25% of the diet, and insects, amphibians and reptiles the remainder. Other studies reported similar percentages of mammals, but often much higher proportions of insects (up to 30% in Utah) or reptiles (up to 64% in Washington) (Sherrod, 1978).

7.6.1 Analyses

Eighteen fresh and addled eggs of Swainson's Hawks were collected from Saskatchewan and Alberta between 1967 and 1973. Eight pooled samples (of two to four eggs each) from Saskatchewan in 1984 and 1985 were also analyzed for organochlorine content. Tissue samples analyzed include brains and livers of adult birds from both provinces between 1967 and 1971, breast muscle from an adult in Alberta in 1968, and whole bodies of nestlings collected in 1971 in Alberta.

7.6.2 Levels and toxic effects

Levels of DDE in eggs were relatively low, always less than 6.0 mg/kg (w.w.) (Table 4). All eight pools analyzed in 1984 and 1985 contained less than 1.0 mg/kg DDE. These data agree with the findings of Bechard (1981), that the low concentrations in Swainson's Hawk eggs reflect the low levels in their primarily mammalian prey.

One egg from Alberta in 1968 which contained 5.9 mg/kg DDE also contained 1.4 mg/kg DDD, 2.1 mg/kg DDT, and over 4.0 mg/kg heptachlor epoxide. Levels of heptachlor epoxide greater than 1.5 mg/kg are known to affect reproductive success in American Kestrel (Henny *et al.*, 1983). However, another study by Henny *et al* (1984) found that the hatching success of eggs of Swainson's Hawks in Oregon appeared to be unaffected by heptachlor epoxide levels in excess of 2.5 mg/kg.

In the latter study, a significant logarithmic relationship between DDE and eggshell thickness in Swainson's Hawk eggs was demonstrated, with 10% shell thinning associated with DDE egg residues of 10.3 mg/kg. However, the significance of 10% shell thinning in this species is not known. It did not appear to affect productivity.

In the data presented here, HCB levels were less than 0.20 mg/kg in all eggs. Bechard (1981) reported HCB in most Swainson's Hawk eggs in Washington with a maximum value of 5.2 mg/kg. He found no discernable effect on nesting success.

Swainson's Hawk eggs collected in 1984 and 1985 were found to contain a number of other contaminants at low levels, including mirex (mean of 0.005 mg/kg) and gamma-HCH (lindane). The amount of total chlordane-related compounds was similar among eggs (with a mean of 0.041 mg/kg). Oxychlordane was the major metabolite, with lesser amounts of trans-nonachlor, cis-chlordane and cis-nonachlor also present.

Mercury levels were as high as 1.5 mg/kg in some livers, but well below concentrations associated with mortality in other birds (Fimreite and Karstad, 1971). Egg mercury levels were very low.

Contaminant levels in whole bodies of nestlings collected in 1971 were higher than those in eggs collected in the same year. This can be interpreted as evidence that contaminants were acquired in the breeding area.

7.6.3 Temporal trends

Organochlorine residues in eggs of Swainson's Hawks are plotted in Figure 10 (1984 and 1985 data are means of pools). A test for differences between eggs collected between 1967 and 1970 and eggs collected in 1984 and 1985, revealed no significant differences in DDE or heptachlor epoxide, but suggested a significant decline ($p < 0.001$) in dieldrin. Although this species winters in the tropics, there is no evidence that continuing use of organochlorine pesticides in Latin America has resulted in increased exposure.

7.6.4 Geographic comparisons

Levels of environmental contaminants in eggs of Swainson's Hawks collected in Saskatchewan in the mid-1980s were similar or lower than those found in eggs in North and South Dakota in the mid-1970s (Stendell *et al.*, 1988), Oregon in the late 1970s (Henny and Kaiser, 1979; Henny *et al.*, 1984) and Washington in the late 1970s (Henny and Kaiser, 1979; Bechard, 1981). Our 1980s data consisted of pooled samples and no comparison of the maximum levels detected in eggs was possible.

7.6.5 Status and conclusions

The low levels of DDE, dieldrin, heptachlor epoxide, oxychlordane, and HCB detected in Swainson's Hawk eggs from Saskatchewan are similar to those in less migratory hawks sampled concurrently. This supports Bechard's (1981) conclusion that the low levels of DDE and HCB in Swainson's Hawk eggs were due to their diet of small mammals, a source of food seldom found to be significantly contaminated. In his study, DDE levels in addled eggs were all less than 3.0 mg/kg, and no DDD or DDT were detected.

Use of organochlorine pesticides in Latin America has been suggested as the source of many contaminants in North American falcons (White and Cade, 1977) and passerines (DeWeese *et al.*, 1986). Swainson's Hawks winter as far south as Argentina and investigators thought that they would also be at risk. However, neither our data or Bechard's data support this hypothesis.

It is possible that falcons wintering in Latin America are feeding on prey that is considerably more contaminated than the species taken by Swainson's Hawks. This could be due to differences in foraging areas and prey species selected. The long migration might also be a factor, if most of the lipids stored while in Latin America are metabolized, and the contaminants mobilized, before the hawks return to their breeding grounds. However, there have been no reports of organochlorine poisoning in this species.

Although the Swainson's Hawk has declined in numbers in parts of its range in the U.S.A., this has been attributed mainly to increased agricultural activity. Fyfe (1976) reported declines in Canada, but populations are currently considered healthy.

7.7 Ferruginous Hawk *Buteo regalis*

The breeding range of the Ferruginous Hawk in Canada is restricted to open arid habitat in southern Saskatchewan and Alberta (Schmutz and Schmutz, 1980). Its wintering area extends from the breeding range southwest of the Mississippi to Northern Mexico.

In Alberta, ground squirrels comprise about 90% of its prey during the breeding season (Schmutz, 1977). Jack-rabbits make up the rest of the diet, and are probably taken to a greater extent outside the breeding season. In the western U.S.A. mammals such as ground squirrels, jack-rabbits and pocket gophers were the main prey. Birds (Horned Larks and Meadowlarks) were only occasionally taken (Palmer, 1988).

7.7.1 Analyses

Fifty fresh and addled eggs of this species were collected in Saskatchewan and Alberta between 1968 and 1971. Two pools of addled eggs collected in

Saskatchewan in 1984 and 1985 were also analyzed for organochlorine content.

The brain and liver of one specimen from Saskatchewan in 1969, and two whole bodies of specimens from Alberta in 1971, were analyzed for organochlorines. The livers of eight of the birds collected from Alberta in 1971 were analyzed for mercury.

7.7.2 Levels and toxic effects

Organochlorine levels were relatively low in eggs of this species (Table 4). The overall mean DDE level in eggs was less than 1.0 mg/kg (w.w.), which is unlikely to cause any eggshell thinning. An exception is an egg from Alberta in 1969, which contained 13 mg/kg DDE. Eggs of Ferruginous Hawks collected in Oregon in the late 1970s were found to contain less than 3.0 mg/kg DDE (Henny *et al.*, 1984). Eggshells in that study were thicker than those collected prior to 1947.

Heptachlor epoxide was detected in most eggs, usually at levels less than 1.0 mg/kg, but as high as 2.3 mg/kg in one sample. Heptachlor epoxide residues greater than 1.5 mg/kg in eggs of American Kestrels (Henny *et al.*, 1983) reduced productivity. Dieldrin was detected at levels of about 0.5 mg/kg with a maximum of 4.3 mg/kg in an addled egg from Alberta in 1969. Dieldrin can have detrimental effects on reproduction at levels greater than 1.0 mg/kg (Chapter 4.0).

About 4% of the eggs of Ferruginous Hawks collected in Canada contained organochlorines at concentrations associated with reproductive effects. Residue levels of the pooled samples obtained in the mid-1980s were low, and, unfortunately, do not provide data on the maximum concentrations attained by individuals.

DDE and dieldrin levels in brain and whole bodies were very low. Heptachlor epoxide levels were occasionally elevated, up to 1.84 mg/kg (w.w.) in whole bodies from Alberta in 1971. The significance of those values in relation to possible poisoning is not known.

Mercury content of the eight livers was always less than 0.20 mg/kg (w.w.), well below values associated with health effects in other birds.

7.7.3 Temporal trends

Comparison of organochlorine residues in fifty eggs collected between 1968 and 1971, and two pooled samples in 1984 and 1985 revealed declines in levels of DDE, dieldrin, and heptachlor epoxide. However, this decline was not statistically significant (Table 11), because of the small sample sizes in the latter time period.

7.7.4 Geographic comparisons

Levels of DDE, dieldrin, heptachlor epoxide, oxychlordane, HCB, PCBs and mercury were similar to those found in eggs of Ferruginous Hawks collected between 1974 and 1979 in North and South Dakota (Stendell *et al.*, 1988).

7.7.5 Status and conclusions

A very small percentage of the organochlorine contaminants found in the eggs of Ferruginous Hawks were high enough to affect productivity. None of the tissues analyzed contained organochlorine residues at levels indicative of pesticide poisoning. Populations in the U.S.A. also appear to have low levels of environmental contaminants.

Nevertheless, population declines have been reported in this species in Canada (Schmutz and Schmutz, 1980; Houston and Bechard, 1984) and the U.S.A. (Lokemoen and Duebbert, 1976; Fitzner *et al.*, 1977). Houston and Bechard (1984) rejected low productivity as a cause of the declines in Saskatchewan, noting that nesting success there was higher than in thriving populations elsewhere. Although shooting of adults had been a problem, they attributed the current declines to loss of suitable habitat, loss of trees for nesting, reductions in the abundance of ground squirrels, and competition from expanding Red-tailed Hawk populations.

7.8 Rough-legged Hawk *Buteo lagopus*

The Rough-legged Hawk breeds across Northern Canada from Alaska to Newfoundland, mainly north of the treeline. It winters irregularly from southern Canada south to Virginia, Tennessee and New Mexico (Godfrey, 1986).

During the breeding season, this species lives on the tundra where cliffs, escarpments, riverbanks, or low trees provide nesting sites. During migration and winters, open fields and marshes are the preferred habitat. The diet of the Rough-legged Hawk consists mainly of small resident arctic mammals, as well as small birds, and, occasionally, carrion (Smith, 1975). In the Northwest Territories, Sealy (1966) reported 83% of prey as mammalian (ground squirrels, hares, lemmings, and voles) and 16% small passerines. In Alaska, mammals usually comprised about 80% of the diet, but ptarmigan, waterfowl and passerines were also taken (Sherrod, 1978). The diet during migration and the winter is more varied, but still consists primarily of small mammals.

7.8.1 Analyses

A total of 20 eggs of Rough-legged Hawks were collected from sites in Northern Quebec in 1967, from the Yukon in 1973, and from the Northwest Territories in 1966, 1968, 1972, 1980, and 1981. Tissues collected included: i) breast muscle and subcutaneous fat from breeding females in Ungava Bay, Quebec, in 1967; ii) liver from a specimen collected in the Northwest Territories in 1974; and iii) brains, livers and fat of two birds collected in the Yukon in 1973.

7.8.2 Levels and toxic effects

Levels of organochlorines in eggs were low (Table 4). DDE levels were always less than 3.0 mg/kg, dieldrin less than 0.3 mg/kg, and heptachlor epoxide less than 0.1 mg/kg in all samples prior to the 1980s. By 1980-81, levels of DDE, DDT, DDD, and dieldrin were somewhat lower than in the earlier samples, while heptachlor epoxide levels were slightly higher. The maximum value of 2.7 mg/kg for heptachlor epoxide in one egg is high enough to reduce viability in eggs of kestrels (Henny *et al.*, 1983) but not Swainson's Hawks (Henny *et al.*, 1984).

Levels of HCB, PCBs, HCH isomers, and oxychlordane in the eggs collected in 1980 and 1981 were well below levels associated with adverse effects based on experimental studies (Chapter 4.0).

Organochlorine levels in all tissues except subcutaneous fat were very low, which is in agreement with the findings of Cade *et al.* (1971), who found low levels of environmental contaminants in this species in Alaska. Nevertheless, certain individuals may accumulate lethal concentrations. Henny *et al.* (1984) reported that a female wintering in Oregon in 1980 was found dead with 20 mg/kg (w.w.) heptachlor epoxide in her brain, well above the lethal values established for this compound (Stickel *et al.*, 1979). Recent treatment of seeds with heptachlor in the area was considered to be the source.

7.8.3 Temporal trends

Analyses of temporal trends in contaminant levels in the Northwest Territories revealed almost significant declines in dieldrin ($p < 0.10$), but no significant changes in levels of DDE or other DDT metabolites (Table 11). Heptachlor epoxide showed an increasing trend.

7.8.4 Status and conclusions

There is no evidence that levels of organochlorines and mercury in this arctic buteo were ever high enough to affect reproduction, even in the late 1960s when organochlorine pesticides were still used on a large scale in North America. There is some indication of increasing residues of components of chlordane, a pesticide which was used in Canada until the late 1970s.

A general flux of contaminants to the arctic over the past decade has been suggested by Norstrom *et al.* (1988), based on levels in Ringed Seal, *Foca hispidia*, and Polar Bears, *Ursus maritimus*. However, due to the Rough-legged

Hawk's preferred diet of small terrestrial mammals, this species is unlikely to accumulate significant contamination on its breeding grounds. Cade and co-workers (1971) noted that levels of organochlorine pesticides in Rough-legged Hawks were considerably lower than those in Peregrine Falcons nesting in the same areas of Alaska, and attributed those differences to diet.

There is no evidence that numbers have declined in recent years. Cade and co-workers (1971) reported no decrease in numbers of Alaskan Rough-legged Hawks since the 1950s. Numbers of Rough-legged Hawks tend to fluctuate because of the population cycles of its major prey and no clear trends in numbers have been discerned (Fyfe, 1976; Heinztelman, 1986).

7.9 Broad-winged Hawk *Buteo platypterus*

The Broad-winged Hawk breeds in wooded areas in southern Canada from Alberta to Nova Scotia. This species is highly migratory, wintering in Latin America from southern Mexico south to Venezuela, Brazil, and Northern Peru (Godfrey, 1986).

This relatively small hawk feeds on a variety of prey, including small mammals, birds, amphibians, reptiles, and invertebrates (Sherrod, 1978). In Alberta, Rusch and Doerr (1972) found voles and jumping mice to be the dominant prey items, but in other studies, insects, frogs, and young turtles were common (Sherrod, 1978).

7.9.1 Analyses

Blood samples obtained from two adults migrating through Whitefish Point, Michigan, in 1986, were analyzed for organochlorine content. One egg collected in New York in 1971 contained 5.83 mg/kg DDE and 0.65 mg/kg dieldrin (Lincer and Clark, 1978), which are less than values associated with reproductive effects in other raptors.

7.9.2 Levels and toxic effects

At 0.14 mg/kg (w.w.), PCBs were the major organochlorine in blood, followed by lesser amounts of mirex and DDE. Only DDE was lower in the blood of Broad-winged Hawks than in the blood of Sharp-shinned Hawks sampled at the same time. Nothing is known of the toxic significance of the observed levels in the blood. Henny and Meeker's (1981) conversion formulae are unlikely to be valid for Broad-winged Hawks.

7.9.3 Status and conclusions

There are no indications of any declines in numbers of Broad-winged Hawks in Canada. However, this species is particularly difficult to census on the breeding grounds and during migration.

Smith (1985) hypothesized that Broad-winged Hawks migrate nonstop thousands of kilometres to their wintering grounds, relying solely on fat laid on after the breeding season. If this results in mobilization of stored organochlorines, they may be exposed to organochlorines as they metabolize lipid reserves during migration. However, no cases of poisoning have been reported for this species.

7.10 Bald Eagle *Haliaeetus leucocephalus*

The breeding distribution of Bald Eagles spans Canada from coast to coast, and extends south to Florida. Bald Eagles normally nest close to large bodies of water that support sufficient fish stocks for raising young. The nest site is typically near the top of one of the tallest trees in the vicinity, a massive structure that is occupied for many years if undisturbed.

The seasonal movements of Bald Eagles are complex, and vary considerably among populations and individuals (Brownell and Oldham, 1980). It appears that most of the northern population (breeding in the boreal forest regions of Ontario, Manitoba, Saskatchewan, Alberta, and the N.W.T.) tend to move further south outside the breeding season than eagles from the Northern U.S.A.. Eagles in the Maritimes and southern Ontario disperse in all directions -- to the coast, northward, and southward. However, virtually no Bald Eagles winter on the Great Lakes. Eagles breeding in Florida often move northward as far as the Maritime provinces outside the breeding season. The populations in British Columbia and Alaska remain resident along the coast.

Clutch size is usually two, and, in Canada, eggs are laid soon after arrival on the breeding grounds. Both Grier (1974) and Postupalsky (1971) suggested that eagles rely on stored body reserves for egg production, rather than on exogenous sources (i.e. local dietary intake). If this is true, organochlorine residues in eggs are probably acquired outside the breeding grounds, unlike the situation for Ospreys which arrive at the breeding grounds after a long migration with greatly reduced lipid reserves.

Bald Eagles are primarily piscivorous, but birds, mammals, and carrion are also taken (Brownell and Oldham, 1980). Fish (mainly herring, bass, bullheads, suckers, chub and perch) comprise from 15 to 85% of the diet. In the Aleutians, Sherrod *et al.* (1977) found birds (shearwaters, fulmars, ducks, geese, alcids and gulls) to comprise 61% of the eagle diet, mammals (mainly rats) about 23% and fish (herring, greenling, and cod) about 15%. In inland sites, however, fish are the main prey. Dunstan and Harper (1975) reported 90% fish (pike, suckers, bullhead, and bass) in Minnesota. Wright (1953) listed alewife, chub, perch, and pickerel as the main prey species in New Brunswick. Their propensity for feeding on crippled waterfowl has resulted in a number of cases of lead poisoning (Kaiser *et al.*, 1980; Pattee *et al.*, 1981). Other foraging methods include following fishing boats and scavenging near flocks of sheep, in tidepools, and along beaches.

7.10.1 Analyses

Thirty-seven eggs, mainly unhatched, were collected from Bald Eagle nests across Canada between 1968 and 1982. The majority of the samples were from Northern Ontario, collected between 1968 and 1972 (in the Lake Nipigon and Lake of the Woods areas) and Northern Saskatchewan. These include four eggs from Northern Ontario whose residues were reported by Grier (1974), as well as three eggs from the Atlantic coast and a few eggs from southern Ontario. No eggs from the N.W.T., southern Maritimes, or B.C. have been analyzed by CWS. Although no eggs from Ontario have been collected and analyzed by CWS since 1976, Grier (1982) determined and reported residues in Bald Eagle eggs from Northern Ontario collected in 1976, 1977, 1980 and 1981.

Several tissue samples were analyzed. The brain of a female sub-adult shot in New Brunswick in 1970, an adult found dead on Langara Island, B.C., in the spring of 1968, and three tissues of a bird from Manitoba in 1969 were analyzed for organochlorines. Muscle and livers of two birds collected in Ontario by Fimreite in 1970 were analyzed for mercury content. A number of blood samples of eagles brought to veterinarians in B.C. were recently analyzed for ALA-d, a biochemical indicator of lead exposure.

7.10.2 Levels and toxic effects

The adverse effects of organochlorines and mercury on Bald Eagles have been documented in a number of studies (Grier, 1974 and 1982; Wiemeyer *et al.*, 1984; International Joint Commission, 1989). In one of the most comprehensive studies, Wiemeyer *et al.* (1984) found that DDE had the most impact on breeding success. In locations where DDE in eggs approached 15 ppm, (w.w.), reproductive failure was almost total. An inverse relationship between DDE content of eggs and eggshell thickness was found such that 10% eggshell thinning was associated with 5.6 ppm (w.w.). We have used this as the threshold critical value (see Table 10). In a recent re-analysis of the US data, Nisbet (1989) examines the exposure-response relationships between DDE, PCBs, dieldrin and reproductive impairment, and concludes that both reproductive impairment and adult mortality were factors in the population declines.

Grier (1982) analyzed trends in productivity in relation to DDE content of eggs between 1966 and 1981, and found a significant negative correlation. The regression between DDE residues and eggshell thickness, however, was not significant, despite a trend for eggs collected in the later years to have thicker shells.

DDE levels in all 19 eggs collected from Ontario and eastern Canada prior to 1980 were considerably higher than 15 mg/kg (w.w.), the critical level calculated by Wiemeyer *et al.* (1984). Some eggs collected in 1970 and 1971 from areas of Northern Ontario where many nesting failures had been reported (Postupalsky, 1971; Grier, 1974) contained almost 100 mg/kg DDE. Eggs from the Prairies were generally less contaminated, with only four of 13 (30%) containing in excess of 15 mg/kg DDE.

Dieldrin exceeded 1.0 mg/kg in 13 of 32 eggs collected prior to 1980. In fact, at least six eggs were contaminated with dieldrin residues greater than 2.0 mg/kg. Dieldrin levels greater than 1.0 mg/kg in eggs of Ospreys (Wiemeyer *et al.*, 1975), and greater than 0.9 mg/kg in eggs of Golden Eagles (Lockie *et al.*, 1969), have been associated with reduced hatching success.

HCB and heptachlor epoxide levels were low, generally less than 0.5 ppm (w.w.), which is well below levels associated with adverse effects in other birds (Henny *et al.*, 1983). PCBs and chlordane compounds were not included in many of the earlier analyses, but occurred at low levels where detected. Grier (1982) noted that PCB levels were still as high as 50 mg/kg (w.w.) in eggs from northwestern Ontario, but the significance of those concentrations in eagles is not known.

Mercury levels in some eggs were relatively high, up to 2.62 mg/kg (w.w.) in eggs from Northern Saskatchewan in 1970. These levels are greater than the values of 0.5 to 1.5 mg/kg associated with reduced hatchability in Mallards (Fimreite, 1971; Heinz, 1979). In all eggs from Ontario, mercury levels were less than 1.5 mg/kg (w.w.).

Levels of organochlorines in tissues of Bald Eagles shot or found dead in New Brunswick, Manitoba, and B.C. during the late 1960s were below concentrations considered indicative of acute poisoning (Mulhern *et al.*, 1970; Kaiser *et al.*, 1980). The significance of liver mercury levels up to 42 mg/kg (w.w.) in eagles collected in Northern Ontario is unknown, but concentrations of 20 mg/kg in livers of Red-tailed Hawks were considered lethal by Fimreite and Karstad (1971). In Grey Herons, 50 mg/kg mercury in the liver was the lethal threshold (Van der Molen *et al.*, 1982).

Of 59 Bald Eagle blood samples analyzed for ALA-d 5 (8.5%) were indicative of lead poisoning, and a further 7 (11.8%) were indicative of significant lead exposure (Elliott *et al.*, 1992).

7.10.3 Temporal trends

Grier (1982), using some of the data here, reported significantly lower residues of DDE in Bald Eagle eggs from northwestern Ontario in the time period after the 1972 ban on DDT than before it. Levels of PCBs and dieldrin remained relatively high, whereas levels of mercury were low throughout the study period. Figure 12 illustrates the changes in levels of DDE, dieldrin, and heptachlor epoxide in eggs collected from Northern Ontario.

Declines in contaminant levels have been reported elsewhere. Residues of DDE, dieldrin, and PCBs in eggs of Bald Eagles breeding along Great Lakes shorelines between 1977 and 1986 were substantially lower than those reported in the late 1960s, but showed no distinct downward trend during that period (International Joint Commission, 1989).

Henny and co-workers (1981) reported low levels of DDT metabolites in blood plasma of Bald Eagles wintering in Colorado and Missouri in 1977-78, as compared to other raptors. By converting the blood levels to egg levels using the Henny and Meeker (1981) equation, they suggested that egg residues would be about 0.7 mg/kg DDE in these birds. Since the midwestern U.S.A. is probably the wintering area of most of the Saskatchewan breeding population (Gerrard *et al.*, 1978), those data suggest a decline in DDE in eggs from Saskatchewan since 1968-1970, when DDE in eggs averaged about 4.0 mg/kg.

7.10.4 Status and conclusions

The Bald Eagle is known to have declined over much of its North American range since the 1940s. Currently, continental populations in the U.S.A. and much of eastern Canada appear to be reduced, whereas populations in the northern boreal forests, coastal B.C., and Alaska are stable (Brownell and Oldham, 1980). Most of the declines are attributed to lower rates of reproduction associated with eggshell thinning from DDE contamination (Wiemeyer *et al.*, 1984). Vermeer *et al.* (1989) suggested that Bald Eagle populations in the Strait of Georgia may be increasing in conjunction with increases in populations of an increasingly important prey item, the Glaucous-winged Gull, *Larus glaucescens*.

Bald Eagle populations have been characterized as stable if at least 0.7 young per active nest are fledged each year (Sprunt *et al.*, 1973). In the U.S.A., extremely low productivity and declines in numbers were documented in the northeastern states, Florida, and near the shores of the Great Lakes (Sprunt *et al.*, 1973; International Joint Commission, 1989).

In Canada, declines in numbers and in reproductive success were reported in only a few subpopulations, mainly in Ontario (Postupalsky, 1971; Grier, 1974; International Joint Commission, 1989). The number of pairs breeding along the Great Lakes in southern Ontario was drastically reduced to fewer than 20 by the late 1960s, and most of these were not producing young (Brownell and Oldham, 1980).

There is no evidence that any other Canadian populations were ever in serious trouble. Stocek and Pearce (1978) reported that its status in New Brunswick in the early 1970s appeared to be stable. The largest subpopulation, in Saskatchewan, estimated to be 14,000 birds in the late 1970s, was reported to have good productivity (i.e. between 0.95 to 1.25 young per occupied nest) (Gerrard *et al.*, 1978). The population along the coast of British Columbia was also considered stable with normal productivity (Brownell and Oldham, 1980).

By the early 1980s, productivity in Bald Eagles in northwestern Ontario had greatly improved, in accordance with lower DDE levels in eggs (Grier, 1982). The number of pairs breeding along the shores of the lower Great Lakes has also increased, although productivity remains low (International Joint Commission, 1989). The increase in breeding pairs has been attributed mainly to recruitment from healthy inland populations in Wisconsin and Michigan, and to foster programs operating in the U.S.A. and Canada (International Joint Commission, 1989).

Lead poisoning of Bald Eagles in the U.S.A. due to ingestion of injured waterfowl containing lead pellets has been reported (Pattee, 1984). Frenzel and Anthony (1989) reported that at least one eagle wintering in California died of lead poisoning, and that lead levels were elevated in many of the waterfowl and voles on which eagles were feeding. Research is currently in progress to determine whether any eagles in B.C. are suffering from lead poisoning.

Other causes of mortality include illegal shooting, trapping, poison baits for coyotes, electrocution, and avian cholera (Brownell and Oldham, 1980). As

Bald Eagles are faithful to their nest site and reluctant to start new nests, habitat destruction and human disturbance in the breeding areas have also affected productivity.

We lack reliable data on levels of environmental contaminants since the early 1970s over most of Canada, as well as more detailed information on such population parameters as annual productivity and annual survivorship. The continuing high levels of DDE, PCBs, and dieldrin found in eggs from nests along the Great Lakes, and the slow recovery of this population are cause for concern. Predation on Herring Gulls, which may be highly contaminated, is considered to be a likely source of current contamination.

7.11 Golden Eagle *Aquila chrysaetos*

The Golden Eagle was resident over most of Canada, but is now restricted mainly to the Yukon, Northwest Territories, B.C., Alberta, Saskatchewan, Manitoba, Northern Ontario, and Quebec (Godfrey, 1986).

Rarely seen, this species prefers mountainous terrain, with cliffs for nesting. Outside the breeding season, individuals wander widely within the breeding range of the species. Their diet consists primarily of mammals, including ground squirrels, jackrabbits, and young deer or lambs (Marquiss *et al*, 1986). Boag (1977) reported 80% mammals (almost entirely ground squirrels) in the diet of eagles in southern Alberta , with grouse, partridge, other birds, and carrion making up the remainder.

7.11.1 Analyses

Twenty-two fresh or addled eggs were collected from sites in Saskatchewan, Alberta, and the Yukon between 1968 and 1975 for organochlorine and mercury analyses. Livers and brains of two nestlings found dead in the Mackenzie River area of the N.W.T. in 1973 were also analyzed for organochlorine content.

7.11.2 Levels and toxic effects

Organochlorines in Golden Eagle eggs from western Canada in the early 1970s were generally low (Table 5). The DDE concentrations in eggs were less than 3.0 mg/kg, below levels associated with significant eggshell thinning or reduced productivity in any raptors.

Heptachlor epoxide levels were all less than 0.9 mg/kg, below the critical concentration determined for American kestrels (Henny *et al.*, 1983).

Dieldrin in one egg from Alberta in 1973 was 2.12 mg/kg (w.w.), higher than the 0.9 mg/kg value considered by Lockie *et al.* (1969) to reduce hatchability of Golden Eagle eggs in Scotland. Dieldrin in the other eggs was 0.6 mg/kg or lower.

The highest detected mercury concentration in the eggs was 0.34 mg/kg (w.w.), a level unlikely to have any effect on reproductive performance.

Organochlorine residues in tissues of two nestlings in the Mackenzie River area were very low, as expected. Nevertheless, there have been recent incidents of poisoning in this species. Henny *et al.* (1984) reported three deaths of Golden Eagles in Oregon, 1977 to 1980, due to elevated (greater than 8.0 mg/kg) brain residues of heptachlor epoxide. The symptoms (convulsions, muscle rigour) of these three individuals were consistent with pesticide poisoning.

7.11.3 Status and conclusions

The population status of the Golden Eagle in Canada is not well known. Heintzelman (1986) noted that the numbers migrating through Hawk Mountain, Pennsylvania, had declined between the early 1960s and the 1980s. Numbers in Canada were considered stable by Fyfe (1976), and sightings in Ontario in the 1980s were much more frequent than between 1950 and 1960 (Cadman *et al.*, 1987). Although never common, its breeding range has been reduced over the past century, as loss of habitat, illegal shooting and poisoned baits continue to take their toll.

The diet of Golden Eagles consists of mammals and resident gamebirds and the exposure to organochlorines is probably low. However, in Scotland, where Golden Eagles now feed extensively on seabirds instead of the extirpated arctic hare, the eagles have high contaminant burdens and reduced breeding success (Furness *et al.*, 1989).

Eagles require immense territories with a plentiful supply of food. They are greatly affected by changes in habitat and corresponding changes in food supply. Rodenticides, current insecticides used on livestock, and herbicides may have more impact on the productivity of Golden Eagles than organochlorines. This impact might not be direct, but through the reduction of the numbers of prey species. In North America, strychnine and other poisons used to control coyotes are also significant causes of mortality to both Bald and Golden Eagles.

7.12 Osprey *Pandion haliaetus*

In Canada, the Osprey breeds from coast to coast south of the treeline. Ospreys are highly migratory, with a wintering range that extends from the southern U.S.A. to Northern Argentina and Peru. (Godfrey, 1986).

Ospreys are always found in the vicinity of large bodies of water (lakes, rivers and coastal bays). This species is almost entirely piscivorous, feeding on a wide variety of species including salmon, whitefish, trout, suckers, chub, smelt, surfperch, herring, shad, bullheads, and others (Sherrod, 1978). On the Great Lakes, the diet is mainly crappies, blue-gills, perch and bass (Palmer, 1988) Small mammals and birds are occasionally taken.

7.12.1 Analyses

Seventeen Osprey eggs, both addled or fresh, were collected from Ontario, Newfoundland, Alberta, B.C., and the Yukon Territory between 1969 and 1975. The brain and liver of an adult shot in southern Ontario in April, 1969, and the brain, liver and muscle of a nestling which died in a nest near Lake of the Woods in 1971 were also analyzed for organochlorines and mercury.

7.12.2 Levels and toxic effects

Ospreys are relatively sensitive to DDE-induced eggshell thinning. Wiemeyer and co-workers (1988) found that 10% eggshell thinning was associated with DDE levels of 2.0 mg/kg, 15% thinning was associated with 4.2 mg/kg DDE and 20% thinning was associated with 8.7 mg/kg DDE. Productivity was also found to be negatively correlated with DDE levels. A value of 4.0 mg/kg DDE was associated with the production of 0.8 young per nest, the minimum required to maintain population stability (Wiemeyer *et al.*, 1988).

Therefore, Osprey eggs with more than 4.0 mg/kg DDE are likely to be more than 15% thinner than normal, and have lower hatching success. This is consistent with findings from other studies. Ten percent eggshell thinning documented in Maryland Ospreys appeared to have little effect on productivity, whereas 18% eggshell thinning reduced productivity in a Connecticut population (Wiemeyer *et al.*, 1978).

Eleven (65%) of the eggs collected by CWS contained DDE residues in excess of 4.0 mg/kg. Two eggs contained more than 12 mg/kg DDE. A previous study by Wiemeyer and co-workers (1975) found that no eggs hatched in nests where a sampled egg contained more than 12 mg/kg DDE.

Dieldrin and heptachlor levels were low in all eggs, well below levels associated with detrimental effects in Ospreys (Wiemeyer *et al.*, 1975) and other raptors (Lockie *et al.*, 1969; Henny *et al.*, 1983). Wiemeyer *et al.* (1975) noted that no Osprey eggs hatched in nests where sampled eggs contained more than 1.0 mg/kg dieldrin. There is no evidence of reproductive effects attributable to any of the other organochlorines (Wiemeyer *et al.*, 1988).

Mercury residues greater than 0.5 mg/kg in two eggs from the Yukon may have had some effect on viability, based on Fimreite's (1971) studies with pheasants.

Organochlorine levels in the brains of the shot adult and dead nestling were well below lethal values established in other studies (Stickel *et al.*, 1969; Stickel *et al.*, 1984). There was no evidence of elevated mercury residues. Although the liver of one specimen was found to contain 3.1 mg/kg of mercury, this is well below the critical values established in other studies (Fimreite and Karstad, 1971; Finley *et al.*, 1979; Scheuhammer, 1988).

Recently there have been no obvious cases of poisoning in the U.S.A.

Wiemeyer *et al.* (1987) concluded that none of 23 Ospreys found dead or moribund in the eastern U.S.A. between 1975 and 1982 appeared to have died of organochlorine poisoning. One individual did have 220 mg/kg of PCBs in its brain, and several individuals had elevated mercury concentrations in their livers.

7.12.3 Geographical comparisons

Levels of organochlorine residues in eggs of Canadian Ospreys in the early 1970s (Table 5) were within the ranges of levels detected in Ospreys from the Atlantic coastal states about the same time (Wiemeyer *et al.*, 1975; Wiemeyer *et al.*, 1978).

Postupalsky (1972) investigated the breeding success of Ospreys near Thunder Bay, Ontario, in the late 1960s and considered the productivity insufficient to maintain a stable population. Eggshells of two eggs were 11 and 16% thinner than prior to 1947, and contained DDE concentrations of 2.7 and 6.7 mg/kg, respectively.

7.12.4 Status and conclusions

Levels of DDE in eggs of Ospreys from several areas of Canada were high enough to cause significant eggshell thinning and reduce productivity. None of the other contaminants occurred at levels high enough to affect reproductive success.

Osprey numbers in the eastern U.S.A. were seriously reduced in the early 1960s (Ames, 1966; Henny, 1972; Spitzer *et al.*, 1977). This was attributed mainly to organochlorine contaminants and DDE-induced eggshell thinning. In a review of population trends of Ospreys in the mid-Atlantic states, Henny *et al.* (1977) noted that productivity had increased substantially since the early 1960s, although populations were still reduced. They also noted that distribution of Ospreys had changed considerably, partly due to their preference for man-made nest-sites.

Despite the declines reported in the 1960s in the U.S.A., numbers of Ospreys in Canada appear to have remained stable (Fyfe, 1976, Prevost *et al.*, 1978). In eastern Canada, populations appear to be flourishing. Fleming (personal communication) notes that productivity in Nova Scotia has increased significantly since the early 1970s.

Although Canadian Osprey populations do not appear to be adversely affected by environmental contaminants, some individuals may be exposed to persistent contaminants in fish from contaminated watersheds such as the St. Lawrence River, or on their wintering grounds in Latin America. The increasing use of mercury for gold mining in the Amazon River basin, the wintering area of many Canadian birds, is another potential hazard (Mallas and Benedicto, 1986).

Virtually nothing has been published recently on the status of the Ospreys breeding in Northern Ontario, or in any part of Canada. Considering previous declines, a review of its current status over all of its Canadian breeding range, and surveys of current levels of environmental contaminants in eggs and tissues seems warranted.

7.13 Northern Harrier *Circus cyaneus*

The Northern Harrier breeds south of the treeline in Canada from the Rocky Mountains to eastern Nova Scotia. Its wintering range extends from southern Canada to the West Indies (Godfrey, 1986).

Harriers prefer open areas (fields, fresh and saltwater marshes) where they have a variety of prey. Mammals, mainly voles, bog lemmings, ground squirrels, and young rabbits, comprise about 50% of their diet (Sherrod, 1978). Avian prey (about 30% of the diet) includes mainly songbirds (meadowlarks, blackbirds, sparrows), gallinaceous birds, small ducks, and even bitterns (Sherrod, 1978). Insects, crayfish, frogs, and snakes account for the remainder.

7.13.1 Analyses

Twenty-two fresh and addled Northern Harrier eggs were collected from the southern parts of the Prairie provinces between 1967 and 1969, and one addled egg was obtained from Northern Quebec in 1969. Brain and liver tissue from three birds from Saskatchewan, and the brain and breast muscle of a specimen from B.C., all collected in 1968, were analyzed for DDT compounds, heptachlor epoxide, dieldrin, and mercury. Blood samples were obtained from two hatching year females at Hawk Cliff, Ontario during fall migration in 1986.

7.13.2 Levels and toxic effects

Levels of organochlorines in most eggs (Table 5) were below values associated with adverse reproductive effects in other raptors (Newton, 1979). However, one egg contained 1.5 mg/kg heptachlor epoxide, and three eggs contained dieldrin residues in excess of 1.0 mg/kg. Those concentrations, particularly as represented by one egg with dieldrin levels greater than 5.0 mg/kg, may have reduced reproductive success (Wiemeyer *et al.*, 1975; Henny *et al.*, 1983).

Four eggs contained more than 10 mg/kg DDE. Two of these contained residues greater than 15 mg/kg (w.w.). Studies on the Harrier, *C. aeruginosus*, in Sweden found that DDE egg levels were significantly negatively correlated with eggshell thickness and productivity (Odsjo and Sondell, 1977). In these Swedish birds the eggshell thickness averaged 14% thinner than pre-1947 eggs. Average levels of total DDT and PCBs were higher in nests with lower breeding success (0 to 2 young versus 3 to 5 young). Unfortunately, the values of total DDT and PCBs cannot be determined from that publication, but appear to range between 10 and 5000 mg/kg in extractable fat (about 0.5 to 250 mg/kg (w.w.).

Hamerstrom (1986) noted that male Northern Harriers in Wisconsin performed fewer courtship displays, that nesting behaviour was desultory and that few eggs were laid during the era of intense pesticide spraying in the 1960s. Individuals exhibiting aberrant behaviour were found to have elevated levels of DDE in their fat. However, partly because so few eggs were laid by contaminated individuals, there was little evidence of serious eggshell thinning (Hamerstrom, 1986).

Hardly any organochlorine contaminants were detected in the two blood samples. Only DDE was detectable in both, at a mean level of 0.019 mg/kg (w.w.).

Mercury concentrations were low in eggs and livers, and were unlikely to have affected breeding success. Similar mercury levels of less than 0.2 mg/kg (w.w.) appeared to have no effect on productivity in the related Harrier in Sweden (Odsjo and Sondell, 1977).

7.13.3 Status and conclusions

Although a few Northern Harrier eggs contained DDE levels high enough to affect productivity in some raptors (Wiemeyer *et al.*, 1975; Fyfe *et al.*, 1976a; Newton, 1979), most contaminants were below levels associated with adverse effects. There is little evidence that this genus is subject to eggshell thinning, although overall productivity may be affected. Reduced productivity may also occur because of contaminant-induced changes in behaviour, as suggested by Hamerstrom (1986), although there has been no evidence of this in Canada.

The diet of the Northern Harrier during migration may include both migratory songbirds and waterfowl. Therefore, some individuals may accumulate significant contaminant burdens.

Although few data are available, the status of this species appears to have been stable in Canada since the 1970s (Fyfe, 1976). Its status in North America overall has not been established. Robbins *et al.* (1986) and Evans (1982) reported declines in numbers of breeding birds, attributed mainly to marsh drainage, but Heintzelman (1986) reported no changes in numbers of Northern Harriers migrating through Hawk Mountain from the early 1960s to the 1980s. However, interpretation of trends are complicated by the dependence of its reproductive success on the density of its main prey, the vole, which leads to cyclic fluctuations in the productivity of Northern Harriers (Duncan, 1986).

No eggs of this species have been analyzed for organochlorines since 1969, and our data includes only one egg east of the Prairies. In view of their association with aquatic systems, a survey of current contaminant levels in eggs of this species, particularly those in contaminated watersheds, seems warranted.

7.14 Merlin *Falco columbarius*

The breeding distribution of the Merlin extends from Alaska to Labrador, and from the treeline south to the Northern U.S.A. (DeSmet, 1982). Three subspecies occur in Canada: the Black Merlin *F.c. suckleyi* in the Pacific coastal rainforests; Richardson's Merlin *F.c. richardsonii* in the arid prairie region of southern Alberta, Saskatchewan, and Manitoba; and the Taiga Merlin *F.c. columbarius* which breeds in the boreal forest region from the Atlantic coast to the Rocky Mountains and in Alaska (Palmer, 1988). Basically a tree-nester, this species often uses abandoned corvid nests, particularly in urban areas, but will also nest in tree cavities or on the ground.

Of the three subspecies, only the Taiga Merlin is highly migratory. The wintering range of that subspecies extends from the southern U.S.A. to Northern Peru and Venezuela (DeSmet, 1982). The Black Merlin may winter as far south as California, and some individuals of the Richardson's Merlin migrate as far south as New Mexico and Texas.

Birds are the principle component of the diet of Merlins, although insects and small mammals are also taken (Sherrod, 1978; Palmer, 1988). Diets of the subspecies reflect the availability of small to medium-sized flocking species of bird in their region. In the Prairies, the Richardson's Merlin preys mainly on larks, longspurs, sparrows, and other ground-nesting birds during the breeding season (Fox, 1964; Hodson, 1978). House Sparrows *Passer domesticus*, Bohemian Waxwings *Bombycilla garrulus*, and Horned Larks *Eremophila alpestris*, were the preferred prey of city Merlins in the western Provinces (Palmer, 1988).

Temple (1972) found Gray Jays *Perisoreus canadensis*, robins and sparrows to be the main prey of the Taiga Merlin in Newfoundland. Migrating shorebirds are often taken during migration and on the wintering grounds (Page and Whitacre, 1975).

7.14.1 Analyses

A large number of eggs were collected, most as part of an investigation of the effects of organochlorines on reproductive behaviour and nesting success in the Richardson's Merlin (Fyfe *et al.*, 1976a; Fox and Donald, 1980).

Viable (fresh or developed) and nonviable (addled or with dead embryos) Richardson's Merlin eggs were collected from southern Alberta and Saskatchewan every year between 1968 and 1978, and analyzed for organochlorine and mercury content. In 1988, fresh Merlin eggs were collected from 14 nest-sites in Saskatchewan, and analyzed individually for organochlorine content.

Eggs of the Taiga Merlin were collected from Northern Quebec in 1969, and from the Yukon and the Northwest Territories in 1973. Only one addled egg of the Black Merlin, collected at Pine Lake, British Columbia in 1969, was ever analyzed.

Tissues analyzed for organochlorine and mercury content include whole bodies, livers, or brains from a total of eight nestlings found dead in Alberta between 1969 and 1976 and the brain of an adult collected on Weston Island, B.C., in 1968. Blood samples were obtained from three autumn migrants in 1986-1988 at Hawk Cliff in southern Ontario and four spring migrants at Whitefish Point, Michigan.

7.14.2 Levels and toxic effects

Eggs of Merlins collected in Canada between 1968 and 1978, inclusive, contained relatively high levels of DDE, DDT, dieldrin, heptachlor epoxide, HCB and oxychlordane (Table 6).

Many of the Merlin eggs collected in Canada contained DDE residues exceeding the critical value of 5.0 mg/kg for eggshell thinning and reduced productivity (Fyfe *et al.*, 1976b; Fox, 1979; Fyfe *et al.*, 1988). The negative correlation between DDE residues in the eggs and eggshell thickness has been well established in this species (Fox, 1979; Fyfe *et al.*, 1988). Fox (1979) calculated a threshold level of 2.5 mg/kg DDE to affect eggshell thickness. Fyfe *et al.* (1988) concluded that Merlins were adversely affected by eggshell thinning of more than 15%, associated with DDE concentrations of about 5.0 mg/kg. Eggshell thinning of 20% corresponded to about 11 mg/kg DDE, and was associated with complete reproductive failure. These estimates are consistent with data on eggshell thinning and DDE residues in Merlin eggs from outside the Prairie provinces. Temple (1972) found only 11% thinning (compared to pre- 1947 values) in Merlin eggs from Newfoundland in 1969, where the DDE content averaged 6.4 mg/kg (w.w.).

In Britain, Newton *et al.* (1978) reported that the shell thicknesses of unhatched Merlin eggs collected between 1973 and 1975 were 22% thinner than those of eggs collected prior to 1947. DDE in the more recent eggs averaged 8 mg/kg. In Newton and co-workers' (1978) study, egg-breakage occurred in about 10% of the nests studied.

DDE egg residues greater than 6.0 mg/kg (w.w.) were associated with decreased productivity of this species in the Canadian prairies during the early 1970s (Fyfe *et al.*, 1976b). Where DDE in eggs exceeded 8.0 mg/kg (w.w.) adults exhibited aberrant behaviour, such as frequent nest desertions, and weak territorial defence (Fyfe *et al.*, 1976b; Fox and Donald, 1980).

Although the effects of dieldrin and heptachlor epoxide on Merlins have not been investigated, dieldrin levels greater than 1.0 mg/kg, and heptachlor epoxide levels greater than 1.5 mg/kg (all wet weights) have been associated with reduced hatchability in other raptors (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975; Henny *et al.*, 1983). In eggs of Richardson's Merlin from southern Alberta, dieldrin concentrations exceeded 1.0 mg/kg in about 5% of the eggs (n = 26). Dieldrin concentrations reached 5.6 mg/kg in one egg.

Heptachlor epoxide in eggs exceeded 1.5 mg/kg in about 8% (n = 35) of the eggs, up to a maximum value of 9.1 mg/kg. About one fifth of the eggs collected in the Prairies exceeded this value. Some adult mortality may occur. An adult originally banded in Alberta was found dead of apparent heptachlor poisoning after migration to New Mexico (Henny *et al.*, 1976).

Mercury levels in Merlins were all less than 1.5 mg/kg, and usually less than 0.5 mg/kg. There may have been some detrimental effects in eggs containing more than 0.5 mg/kg mercury, based on studies with pheasants (Fimreite, 1971).

The single egg of a Black Merlin from B.C. contained no organochlorines at levels high enough to be associated with reduced hatchability or eggshell thinning. In five eggs of the Taiga Merlin collected between 1969 and 1975, DDE was greater than 10 mg/kg in all eggs, dieldrin was above 1.0 mg/kg in 50% of them, and other organochlorine concentrations were relatively low.

7.14.3 Temporal trends

Although both DDE and heptachlor epoxide residues increased significantly between the late 1960s and the 1970s, dieldrin exhibited no significant trend (Table 11). By the 1980s, DDE and dieldrin had declined significantly, while heptachlor epoxide showed no significant trend. Figure 11 illustrates the changes in residue levels of these three compounds in eggs of Merlins collected from the Prairies.

There was some evidence of improvement in the proportion of eggs contaminated with dieldrin. Dieldrin residues exceeded 1.0 mg/kg in 17% of the eggs collected between 1965 and 1972, in 12% of the eggs collected between 1973 and 1979, but in none of the 14 eggs collected in 1988. There was, however, no evidence of any change in contamination by heptachlor epoxide. Heptachlor epoxide residues exceeded 1.5 mg/kg in 17% of the eggs of Merlins from the Prairies during the period 1965-1972, in 12% of the eggs collected between 1973 and 1979, and in 21% of the eggs collected in 1988.

In the Prairies, about 40% of the Merlin eggs collected between 1969 and 1978 contained DDE in excess of 15 mg/kg, and 50.2% of the eggs contained DDE in excess of 7.0 mg/kg. By 1988, 36% of the eggs had DDE residues greater than 7.0 mg/kg, with a maximum value was 65.8 mg/kg. There seems to be no temporal trend in the proportion of eggs with elevated residues of DDE.

7.14.4 Status and conclusions

Merlin populations in eastern North America are generally considered to have declined during the 1950s and 1960s (Fox, 1971; Fyfe, 1976; DeSmet, 1982; Heintzelman, 1986).

Some Canadian populations, however, appeared to be recovering by the mid-1970s (DeSmet, 1982). In Saskatchewan, numbers of Richardson's Merlin have increased over the past decade, mainly due to the increase in the number of breeding attempts in urban centres (Oliphant and Thompson, 1978). This was attributed to the loss of suitable habitat elsewhere. The declines prior to the 1970s were concurrent with reports of reduced productivity (Temple, 1972), but recent studies in the Prairies report higher productivity (DeSmet, 1982).

Based on the data in this report, DDE and other organochlorine levels were still high enough in the mid-1970s to reduce reproductive success (by eggshell thinning, embryotoxic effects, or by affecting parental behaviour) in individuals. It is possible that the relatively high fecundity of this species has allowed the populations to recover. Nevertheless, as this species preys to a large extent on migratory birds, contaminants originating in Latin America may be a problem. Contamination in the USA may still be a problem.

7.15 Prairie Falcon *Falco mexicanus*

In Canada, the breeding range of the Prairie Falcon is restricted to arid open areas in southern Saskatchewan, Alberta, and B.C. (Godfrey, 1986). Although basically a resident species, some individuals, particularly first year birds, may winter in winter-wheat areas of the Northern U.S.A. (Woodsworth and Freemark, 1979).

Prairie Falcons require open habitat for hunting, as most prey are taken from the ground, and suitable cliffs or river banks for nesting. During the breeding season, a variety of mammalian and avian prey are taken. In Idaho, the principle prey was ground squirrels (Newton, 1979), but gophers, pikas, voles, cottontails, doves, Killdeer, meadowlarks, Horned Larks and other passerines are also taken (Sherrod, 1978). During the winter, Horned Larks are preferred prey, and some Prairie Falcons will follow movements of this species until the next breeding season.

Adults arrive at the breeding sites in early spring, establish their territories, and start incubation of the four to six eggs in about a month (Woodsworth and Freemark, 1979). In areas of plentiful prey, Prairie Falcons will nest quite densely, with several pairs occupying the same cliff-face.

7.15.1 Analyses

Over four hundred fresh, developed, addled, or infertile eggs were collected from nests mainly in southern Alberta (1967 to 1980) and southern Saskatchewan (1967 to 1978). All eggs were analyzed for organochlorine content and most for mercury. In 1988, another 14 fresh eggs were collected from sites in Alberta.

These were analyzed for organochlorine content by combining portions of eggs to obtain one pool of nine and one pool of five eggs. Only four of the fourteen eggs were analyzed individually.

Tissues of adult Prairie Falcons analyzed include: 1) the brain, liver, and fat from an Albertan specimen in 1973; 2) five tissues of a breeding female found dead in 1969; and 3) the brains and livers of an adult female poisoned by strychnine in 1975, another two females found dead in 1975 and in 1977, and an adult male found drowned in 1976.

Tissues of nestlings analyzed include: 1) the brain and liver of a nestling collected in May, 1969; 2) the whole body of a three-day old nestling found dead in 1971; 3) the brain, liver, muscle, and fat of three 4-week old nestlings found dead in 1972; and 4) the brain, livers and fat of seven one- week-old nestlings found dead in 1976.

Some data on contaminant levels in Prairie Falcon eggs from 1967 to 1972 inclusive were previously reported in Fyfe *et al.* (1969), Keith and Gruchy (1972), and Fyfe *et al.* (1976a).

7.15.2 Levels and toxic effects

Levels of most organochlorines were relatively low in Prairie Falcons compared to Peregrine Falcons or Merlins.

Between 1967 and 1980, the geometric mean of DDE in eggs was 1.72 mg/kg (w.w.), but levels in individual eggs ranged from less than 0.10 mg/kg to over 40 mg/kg. By 1988, levels in all eggs appeared to be very low. DDE residues in the two pools were 0.06 and 0.04 mg/kg, respectively (Table 6). The most contaminated egg analyzed separately contained only 0.24 mg/kg DDE.

Prairie Falcons are very sensitive to DDE-induced eggshell thinning. In a detailed examination of the relationships between DDE, eggshell thickness, and productivity in the genus *Falco*, Fyfe *et al.* (1988) confirmed the inverse relationship between eggshell thickness and DDE residues in eggs reported in earlier studies (Enderson and Berger, 1970; Enderson and Wrege, 1973). Fyfe and co-workers (1988) determined that the threshold effect level of eggshell thinning on productivity was 8%, and that productivity was reduced to almost nothing when eggshell thinning reached 14%. The corresponding concentrations of DDE in the eggs associated with that range of eggshell thinning were 1.2 mg/kg and 3.0 mg/kg (w.w.).

The determination of a critical range of DDE in eggs ranging from 1.2 to 3.0 mg/kg is consistent with earlier studies. Fyfe *et al.* (1976a) noted that productivity was decreased where DDE egg concentrations exceeded 2.0 mg/kg. Enderson and Berger (1970) found that both eggshell thickness and productivity were significantly reduced in birds with DDE content greater than 6.0 mg/kg. They also reported several cases of egg-breakage. Enderson and Wrege (1973) investigated DDE levels in wild falcons in Colorado and found 14% eggshell thinning where DDE averaged 5.7 mg/kg and 10% thinning where DDE averaged 3.1 mg/kg.

Dieldrin levels were relatively low, averaging 0.12 mg/kg (w.w.) between 1967 and 1980, and 0.002 mg/kg in 1988. Dieldrin residues greater than 1.0 mg/kg in eggs have been associated with reduced reproductive success in other raptors (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975). The proportions of eggs with dieldrin levels in excess of 1.0 mg/kg were 2.4%, 5.1%, and 0% in the time periods 1965-72, 1973-79, and 1980-88, respectively.

Prior to the 1980s, heptachlor epoxide levels averaged 0.24 mg/kg (w.w.), but ranged from nondetectable to 7.0 mg/kg. In 1988, heptachlor epoxide averaged 0.01 mg/kg. Heptachlor epoxide levels greater than 1.5 mg/kg have been associated with reduced breeding success in American Kestrels (Henny *et al.*, 1983). The proportions of eggs with heptachlor epoxide residues in excess of 1.5 mg/kg were 5.7%, 6.9%, and 0% for the periods 1965-72, 1973-79, and 1980-88, respectively. Fyfe *et al.* (1969) attributed the deaths of two nestlings to heptachlor epoxide, based on the finding of concentrations greater than 5 mg/kg in their brains.

There was no evidence that any of the other contaminants found in eggs were high enough to adversely affect reproductive success. PCBs attained a maximum value of 9.6 mg/kg, oxychlordane a concentration of 0.43 mg/kg, HCB a value of 1.42 mg/kg, and beta-HCH a value of 0.04 mg/kg.

Mercury concentrations in eggs ranged from nondetectable to 1.71 mg/kg (w.w.). The hatchability of pheasant eggs was found to be adversely affected by mercury levels between 0.5 and 1.5 mg/kg (Fimreite, 1971). Based on those findings, three percent of the Prairie Falcon eggs sampled contained hazardous concentrations of mercury.

7.15.3 Temporal trends

As there were no consistent differences between viable (fresh or developed) and nonviable (addled, infertile, or rotten) eggs, all egg samples were combined for the analyses of temporal trends.

Although DDE, dieldrin, and heptachlor epoxide residues fluctuated considerably among years, all three compounds generally declined between 1968 and 1988 (Table 6). DDE appeared to decrease most between 1968 and 1971, then rise to a new peak in 1975 before declining to very low levels in 1980 and 1988. In eggs from Alberta only, both viable and nonviable eggs showed the same pattern. Heptachlor epoxide showed a similar pattern of decline. Dieldrin, on the other hand, appears to have declined irregularly since 1968, except for a peak in 1980.

While as many as 80% of the eggs contained more than 2.0 mg/kg DDE in 1968, no eggs exceeded that amount in the 1980s. The percentage of eggs with DDE residues in excess of 7.0 mg/kg are 7.6%, 9.1%, and 0% for the periods 1965-72, 1973-79, and 1980-88, respectively.

7.15.4 Status and conclusions

The evidence for population declines is equivocal. Fyfe *et al.* (1969) documented a significant reduction in the occupancy of breeding territories during the 1960s. Productivity rates were lowest in nests containing the most contaminated eggs. Oliphant *et al.* (1976) disputed the validity of these declines, where only known territories were surveyed to determine changes in occupancy rates. By the mid 1970s, the Prairie Falcon population was considered stable or increasing in Alberta and Saskatchewan (Fyfe, 1976).

Although DDE-induced eggshell thinning lowered reproductive success in the past, none of the most recently sampled eggs (1988) contained DDE, heptachlor epoxide, or mercury at levels associated with serious adverse effects. The other organochlorines were never detected at critical concentrations.

Further surveys of population numbers and productivity would be useful in confirming the stability of Prairie Falcon populations. It seems likely that loss of habitat due to agricultural encroachment is currently a more serious threat to Prairie Falcons than organochlorine pesticides.

7.16 Gyrfalcon *Falco rusticolus*

The Gyrfalcon breeds in the Canadian arctic--the Yukon Territory, the Northwest Territories, and Ungava Bay in Northern Quebec. Primarily a cliff-nester, this species occurs in low densities in suitable arctic habitat. Although basically resident, northern birds wander irregularly southward outside the breeding season (Godfrey, 1986).

Resident species of birds and mammals comprise the majority of Gyrfalcon prey (Sherrod, 1978; Palmer, 1988), but individuals vary widely in prey selection. The most important species are probably Willow and Rock Ptarmigan, ground squirrels, microtine rodents, and small passerines. On Ellesmere Island, Gyrfalcons specialize on arctic hare. Waterfowl and shorebirds are taken where available, as are seabirds near seabird colonies (Martin, 1978).

7.16.1 Analyses

The seventeen eggs collected for organochlorine and mercury analyses include one from Cape Dorset in 1969, nine from the Yukon between 1973 and 1975, one near Inuvik in 1974, and six from the central arctic/western Hudson Bay region between 1980 and 1983.

Two nestlings found dead in the Northwest Territories in 1973, and four tissues from a bird of unknown age collected in B.C. in 1971 were analyzed for organochlorines, the latter also for mercury.

7.16.2 Levels and toxic effects

DDE levels in Gyrfalcon eggs were extremely variable, ranging from less than 1.0 mg/kg in all eggs from the Yukon, to over 9 mg/kg (w.w.) in the egg from Cape Dorset. Cade *et al.* (1971) found no eggshell thinning in Gyrfalcons from Alaska, where DDE egg levels averaged 3.9 mg/kg, and ranged from nondetectable to 20 mg/kg (w.w.). There been no reports of eggshell thinning, egg breakage, or behavioural effects of DDE in this species.

The dieldrin concentration of 1.34 mg/kg in an addled egg collected in 1981 was the only other organochlorine contaminant detected at a level associated with reproductive effects in other raptors (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975).

Mercury concentrations exceeded the critical value of 1.0 mg/kg (w.w.) in two (20%) of the eggs analyzed for mercury. Mercury in Gyrfalcon eggs in Sweden was considered to have been acquired from migratory waterbirds in the diet (Lindberg, 1984).

7.16.3 Temporal trends

Examination of egg contaminant data from several locations in the Northwest Territories between 1969 and 1983, revealed few distinct trends in contaminant levels (Figure 13). Only DDE and dieldrin appear to have declined. Analysis of variance revealed no significant differences in contamination among time periods (Table 11), probably because DDE and most organochlorines ranging irregularly over several orders of magnitude, and sample sizes were usually very small.

7.16.4 Status and conclusions

It is difficult to determine population trends for Gyrfalcons. They tend to breed at low densities in remote locations, and are not particularly tenacious to the nest site (Martin, 1978). According to Barichello and Mossop (1983), numbers of breeding pairs in the Yukon vary in accordance with their main prey, the Willow Ptarmigan, *Lagopus lagopus*. In other areas, where arctic hare or lemmings are the main prey, the productivity of Gyrfalcons depends on the abundance of those species.

There are no indications of declining numbers of Gyrfalcons in Canada. Bromley (1986) noted that recent surveys had revealed more eyries than previously known, and that productivity rates appeared normal throughout the species' range. Occupancy rates of eyries in the eastern Northwest Territories showed no consistent trend between 1957 and 1969 (Kuyt, 1980).

Kuyt (1980) and Calef and Heard (1979) noted that Gyrfalcons arrived at nest sites along the Thelon River and Wager Bay, respectively, as early as January, and bred earlier than other raptors. Egg laying therefore occurs long before the arrival of migratory birds, so few contaminants are transferred to the eggs. Although the data presented here are quite variable, most eggs contained low levels of contaminants.

Organochlorine contaminants in nestlings were also low and do not suggest significant accumulation over the season.

7.17 American Kestrel *Falco sparverius*

The range of the American Kestrel (or Sparrowhawk) in Canada extends from coast to coast, north to the Yukon in the west and southern Newfoundland in the east (Godfrey, 1986). It prefers open country (fields, meadows, woodland openings) often associated with agricultural lands. Canadian birds probably winter in the southern U.S.A.

The diet consists mainly of invertebrates (grasshoppers, beetles, and crickets), small mammals (voles and mice), and small birds (sparrows, cowbirds) (Sherrod, 1978). In Ontario, Young and Blome (1975) found the diet to consist of 3% mammals, 20% birds, and 76% invertebrates. In New York, Lincer and Sherburne (1974) reported Microtus in 70%, sparrows in 30%, and insects in 80% of the samples.

7.17.1 Analyses

Nine eggs were collected for analysis of organochlorine and mercury content during the late 1960s: one from New Brunswick in 1967, five from Saskatchewan in 1967, and three from Alberta in 1968. In 1987, 31 eggs were collected from three locations in Ontario. These were analyzed in three pools (of seventeen, nine and five eggs). In 1988, nineteen eggs were collected from two locations in Ontario, and analyzed in two pools. All recent samples were analyzed only for organochlorines.

The brains and livers of two Albertan specimens (a female shot in June, 1968, and a male shot in August, 1968) were also analyzed; brains for organochlorines and livers for mercury.

7.17.2 Levels and toxic effects

DDE residues in the egg from New Brunswick and in one addled egg from Alberta were found to exceed 10 mg/kg (w.w.). Of the five egg pools analyzed in 1987 and 1988, DDE exceeded 10 mg/kg in only one pooled sample, one of 17 eggs from southern Ontario (Table 6). This implies that about half of those eggs in the pool contained DDE residues in excess of 10 mg/kg.

DDE residues are known to cause eggshell thinning in American Kestrels (Porter and Wiemeyer, 1969). Lincer (1975) demonstrated that eggshell thickness was inversely related to the log of DDE concentrations. However, Kestrels appear to be less sensitive to DDE than other members of their genus. Fyfe *et al.* (1988) found that shell thickness of Kestrel eggs was unaltered by DDE residues less than 1.0 mg/kg, the highest threshold effect level within this genus. Moreover, DDE residues of 20 mg/kg in eggs were associated with only 14% eggshell thinning. DDE residues of 10 mg/kg were associated with 11% shell thinning (Fyfe *et al.*, 1988).

The degree of eggshell thinning that would significantly affect productivity has not been established in this species. Eggshell thinning was induced in experimentally-dosed birds by Wiemeyer and Porter (1970), who reported a greater incidence of egg-breakage and egg-eating in the dosed birds laying eggs with a mean of 10 mg/kg DDE.

Dieldrin in eggs exceeded 0.5 mg/kg in two addled eggs collected from Alberta: 0.8 mg/kg and 1.25 mg/kg, respectively. Dieldrin egg levels greater than 1.0 mg/kg have been associated with reduced viability in other raptors (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975). In the same two eggs, heptachlor epoxide levels were 1.35 mg/kg and 4.8 mg/kg. Henny *et al.* (1983) reported reduced hatchability and increased early nestling mortality in American Kestrels where heptachlor epoxide levels in eggs were greater than 1.5 mg/kg.

Means for the pooled samples from Ontario in 1987 and 1988 were low. None of the means for dieldrin exceeded 0.10 mg/kg, and none of those for heptachlor epoxide exceeded 0.12 mg/kg.

Mercury concentrations in all eggs were less than 0.25 mg/kg, below levels associated with reproductive effects in any avian species.

Contaminant levels in tissues of the two shot specimens were also low, well below known lethal concentrations.

7.17.3 Status and conclusions

There is little evidence that American Kestrels have ever been adversely affected by organochlorine pesticides in Canada or the U.S.A. Henny (1972) reported low productivity in American Kestrels and considered the recruitment rate insufficient to replace losses due to mortality. He also cited declines in migrants at hawk watching stations in Maryland since 1959. However, this species may fluctuate in numbers in relation to prey abundance. Heintzelman (1986) found numbers of migrating Kestrels at Hawk Mountain, Pennsylvania, to be cyclic. In Canada, populations were considered stable during the early 1970s by Fyfe (1976).

It appears unlikely that numbers of this abundant species are being seriously affected by organochlorine contaminants. However, some individuals in southern Ontario are laying eggs with levels greater than 10 mg/kg, and might be experiencing slightly reduced productivity. Certain individuals may be exposed to potentially lethal doses of heptachlor (recently used in the U.S.A.) or nonchlorinated pesticides because of their close association with agricultural land. Dicofol (an acaricide that used to be contaminated with up to 15% DDT compounds) has been used in southern Ontario orchards and may have affected the health of kestrels in those areas. Since kestrels are mainly insectivorous during the breeding season, they are generally at less risk through the food chain than larger falcons that are feeding on migratory birds.

7.18 Peregrine Falcon *Falco peregrinus*

Peregrine Falcons have a global distribution. The three races which occur in Canada have markedly different migratory habits (Palmer 1988) which affect their exposure to environmental contaminants. Peale's Peregrine, *Falco peregrinus pealei*, is nonmigratory and essentially maritime, breeding in the Queen Charlotte Islands of B.C., southern Alaska, and the Aleutian Islands. In contrast, the Arctic Peregrine, *Falco peregrinus tundrius*, is highly migratory. It breeds north of the treeline in Canada (including Baffin Island, Ungava Bay, the central Arctic coast, western Hudson Bay, and the interior barrens of the Northwest Territories), Alaska, and Greenland, and winters in southern Latin America. The American Peregrine, *Falco peregrinus anatum*, which breeds in forested areas of Canada and south to California and Mexico, is also migratory but tends to winter further north than the Arctic Peregrine.

Peregrines feed primarily on waterfowl, shorebirds, and passerines, although almost all species of birds and small mammals found in North America have been recorded in their diet (Palmer, 1988). The pealei race in B.C. specializes on small alcids, such as the Ancient Murrelet *Synthliboramphus antiquus* (Nelson and Myers, 1977) as well as terns, small sea ducks, and shorebirds (Baril *et al.*, 1989). The tundrius race in Alaska feeds to a large extent on passerines, ptarmigan and shorebirds (Cade, 1960). The diet of anatum is the most diverse, ranging from small woodland passerines to waterfowl (Baril *et al.*, 1989). The diet is likely to differ on the breeding grounds, during migration and in the wintering area.

7.18.1 Analyses

Twelve eggs of the pealei race from Langara Island, B.C., between 1965 and 1972, and another four were collected in 1986 were analyzed. Five analyses of eggs (including two pools of four and eight eggs each) from Ontario and Quebec were carried out between 1985 and 1987. Thirty-nine eggs of this subspecies from Alberta were analyzed between 1968 and 1987, as well as 19 eggs from the Yukon and 17 eggs from the Northwest Territories (Mackenzie River area) between 1969 and 1981.

Twenty-four eggs of the tundrius subspecies were collected in Northern Quebec between 1967 and 1986, and 44 eggs were collected from the Northwest Territories between 1966 and 1982.

Tissues of all three subspecies were sampled for organochlorines and mercury. Usually, more than one tissue of a specimen was analyzed. The total numbers of specimens is three of the pealei (1966 to 1969), seven of the anatum race (1967 to 1987), and 19 of the tundrius race (1966 to 1981).

7.18.2 Levels and toxic effects

Organochlorine residues in Peregrine eggs and tissues were extremely variable (Table 6).

DDE levels in eggs ranged from 0.6 mg/kg to 194 mg/kg (w.w.). Of the three races, anatum was generally the most contaminated, particularly in samples collected during the 1965 to 1972 period.

All experts agree that DDE causes eggshell thinning in falcons, including Peregrine Falcons. Peakall and co-workers (1975) suggested that DDE concentrations of 15 to 20 mg/kg in eggs were enough to cause significant (ie 20%) eggshell thinning and would lead to a population decline.

Based on studies on productivity and eggshell thinning in other raptors (Hickey and Anderson, 1968; Lincer, 1975; Newton, 1979), Ratcliffe (1980) concluded that although 20% eggshell thinning inevitably led to population declines in Peregrines, productivity could be maintained when eggshell thinning was between 6 and 10%. Peakall and Kiff (1988) presented data on the degree of eggshell thinning of 30 populations of Peregrines in relation to their status, and noted that virtually no populations exhibiting more than 17% eggshell thinning were stable.

Peakall and Kiff (1988) then reviewed the evidence for an inverse linear relationship between DDE residues in eggs of Peregrine Falcons and eggshell thickness. They confirmed the original assertion that 15 to 20 mg/kg DDE in eggs would cause a level of eggshell thinning (in this case 17%) leading to a population decline.

During the period 1965 to 1972, 42% of the pealei eggs, 83% of the anatum eggs, and 18% of the tundrius eggs contained DDE residues in excess of the critical value of 15 mg/kg.

By the period 1973 to 1979, only 29% of the eggs of the anatum race, but 50% of the tundrius race, contained elevated concentrations of DDE. During the 1980's, none of the pealei or tundrius eggs, and 23% of the anatum eggs contained DDE residues in excess of 15 mg/kg.

Overall, thirteen percent of the anatum eggs, 46% of the tundrius eggs, and none of the pealei eggs contained dieldrin at concentrations greater than the critical value of 1.0 mg/kg (but see Nisbet, 1988). Studies on American Kestrels by Wiemeyer *et al.* (1986) suggest that dieldrin levels greater than 4.0 mg/kg in eggs are associated with reduced viability. However, field studies on Golden Eagles (Lockie *et al.*, 1969) and Ospreys (Wiemeyer *et al.*, 1975) suggest that dieldrin levels in excess of 1.0 mg/kg in eggs may be hazardous.

One egg collected from the nest in the Mackenzie River area of the Northwest Territories contained more than 1.5 mg/kg of heptachlor epoxide, the critical level associated with reduced productivity in studies with American Kestrels (Henny *et al.*, 1983). Mercury in two eggs collected from eyries in the Queen Charlotte Islands in 1969 exceeded 1.5 mg/kg, which is well within the hazardous range of mercury levels in eggs suggested by Fimreite (1971) in work with Ring-necked Pheasants.

Although none of the levels of organochlorines found in tissues of Canadian Peregrines are indicative of acute pesticide poisoning, two individuals contained levels in the hazardous ranges. The most likely possibility of pesticide poisoning is an adult male tundrius found dead at Rankin Inlet in the Northwest Territories in 1982, with brain levels of 2.0 mg/kg dieldrin, 14 mg/kg DDE, 1.1

mg/kg oxychlordane, and 60 mg/kg PCBs. A three-year old female anatum shot in eastern Ontario in 1983 had accumulated 110 mg/kg PCBs, 30 mg/kg DDE, and 2.45 mg/kg dieldrin in her fat.

Nisbet (1988) reported that a migrant in North Carolina in 1973 and a breeding bird in New York city in 1985 died with lethal levels of dieldrin in their brains.

7.18.3 Temporal trends

There was a significant decline in DDE residues in eggs of all three subspecies. In anatum, the most marked decline in DDE occurred during the early 1970s. Dieldrin also declined in all three subspecies, although less markedly. Heptachlor epoxide levels appear to be increasing. No distinct trends can be determined from the PCB, oxychlordane, HCB, or HCH data.

Eggs of anatum from the Yukon and Northern Alberta were similar in residue levels and temporal trends, compared to eggs from the Northwest Territories and Quebec (Peakall *et al.*, in press).

7.18.4 Spatial trends

During the period 1965 to 1972, DDE was significantly lower in the central arctic tundrius than in other populations and subspecies. Dieldrin and heptachlor epoxide residues were significantly lower in pealei eggs. No data on PCBs or oxychlordane are available for this period (Peakall *et al.*, 1990).

During the period 1973 to 1979, only oxychlordane exhibited spatial differences. Levels of this compound were significantly higher in eggs of the anatum subspecies from Alberta and the Mackenzie River area, N.W.T., than in tundrius eggs from the central arctic. As chlordane use in North America was relatively high at that time, this might be explained by the fact that anatum birds were exposed to chlordane on their wintering grounds in the U.S.A.

Between 1980 and 1988, DDE, dieldrin, oxychlordane, and beta-HCH levels in eggs differed significantly (SNK multiple comparisons) among subpopulations. The highest levels of DDE were recorded in Alberta, those of dieldrin in Northern Quebec, and those of oxychlordane in southern Quebec. It is possible that the eastern Peregrines are exposed to some contaminants, such as oxychlordane and PCBs, via the Great Lakes - St. Lawrence River systems. Levels of beta-HCH in eggs of pealei collected in the Queen Charlotte Islands were an order of magnitude higher than elsewhere, in agreement with high levels of this compound detected in the eggs of one of their principal prey, the Ancient Murrelet (Elliott *et al.*, 1989b).

7.18.5 Status and conclusions

The declines of the Peregrine Falcon in western and Northern Canada, and its extirpation from eastern Canada, have been attributed mainly to DDE- induced eggshell thinning and reductions in productivity (Peakall and Kiff, 1988). The effects of dieldrin on adult mortality and egg viability may also have been significant factors (Peakall *et al.*, 1990).

Peregrine Falcons were extirpated from eastern Canada by the early 1970s (Fyfe, 1976), but appear to be slowly recovering. Reintroduction programs in eastern Canada and the U.S.A. have bolstered the eastern anatum population somewhat, and a number of breeding attempts have been reported in Canada and the U.S.A. Although never extirpated in Alberta, this population also appears to be increasing. The tundrius race in the arctic showed some evidence of declines in the mid-1970s, but is currently considered stable. The pealei race, which declined in the 1950s and 1960s, has also shown signs of recovery (Munro and van Drimmelen, 1988), in accordance with lower organochlorine residue levels in eggs (Table 6). On Langara Island, the population has remained low but stable since the early 1970s (Nelson, pers. comm.).

Some Canadian peregrines continue to accumulate potentially hazardous concentrations in their tissues, even in sites as remote as western Hudson Bay (Table 9). Dependence on migratory avian prey, southern wintering areas, and the high trophic level of the diet have been suggested as the main reasons for the Peregrine's vulnerability. Although most members of the genus *Falco* are relatively sensitive to the effects of DDE in eggs, Peregrine Falcons are probably less sensitive than Prairie Falcons or Merlins (Fyfe *et al.*, 1988).

Although the levels of most compounds, including DDE and dieldrin, have decreased in eggs over most of the Peregrine's range since the late 1960s, a number of eggs still contain DDE or dieldrin above the critical values. There is some suggestion that heptachlor epoxide and oxychlordane levels may be increasing in some areas, but no population effects due to these compounds have been demonstrated for any raptors.

Like many raptors in Canada, Peregrine Falcons have also been affected by loss of habitat, reductions in certain prey species, shooting, disturbance at the nest sites, and illegal poaching. Nevertheless, Peregrines are apparently able to survive in urban situations, feeding on pigeons, starlings, and other resident urban species. Although contamination originating from organochlorine pesticide use in Latin America (in their migratory prey or picked up themselves during their winters in Latin America) may be a cause for concern, most Latin American countries are currently implementing restrictions (Burton and Philogene, 1986). If the levels of DDE and dieldrin in eggs continue to decline, the prognosis for Canadian Peregrine Falcon populations should improve.

7.19 Turkey Vulture *Cathartes aura*

Although two species of vultures occur in Canada, only the Turkey Vulture breeds here. Its breeding range covers southern B.C., Alberta, Saskatchewan, Manitoba, and the Great Lakes region of southern Ontario (Godfrey, 1986). In Canada, this species is largely migratory.

Vultures feed almost exclusively on carrion and are found in all terrestrial habitats except unbroken forest. The animals that form their diet potentially expose the birds to a diverse array of chemical pollutants and pathogens. These would include lead shot, organochlorine insecticides, mercury, rodenticides, strychnine, and other deliberately used poisons.

7.19.1 Analyses

Breast muscle and livers from three specimens collected in southern Ontario in 1973 were analyzed for mercury content.

7.19.2 Levels and toxic effects

Of the three Turkey Vulture livers analyzed for mercury, two contained residues in excess of 20 mg/kg, one as high as 60 mg/kg. This concentration probably contributed to mortality. Mercury levels of 20 mg/kg in livers of Red-tailed Hawks were associated with mortality (Fimreite and Karstad, 1971). Van der Molen and co-workers (1982) found mercury to be lethal to Grey Herons at liver levels greater than 50 mg/kg (w.w.).

7.19.3 Status and conclusions

Little is known of the current status of the Turkey Vulture in Canada, but there is no obvious evidence of declines. Comparatively little work has been done on the effects of organochlorines on vulture reproduction. Kiff *et al.* (1983) found that from 14 to 30% of the Turkey Vulture eggs collected in the southern U.S.A. between 1947 and 1974 had significantly (i.e. 20%) thinner-shelled eggs. It is possible that vultures as a family are relatively sensitive to DDE because Kiff *et al.* (1979) found 20% eggshell thinning induced by only 5 mg/kg DDE in the eggs of California Condors.

There is no information about the effects of other types of pollutants (heavy metals, industrial chemicals, nonorganochlorine pesticides) on vultures.

7.20 Common Barn Owl *Tyto alba*

A cosmopolitan species, Barn Owls breed in Canada only in southern Ontario and southwestern British Columbia. In B.C., Barn Owls are sedentary, but in southern Ontario with its heavier snowfalls, they tend to migrate short distances

(Campbell and Campbell, 1983; Godfrey, 1986). This species prefers open country, such as agricultural land, natural grasslands, and meadows.

Typical prey species are voles, other small mammals, and small birds (Klaas *et al.*, 1978). In British Columbia, Campbell (1983) found that *Microtus species* comprised 75% of their diet, *Sorex* species about 11%, and birds about 2%. However, one urban pair specialized on the starling *Sturnus vulgaris*, Rock Doves *Columbia livia*, and House Sparrows *Passer domesticus*.

7.20.1 Analyses

Eight livers of Barn Owls collected in British Columbia in 1984 and 1985 were analyzed for organochlorines. Some livers were also analyzed for heavy metals.

7.20.2 Levels and toxic effects

Levels of organochlorines in livers were low (Table 7). Maximum individual concentrations were: 4.3 mg/kg DDE, 0.14 mg/kg dieldrin, 0.20 mg/kg heptachlor epoxide, and 3.5 mg/kg PCBs, all wet weights. These are well below the critical liver levels of 100 mg/kg DDE and 10 mg/kg dieldrin, heptachlor epoxide, or oxychlordane suggested by Cooke *et al.* (1982) .

There has been some work on the effects of organochlorine contaminants in eggs of owls, although these are not strictly comparable to levels in livers. Klaas *et al.* (1978) found that DDE egg levels greater than 5.0 mg/kg in Barn Owls were associated with significantly thinner shells. Mendenhall *et al.* (1983) found that levels of dieldrin from 0.3 to 0.4 mg/kg in eggs of Screech Owls had no effect on reproduction. A Barn Owl found dead of suspected heptachlor poisoning in Oregon was reported to have 1.1 mg/kg heptachlor epoxide, 0.31 mg/kg oxychlordane, and 0.18 mg/kg DDE in its brain (Henny *et al.*, 1983).

Mercury residues in livers were low, less than 1.0 mg/kg in all cases. In a review of mercury toxicity to birds, lethal levels in a number of species ranged from 20 mg/kg to 50 mg/kg (Scheuhammer, 1987). Lead residues were all less than 0.5 mg/kg.

7.20.3 Geographical comparisons

DDE residues in livers reported here are similar to those reported for livers of two Barn Owls collected by Friis in the early 1970s and in British Columbia (Campbell and Campbell, 1983). DDE levels in those two birds were 0.3 and 1.1 mg/kg, respectively.

7.20.4 Status and conclusions

Barn Owls have a close association with agricultural areas and are probably exposed to relatively high levels of organochlorines in their prey, particularly those specializing on birds, . Nevertheless, Henny (1972) found no differences in adult mortality or recruitment rates in this species before and during the pesticide era.

This species is considered to be declining in Ontario, where there is a small population, but stable in southern British Columbia, where the population is much larger (Campbell and Campbell, 1983). Its propensity for nesting in close proximity to farmland, often using man-made structures, means that it is exposed to a variety of agricultural chemicals including currently used organophosphates, rodenticides, and herbicides.

However, the demographics of Barn Owl populations suggest that pesticides would have little long-term impact on populations. Barn Owl mortality is relatively high because of its dependence on the availability of small mammals. Campbell and Campbell (1983) considered cold-stress and heavy snowfall to be the major causes of mortality in Canada. This species is also highly prolific, breeding in its second year, and sometimes producing two clutches of up to 11 eggs each. These factors make long-term declines less likely than in longer-lived species.

7.21 Snowy Owl *Nyctea scaniaca*

The Snowy Owl has a circumpolar distribution. In Canada, it breeds north of the treeline, but winters irregularly as far south as the southern U.S.A. (Godfrey, 1986). These flights to southern localities are cyclic, correlated primarily with fluctuations in the abundance of lemmings, their staple diet in the arctic. Other prey taken include other small mammals, birds, and occasionally fish.

7.21.1 Analyses

Only one Snowy Owl egg, collected from a nest in the N.W.T. in 1973, has been analyzed for organochlorine content.

7.21.2 Levels and toxic effects

Levels of organochlorines and mercury were relatively low (Table 7), well below values associated with reproductive effects in owls (Klaas *et al.*, 1978; Mendenhall *et al.*, 1983). Although little can be concluded from a sample of one, the DDE level of 3.27 mg/kg (w.w.) in this egg suggests some exposure to organochlorine contaminants, perhaps from migratory prey. Resident prey, such as lemmings, usually contain very few contaminants at low levels (Cade *et al.*, 1971).

7.21.3 Status and Conclusions

There is no evidence of population declines of Snowy Owls anywhere in its breeding range. The typically mammalian prey and remote breeding areas minimize its exposure to pesticides. Despite some evidence of increasing contaminant levels in arctic biota (Muir *et al.*, 1988), Snowy Owls feeding primarily on lemmings are unlikely to be adversely affected.

7.22 Great Grey Owl *Strix nebulosa*

In North America, Great Grey Owls breed from near the treeline south to the Northern U.S.A. and Northern Ontario. They tend to winter in their breeding range and, irregularly, in southern Ontario, Quebec and the Maritimes (Godfrey, 1986). These owls breed in boreal forests, although much of their foraging is done in open areas, particularly during the winter. Mice are the staple diet.

7.22.1 Analyses

Three addled eggs of this species were collected from Northern Minnesota/ southern Manitoba in 1984 and analyzed for organochlorine content (Table 7).

7.22.2. Levels and toxic effects

Levels of organochlorines were extremely low in these three eggs. The total organochlorine content did not exceed 0.30 mg/kg (w.w.) in any of the eggs. This is attributed to their diet of mice and other small mammals, which are rarely found to be contaminated.

7.22.3 Status and conclusions

Nero (1979) classified this species as a sparse resident over most of the known breeding area. Virtually nothing is known of the historical status of this owl, but there are no indications of declines. The stability of the population is dependent on small mammal populations and the forest habitat that supports them. Although shooting, leg-hold traps, and other human-related activities increase mortality, and deforestation reduces its habitat, pesticide contamination does not appear to be a factor affecting Great Grey Owl populations.

7.23 Long-eared Owl *Asio otus*

The Long-eared Owl breeds in wooded areas over most of Canada from southern B.C. to the Maritimes. In winter this species moves to the south of its breeding range, often wintering in southern Ontario, southern B.C. and the Maritimes (Godfrey, 1986).

Long-eared Owls feed primarily on mice and other small mammals. Marks (1984) found 90% of the diet in Idaho to be *Peromyscus* sp., *Perognathus* sp., and *Dipodomys* sp.

7.23.1 Analyses

Nine eggs of Long-eared Owls collected in Saskatchewan between 1967 and 1969 and the brain and breast muscle of an adult found dead on the road in Saskatchewan in 1967 were analyzed for organochlorines and mercury.

7.23.2 Levels and toxic effects

Organochlorine levels in Long-eared Owl eggs were relatively low (Table 7), with DDE up to 3.1 mg/kg, dieldrin up to 0.15 mg/kg, and heptachlor epoxide up to 0.018 mg/kg. None of the concentrations detected were associated with adverse effects in studies with other owls (Klaas *et al.*, 1978; Mendenhall *et al.*, 1983). DDE levels in eggs of this species in Oregon were less than 0.5 mg/kg, and no eggs showed any evidence of thinning (Henny *et al.*, 1984).

7.23.3 Status and conclusions

Although little is known of the status of this seldom-seen owl, there are no indications of declines anywhere. Like many owls which depend on prey which fluctuates in abundance, productivity and mortality varies with food availability. Due to their diet of relatively uncontaminated small mammals, it is unlikely that Long-eared Owls ever accumulate a significant burden of organochlorine contaminants.

7.24 Short-eared Owl *Asio flammeus*

The Short-eared Owl breeds over most of Canada from British Columbia to Newfoundland, in open country meadows, fresh and saltwater marshes, and low arctic tundra. In winter, Canadian birds withdraw from the northern parts of their range to southern Ontario, southern B.C., and further south (Godfrey, 1986).

Its diet includes a variety of small rodents and birds associated with marshes.

7.24.1 Analyses

Six eggs of this species collected from Saskatchewan and Alberta in 1969 were analyzed for organochlorine content. Other tissues analyzed for organochlorines include brains and breast muscle of three birds collected in B.C. in 1968, and gonads and subcutaneous fat of a specimen from Saskatchewan in 1967. Livers of three birds shot in Alberta in 1969 were analyzed for mercury.

7.24.2 Levels and toxic effects

Levels of organochlorines in the eggs of the Short-eared Owl were, for owls, comparatively high. Individual samples contained up to 7.6 mg/kg DDE and 0.95 mg/kg dieldrin (Table 7). DDE egg levels greater than 5.0 mg/kg were associated with thinner shelled eggs in Barn Owls (Klaas *et al.*, 1978). Dieldrin levels close to 1.0 mg/kg in eggs have been associated with reduced viability (Lockie *et al.*, 1969; Wiemeyer *et al.*, 1975). Although organochlorine levels in eggs of Short-eared Owls were lower than critical values established for owls, DDE concentrations in some eggs were high enough to induce serious eggshell thinning in some falcons (Fyfe *et al.*, 1988). The degree of shell thinning that owls are able to tolerate is not known. Henny *et al.* (1984) found no evidence of shell thinning in Oregon, where DDE residues averaged 0.30 mg/kg. However, one egg in that study contained 1.7 mg/kg heptachlor epoxide.

Organochlorine levels in tissues were well below lethal values established in other studies (Stickel *et al.*, 1979; Cooke *et al.*, 1982; Blus *et al.*, 1984). The highest mercury level detected, 11.3 mg/kg in one of the livers, is below critical levels established in other studies (Scheuhammer, 1987).

7.24.3 Status and conclusions

Little is known of the status of the Short-eared Owl in Canada. It was blue-listed in 1982 (Tate and Tate, 1982), the declines being largely attributed to the destruction of wetlands rather than contamination. However, as the preferred prey is often migratory or associated with aquatic systems, this owl may be exposed to more contaminants than most other owls.

7.25 Great Horned Owl *Bubo virginianus*

The Great Horned Owl is resident over most of Canada south of the treeline. During winter, individuals may wander widely, but most are basically sedentary (Godfrey, 1986). Great Horned Owls inhabit both deciduous and coniferous woods, small groves, and are often found close to humans in cities and on farms.

They feed on a wide variety of prey, including rabbits, rats, mice, skunks, grouse, waterfowl, and seabirds (Godfrey, 1986), many of which are themselves relatively high on the food chain.

7.25.1 Analyses

Thirty-three fresh or addled eggs of this species were collected mainly from Alberta and Saskatchewan, but also Ontario and the N.W.T., between 1967 and 1970. Most egg samples were analyzed for both organochlorine and mercury content.

Liver of a specimen from Ontario collected in 1968 was analyzed for mercury. Four tissues of a road-killed owl from Saskatchewan in 1967, brain tissue of a two-week old nestling from Saskatchewan and two adults from New Brunswick in 1969, and the liver of a nestling from Alberta were analyzed for organochlorines.

7.25.2 Levels and toxic effects

DDE levels in this species varied from very low to 16.2 mg/kg in an addled egg (Table 7). Generally, eggs from the Prairie provinces in 1969 and 1970 were most contaminated.

The critical shell-thinning effect level has not been established in this species, but it is possible that some thinning occurs at levels as low as 5.0 mg/kg. Springer (1980) and Seidensticker and Reynolds (1971) found that DDE levels less than 5.0 mg/kg had no effect on shell thickness. However, DDE levels greater than 5.0 mg/kg in eggs of Barn Owls were associated with significantly thinner eggshells (Klaas *et al.*, 1978). About 50% of the eggs sampled contained DDE residues in excess of 5.0 mg/kg; about 25% of the eggs contained more than 10 mg/kg of DDE.

Dieldrin concentrations in eggs were all less than 0.80 mg/kg, which probably had no effect on hatchability. Heptachlor epoxide levels in two eggs from Saskatchewan, however, exceeded 1.5 mg/kg, a value associated with reduced productivity in kestrels (Henny *et al.*, 1983).

Contaminant levels in all tissues except subcutaneous fat were low in the shot adults and nestlings found dead during the late 1960s. DDE in the livers of two Great Horned Owls allegedly exhibiting unusual behaviour at a ski resort in Banff during the winter of 1984 averaged 15 mg/kg, relatively high but below lethal levels established in investigations of other raptors (Cooke *et al.*, 1982).

There have been a number of incidences of pesticide poisoning elsewhere. The brain of a Great Horned Owl that died of chlordane poisoning in the late 1970s (Blus *et al.*, 1983) contained 3.7 mg/kg oxychlordane, 5.1 mg/kg heptachlor epoxide, 0.8 mg/kg dieldrin, and 28 mg/kg DDE. Of these values, only the chlordane related compounds (heptachlor epoxide and oxychlordane) were considered to be at diagnostically lethal levels (Stickel *et al.*, 1979). It is noteworthy that the carcass contaminant levels were much lower (4.5 mg/kg DDE, 0.10 mg/kg dieldrin, 0.70 mg/kg heptachlor epoxide, and 0.40 mg/kg oxychlordane). This pattern is consistent with the hypothesis that sick or starving birds soon metabolize stored body fat, thereby increasing concentrations of lipophilic contaminants in the blood and other tissues.

The deaths of at least nine Great Horned Owls in New York State between 1982 and 1986 were variously attributed to poisoning by dieldrin, oxychlordane and heptachlor epoxide, based on diagnostic levels in the brains (Stone and Okoniewski, 1988). Another Great Horned Owl found dead in 1981 contained PCB residues in the brain of 357 mg/kg, one of the two reported cases of PCB poisoning in birds (Stone and Okonieski, 1983).

7.25.3 Temporal trends

Comparison of contaminant levels in Great Horned owls collected in 1970 or earlier compared to levels in the tissues of those collected in 1984 revealed no significant change in DDE in breast muscle. No other comparisons were possible.

7.25.4 Status and conclusions

Organochlorine levels in Great Horned Owls may have affected survival and/or reproductive success in some individuals, based on critical levels established in other studies. Nevertheless, there have been no detectable effects on populations of this species, which appears to have adapted well to human activities (Cadman *et al.*, 1987). Henny (1972) analyzed recoveries of banded Great Horned Owls and found mortality rates to be balanced with recruitment rates. Populations of Great Horned Owls appeared to have been stable during the period 1930 to 1970.

Elevated levels in some individuals certainly occur where migratory birds or waterbirds are a major component of the diet. Great Horned Owls preying on Great Lakes gulls, for example, would probably contain some of the highest levels of organochlorines, but there are few indications of poor reproductive success or adult mortality in this region. One Great Horned Owl found dead by Stone and Okoniewski (1988) contained elevated levels of mirex, an indication that it had been feeding on wildlife associated with Lake Ontario (Norstrom *et al.*, 1980).

7.26 Burrowing Owl *Athene cunicularia*

The Burrowing Owl has a breeding distribution which includes parts of southern Manitoba, Saskatchewan, and Alberta. There is also a remnant population in the Okanagan Valley, B.C. (Wedgewood, 1978). This owl inhabits dry grassland areas, nesting in abandoned mammal burrows. On the Prairies, Burrowing owls are migratory, wintering in southern U.S.A. and Central America.

Their diet consists mainly of insects (grasshoppers and ground beetles), but also includes small mammals (mice, voles, and ground squirrels), small birds, and snakes (Wedgewood, 1978).

7.26.1 Analyses

One egg collected in Saskatchewan in 1968 was analyzed for organochlorines and mercury (Table 7). In addition, three adult Burrowing owls were collected in 1968. The brains were analyzed for organochlorine content, the livers for mercury.

7.26.2 Levels and toxic effects

Levels of organochlorines in the egg were very low (0.68 mg/kg DDE, 0.42 mg/kg dieldrin, and 0.15 mg/kg heptachlor epoxide), well below levels associated with reproductive effects in other avian species. Organochlorine levels in the brains were also below critical levels established elsewhere. The relatively elevated amount of heptachlor epoxide (0.71 mg/kg) suggests a local or recent source. Henny *et al.* (1984) reported low levels of DDE in eggs of this species in Oregon and Haug (M.Sc Thesis, University of Saskatchewan, 1985) found very low levels of DDE, DDD and DDT in tissues and one egg of Burrowing owls collected in Saskatchewan.

Mercury levels were as high as 6.2 mg/kg (w.w.) in livers, but well below lethal values determined for other raptors (Fimreite and Karstad, 1971).

7.26.3 Status and conclusions

Burrowing Owl numbers on the Prairies have been declining for some time. In 1979, this species was declared a threatened species in Canada. Declines have been attributed mainly to indiscriminant shooting, destruction of burrows (or the animals which excavate them), and the use of pesticides to control grasshoppers (Wedgewood, 1978).

As organochlorine residues are relatively low and productivity outside areas sprayed with carbofuran appears normal, organochlorine contaminants are probably not a factor in the decline of this species. However, currently used pesticides are a problem.

In a study on the impact of the insecticide carbofuran (tradename Furadan 480F) on Burrowing Owls, Fox *et al.* (1989) found that survival and reproductive success was reduced when carbofuran was sprayed over the burrows. Their data suggested that carbofuran was directly toxic to the owls, either dermally or by ingestion of contaminated prey. Considering the active program to rehabilitate the Burrowing Owl in Canada, Fox *et al.* (1989) recommended suspension of carbofuran use, or at least restrictions on its use, near owl colonies.

8.0 CONCLUSIONS

8.1 Raptor samples analyzed

Between 1965 and 1988, over one thousand raptor eggs, of twenty-four species of raptors known to breed in Canada, were analyzed for their organochlorine and mercury content. The majority of the samples were eggs of Merlins and Prairie Falcons from Saskatchewan and Alberta, but all geographical regions of Canada were represented.

More than one hundred samples of raptor tissues were also analyzed during the same period. For most specimens, the liver and brain were the tissues selected, but in some cases, muscle, fat, gonads or whole bodies were also analyzed. Additionally, a series of blood samples were obtained in the late 1980s from several species of raptors migrating through Ontario.

8.2 Contaminants

The following contaminants were found in the eggs and tissue samples of raptors in Canada: DDE, dieldrin, heptachlor epoxide, PCBs, oxychlordane, HCB, DDT, DDD, mirex, a-HCH, b-HCH, lindane, cis and trans chlordane, cis and trans nonachlor, as well as mercury and lead. The presence of certain compounds only in recent samples reflects improvements in analytical methodology. Prior to the mid 1970s, the HCH isomers, the chlordane-related compounds and PCBs could not be reliably measured.

8.3 Adult Mortality

Very few tissues contained residues suggestive of pesticide or heavy metal poisoning. Mercury in the livers of two Turkey Vultures and one Bald Eagle, from Ontario in 1970, exceeded the critical value of 20 mg/kg. DDE in liver of one Sharp-shinned Hawk collected in B.C. in 1984-85 was greater than 100 mg/kg, wet weight.

However, mobilization of stored lipophilic contaminants during migration may be a hazard for some individuals. Reports of pesticide poisoning in the USA include one Canadian-banded Merlin with lethal levels of heptachlor epoxide in its brain (Henny *et al.*, 1976).

8.4 Effects on reproduction

Organochlorine levels in many raptor eggs exceeded critical threshold levels calculated from the toxicological literature (Table 10). However, there are significant interspecific differences in toxic effects. For example, DDE probably reduces productivity in Prairie Falcons at egg levels as low as 1.2 mg/kg, whereas the critical value for Peregrine Falcons is about 15 mg/kg.

Based on the derived critical values, DDE in eggs was high enough to cause eggshell thinning in Bald Eagles, Osprey, Red-tailed Hawks, Northern Harriers, Merlins, Prairie falcons, Peregrine Falcons and Great Horned Owls in the late 1960s and early 1970s. Significant eggshell thinning is probably still occurring in some Sharp-shinned Hawks, Cooper's Hawks, Peregrine Falcons and Merlins.

Although the critical level of dieldrin in eggs has not been established, we considered concentrations in excess of 1.0 mg/kg to be hazardous. Egg residues exceeded this value in one Sharp-shinned Hawk, one Golden Eagle, one Gyrfalcon, one American Kestrel, several Red-tailed Hawks, Swainson's Hawks, Ferruginous Hawks, Bald Eagles, Northern Harriers, Peregrine Falcons, Prairie Falcons and Merlins.

Heptachlor epoxide concentrations greater than 1.5 mg/kg may have impaired the viability of at least one egg of a Red-tailed Hawk, Swainson's Hawk, Ferruginous Hawk, Rough-legged Hawk, Northern Harrier and Kestrel, several eggs of Merlins, Peregrine Falcons, Prairie Falcons and two Great Horned Owl eggs. Mercury residues greater than 0.5 mg/kg were found in Bald Eagles, Prairie Falcons and a Red-tailed Hawk.

8.5 Influence of diet and migration

The main factor accounting for interspecific differences in residue levels was diet. Species which preyed on migratory and/or aquatic birds or fish were generally more contaminated than those which fed on mammals - for all organochlorines. The main sources of mercury appeared to be fish and carrion.

Migratory behaviour was also a factor, with resident raptors less contaminated than migratory species. However, there was no consistent pattern of contaminant residues with respect to wintering area. Species that winter in South and Central America (eg. Swainson's Hawk and Osprey) where many organochlorine pesticides continue to be used were not consistently more contaminated than species wintering in the USA (eg. Bald Eagles and Red-shouldered Hawks).

Species which undertake prolonged migratory flights relying solely on body fat may be at risk due to the mobilization of stored lipophilic contaminants, but there is little evidence of this.

8.6 Temporal trends

It was possible to analyze for temporal trends in a few species, most from the Prairie provinces.

In the eggs of Swainson's and Ferruginous Hawks from Alberta and Saskatchewan, DDE and heptachlor epoxide levels changed little between the late 1960s and the mid 1980s. Only dieldrin in the Swainson's Hawk eggs declined.

In Merlin eggs, dieldrin and DDE declined significantly, but heptachlor epoxide levels showed no consistent trend. In Prairie Falcons, all three of those compounds declined.

Both DDE and dieldrin decreased in all three races of Peregrine, DDE significantly. Heptachlor epoxide levels appeared to be increasing, and other compounds showed no trends.

In Bald Eagles breeding in Northern Ontario, only DDE declined significantly between 1968 and the mid 1980s. In the arctic, only dieldrin in eggs of Rough-legged Hawks declined. Levels of DDE and heptachlor epoxide in Rough-legged Hawks and Gyrfalcons showed no significant change.

8.7 Status of Canadian raptor populations

Based on sources in Canada and the USA, we conclude that a number of Canadian raptor populations did experience declines attributable to pesticides.

The best known examples are the Bald Eagles from the Great Lakes and Northern Ontario, and the anatum race of the Peregrine Falcon which was extirpated from all of its eastern range. Aided by re-introductions, both of these species are reclaiming their former range. Although the evidence for population declines in some other species is less conclusive, it seems likely that Osprey, Prairie Falcons, Merlins and Cooper's Hawks also experienced declines during the pesticide era. Populations of these species are currently stable.

A few species such as Ferruginous Hawks, Red-shouldered Hawks, Barn Owls and Burrowing Owls have also declined, but this has been attributed mainly to loss of habitat and disturbance.

Turkey Vultures, Red-tailed Hawks and Great Horned Owls have expanded their ranges. However, we know little of the status of the remaining species, particularly arctic residents, the boreal forest owls and species with cyclic fluctuations in numbers (eg. Northern Harriers).

8.8 Raptors as monitors of environmental contamination

Raptors can be used to monitor levels of contamination in the terrestrial environment because they are exposed to high levels of biomagnifying compounds. Moreover, because of the toxic effects of those compounds, health effects in raptors may be the first indication of the hazard to the ecosystem.

Analyses of specimens found dead may be qualitatively useful in monitoring incidences of pesticide poisoning. Analyses of unhatched eggs provide an idea of the frequency of contaminant-related effects on reproduction, while collections of fresh eggs can be used to monitor average levels of contamination.

However, due to individual differences in diet, geographical and seasonal differences in prey availability, and the large ranges of most raptors, levels in eggs and tissues are extremely variable, and results of analyses may be difficult to interpret. Sampling would be best carried out in conjunction with reproductive and diet studies.

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APPENDIX A.

The tables in Appendix A contain data on the detected concentrations of eleven environmental contaminants in raptor eggs and tissues analyzed by the Canadian Wildlife Service between 1965 and 1989. Note that the 1989 data included in this appendix are not included in Tables 1 and 3 - 10, which cover the period 1965 to 1988. A few recently analyzed samples (mainly Osprey, Bald Eagles and accipiters) are not included in this report pending further analyses of the data by the investigators of those projects.

Because raptor nests are dispersed, egg data are summarized by region (usually a province), year of collection, and condition, for each species. Tissue data are generally presented individually, or on a nest by nest basis, for each tissue analyzed from a particular locality and year. Individual or mean percentage fat and percentage water are also provided in Appendix A.

The Mean (geometric mean), N (number of individuals in a sample set), #det (number of samples within a data set with detectable quantities of a particular compound), min (the lowest value detected) and the max (the highest value detected) are presented for each compound. A value of one half the detection limit (usually 0.0005) was assigned for each compound analyzed for, but not detected. For all species, the Mean is the geometric mean based on all samples analyzed for that compound, including those below the detection limit. For Merlins, Prairie Falcons and Peregrine Falcons, the Mean is the geometric mean of those samples with detectable concentrations.

Eggs collected from nests were classified as fresh, addled, rotten, or infertile. Viable eggs refer to eggs that were fresh (collected early in the incubation period) or showed some evidence of embryonic development. Nonviable eggs were generally rotten or infertile. The condition of some eggs was not recorded.

Both eggs and tissues may have become dehydrated, thus elevating the detected concentrations. This can be detected from the low percent water in those samples. Eggs with percent water less than 60% were excluded from statistical analyses.

Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: NORTHERN GOSHAWK (*Accipiter gentilis*)																
NB	1969	Fresh egg	6.3	80		-	0.15	3.90	0.042	0.049	0.019	-	-	-	ND	-
Ontario (South)	1987	Fresh eggs	4.3	83	Mean #det/N min max	-	0.015 4/4 0.007 0.027	0.99 4/4 0.27 1.82	0.020 4/4 0.012 0.026	0.089 4/4 0.036 0.20	0.040 4/4 0.036 0.20	0.004 4/4 0.002 0.008	0.56 4/4 0.25 0.89	0.064 4/4 0.038 0.12	0.0015 4/4 0.0015 0.0015	0.007 3/3 0.0005 0.019
Ontario (South)	1989	Fresh eggs	5.6	81	Mean #det/N min max	-	0.005 4/4 0.003 0.008	0.81 4/4 0.64 1.18	0.008 4/4 0.002 0.024	0.036 4/4 0.019 0.10	0.011 4/4 0.008 0.025	0.002 4/4 0.001 0.003	0.32 4/4 0.16 1.48	0.014 4/4 0.010 0.024	0.0007 1/1 0.0004 0.029	0.048 4/4 0.019 0.19

- indicates that chemical was not included in analysis; ND indicates chemical was included in analysis but not detected; [a] PCBs are presented on the basis of Aroclor 1260, otherwise PCBs are based on a 1:1 mixture of Aroclors 1254:1260; [b] methyl mercury

Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: COOPER'S HAWK (*Accipiter cooperii*)																
Manitoba	1967	Addled egg	8.3	80		-	3.42	14.6	0.11	5.87	0.17	-	-	-	-	-
Saskatchewan	1967-70	Addled eggs	4.7	81	Mean	0.11	0.080	4.19	0.059	0.11	0.11	0.006	0.27[a]	-	ND	ND
					#det/N	2/2	9/9	9/9	9/9	9/9	9/9	1/1	4/4			0/1
					min	0.10	0.011	2.35	0.003	0.035	0.012		0.087			
					max	0.13	0.62	6.02	0.44	0.22	0.56		1.49			
Saskatchewan	1968-69	Fresh eggs	4.7	84	Mean	0.044	0.018	3.55	0.013	0.28	0.11	-	0.057[a]	-	0.051	-
					#det/N	1/1	2/2	2/2	2/2	2/2	2/2		1/1		1/1	
					min		0.007	3.38	0.004	0.16	0.042					
					max		0.044	3.73	0.041	0.49	0.26					
Alberta	1971	Addled eggs	4.0	82	Mean	0.081	0.0023	4.41	0.030	0.17	0.056	0.010	0.63[a]	-	ND	ND
					#det/N	3/3	2/3	3/3	1/3	3/3	3/3	3/3	3/3			
					min	0.050	0.0005	3.73	0.0005	0.13	0.050	0.010	0.60			
					max	0.12	0.05	5.39	0.030	0.29	0.070	0.010	0.71			
Alberta	1971-73	Fresh eggs	4.2	83	Mean	0.066	0.024	2.64	ND	0.46	0.089	0.024	0.77[a]	-	ND	ND
					#det/N	2/2	2/2	2/2		2/2	2/2	2/2	2/2			
					min	0.040	0.014	1.17		0.16	0.050	0.010	0.61			
					max	0.11	0.040	5.95		1.31	0.16	0.057	0.98			
Alberta	1975	Addled egg	5.4	81		0.03	0.14	3.91	0.15	0.11	0.09	0.038	0.64	-	-	0.02
Alberta	1978	Egg condition not recorded	4.4	81		-	0.25	5.46	0.010	0.12	0.030	0.030	7.98	0.060	0.005	-
Ontario (South)	1986	Addled eggs	4.5	82	Mean	-	0.022	5.19	0.018	0.32	0.11	0.008	2.37	0.18	0.004	0.17
					#det/N		4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	2/2	4/4
					min		0.008	2.42	0.005	0.18	0.091	0.005	1.53	0.14	0.004	0.08
					max		0.049	9.12	0.055	0.61	0.14	0.016	2.95	0.25	0.004	0.27
Ontario (South)	1987	Fresh eggs	4.6	83	Mean	-	0.027	3.40	0.030	0.40	0.14	0.009	1.55	0.28	0.008	0.005
					#det/N		5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	2/2
					min		0.0095	1.19	0.0075	0.21	0.078	0.005	0.83	0.19	0.002	0.0005
					max		0.22	24.7	0.23	0.69	0.29	0.013	2.90	0.37	0.26	0.021
Ontario (South)	1988	Fresh eggs	4.6	82	Mean	-	0.019	6.03	0.020	0.20	0.29	0.012	2.21	0.23	0.0025	0.13
					#det/N		4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
					min		0.0025	2.00	0.008	0.066	0.029	0.003	0.67	0.029	0.0025	0.073
					max		0.14	25.3	0.074	0.59	1.07	0.026	9.23	1.66	0.0025	0.24
Ontario (South)	1989	Fresh eggs	5.6	81	Mean	-	0.022	4.14	0.020	0.16	0.068	0.005	0.78	0.096	0.003	0.15
					#det/N		5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5
					min		0.008	0.75	0.007	0.046	0.026	0.002	0.28	0.037	0.0004	0.045
					max		0.33	50.5	0.396	0.46	0.27	0.014	2.25	0.40	0.032	1.46

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: COOPER'S HAWK *(Accipiter cooperii)*																
BC	1967	Brain	6.3	81		-	0.034	0.58	0.023	0.013	ND	-	-	-	-	-
BC	1984	Livers	3.2	-	Mean #det/N min max	0.50 3/3 0.18 1.87	0.115 3/3 0.090 0.13	12.3 3/3 5.88 37.8	0.016 3/3 0.010 0.020	0.63 3/3 0.19 1.19	0.33 3/3 0.26 0.49	0.012 3/3 0.007 0.028	4.78 3/3 2.40 6.93	0.48 3/3 0.33 0.72	0.008 3/3 0.005 0.010	0.024 3/3 0.01 0.07
Whitefish Point, Michigan (Spring migration)	1986-88	Blood	-	-	Mean #det/N min max	-	ND	0.200 5/5 0.064 0.272	ND	0.020 5/5 0.002 0.033	0.047 5/5 0.008 0.063	0.0032 3/5 0.0005 0.001	0.119 5/5 0.022 0.180	0.034 5/5 0.004 0.099	ND	0.0417 5/5 0.005 0.050

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: SHARP-SHINNED HAWK (*Accipiter striatus*)																
Saskatchewan	1968	Addled egg	6.3	82		0.12	0.10	7.0	0.089	0.12	0.057	-	-	-	-	-
NB	1983	Infertile eggs	6.5	78	Mean	-	0.090	7.03	0.075	0.53	0.34	0.041	4.24	0.76	0.036	0.31
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.080	5.42	0.060	0.39	0.30	0.025	3.52	0.67	0.030	0.23
					max		0.100	9.12	0.100	0.75	0.41	0.062	4.87	0.85	0.050	0.40
Ontario (South)	1986	Fresh eggs	5.3	82	Mean	-	0.033	10.1	0.048	0.44	0.29	0.051	2.27	0.47	0.0067	0.16
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.014	4.10	0.022	0.088	0.077	0.041	1.99	0.16	0.005	0.13
					max		0.055	18.6	0.076	1.19	0.65	0.067	2.68	0.88	0.010	0.18
Ontario (South)	1987	Fresh eggs	7.0	81	Mean	-	0.029	9.30	0.035	0.30	0.24	0.021	2.60	0.39	0.014	0.021
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.007	3.52	0.011	0.11	0.084	0.019	1.62	0.19	0.003	0.015
					max		0.060	16.4	0.077	0.68	0.82	0.026	3.69	0.61	0.033	0.028
Ontario (South)	1988	Fresh eggs	5.4	82	Mean	-	0.0075	5.95	0.010	0.15	0.10	0.010	1.66	0.045	0.0025	0.31
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.0025	3.72	0.0078	0.12	0.091	0.0095	1.51	0.02	0.0025	0.19
					max		0.017	10.2	0.014	0.19	0.11	0.011	1.77	0.094	0.0025	0.39
Ontario (South)	1989	Fresh eggs	6.0	81	Mean	-	0.029	4.88	0.051	0.17	0.12	0.015	0.96	0.11	0.003	0.13
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.019	2.19	0.027	0.07	0.074	0.014	0.82	0.10	0.003	0.10
					max		0.037	7.5	0.080	0.29	0.27	0.015	1.11	0.12	0.004	0.17
BC	1969	Brain	6.5	78		-	0.043	0.35	0.034	0.043	ND	-	-	-	-	-
BC	1982-85	Liver	3.6	-	Mean	2.13	0.16	5.03	0.020	0.13	0.095	0.044	3.51	0.18	0.018	0.040
					#det/N	2/2	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	6/7	7/7
					min	1.7	0.010	0.090	0.005	0.040	0.030	0.007	0.24	0.020	0.0005	0.01
					max	2.7	2.71	159	0.070	0.55	0.48	0.16	20.8	2.62	0.070	0.15

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: SHARP-SHINNED HAWK (*Accipiter striatus*)																
Whitefish Point, Michigan (Spring migration)	1986	Blood	-	-	Mean	-	-	0.204	-	0.0105	0.0114	0.0010	0.0885	0.0097	0.0011	0.0151
					#det/N			33/33		33/33	33/33	19/33	33/33	33/33	9/33	33/33
					min			0.056		0.002	0.004	0.0005	0.028	0.002	0.0005	0.003
					max			4.37		0.043	0.187	0.005	0.307	0.049	0.092	0.115
	1987	Blood	-	-	Mean	-	-	0.197	-	0.0225	0.0180	0.0014	0.0738	0.012	0.0013	0.0226
					#det/N			21/21		21/21	21/21	16/21	21/21	21/21	10/21	21/21
					min			0.096		0.005	0.002	0.0005	0.029	0.003	0.0005	0.001
					max			0.553		0.132	0.133	0.004	0.249	0.050	0.0080	0.305
	1988	Blood	-	-	Mean	-	-	0.258	-	0.0234	0.0244	0.0012	0.114	0.0164	0.0025	0.0252
					#det/N			28/28		28/28	28/28	24/28	28/28	28/28	15/28	28/28
					min			0.070		0.0035	0.0041	0.001	0.039	0.0036	0.0006	0.0051
					max			1.133		0.251	0.486	0.0035	0.824	0.0682	0.0172	0.249
Hawk Cliff, Ontario (Fall migration)	1985	Blood	-	-	Mean	-	-	0.0584	-	0.0044	0.0026	0.0007	0.0366	0.0034	ND	0.0005
					#det/N			4/4		4/4	4/4	2/4	4/4	4/4		4/4
					min			0.014		0.002	0.0015	0.0005	0.017	0.0013		0.0001
					max			0.361		0.0059	0.0049	0.0013	0.104	0.0064		0.0016
	1986	Blood	-	-	Mean	-	-	0.148	-	0.0115	0.0029	ND	0.037	0.0039	ND	0.0039
					#det/N			3/3		3/3	3/3		3/3	3/3		3/3
					min			0.046		0.007	0.002		0.023	0.003		0.002
					max			0.447		0.024	0.004		0.046	0.005		0.006
	1987	Blood	-	-	Mean	-	-	0.120	-	0.0071	0.0049	0.0006	0.0816	0.0061	0.0005	0.0125
					#det/N			25/25		25/25	25/25	23/25	25/25	25/25	1/25	24/24
					min			0.012		0.0028	0.0009	0.0001	0.014	0.0011	0.001	0.0005
					max			1.681		0.0383	0.0153	0.0022	0.440	0.0248		0.3089
	1988	Blood	-	-	Mean	-	-	0.0228	-	0.0101	0.0029	0.0004	0.0344	0.0008	ND	0.0026
					#det/N			10/10		10/10	10/10	9/10	9/10	10/10		9/10
					min			0.0017		0.0032	0.0005	0.0001	0.003	0.0015		0.0001
					max			0.183		0.0089	0.0094	0.0004	0.0973	0.0053		0.0089

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: RED-TAILED HAWK (*Buteo jamaicensis*)																
Manitoba	1967	Addled egg	11.0	73		-	0.094	2.10	0.10	3.21	0.24	-	-	-	-	-
Saskatchewan	1968	Fresh eggs	9.0	77	Mean #det/N min max	0.046 4/4 0.023 0.080	0.11 4/4 0.038 1.04	1.23 4/4 0.75 2.35	0.062 4/4 0.021 0.57	0.24 4/4 0.20 0.32	0.0035 4/4 0.0005 0.18	-	-	-	-	-
Saskatchewan	1969	Addled eggs	6.1	80	Mean #det/N min max	-	0.033 5/5 0.008 0.81	1.09 5/5 0.44 10.8	0.0045 5/5 0.003 0.010	0.77 5/5 0.15 5.94	0.21 5/5 0.073 0.96	-	0.18[a] 5/5 0.026 0.82	-	ND	-
Saskatchewan	1967	Fresh eggs	5.1	81	Mean #det/N min max	-	0.042 22/22 0.0005 1.37	0.95 22/22 0.29 7.92	0.033 22/22 0.0005 0.84	0.25 22/22 0.033 0.60	0.040 22/22 0.004 0.26	-	-	-	-	-
Alberta	1968	Fresh eggs	9.2	74	Mean #det/N min max	0.093 5/5 0.035 0.36	0.082 5/5 0.044 0.18	1.65 5/5 0.48 16.4	0.076 5/5 0.036 0.18	0.56 5/5 0.23 1.65	0.055 5/5 0.0005 0.84	-	-	-	-	-
Alberta	1968	Addled egg	4.3	82		0.91	0.30	10.9	0.047	0.42	0.17	-	-	-	-	-
Alberta	1968	Egg condition not recorded	9.6	75	Mean #det/N min max	0.13 4/4 0.026 1.62	0.12 8/8 0.030 0.85	1.55 8/8 0.46 16.8	0.069 8/8 0.023 0.59	0.48 8/8 0.089 1.08	0.073 7/8 0.0005 2.55	-	-	-	-	-
BC	1969	Egg condition not recorded	3.7	84		-	0.62	4.72	0.41	0.26	0.11	-	0.37[a]	-	ND	-
Ontario	1970	Nonviable eggs	6.3	80	Mean #det/N min max	0.089 2/2 0.080 0.100	0.023	0.4870	0.0130	0.1700	0.018 2/2 0.015 0.021	0.038 2/2 0.035 0.042	0.85[a] 2/2 0.80 0.89	-	ND	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: RED-TAILED HAWK (*Buteo jamaicensis*)																
Southern Saskatchewan (Two adults)	1967	Breast muscle	3.1	74	Mean #det/N min max	-	0.004 2/2 0.0005 0.029	0.26 2/2 0.16 0.44	0.013 2/2 0.006 0.028	0.18 2/2 0.14 0.23	0.084 2/2 0.015 0.47	-	-	-	-	-
		Brain	7.8	77	Mean #det/N min max	-	0.017 2/2 0.013 0.022	0.068 2/2 0.054 0.086	0.017 2/2 0.015 0.020	0.075 2/2 0.067 0.084	0.016 2/2 0.008 0.032	-	-	-	-	-
		Subcut. fat	90.3	10	Mean #det/N min max	-	0.15 2/2 0.018 1.19	1.76 2/2 0.19 15.9	0.21 2/2 0.091 0.48	0.51 2/2 0.023 11.5	0.37 2/2 0.038 3.53	-	-	-	-	-
		Ovaries	2.9	83	Mean #det/N min max	-	0.019 2/2 0.009 0.040	0.15 2/2 0.090 0.23	0.008 2/2 0.004 0.018	0.10 2/2 0.074 0.14	0.025 2/2 0.012 0.052	-	-	-	-	-
Central Alberta (Adult)	1968	Brain	7.1	79		-	0.014	0.47	0.008	0.15	0.057	-	-	-	-	-
		Liver	-	68		0.48	-	-	-	-	-	-	-	-	-	-
British Columbia (Adult)	March 1968	Breast muscle	3.8	66		-	1.17	2.81	1.82	0.032	ND	-	-	-	-	-
		Brain	6.1	77		-	0.053	0.40	0.12	0.013	ND	-	-	-	-	-
British Columbia (Nestling)	1969	Brain	3.2	88		-	0.003	0.075	ND	0.037	0.006	-	0.024[a]	-	ND	-
Hawk Cliff, Ontario (Fall migration)	1986	Blood	-	-	Mean #det/N min max	0.005 3/3 0.0005 0.009	ND	0.009 3/3 0.002 0.031	ND	0.003 1/3 0.0005 0.005	0.001 2/3 0.001 0.001	ND	ND	0.0010 2/3 0.0005 0.002	ND	0.0010 1/3 0.0005 0.004

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: RED-SHOULDERED HAWK (*Buteo lineatus*)																
Ontario (South)	1973	Fresh eggs	3.9	81	Mean #det/N min max	-	0.38 3/3 0.24 0.53	2.427 3/3 1.40 3.78	0.50 3/3 0.23 1.10	0.182 3/3 0.008 0.42	0.046 3/3 0.030 0.080	0.015 3/3 0.009 0.019	1.885 3/3 1.05 3.11	-	ND	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: SWAINSON'S HAWK (*Buteo swainsoni*)																
Saskatchewan	1968	Fresh egg	6.7	80		0.28	0.039	0.64	0.058	1.25	0.27	-	-	-	-	-
Saskatchewan	1968	Addled egg	5.3	70		-	0.044	1.16	0.011	0.62	0.066	-	-	-	-	-
Saskatchewan	1969	Addled egg	6.0	80		-	0.007	0.86	0.002	0.12	0.063	-	0.029[a]	-	ND	-
Alberta	1968	Fresh eggs	5.6	78	Mean #det/N min max	0.11 7/7 0.03 0.42	0.058 7/7 0.019 1.40	1.02 7/7 0.37 5.92	0.058 7/7 0.021 2.11	0.44 7/7 0.20 1.01	0.16 7/7 0.028 4.08	-	-	-	-	-
Alberta	1969	Addled egg	5.7	83		-	0.009	0.092	0.004	0.021	0.36	-	-	-	ND	-
Alberta	1967	Egg condition not recorded	5.1	83	Mean #det/N min max	-	0.010 5/6 0.005 0.096	0.45 6/6 0.18 1.52	0.005 4/6 0.0005 0.082	0.38 6/6 0.14 0.85	0.33 6/6 0.023 1.34	-	-	-	-	-
Alberta	1973	Fresh egg	5.7	83		0.16	0.056	0.66	0.038	0.080	0.030	0.019	0.09[a]	-	-	-
Saskatchewan	1984-85	Addled eggs (8 pools)	5.3	79	Mean #det/N min max	-	0.012 8/8 0.004 0.043	0.40 8/8 0.083 1.02	0.008 8/8 0.003 0.050	0.050 8/8 0.014 0.20	0.12 8/8 0.029 0.29	0.021 8/8 0.004 0.13	0.15 8/8 0.022 0.48	0.025 8/8 0.010 0.036	0.0027 8/8 0.0010 0.0070	0.0051 8/8 0.001 0.013
Saskatchewan	1968	Adult brain	7.7	80	Mean #det/N min max	-	0.011 4/4 0.004 0.030	0.085 4/4 0.031 0.17	0.003 4/4 0.002 0.006	0.19 4/4 0.059 0.89	0.033 3/4 0.0005 0.52	-	-	-	-	-
Saskatchewan	1968	Adult liver	-	70	Mean #det/N min max	0.36 7/7 0.22 0.50	-	-	-	-	-	-	-	-	-	-
Alberta (Adult)	1968	Liver	-	70	Mean #det/N min max	0.64 6/6 0.23 1.48	-	-	-	-	-	-	-	-	-	-
Alberta (Adult)	1968	Brain	6.5	82	Mean #det/N min max	-	0.003 4/4 0.002 0.004	0.058 4/4 0.028 0.13	0.004 4/4 0.002 0.007	0.049 4/4 0.031 0.14	0.019 3/4 0.0005 0.24	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: SWAINSON'S HAWK (*Buteo swainsoni*)																
Alberta (adult)	1971	Whole body	9.5	61		-	0.040	0.87	0.080	0.34	0.15	ND	ND	-	ND	ND
		liver				0.14	-	-	-	-	-	-	-	-	-	-
Alberta (2 Nestlings)	1971	Whole body	3.0	83.9	Mean #det/N min max	-	0.010 1/2 0.0005 0.200	0.290 2/2 0.060 1.400	ND	0.040 2/2 0.020 0.080	0.028 2/2 0.020 0.040	ND	0.0157[a] 1/2 0.0005 0.490	-	ND	ND
		Liver	-	-	Mean #det/N min max	0.0173 2/2 0.010 0.030	-	-	-	-	-	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: FERRUGINOUS HAWK (*Buteo regalis*)																
Saskatchewan	1968	Fresh eggs	9.9	76	Mean	0.033	0.031	0.92	0.036	0.19	0.50	-	-	-	-	-
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3					
					min	0.023	0.019	0.53	0.020	0.083	0.40					
					max	0.061	0.050	2.06	0.065	0.42	0.58					
Saskatchewan	1969	Addled eggs	6.1	80	Mean	0.024	0.0048	0.92	0.0071	0.075	0.15	-	0.090[a]	-	ND	-
					#det/N	1/1	3/5	5/5	4/5	5/5	5/5		3/3			
					min		0.0005	0.18	0.0005	0.021	0.049		0.019			
					max		0.093	3.37	0.079	0.46	0.30		0.544			
Saskatchewan	1970	Egg condition not recorded	6.2	80	Mean	-	0.029	0.41	0.0059	0.53	0.21	ND	ND	-	ND	ND
					#det/N		2/2	2/2	1/2	2/2	2/2					
					min		0.017	0.27	0.0005	0.15	0.21					
					max		0.051	0.61	0.069	1.84	0.22					
Alberta	1968	Fresh eggs	7.9	75	Mean	0.084	0.067	1.01	0.067	0.14	0.64	-	-	-	-	-
					#det/N	3/3	5/5	5/5	5/5	5/5	5/5					
					min	0.034	0.009	0.22	0.016	0.027	0.10					
					max	0.25	0.62	13.1	0.99	0.70	2.33					
Alberta	1969	Addled eggs	5.5	80	Mean	0.025	0.025	0.44	0.012	0.18	0.24	-	-	-	ND	-
					#det/N	4/4	8/8	8/8	8/8	8/8	8/8					
					min	0.011	0.008	0.25	0.003	0.030	0.062					
					max	0.046	0.11	1.03	0.038	4.34	0.67					
Alberta	1971	Fresh eggs	3.2	84	Mean	0.047	0.0012	0.23	0.011	0.023	0.052	0.0007	0.0012[a]	-	ND	ND
					#det/N	9/9	7/9	9/9	7/9	8/9	9/9	1/9	1/9			
					min	0.010	0.0005	0.030	0.0005	0.0005	0.020	0.0005	0.0005			
					max	0.200	0.050	1.27	0.040	0.44	0.69	0.010	1.15			
Alberta	1971	Addled eggs	4.0	82	Mean	0.029	0.030	0.10	0.015	0.056	0.088	ND	ND	-	ND	ND
					#det/N	17/18	18/18	18/18	16/18	18/18	18/18					
					min	0.010	0.010	0.040	0.0005	0.020	0.030					
					max	0.15	0.14	0.26	0.11	0.21	0.55					
Alberta	1984-85	Addled eggs (2 pools)	4.6	81	Mean	-	0.004	0.089	0.012	0.049	0.11	0.006	0.19	0.021	0.003	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	
					min		0.001	0.053	0.003	0.047	0.085	0.003	0.17	0.019	0.002	
					max		0.014	0.15	0.049	0.050	0.14	0.011	0.21	0.024	0.004	
Saskatchewan (Nestling)	1969	Brain	3.8	87		-	ND	0.12	0.001	0.013	0.85	-	0.074[a]	-	ND	-
		Liver		77		0.18	-	-	-	-	-	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: FERRUGINOUS HAWK (*Buteo regalis*)																
Southern Alberta (Nestling)	1971	Liver			Mean #det/N min max	0.020 8/8 0.005 0.16	-	-	-	-	-	-	-	-	-	-
		Whole body	3.8	73	Mean #det/N min max	-	0.0011 2/9 0.0005 0.020	0.049 9/9 0.020 0.11	0.0014 2/9 0.0005 0.070	0.0029 5/9 0.0005 0.040	0.025 8/9 0.0005 1.84	ND	ND[a]	-	ND	ND
Southern Alberta (Adult)	1971	Whole body	10.0	9.2		-	ND	0.09	ND	0.03	.07	ND	ND[a]	-	ND	ND

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: ROUGH-LEGGED HAWK (*Buteo lagopus*)																
Quebec (Ungava)	1967	Fresh eggs	4.5	81	Mean #det/N min max	-	0.056 9/9 0.011 0.21	0.36 9/9 0.10 1.16	0.044 8/9 0.0005 0.220	0.008 9/9 0.007 0.250	ND	-	-	-	-	-
NWT (Keewatin)	1968	Addled egg	10.0	74	Mean	0.045	0.049	0.27	0.050	0.30	0.074	-	-	-	-	-
NWT (Keewatin)	1972	Addled eggs	7.8	82	Mean #det/N min max	0.27 2/2 0.22 0.32	0.014 2/2 0.010 0.020	2.08 2/2 1.84 2.35	0.010 2/2 0.010 0.010	0.080 2/2 0.080 0.080	0.040 2/2 0.040 0.040	0.010 2/2 0.010 0.010	3.36[a] 2/2 3.36 3.37	-	-	-
NWT (Mackenzie)	1966	Fresh eggs	4.6	83	Mean #det/N min max	-	0.006 2/2 0.001 0.032	0.29 2/2 0.22 0.36	0.008 2/2 0.001 0.061	0.086 2/2 0.060 0.12	-	-	-	-	-	-
NWT (Mackenzie)	1980-81	Fresh eggs	7.3	80	Mean #det/N min max	0.070 1/1	0.0032 1/2 0.0005 0.020	0.52 2/2 0.48 0.56	0.0022 1/2 0.0005 0.010	0.022 2/2 0.010 0.050	0.12 2/2 0.001 1.43	0.055 2/2 0.010 0.300	0.93 2/2 0.27 3.23	0.030 2/2 0.010 0.090	0.002 1/2 0.0005 0.010	0.035 2/2 0.02 0.06
NWT (Mackenzie)	1980-81	Addled eggs	8.2	76.8	Mean #det/N min max	0.040 1/1	0.0014 1/4 0.0005 0.030	0.26 4/4 0.03 1.19	0.0014 1/4 0.0005 0.030	0.039 4/4 0.010 0.140	0.29 4/4 0.005 2.69	0.037 4/4 0.010 0.610	1.57 4/4 0.53 5.08	0.046 4/4 0.010 0.190	0.0013 1/4 0.0005 0.0020	0.11 4/4 0.03 0.32
Yukon Territory	1973	Fresh eggs	5.7	80		-	ND	0.46	ND	0.050	0.030	0.019	0.32[a]	-	-	-
Northern Quebec (Biopsies from breeding adults)	1967	Subcut. fat	77		Mean #det/N min max	-	0.34 4/4 0.098 1.08	5.89 4/4 2.93 14.2	0.51 4/4 0.27 1.50	2.71 4/4 0.73 12.6	ND	-	-	-	-	-
		Breast muscle	0.3	75		-	ND	0.027	ND	ND	ND	-	-	-	-	-
NWT (Franklin)	1974	Liver	1.0	66		0.030	0.0005	0.13	0.0005	0.020	0.010	0.020	1.13	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: ROUGH-LEGGED HAWK (*Buteo lagopus*)																
Yukon (Nestlings)	1973	Liver	2.5	74	Mean	-	0.0050	0.074	0.0016	0.007	0.0016	0.007	0.21	-	0.0005	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min		0.0050	0.050	0.0005	0.005	0.0005	0.005	0.15		0.0005	
					max		0.0050	0.110	0.0050	0.010	0.0050	0.010	0.30		0.0005	
		Brain	4.4	85	Mean	-	0.0005	0.21	0.0005	0.014	0.0005	0.010	0.61	-	0.0005	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min		0.0005	0.12	0.0005	0.010	0.0005	0.005	0.41		0.0005	
					max		0.0005	0.36	0.0005	0.020	0.0005	0.020	0.91		0.0005	
		Fat	5.3	39	Mean	-	0.0016	0.99	0.0016	0.41	0.014	0.13	1.23	-	0.0016	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min		0.0005	0.69	0.0005	0.40	0.10	0.11	1.08		0.0005	
					max		0.005	1.43	0.005	0.41	0.20	0.16	1.37		0.005	

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: BROAD-WINGED HAWK (*Buteo platypterus*)																
Whitefish Point, Michigan (Spring migration)	1986	Blood	-	-	Mean	-	ND	0.011	ND	0.009	0.0045	0.0007	0.14	0.014	ND	0.068
					#det/N			2/2		2/2	2/2	1/2	2/2	2/2		2/2
					min			0.008		0.006	0.004	0.0005	0.10	0.011		0.052
					max			0.014		0.013	0.005	0.001	0.20	0.017		0.084

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: BALD EAGLE (*Haliaeetus leucocephalus*)																
Labrador	1971	Fresh egg	6.8	78		0.24	0.44	23.1	0.050	0.53	ND	0.020	17.4[a]	-	-	-
Cape Breton	1982	Addled eggs	-	-	Mean	-	-	2.23	-	-	-	0.024	8.11	-	-	0.042
					#det/N			2/2				2/2	2/2			2/2
					min			1.03				0.019	4.22			0.025
					max			4.84				0.032	15.6			0.072
South Ontario	1971	Addled eggs	8.1	75	Mean	0.54	1.59	47.3	0.035	1.26	0.094	0.13	131[a]	-	ND	ND
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.52	0.88	22.5	0.020	0.68	0.040	0.10	83.2			
					max	0.57	2.89	99.3	0.060	2.34	0.22	0.16	202			
South Ontario	1974	Addled eggs	7.6	75	Mean	0.24	1.49	33.8	0.022	0.85	0.052	0.293	18.8	0.108	-	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2		
					min	0.18	1.16	32.0	0.005	0.56	0.030	0.266	17.3	0.036		
					max	0.31	1.90	35.8	0.1	1.29	0.090	0.323	20.4	0.324		
North Ontario	1968	Addled egg	15.3	71		-	1.50	35.1	0.76	1.69	0.26	-	-	-	-	-
North Ontario (Lake Nipigon)	1969	Addled eggs	9.1	75	Mean	0.43	1.95	47.4	0.16	2.55	0.23	-	21.0[a]	-	ND	-
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3		3/3			
					min	0.40	1.82	24.2	0.060	2.35	0.16		10.1			
					max	0.51	2.19	68.9	0.48	2.87	0.30		30.6			
North Ontario	1970	Fresh eggs	4.2	83	Mean	0.26	0.27	19.4	0.16	0.92	0.20	-	13.5[a]	-	ND	ND
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4		4/4			
					min	0.19	0.22	17.8	0.10	0.59	0.14		9.4			
					max	0.32	0.47	21.8	0.27	1.15	0.24		19.6			
North Ontario	1970	Addled eggs	5.4	82	Mean	0.34	0.62	41.8	0.62	1.13	0.28	-	20.7[a]	-	ND	ND
					#det/N	6/6	6/6	6/6	6/6	6/6	6/6		6/6			
					min	0.27	0.34	21.2	0.34	0.66	0.14		9.35			
					max	0.48	0.88	81.8	1.03	2.51	0.69		53.0			
North Ontario	1971	Addled eggs	5.1	78	Mean	0.66	2.39	23.0	0.060	1.32	ND	0.025	80.6[a]	-	ND	ND
					#det/N	2/2	2/2	2/2	2/2	2/2		2/2	2/2			
					min	0.60	2.26	21.3	0.060	1.26		0.010	38.9			
					max	0.73	2.53	24.9	0.060	1.38		0.060	167			
North Ontario	1972	Dried egg	21.8	14		1.02	1.61	75.2	ND	7.1	0.86	ND	15.2[a]	-	ND	ND
Saskatchewan	1968	Addled eggs	7.8	77	Mean	-	0.28	1.96	0.12	0.18	0.007	-	-	-	-	-
					#det/N		3/3	3/3	3/3	3/3	2/3					
					min		0.15	1.37	0.056	0.069	0.0005					
					max		0.42	3.75	0.24	0.28	0.038					

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: BALD EAGLE (*Haliaeetus leucocephalus*)																
Saskatchewan	1969	Fresh egg	4.7	73		0.20	0.60	28.5	0.022	0.52	0.12	-	8.47[a]	-	0.066	-
Saskatchewan	1970	Fresh eggs	6.1	81	Mean #det/N min max	0.066 3/3 0.060 0.070	0.10 3/3 0.076 0.15	3.50 3/3 2.06 6.37	0.0005 1/3 0.0005	0.26 3/3 0.092 1.06	0.0005 1/3 0.0005	0.011 3/3 0.004 0.030	2.05[a] 3/3 1.05 3.90	-	ND	ND
Saskatchewan	1970	Addled eggs	6.2	81	Mean #det/N min max	0.13 6/6 0.04 2.62	0.092 6/6 0.048 0.22	4.67 6/6 2.10 15.5	0.0012 1/6 0.0005 0.12	0.19 6/6 0.033 1.00	0.001 1/6 0.0005 0.037	0.011 6/6 0.004 0.025	3.09[a] 6/6 1.09 5.71	-	ND	ND
Grand Manan Island, NB (Female subadult)	1970	Brain	6.4	80		-	0.42	7.09	0.098	0.18	0.062	0.005	10.4	-	ND	ND
Northern Ontario (Two adults)	1970	Breast muscle	-	-	Mean #det/N min max	14.4 2/2 6.88 30.2	-	-	-	-	-	-	-	-	-	-
		Liver	-	-	Mean #det/N min max	30.6 2/2 22.1 42.3	-	-	-	-	-	-	-	-	-	-
Manitoba (Nestling)	1969	Brain	3.7	90		-	0.022	0.53	ND	0.045	0.009	-	0.18	-	ND	-
		Breast Muscle	1.6	78		-	0.010	0.35	ND	0.024	0.007	-	0.25	-	ND	-
		Liver	2.0	76		-	0.095	2.12	0.013	0.11	0.017	-	1.45	-	ND	-
Langara Island, BC (Two adults)	1969	Brain	1.6	80.2	Mean #det/N min max	-	0.20 2/2 0.10 0.39	3.99 2/2 2.56 6.22	0.11 2/2 0.059 0.22	0.53 2/2 0.028 0.10	ND	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: GOLDEN EAGLE (*Aquila chrysaetos*)																
Saskatchewan	1969	Fresh egg	2.7	86		0.032	0.004	0.39	ND	0.17	0.18	-	-	-	ND	-
Saskatchewan	1972	Fresh egg	4.8	84		ND	ND	0.29	ND	0.13	0.070	ND	0.12[a]	-	-	-
Saskatchewan	1972-73	Addled eggs	6.4	82	Mean #det/N min max	0.0074 2/3 0.0005 0.040	ND	0.66 3/3 0.42 0.88	ND	0.088 3/3 0.060 0.16	0.054 3/3 0.020 0.13	0.0056 2/3 0.0005 0.019	0.30[a] 3/3 0.15 0.58	-	-	-
Alberta	1968-69	Addled eggs	4.7	82	Mean #det/N min max	0.048 4/4 0.017 0.22	0.0067 3/5 0.0005 0.24	1.19 5/5 0.47 2.81	0.017 5/5 0.005 0.22	0.18 5/5 0.056 0.56	0.21 5/5 0.052 0.86	-	0.71[a] 2/2 0.42 1.23	-	ND	-
Alberta	1974-75	Fresh eggs	12.8	73	Mean #det/N min max	0.020 3/3 0.005 0.16	0.005 3/3 0.0007 0.028	0.42 3/3 0.23 1.38	0.0088 3/3 0.0019 0.019	0.048 3/3 0.020 0.18	0.046 3/3 0.030 0.11	0.015 3/3 0.0095 0.038	0.32 3/3 0.11 2.61	-	-	-
Alberta	1973-75	Addled eggs	4.4	83	Mean #det/N min max	0.052 8/8 0.010 0.34	0.007 8/8 0.0005 0.028	1.07 8/8 0.53 2.05	0.0037 8/8 0.0005 0.076	0.17 8/8 0.040 2.12	0.095 8/8 0.020 0.89	0.015 8/8 0.0095 0.032	1.66 4/4 0.95 3.64	-	ND	-
Yukon Territory	1973	Addled egg	2.9	81		ND	ND	0.080	ND	0.010	0.010	ND	0.33[a]	-	ND	-
Northwest Territories, Mackenzie District (Two nestlings)	1973	Brain	4.8	86	Mean #det/N min max	-	0.005 2/2 0.005 0.005	0.21 2/2 0.18 0.25	0.0005 2/2	0.010 2/2 0.010 0.010	0.0016 2/2 0.0005 0.010	0.007 2/2 0.005 0.010	0.57 2/2 0.52 0.62	-	0.0005 2/2	-
		Liver	1.3	75	Mean #det/N min max	0.11[b] 2/2 0.080 0.15	0.0005 2/2	0.28 2/2 0.21 0.38	0.0005 2/2	0.007 2/2 0.005 0.010	0.0005 2/2	0.010 2/2 0.005 0.020	0.54 2/2 0.45 0.64	-	0.0005 2/2	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: OSPREY (*Pandion haliaetus*)																
Labrador	1971-72	Fresh eggs	3.5	84	Mean	0.097	0.70	6.17	0.093	0.0014	ND	0.0014	8.05[a]	-	-	-
					#det/N	3/3	3/3	3/3	3/3	1/3		1/3	3/3			
					min	0.070	0.17	5.67	0.090	0.0005		0.0005	6.9			
					max	0.13	0.44	7.15	0.100	0.010		0.010	9.8			
Ontario (North)	1971	Fresh eggs	2.5	85	Mean	0.092	0.17	1.98	0.033	0.026	ND	ND	1.47[a]	-	ND	ND
					#det/N	3/3	3/3	3/3	3/3	3/3			3/3			
					min	0.070	0.080	1.71	0.030	0.010			1.0			
					max	0.14	0.41	2.63	0.040	0.060			2.5			
Ontario (North)	1971	Addled eggs	5.0	85	Mean	0.11	0.80	5.89	0.010	0.103	0.0013	0.004	5.57[a]	-	ND	ND
					#det/N	5/5	5/5	5/5	3/5	5/5	5/5	5/5	5/5			
					min	0.060	0.41	3.12	0.0005	0.040	0.0005	0.0005	1.0			
					max	0.23	1.64	9.61	0.11	0.31	0.050	0.20	74.5			
Alberta	1974	Addled egg	6.8	80		0.010	1.69	9.29	1.63	0.33	0.030	0.0095	1.24	-	0.0005	0.020
Alberta	1975	Fresh egg	3.6	78		0.040	0.21	2.3	0.34	0.030	0.040	0.038	0.72	-	-	0.0005
BC (Eastern)	1969	Fresh eggs	4.0	82	Mean	-	0.16	4.54	0.057	0.009	0.017	-	0.34[a]	-	ND	-
					#det/N		2/2	2/2	2/2	2/2	2/2		2/2			
					min		0.15	3.37	0.023	0.005	0.014		0.33			
					max		0.17	6.11	0.14	0.017	0.020		0.35			
Yukon Territory	1973	Fresh eggs	9.6	65	Mean	0.70	0.31	17.9	0.093	0.039	0.063	0.027	1.34[a]	-	ND	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.62	0.070	13.3	0.076	0.030	0.050	0.019	0.87			
					max	0.79	1.37	24.0	0.11	0.050	0.080	0.038	2.08			
Southern Ontario (Adult)	April 1969	Brain	6.4	81		-	0.039	0.22	ND	0.013	ND	0.017	0.15	-	-	ND
		Liver	3.2	73		3.1	0.053	0.22	ND	0.021	ND	0.012	0.33	-	-	ND
Lake-of-the-Woods, Ontario (4-6 week-old nestling)	June 1971	Brain	2.9	84		0.25	ND	0.10	ND	0.020	ND	ND	1.1[a]	-	-	ND
		Breast Muscle	2.0	76		0.50	ND	0.46	ND	0.020	ND	ND	2.6[a]	-	-	ND
		Liver	2.9	76		0.68	ND	0.54	ND	ND	ND	ND	2.0[a]	-	-	ND

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: NORTHERN HARRIER (*Circus cyaneus*)																
Quebec (Ungava)	1969	Addled egg	5.9	78		0.09	0.066	14.5	ND	0.99	0.069	ND	3.0[a]	-	ND	ND
Manitoba	1967	Addled egg	8.3	77		0.28	0.062	2.65	0.12	1.31	0.13	-	-	-	-	-
Saskatchewan	1967	Egg condition not recorded	4.6	82		-	0.13	0.79	0.11	0.80	0.094	-	-	-	-	-
Alberta	1968	Egg condition not recorded	3.2	84		0.24	0.83	20.4	0.87	0.79	0.51	-	-	-	-	-
Saskatchewan-Alberta	1969	Fresh eggs	4.6	84	Mean #det/N min max	0.028 4/4 0.014 0.06	0.052 7/7 0.016 0.127	2.43 7/7 1.16 12.1	0.059 7/7 0.007 0.17	0.27 7/7 0.029 0.70	0.13 7/7 0.017 1.56	-	0.091[a] 2/2 0.03 0.28	-	0.0018 2/7 0.0005 0.046	-
Saskatchewan-Alberta	1969	Addled eggs	6.3	82	Mean #det/N min max	0.019 2/2 0.018 0.020	0.0048 8/12 0.0005 0.044	0.82 12/12 0.013 15.9	0.056 10/12 0.013 0.030	0.20 12/12 0.010 5.2	0.057 11/12 0.0005 0.59	-	0.093[a] 6/6 0.02 0.84	-	0.0014 12/12 0.0005 0.048	-
Saskatchewan (Three adults)	1968	Brain	6.6	81	Mean #det/N min max	-	0.004 3/3 0.003 0.007	0.039 3/3 0.02 0.084	0.008 3/3 0.007 0.009	0.007 3/3 0.004 0.015	0.030 3/3 0.021 0.048	-	-	-	-	-
		Liver	-	72	Mean #det/N min max	0.057 3/3 0.028 0.13	-	-	-	-	-	-	-	-	-	-
Vancouver Island, BC (One adult)	1968	Brain Breast Muscle	6.3 5.0	75 68	Mean #det/N min max	- -	0.081 0.78	0.55 4.17	0.20 1.27	0.048 0.092	ND ND	- -	- -	- -	- -	- -
Hawk Cliff, Ontario (Fall migration)	1986	Blood	-	-	Mean #det/N min max	-	ND	0.019 2/2 0.009 0.029	ND	0.0012 1/2 0.0005 0.003	0.0007 1/2 0.0005 0.001	ND	ND	0.0007 1/2 0.0005 0.001	ND	0.001 2/2 0.001 0.001

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: MERLIN (*Falco columbarius*)																
Prairie race:																
Alberta	1968	Fresh egg	14.8	74		0.18	0.33	27.5	0.96	2.21	5.40	-	-	-	-	-
		Addled egg	5.3	84		0.514	0.051	5.08	0.010	0.072	0.11	-	1.03[a]	-	ND	-
Alberta	1969	Viable eggs	6.2	81	Mean	0.259	0.019	9.92	0.076	0.417	0.543	-	0.561[a]	-	0.0082	-
					#det/N	11/12	10/12	12/12	12/12	12/12	12/12		11/11		8/12	
					min	0.12	0.0005	2.27	0.018	0.036	0.10		0.147		0.0005	
					max	1.29	0.175	84.6	0.304	2.25	2.41		1.96		0.171	
		Nonviable eggs	7.6	79	Mean	0.201	0.012	11.1	0.065	0.91	1.00	-	0.48[a]	-	0.0046	-
					#det/N	6/6	5/7	7/7	7/7	7/7	7/7		7/7		3/7	
					min	0.11	0.0005	1.57	0.019	0.24	0.090		0.16		0.0005	
					max	0.45	0.11	65.8	0.17	2.10	1.74		1.72		0.248	
Alberta	1970	Viable eggs	6.8	80	Mean	0.17	0.0080	6.25	0.069	0.21	0.43	0.025	0.969[a]	-	ND	ND
					#det/N	37/37	26/37	37/37	37/37	37/37	37/37	37/37	37/37			
					min	0.050	0.0005	1.17	0.013	0.029	0.076	0.008	0.366			
					max	1.02	0.157	135.0	0.10	1.81	4.63	0.63	9.7			
		Nonviable eggs	6.1	81	Mean	0.21	0.024	13.5	0.034	0.22	0.26	0.023	1.052[a]	-	ND	ND
					#det/N	5/5	4/5	5/5	4/5	5/5	5/5	5/5	5/5			
					min	0.070	0.0005	2.64	0.0005	0.058	0.079	0.012	0.601			
					max	0.67	0.12	72.9	0.721	0.72	0.97	0.081	2.28			
Alberta	1971	Viable eggs	5.7	82	Mean	0.23	0.0090	8.77	0.0126	0.34	0.28	0.019	1.169[a]	-	ND	ND
					#det/N	26/26	18/26	26/26	18/26	26/26	26/26	26/26	26/26			
					min	0.060	0.0005	2.48	0.0005	0.070	0.080	0.010	0.450			
					max	1.20	0.12	85.2	0.34	2.90	2.84	0.24	5.61			
		Nonviable eggs	5.1	82	Mean	0.12	0.0032	8.20	0.0045	0.30	0.10	0.020	3.35	-	ND	ND
					#det/N	2/2	1/2	2/2	1/2	2/2	2/2	2/2	2/2			
					min	0.11	0.0005	3.54	0.0005	0.11	0.10	0.020	1.85			
					max	0.14	0.020	19.0	0.040	0.84	0.11	0.020	6.03			

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: MERLIN (*Falco columbarius*)																
Alberta	1972	Viable eggs	10.4	80	Mean	0.12	0.0022	5.50	0.0276	0.38	0.24	0.049	1.008[a]	-	-	-
					#det/N	46/46	17/46	46/46	41/46	46/46	46/46	46/46	46/46			
					min	0.040	0.0005	1.13	0.0005	0.050	0.040	0.010	0.420			
					max	0.48	0.13	43.6	0.38	2.33	1.45	1.84	2.880			
		Nonviable eggs	10.4	80	Mean	0.138	0.0130	11.9	0.0147	0.43	0.29	0.047	1.313[a]	-	-	-
					#det/N	24/24	16/25	25/25	17/25	25/25	25/25	25/25	25/25			
					min	0.060	0.0005	1.80	0.0005	0.040	0.070	0.020	0.630			
					max	0.570	0.50	66.7	0.26	3.10	0.75	0.120	4.70			
Saskatchewan	1972	Viable eggs	8.1	79	Mean	0.078	0.0594	1.92	0.348	3.00	2.16	0.222	0.971[a]	-	-	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.060	0.042	1.66	0.114	2.78	2.00	0.190	0.890			
					max	0.10	0.084	2.23	1.06	3.24	2.33	0.266	1.060			
Alberta	1973	Viable eggs	9.7	75	Mean	0.069	0.0807	10.7	0.0949	0.61	0.46	0.0894	1.824[a]	-	-	-
					#det/N	21/23	23/23	23/23	21/23	23/23	23/23	23/23	23/23			
					min	0.0005	0.014	1.32	0.0005	0.19	0.12	0.038	0.660			
					max	0.56	3.178	56.9	8.702	4.30	1.54	0.532	5.540			
		Nonviable eggs	9.6	75	Mean	0.034	0.0564	21.4	0.240	0.65	0.61	0.137	2.158[a]	-	-	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4			
					min	0.010	0.042	8.97	0.076	0.31	0.34	0.057	0.870			
					max	0.21	0.308	82.7	0.304	0.98	1.61	0.209	3.11			
Saskatchewan	1973	Addled egg	11.2	74		0.01	0.080	45.9	0.060	0.29	0.23	0.070	3.32[a]	-	-	-
Yukon	1973	Viable eggs	5.9	80	Mean	0.27	0.21	18.8	0.012	0.79	0.18	0.049	4.19[a]	-	-	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.21	0.17	18.6	0.0005	0.42	0.18	0.030	3.68			
					max	0.34	0.25	19.0	0.29	1.47	0.19	0.080	4.78			
NWT (District of Mackenzie)	1973	Addled egg	16	79		0.040	0.53	19.7	0.20	2.64	0.39	0.050	3.77[a]	-	-	-
Alberta	1974	Viable eggs	5.9	78	Mean	0.048	0.042	11.5	0.056	0.30	0.38	0.0982	1.68	-	0.023	0.0583
					#det/N	28/28	28/28	28/28	28/28	28/28	28/28	828/28	28/28		28/28	28/28
					min	0.010	0.014	2.78	0.002	0.070	0.030	0.009	0.62		.005	.005
					max	0.20	0.57	80.9	4.52	1.80	4.18	1.50	4.28		0.430	0.760
		Nonviable eggs	6.6	81	Mean	0.040	0.028	11.8	0.12	0.21	0.23	0.059	2.09	-	0.0320	0.0719
					#det/N	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5		5/5	5/5
					min	0.010	0.014	2.36	0.076	0.040	0.070	0.038	1.05		0.005	0.020
					max	0.10	0.056	27.3	0.46	0.46	1.06	0.095	3.73		0.080	0.760

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: MERLIN (*Falco columbarius*)																
Alberta	1975	Viable eggs	6.3	81	Mean	0.053	0.039	8.01	0.0364	0.38	0.59	0.062	1.34	-	-	0.0817
					#det/N	13/13	13/13	13/13	13/13	13/13	13/13	13/13	13/13			13/13
					min	0.010	0.014	1.73	.005	0.13	0.28	0.019	0.84			0.005
					max	0.14	0.21	44.5	0.320	1.86	1.21	0.87	2.91			0.400
		Nonviable eggs	6.3	81	Mean	0.032	0.049	8.22	0.064	0.49	0.53	0.029	1.24	-	-	0.757
					#det/N	12/12	12/12	12/12	12/12	12/12	12/12	12/12	12/12			12/12
					min	0.005	0.014	3.23	0.005	0.060	0.090	0.0095	0.93			0.010
					max	0.10	0.17	33.8	0.10	5.61	4.95	0.35	2.49			0.280
NWT	1975	Viable eggs	6.9	79	-	0.010	0.003	10.7	ND	0.50	0.55	0.040	1.30	-	-	-
Alberta	1976	Viable eggs	5.1	81	Mean	0.049	0.014	7.25	0.21	0.094	0.64	0.040	1.02	0.27	-	0.176
					#det/N	33/33	33/33	33/33	33/33	33/33	33/33	33/33	33/33	33/33		33/33
					min	0.020	0.007	0.24	0.038	0.005	0.005	0.0095	0.22	0.090		0.020
					max	0.24	0.18	90.9	1.71	1.72	6.16	3.29	2.95	1.31		0.550
		Nonviable eggs	5.1	81	Mean	0.057	0.038	10.1	0.087	0.14	0.66	0.032	1.17	0.17	-	0.192
					#det/N	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10		10/10
					min	0.020	0.007	3.05	0.019	0.005	0.070	0.001	0.71	0.036		0.090
					max	0.16	0.70	22.7	0.27	0.40	2.54	0.42	2.16	0.54		0.260
Alberta	1977	Viable eggs	5.4	78	Mean	-	0.028	16.0	0.019	0.13	1.15	0.13	2.00	-	0.052	0.124
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	2/2
					min		0.028	14.7	0.019	0.090	1.10	0.057	1.77		0.030	0.090
					max		0.028	17.5	0.019	0.20	1.21	0.29	2.25		0.090	0.170
		Nonviable eggs	7.2	77	Mean	-	0.043	14.7	0.13	0.25	1.81	0.31	1.21	-	0.079	0.059
					#det/N		5/5	10/10	10/10	10/10	10/10	10/10	10/10		10/10	9/9
					min		0.014	3.50	0.019	0.050	0.72	0.038	0.47		0.010	0.020
					max		0.15	71.3	3.42	1.89	9.09	10.1	3.95		0.75	0.180
Alberta	1978	Viable eggs	4.3	82	Mean	-	0.115	16.21	0.042	0.232	0.411	0.057	1.44	0.140	0.098	-
					#det/N		8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	
					min		0.020	3.21	0.010	0.030	0.26	0.040	0.82	0.090	0.010	
					max		1.24	57.8	0.30	0.91	0.700	0.11	3.10	0.22	0.93	
		Nonviable eggs	6.3	78	Mean	-	0.081	2.13	0.0056	0.0298	0.0838	0.023	1.316	0.063	0.0066	-
					#det/N		3/5	9/9	6/9	9/9	9/9	9/9	9/9	9/9	7/9	
					min		0.0005	0.090	0.0005	0.005	0.010	0.0005	0.250	0.010	0.0005	
					max		0.17	24.5	0.23	0.42	3.62	0.13	7.02	0.69	0.050	

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: MERLIN (*Falco columbarius*)																
Saskatchewan/Alberta	1988	Fresh eggs	6.0	81	Mean	-	0.0034	2.95	0.012	0.042	0.30	0.014	0.24	0.080	0.008	-
					#det/N		14/14	14/14	14/14	14/14	14/14	14/14	14/14	14/14	14/14	
					min		0.0030	0.28	0.003	0.007	0.065	0.005	0.13	0.023	0.003	
					max		0.016	65.8	0.089	0.59	2.03	0.23	0.31	0.30	0.082	
Alberta (Nestling)	1969	Brain	2.4	85.6		-	0.019	0.294	0.028	0.068	0.181	-	-	-	ND	-
		Liver	-	-		0.10	-	-	-	-	-	-	-	-	-	-
Alberta (Nestling)	1969	Brain	4.6	86.4		-	ND	0.235	ND	0.017	0.014	-	-	-	-	-
		Liver	-	71.0		0.084	-	-		-	-	-	-	-	-	-
Alberta (One-day-old nestling)	1969	Whole body	3.7	85		0.21	0.066	8.02	0.032	1.41	0.52	-	0.142[a]	-	ND	-
Alberta (Nestling)	1971	Whole body	5.2	74.1		-	0.020	0.70	0.020	0.020	0.030	ND	ND	-	ND	ND
		Liver	-	-		0.050	-	-	-	-	-	-	-	-	-	-
Alberta (Four-weeks-old nestling)	1972	Brain	10.4	86.7		-	ND	0.070	ND	0.010	ND	ND	-	-	-	-
		Liver	4.3	74.0		0.040	ND	0.11	ND	0.060	0.030	ND	ND	-	-	-
		Breast muscle	5.6	79.6		0.010	ND	0.12	ND	0.010	ND	ND	ND	-	-	-
		Fat	47.6	41.5		-	ND	6.89	ND	0.48	0.52	0.050	1.55[a]	-	-	-
Alberta (Two one-week-old nestlings)	1973	Liver	1.6	76.7	Mean	0.062[b]	0.010	3.17	0.005	0.079	0.049	0.025	1.56	-	ND	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.060	0.010	2.71	0.005	0.070	0.040	0.020	1.33			
					max	0.080	0.010	3.70	0.005	0.090	0.060	0.030	1.83			
		Brain	2.0	88.0	Mean	-	0.010	1.09	0.007	0.035	0.010	0.010	1.87	-	ND	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min		0.010	0.80	0.005	0.030	0.010	0.010	1.50			
					max		0.010	1.49	0.010	0.040	0.010	0.010	2.34			
		Fat	26.1	56.5		-	0.66	49.3	0.040	0.79	0.67	0.10	13.5	-	ND	-
Southern Alberta (Nestling)	1976	Liver	1.2	73.7		0.030	0.0007	0.15	0.002	0.010	0.090	0.0095	0.0005	0.018	-	0.0005
		Fat	65.2	30.5		-	0.0005	3.03	0.0005	0.010	0.18	0.005	0.32	0.060	-	0.010

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: MERLIN (*Falco columbarius*)																
Eastern race:																
Kujuak (Quebec)	1969	Fresh egg	5.2	79.6		0.72	0.873	33.2	ND	0.23	0.082	0.003	7.83[a]	-	ND	-
Whitefish Point, Michigan (Spring migration)	1986-88	Blood	-	-	Mean #det/N min max	-	-	0.640 4/4 0.164 0.803	-	0.047 4/4 0.002 0.124	0.0254 4/4 0.003 0.048	0.0014 3/3 0.0004 0.0016	0.226 4/4 0.055 0.302	0.0367 4/4 0.004 0.0124	0.0057 1/4 0.0005 0.004	0.0408 4/4 0.005 0.027
Hawk Cliff, Ontario (Fall migration)	1986-87	Blood	-	-	Mean #det/N min max	-	ND	0.467 3/3 0.031 3.29	ND	0.006 3/3 0.001 0.027	0.0096 3/3 0.0013 0.255	0.0014 3/3 0.0004 0.0016	0.239 3/3 0.0504 0.63	0.0136 3/3 0.0021 0.042	0.0007 1/3 0.0005 0.0015	0.0315 3/3 0.005 0.125
British Columbian race:																
BC (Pine Lake)	1969	Addled egg	7.7	80		0.517	0.135	8.38	0.246	0.201	0.435	-	1.72[a]	-	ND	-
Weston Island, B.C. (Adult)	Nov 1968	Brain	12.6	65.3		0.77	2.10	15.8	0.849	0.379	0.224	ND	ND	-	ND	ND

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Alberta	1967	Fresh eggs	5.7	81	Mean	0.17	0.024	1.19	0.036	0.018	0.43	-	0.51[a]	-	-	-
					#det/N	5/5	9/9	9/9	9/9	9/9	9/9		5/5			
					min	0.13	0.002	0.46	0.0005	0.0005	0.21		0.26			
					max	0.48	0.048	3.22	0.16	0.19	1.95		0.87			
		Nonviable eggs	7.6	81	Mean	-	0.033	2.98	0.058	0.058	0.25	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2	2/2					
					min		0.027	2.79	0.043	0.028	0.16					
					max		0.040	3.18	0.077	0.12	0.39					
Alberta	1968	Fresh eggs	5.0	82.1	Mean	0.30	0.14	3.12	0.10	0.18	0.83	-	1.45[a]	-	-	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2		1/1			
					min	0.12	0.032	1.00	0.026	0.057	0.23					
					max	0.73	0.58	9.81	0.38	0.55	2.93					
		Egg condition not recorded	8.3	74	Mean	0.23	0.092	4.56	0.092	0.26	0.87	-	1.54[a]	-	-	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4		4/4			
					min	0.14	0.035	2.46	0.047	0.071	0.32		0.53			
					max	0.37	0.23	6.96	0.19	0.67	2.77		3.90			
		Addled eggs	9.0	75	Mean	0.63	0.075	4.17	0.091	0.220	0.60	-	0.54[a]	-	-	-
					#det/N	6/6	9/9	9/9	9/9	9/9	9/9		3/3			
					min	0.069	0.014	0.47	0.016	0.027	0.34		0.45			
					max	1.71	0.47	13.2	0.26	1.36	2.58		0.69			
Alberta	1969	Viable eggs	5.8	81	Mean	0.15	0.017	1.63	0.023	0.13	0.031	-	0.65[a]	-	0.0006	-
					#det/N	33/33	32/34	34/34	34/34	34/34	34/34		32/32		2/34	
					min	0.035	0.0005	0.27	0.002	0.022	0.050		0.14		0.0005	
					max	0.95	0.049	9.0	0.33	0.77	2.30		2.0		0.043	
		Egg condition not recorded	8.8	80	Mean	0.14	0.024	4.1	0.040	0.26	1.10	-	0.69[a]	-	0.0035	-
					#det/N	7/7	7/7	7/7	7/7	7/7	7/7		6/6		3/7	
					min	0.052	0.012	0.76	0.015	0.080	0.43		0.55		0.0005	
					max	0.51	0.25	28.9	0.13	6.45	30.2		0.98		0.169	
		Infertile eggs	4.9	83	Mean	0.19	0.036	1.67	0.029	0.23	0.42	-	1.03[a]	-	ND	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2		2/2			
					min	0.14	0.031	0.97	0.026	0.11	0.40		1.00			
					max	0.24	0.043	2.88	0.032	0.48	0.43		1.07			
		Addled eggs	6.3	82	Mean	0.14	0.017	1.89	0.015	0.25	0.26	-	0.23[a]	-	0.001	-
					#det/N	11/11	14/14	14/14	14/14	14/14	14/14		11/11		3/14	
					min	0.019	0.003	0.38	0.003	0.035	0.12		0.0005		0.0005	
					max	0.53	0.11	13.1	0.057	8.94	0.98		0.66		0.016	

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Alberta	1970	Viable eggs	6.5	81	Mean	0.085	0.0015	2.42	0.0028	0.13	0.42	0.019	0.821[a]	-	ND	ND
					#det/N	33/33	8/33	33/33	15/33	33/33	33/33	33/33	32/32			
					min	0.020	0.0005	0.52	0.0005	0.028	0.065	0.004	0.242			
					max	1.22	0.176	13.9	0.55	1.0	7.0	0.21	9.28			
		Nonviable eggs	7.2	81	Mean	0.13	0.0010	1.23	0.0008	0.11	0.41	0.013	0.525[a]	-	ND	ND
					#det/N	6/6	1/6	6/6	1/6	6/6	6/6	6/6	6/6			
					min	0.050	0.0005	0.50	0.0005	0.050	0.11	0.005	0.190			
					max	0.60	0.034	2.74	0.0080	0.23	1.69	0.059	0.986			
Alberta	1971	Viable eggs	5.6	81	Mean	0.072	0.0009	1.69	0.0009	0.13	0.22	0.027	0.789[a]	-	ND	ND
					#det/N	18/18	3/18	18/18	2/18	18/18	18/18	17/18	18/18			
					min	0.020	0.0005	0.29	0.0005	0.020	0.050	0.0005	0.200			
					max	0.81	0.030	5.95	0.17	0.95	1.02	0.41	1.68			
		Egg condition not recorded	5.8	82	Mean	0.040	ND	0.99	ND	0.042	0.23	0.0011	0.0275[a]	-	ND	ND
					#det/N	5/5		5/5		4/5	5/5	1/5	3/5			
					min	0.020		0.41		0.0005	0.070	0.0005	0.0005			
					max	0.17		3.0		0.55	0.46	0.030	0.68			
		Nonviable eggs	5.8	81	Mean	0.047	0.0010	1.03	0.0008	0.12	0.19	0.0103	0.298[a]	-	ND	ND
					#det/N	21/21	3/21	21/21	2/21	21/21	21/21	17/21	17/21			
					min	0.020	0.0005	0.21	0.0005	0.010	0.040	0.0005	0.0005			
					max	0.21	0.14	6.15	0.15	1.38	2.98	0.30	4.92			
Alberta	1972	Viable eggs	10.3	81	Mean	0.043	0.0010	1.28	0.0014	0.208	0.19	0.032	0.554[a]	-	-	-
					#det/N	24/24	5/25	25/25	7/25	25/25	25/25	24/25	25/25			
					min	0.0005	0.0005	0.61	0.0005	0.020	0.030	0.0005	0.170			
					max	1.11	0.056	7.29	0.076	4.45	0.71	0.15	1.87			
		Nonviable eggs	10.1	80	Mean	0.071	0.008	1.15	0.0009	0.12	0.17	0.034	0.461[a]	-	-	-
					#det/N	13/13	2/13	13/13	2/13	13/13	13/13	13/13	13/13			
					min	0.030	0.0005	0.74	0.0005	0.050	0.050	0.020	0.240			
					max	0.25	0.014	3.89	0.038	0.57	0.76	0.13	0.790			
Alberta	1973	Viable eggs	5.9	81	Mean	0.019	0.0026	1.76	0.0025	0.17	0.12	0.0066	1.002[a]	-	-	-
					#det/N	30/34	16/34	34/34	12/34	34/34	34/34	21/34	34/34			
					min	0.0005	0.0005	0.49	0.0005	0.020	0.005	0.0005	0.21			
					max	0.12	0.042	14.2	0.11	2.84	0.51	0.40	3.53			
		Nonviable eggs	6.4	81	Mean	0.011	ND	1.11	ND	0.12	0.13	0.0105	1.138[a]	-	-	-
					#det/N	4/5		5/5		5/5	5/5	4/5	5/5			
					min	0.0005		0.60		0.040	0.050	0.0005	0.51			
					max	0.030		2.04		0.40	0.37	0.038	3.84			

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Alberta	1974	Viable eggs	5.6	81	Mean	0.014	0.0069	2.10	0.026	0.097	0.19	0.050	0.82	-	0.0030	0.0119
					#det/N	33/33	33/33	33/33	33/33	33/33	33/33	33/33	33/33		18/33	29/33
					min	0.005	0.0007	0.31	0.0019	0.010	0.010	0.0095	0.22		0.0005	0.0005
					max	0.090	0.098	33.4	0.46	2.18	2.19	0.93	3.33		0.18	0.090
		Nonviable eggs	5.6	81	Mean	0.014	0.0079	2.13	0.028	0.11	0.28	0.048	0.91	-	0.0013	0.0119
					#det/N	16/16	16/16	16/16	16/16	16/16	16/16	16/16	16/16		6/16	14/16
					min	0.005	0.0007	0.68	0.0019	0.020	0.060	0.019	0.39		0.0005	0.0005
					max	0.060	0.056	17.5	0.27	2.50	2.43	0.49	9.57		0.030	0.060
Alberta	1975	Viable eggs	7.3	78	Mean	0.097	0.016	1.77	0.0068	0.099	0.14	0.027	0.63	-	-	0.0135
					#det/N	19/19	19/19	19/19	19/19	19/19	19/19	19/19	19/19			18/19
					min	0.005	0.005	0.33	0.005	0.010	0.005	0.010	0.16			0.0005
					max	0.13	0.100	10.9	0.020	7.20	1.87	0.100	2.80			0.22
		Nonviable eggs	7.3	78	Mean	0.008	0.017	3.22	0.009	0.24	0.20	0.047	1.65	-	-	0.0128
					#det/N	18/18	18/18	18/18	18/18	18/18	18/18	18/18	18/18			15/18
					min	0.005	0.005	1.26	0.005	0.030	0.070	0.010	0.74			0.0005
					max	0.020	0.050	7.35	0.030	3.97	1.23	0.35	3.16			0.050
Alberta	1976	Viable eggs	5.5	81	Mean	0.024	0.0054	1.07	0.024	0.042	0.22	0.023	0.45	0.042	-	0.0286
					#det/N	17/17	17/17	17/17	17/17	17/17	17/17	17/17	17/17	17/17		16/16
					min	0.010	0.0007	0.20	0.0019	0.010	0.030	0.0095	0.12	0.009		0.005
					max	0.060	0.0070	4.99	0.19	0.51	2.43	0.076	1.44	0.13		0.150
		Nonviable eggs	5.5	80	Mean	0.018	0.0063	1.85	0.030	0.077	0.34	0.022	0.76	0.068	-	0.0571
					#det/N	23/23	23/23	23/23	23/23	23/23	23/23	23/23	23/23	23/23		23/23
					min	0.005	0.0007	0.50	0.002	0.010	0.030	0.009	0.30	0.009		0.005
					max	0.12	0.0070	5.81	0.23	0.51	2.07	0.25	5.77	0.43		0.150
Alberta	1977	Viable eggs	4.2	82	Mean	-	-	0.52	0.027	0.017	0.094	0.027	0.39	0.018	0.005	0.010
					#det/N			2/2	2/2	2/2	2/2	2/2	2/2	1/1	2/2	2/2
					min			0.41	0.019	0.010	0.040	0.019	0.32		0.005	0.010
					max			0.65	0.038	0.030	0.22	0.038	0.48		0.005	0.010
		Nonviable eggs	5.6	80	Mean	-	0.084	1.35	0.029	0.060	0.27	0.048	0.64	0.054	0.0065	0.0231
					#det/N		1/1	17/17	17/17	17/17	17/17	17/17	17/17	1/1	16/17	16/16
					min			0.36	0.002	0.010	0.050	0.019	0.019		0.0005	0.005
					max			8.32	0.15	1.76	1.20	0.68	4.02		0.030	0.240

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Alberta	1978	Viable eggs	4.7	83	Mean	-	0.005	0.98	0.002	0.024	0.39	0.057	0.28	0.050	0.0103	-
					#det/N		7/7	7/7	7/7	7/7	7/7	7/7	7/7	1/1	6/7	
					min		0.0005	0.11	0.0005	0.010	0.080	0.020	0.10		0.0005	
					max		0.020	7.06	0.010	0.070	2.31	1.42	0.65		0.120	
		Infertile eggs	6.3	78	Mean	-	0.008	0.53	0.008	0.032	0.11	0.018	0.28	0.030	0.0063	-
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	1/1	3/3	
					min		0.005	0.080	0.005	0.010	0.006	0.010	0.10	0.0005	0.005	
					max		0.010	1.49	0.010	0.080	0.25	0.030	0.63	0.030	0.010	
		Nonviable eggs	6.9	81	Mean	-	0.013	0.60	0.008	0.057	0.12	0.012	0.33	0.025	0.0023	-
					#det/N		5/5	5/5	5/5	5/5	5/5	5/5	5/5	3/3	3/5	
					min		0.005	0.33	0.005	0.005	0.030	0.010	0.14	0.010	0.0005	
					max		0.040	1.21	0.010	0.35	0.36	0.020	0.62	0.080	0.010	
Alberta	1980	Viable eggs	6.1	80	Mean	0.016	0.0012	0.79	0.002	0.14	0.11	0.093	0.36	0.030	0.014	0.031
					#det/N	9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9
					min	0.010	0.0005	0.32	0.005	0.010	0.040	0.017	0.17	0.010	0.005	0.010
					max	0.050	0.010	1.63	0.030	1.02	0.22	0.35	0.93	0.060	0.040	0.050
		Nonviable eggs	6.1	81	Mean	0.026	0.0005	0.33	0.0014	0.28	0.25	0.045	0.50	0.040	0.033	0.010
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min	0.010	0.0005	0.15	0.0005	0.020	0.12	0.022	0.19	0.030	0.030	0.005
					max	0.060	0.0005	0.85	0.010	1.05	0.76	0.16	0.82	0.070	0.040	0.020
Saskatchewan	1967	Viable eggs	7.6	76	Mean	0.080	0.024	8.05	0.047	0.0051	0.71	-	0.51[a]	-	-	-
					#det/N	3/3	6/6	6/6	6/6	3/6	6/6		3/3			
					min	0.070	0.007	1.52	0.006	0.0005	0.27		0.42			
					max	0.090	0.061	41.4	0.30	0.236	2.56		0.70			
		Addled egg	5.0	81		-	0.039	2.52	0.048	0.123	0.022	-	-	-	-	-
Saskatchewan	1968	Viable eggs	9.8	75	Mean	0.19	0.069	5.30	0.078	0.61	0.49	-	0.70[a]	-	-	-
					#det/N	6/6	6/6	6/6	6/6	6/6	6/6		6/6			
					min	0.095	0.023	1.79	0.021	0.075	0.13		0.39			
					max	0.43	0.52	8.68	0.59	3.96	1.50		1.30			
Saskatchewan	1969	Viable eggs	5.4	81	Mean	0.098	0.021	2.20	0.018	0.28	0.30	-	0.46[a]	-	ND	-
					#det/N	5/5	7/7	7/7	7/7	7/7	7/7		6/6			
					min	0.033	0.010	0.90	0.008	0.062	0.12		0.25			
					max	0.25	0.034	4.86	0.074	1.09	1.75		0.79			
		Nonviable egg	6.0	80		0.091	0.014	1.33	0.014	0.070	0.467	-	0.23[a]	-	ND	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON *(Falco mexicanus)*																
Saskatchewan	1970	Viable eggs	7.9	81	Mean	0.044	0.0014	3.28	0.029	0.17	0.52	0.029	1.40[a]	-	ND	ND
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4			
					min	0.030	0.0005	0.14	0.016	0.040	0.22	0.016	0.72			
					max	0.060	0.028	31.4	0.079	0.50	2.26	0.066	3.39			
		Nonviable eggs	6.0	83	Mean	0.010	0.0013	2.08	0.0019	0.11	0.37	0.018	0.39[a]	-	ND	ND
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3			
					min	0.010	0.0005	1.24	0.0005	0.025	0.20	0.009	0.18			
					max	0.010	0.009	2.85	0.029	0.68	0.57	0.029	0.69			
Saskatchewan	1972	Viable eggs	10.6	79	Mean	0.0337	ND	1.66	ND	0.142	0.119	0.019	0.402[a]	-	-	-
					#det/N	6/6		6/6		6/6	6/6	6/6	6/6			
					min	0.012		0.68		0.030	0.060	0.010	0.170			
					max	0.050		4.47		0.37	0.17	0.060	0.710			
		Nonviable eggs	9.1	80	Mean	0.039	ND	1.55	0.0008	0.091	0.16	0.0077	0.541[a]	-	-	-
					#det/N	9/9		9/9	1/9	9/9	9/9	8/9	9/9			
					min	0.010		0.67	0.0005	0.010	0.050	0.0005	0.190			
					max	0.27		3.35	0.020	0.49	1.13	0.020	1.42			
Saskatchewan	1973	Viable eggs	4.9	81	Mean	0.083	0.0028	2.29	0.0124	0.49	0.43	0.060	0.933[a]	-	-	-
					#det/N	5/5	2/5	5/5	3/5	5/5	5/5	5/5	5/5			
					min	0.020	0.0005	1.16	0.0005	0.22	0.19	0.019	0.45			
					max	0.38	0.098	6.05	0.266	1.94	2.42	0.99	1.75			
		Nonviable eggs	6.3	80	Mean	0.0237	0.0047	1.10	0.0059	0.075	0.24	0.029	0.637[a]	-	-	-
					#det/N	5/6	3/6	6/6	3/6	6/6	6/6	6/6	6/6			
					min	0.0005	0.0005	0.42	0.0005	0.030	0.12	0.019	0.19			
					max	0.070	0.462	6.24	0.228	0.31	0.59	0.057	1.09			
Saskatchewan	1975	Nonviable eggs	12.6	71	Mean	0.011	0.025	5.20	0.009	0.33	1.54	0.086	3.61	-	-	0.173
					#det/N	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5			5/5
					min	0.005	0.010	2.76	0.005	0.27	0.83	0.060	1.95			0.090
					max	0.030	0.060	8.08	0.010	0.45	2.43	0.10	6.74			0.300
Saskatchewan	1978	Infertile eggs	5.7	78	Mean	-	0.024	1.65	0.004	0.12	0.48	0.020	0.51	-	0.01	-
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min		0.010	1.11	0.0005	0.050	0.43	0.010	0.37		0.010	
					max		0.060	2.46	0.030	0.29	0.53	0.040	0.71		0.010	
Saskatchewan	1988	Fresh eggs	5.5	82	Mean	-	0.005	0.87	0.0013	0.003	0.020	0.012	0.066	0.009	0.0006	0.0029
					#det/N		4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
					min		0.005	0.041	0.0012	0.002	0.013	0.008	0.036	0.007	0.0003	0.0016
					max		0.005	0.24	0.0014	0.004	0.031	0.016	0.12	0.014	0.0015	0.0044

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Saskatchewan	1988	Fresh eggs	7.2	77	Pool(9)	-	ND	0.056	0.001	0.002	0.012	0.11	0.072	0.004	ND	0.0027
			7.1	78	Pool(5)	-	ND	0.041	0.001	0.002	0.009	0.010	0.15	0.003	ND	0.0003
Alberta (Nestling)	1969	Brain	3.0	89		-	0.006	0.095	0.005	0.014	0.007	-	-	-	ND	-
		Liver	-	77		0.153	-	-	-	-	-	-	-	-	-	-
Alberta (Adult female)	1969	Brain	9.2	79		-	0.035	0.374	0.023	0.033	0.182	-	-	-	ND	-
		Breast muscle	3.4	70		-	0.091	0.648	0.076	0.051	0.42	-	-	-	ND	-
		Liver	2.4	72		1.26	0.048	0.285	0.042	0.056	0.426	-	-	-	ND	-
		Fat	85.2	15		-	ND	16.9	0.33	1.77	13.8	-	29.8[a]	-	ND	-
		Gonads	2.7	81		-	0.035	0.356	0.031	0.036	0.189	-	-	-	ND	-
Alberta (Three-day-old nestling)	1971	Whole body	2.8	87		0.16	ND	1.31	ND	0.040	0.47	0.010	0.66[a]	-	ND	ND
Alberta (Three four-week-old nestlings)	1972	Brain	9.8	83	Mean #det/N min max	ND	ND	0.13 3/3 0.060 0.20	ND	0.016 3/3 0.010 0.020	0.060 3/3 0.010 0.020	0.0014 3/3 0.0005 0.010	0.098[a] 3/3 0.070 0.150	-	-	-
		Breast muscle	7.0	77	Mean #det/N min max	0.0014 3/3 0.0005 0.010	ND	0.14 3/3 0.090 0.29	ND	0.0014 1/3 0.0005 0.10	0.017 3/3 0.005 0.10	0.0017 3/3 0.0005 0.020	0.060[a] 3/3 0.040 0.11	-	-	-
		Liver	8.1	75	Mean #det/N min max	0.0067 3/3 0.0003 0.030	ND	0.33 3/3 0.10 0.67	ND	0.023 3/3 0.020 0.030	0.026 3/3 0.0005 0.43	0.0014 3/3 0.0005 0.010	0.14[a] 3/3 0.09 0.22	-	-	-
		Fat	65.6	27	Mean #det/N min max	-	ND	9.46 2/2 3.89 23.0	ND	0.20 2/2 0.14 0.30	1.16 2/2 0.15 8.91	0.055 2/2 0.030 0.10	1.96[a] 2/2 1.85 2.08	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: PRAIRIE FALCON (*Falco mexicanus*)																
Alberta (Nestling)	1973	Brain	6.3	85.3		-	0.005	0.36	0.005	0.020	0.020	0.010	0.75	-	0.0005	-
		Liver	1.0	75.9		0.03[b]	0.0005	0.34	0.0005	0.010	0.020	0.010	0.29	-	0.0005	-
		Fat	25.6	62.8		-	0.050	13.6	0.010	0.93	2.92	0.13	3.98	-	0.030	-
Alberta (Adult female with suspected strychnine poisoning)	1975	Brain	7.5	78		-	0.030	1.97	0.020	0.080	0.11	0.020	0.31	-	-	0.010
		Liver	4.2	72		0.11	0.020	4.50	0.010	0.13	0.13	0.030	0.54	-	-	0.010
Alberta (Nestling)	1975	Brain	5.0	80		0.005	0.005	0.15	0.005	0.005	0.005	0.010	0.57	-	-	-
		Liver	0.5	72		0.020	ND	0.030	ND	ND	ND	0.005	0.18	-	-	-
Alberta (Adult male)	1976	Brain	8.8	79		0.11	0.0005	0.42	0.0005	0.040	0.090	0.005	0.44	0.010	-	-
		Liver	1.2	74		0.42	0.0005	0.84	0.0005	0.090	0.36	0.010	0.80	0.030	-	0.005
Alberta (Seven one-week-old nestlings)	1976	Brain	2.4	88	Mean #det/N min max	0.030 1/1	0.001 7/7 0.0005 0.005	0.43 7/7 0.080 2.56	0.0009 7/7 0.0005 0.010	0.039 7/7 0.010 0.26	0.16 7/7 0.030 4.10	0.007 7/7 0.0005 0.18	0.13 7/7 0.0005 1.36	0.011 7/7 0.0005 0.15	-	ND
		Liver	3.6	77	Mean #det/N min max	0.022 3/3 0.010 0.050	0.0025 7/7 0.0005 0.010	1.58 7/7 0.090 9.68	0.001 7/7 0.0005 0.010	0.12 7/7 0.010 0.83	0.55 7/7 0.070 20.9	0.030 7/7 0.005 0.34	0.74 7/7 0.050 4.02	0.069 7/7 0.010 0.84	-	ND
		Visceral Fat	28.2	61		-	0.0005	0.18	0.0005	0.020	0.030	0.030	0.080	0.010	-	ND
Alberta (Adult female)	1977	Brain	7.3	81		-	-	0.73	0.005	0.020	0.060	0.020	0.35	-	0.030	-
		Liver	2.0	72		-	0.005	0.94	0.005	0.060	0.21	0.020	0.51	-	0.060	-
		Fat	4.6	70		-	0.020	4.49	0.005	0.080	0.32	0.070	1.94	-	0.220	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: GYRFALCON (*Falco rusticolus*)																
Western NWT	1969	Dehydrated egg	46	7.3	Mean	-	ND	3.42	ND	0.023	0.084	-	3.45[a]	-	ND	-
NWT (C. Dorset)	1969	Fresh egg	3.6	84		1.43	0.048	9.02	ND	0.17	0.057	0.02	25.5[a]	-	ND	ND
Yukon	1973	Fresh eggs	5.6	81	Mean	0.030	ND	0.39	ND	0.014	0.025	0.027	0.52[a]	-	-	-
					#det/N	2/2		2/2		2/2	2/2	2/2	2/2			
					min	0.0005		0.34		0.010	0.020	0.019	0.27			
					max	0.03		0.44		0.020	0.030	0.038	0.99			
Yukon	1973	Addled eggs	7.1	80	Mean	0.025	ND	0.15	ND	0.010	0.13	0.024	0.36	-	-	-
					#det/N	2/3		3/3		3/3	3/3	3/3	3/3			
					min	0.020		0.07		0.010	0.010	0.019	0.17			
					max	0.030		0.30		0.010	0.020	0.038	0.58			
NWT (Inuvik)	1974	Addled egg	5.3	80		0.005	0.007	0.35	0.076	0.005	0.005	0.019	0.40	-	-	0.020
Yukon	1975	Fresh eggs	4.2	81	Mean	0.005	0.005	0.55	0.005	0.035	0.020	0.006	0.66	-	-	0.0047
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4			3/4
					min	0.005	0.005	0.53	0.005	0.030	0.020	0.005	0.58			0.0005
					max	0.005	0.005	0.57	0.005	0.040	0.020	0.010	0.77			0.010
NWT	1980	Egg condition not recorded	7.9	84		-	0.13	5.11	0.0005	0.45	0.27	0.90	10.7	0.43	0.060	0.13
NWT (Rankin Inlet)	1981	Addled egg	5.4	83		2.20	0.13	3.49	0.18	1.34	0.30	0.87	16.5	0.45	0.090	0.080
NWT (Cambridge Bay)	1983	Nonviable eggs	6.0	81	Mean	-	ND	0.021	0.0008	0.003	0.009	0.019	0.090	0.008	0.004	ND
					#det/N			4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	
					min			0.014	0.0005	0.001	0.006	0.011	0.033	0.005	0.002	
					max			0.045	0.0030	0.006	0.015	0.028	0.14	0.012	0.006	
Langara Island (Nestlings)	1971	Brain	6.0	82		0.16	ND	0.58	ND	ND	ND	0.030	0.68[a]	-	0.030	-
		Breast muscle	5.3	75	Mean	0.35	ND	1.43	ND	0.010	ND	0.014	1.14[a]	-	0.004	-
					#det/N	2/2		2/2		2/2		2/2	2/2		2/2	
					min	0.34		1.06		0.010		0.010	0.74		0.0005	
					max	0.36		1.94		0.010		0.020	1.77		0.040	
		Liver	3.7	75		0.68	ND	0.80	ND	0.010	ND	0.010	0.80[a]	-	ND	-
		Fat	58.5	34	Mean	-	ND	84.0	0.039	0.085	0.067	1.88	68.4[a]	-	5.54	-
					#det/N			2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min			73.2	0.030	0.080	0.050	1.33	60.7		4.93	
					max			96.5	0.050	0.090	0.090	2.66	77.2		6.23	
NWT (Nestling)	1973	Liver	0.4	76		0.005	0.0005	0.04	0.0005	0.0005	0.0005	0.005	0.14	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: GYRFALCON (*Falco rusticolus*)																
		Fat	70.6	11		-	0.005	0.39	0.0005	0.020	0.010	0.090	0.73	-	0.0005	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: AMERICAN KESTREL (*Falco sparverius*)																
New Brunswick	1967	Egg condition not recorded	6.1	80		-	0.28	12.4	0.34	0.44	ND	-	-	-	-	-
Saskatchewan	1967	Fresh eggs	7.0	79	Mean #det/N min max	-	0.013 4/5 0.0005 0.032	1.11 5/5 0.60 1.76	0.13 5/5 0.004 0.025	0.009 5/5 0.002 0.017	0.26 5/5 0.034 0.47	-	-	-	-	-
Alberta	1968	Fresh egg	13.1	72		0.16	0.017	1.89	0.033	0.060	0.58	-	-	-	-	-
Alberta		Addled eggs	16.6	64	Mean #det/N min max	0.28 2/2 0.27 0.29	0.16 2/2 0.11 0.22	7.19 2/2 4.47 11.9	0.18 2/2 0.16 0.21	1.00 2/2 0.80 1.25	2.54 2/2 1.35 4.79	-	-	-	-	-
South Ontario	1987	Fresh eggs	7.7	79	Pool(17)	-	0.0179	10.8	0.682	0.077	0.11	0.022	0.86	0.11	0.0034	0.0603
Central Ontario	1987	Fresh eggs	6.5	81	Pool(9)	-	0.0038	0.44	0.0088	0.13	0.009	0.017	0.18	0.027	ND	0.0037
North Ontario	1987	Fresh eggs	9.0	77	Pool(5)	-	ND	2.80	0.0201	0.081	0.078	0.007	0.35	0.061	0.0049	1.828
South Ontario	1988	Fresh eggs	6.4	81	Pool(10)	-	ND	3.83	0.0357	0.042	0.043	0.007	0.32	0.051	0.0046	0.0362
Central Ontario	1988	Fresh eggs	6.2	81	Pool(9)	-	ND	0.43	0.0045	0.066	0.039	0.005	0.17	0.038	ND	0.0546
Alberta (Adult)	June 1968	Brain	8.8	79		-	0.008	0.26	0.015	0.017	0.062	-	-	-	-	-
		Liver	-	70		0.74	-	-	-	-	-	-	-	-	-	-
Lethbridge, Alberta (Adult)	August 1968	Brain	6.4	81		-	0.010	0.079	0.023	0.009	0.020	-	-	-	-	-
		Liver	-	69		0.46	-	-	-	-	-	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Eastern Canadian population:																
Montreal	1985	Nonviable eggs	10.0	75	Mean	-	0.034	11.7	0.089	0.78	0.36	0.042	10.3	0.30	0.083	0.103
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.015	30.1	0.011	0.40	0.16	0.019	4.77	0.11	0.023	0.210
					max		0.085	46.5	0.58	2.21	1.09	0.088	28.0	1.08	0.34	0.747
Montreal	1986	Fresh eggs	6.2	79	Pool (4)	-	0.010	10.25	0.058	0.29	0.26	ND	12.7	0.30	ND	0.211
Ste Foy	1987	Addled eggs	6.7	80	Pool (8)	-	0.005	3.02	0.008	0.050	0.035	ND	7.26	0.14	0.011	0.168
New Brunswick (Adult female)	1969	Brain	7.2	80		-	ND	0.17	ND	0.017	0.050	ND	1.28[a]	-	ND	ND
		Liver	5.6	68		-	0.050	0.19	ND	0.036	0.061	ND	0.207[a]	-	ND	ND
		Fat	96.0	3.2		-	1.28	5.18	0.79	0.44	0.16	0.024	2.37[a]	-	ND	ND
Eastern Ontario (Adult female)	1983	Brain	6.7	79		-	0.003	1.31	0.005	0.049	0.10	0.006	0.92	0.085	-	-
		Liver	1.7	74		-	0.006	2.45	0.004	0.088	0.10	0.006	3.08	0.18	-	-
		Breast muscle	4.5	70		-	0.009	10.0	0.026	0.22	0.51	0.017	9.11	0.44	-	-
Ottawa, Ontario (Juvenile)	1986	Brain	-	79		-	ND	0.45	0.001	0.045	0.070	0.87	0.023	0.023	ND	ND
		Liver	3.2	72		-	0.003	2.4	ND	0.25	0.68	0.010	5.10	0.061	ND	ND
Ottawa, Ontario (Juvenile)	1987	Brain	10.6	80.2		-	ND	0.018	ND	0.007	0.002	ND	ND	0.001	ND	ND
		Liver	4.5	71.9		-	0.001	0.036	ND	0.007	0.042	ND	ND	0.025	ND	ND
Western Canadian populations:																
South Alberta	1968	Addled egg	8.0	78		0.361	0.706	21.1	0.614	0.393	0.230	-	8.02[a]	-	-	-
North Alberta	1972	Fresh eggs	7.7	81	Mean	0.36	0.085	41.9	0.14	1.67	0.28	0.061	12.41[a]	-	0.15	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4		4/4	
					min	0.13	0.040	12.6	0.12	0.61	0.20	0.040	9.79		0.13	
					max	0.56	0.13	78.5	0.17	2.48	0.42	0.070	14.70		0.17	

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Alberta	1974	Fresh egg	3.9	84		0.14	0.007	16.8	0.27	0.63	0.13	0.095	8.56	-	0.07	0.53
		Addled eggs	6.2	77	Mean	0.32	0.007	8.16	0.057	0.48	0.12	0.013	5.06	-	0.0093	0.40
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4		4/4	4/4
					min	0.23	0.007	1.86	0.019	0.14	0.030	0.0095	2.34		0.0005	0.12
					max	0.50	0.007	18.4	0.19	1.04	0.29	0.019	8.58		0.06	0.83
Alberta	1977	Addled eggs	4.4	80	Mean	-	-	11.1	0.73	0.50	0.37	0.050	7.10	-	0.069	0.327
					#det/N			3/3	3/3	3/3	3/3	3/3	3/3		3/3	3/3
					min			7.31	0.46	0.20	0.24	0.038	3.27		0.06	0.16
					max			16.9	1.33	0.87	0.52	0.057	11.1		0.09	0.78
Alberta	1978	Nonviable eggs	3.7	82	Mean	-	0.0058	10.4	0.023	0.42	0.22	0.031	5.26	0.089	0.050	-
					#det/N		2/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	
					min		0.0005	5.72	0.010	0.23	0.10	0.020	3.02	0.070	0.03	
					max		0.24	16.5	0.050	1.07	0.38	0.12	9.86	0.12	0.07	
Alberta	1979	Fresh eggs	4.9	82	Mean	-	0.016	13.2	0.058	0.32	0.32	0.034	7.51	0.14	0.059	0.196
					#det/N		5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5
					min		0.010	7.36	0.050	0.24	0.28	0.030	5.55	0.12	0.030	0.120
					max		0.12	18.1	0.070	0.43	0.40	0.040	8.73	0.19	0.070	0.460
		Addled eggs	7.7	82	Mean	-	0.085	8.12	0.14	0.33	0.38	0.024	3.95	0.14	0.032	0.330
					#det/N		2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
					min		0.060	8.01	0.080	0.21	0.34	0.020	3.80	0.13	0.020	0.320
					max		0.12	8.24	0.24	0.51	0.42	0.030	4.10	0.15	0.050	0.340
Alberta	1980	Fresh eggs	3.4	83	Mean	-	0.091	14.1	0.0017	0.73	0.38	0.039	5.31	0.14	0.10	0.299
					#det/N		3/3	3/3	1/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.0005	10.7	0.0005	0.54	0.20	0.030	3.47	0.11	0.030	0.17
					max		1.39	16.5	0.020	1.13	0.80	0.050	10.5	0.18	0.21	0.54
Alberta	1981	Fresh eggs	5.5	82	Mean	0.27	0.045	8.81	0.087	0.32	0.35	0.051	4.30	0.082	0.079	0.272
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
					min	0.12	0.020	2.07	0.020	0.15	0.060	0.006	2.61	0.030	0.020	0.21
					max	0.98	0.17	29.2	0.64	1.52	2.71	1.06	11.7	0.15	0.15	0.39
		Addled eggs	5.2	81	Mean	0.51	0.040	8.91	0.089	0.42	0.75	0.041	5.31	0.098	0.096	0.243
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
					min	0.46	0.010	8.50	0.040	0.18	0.60	0.034	2.66	0.080	0.040	0.74
					max	0.57	0.16	9.34	0.20	0.99	0.94	0.049	10.6	0.12	0.23	0.08

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[c]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Alberta	1982	Fresh eggs	5.1	77	Mean	0.65	0.059	18.3	ND	0.81	1.49	0.16	10.5	-	0.55	0.244
					#det/N	2/2	2/2	2/2		2/2	2/2	2/2	2/2		2/2	2/2
					min	0.37	0.050	14.1		0.65	1.19	0.13	8.41		0.43	0.18
					max	1.14	0.070	23.7		1.00	1.87	0.19	13.2		0.70	0.33
		Addled eggs	5.6	81	Mean	0.33	0.053	4.43	0.063	0.17	0.14	0.016	3.92	0.12	0.035	0.212
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min	0.27	0.050	2.69	0.050	0.050	0.060	0.011	3.58	0.080	0.020	0.14
					max	0.44	0.060	10.2	0.080	0.76	0.29	0.030	4.48	0.20	0.11	0.38
Southern Alberta (Adult)	1967	Breast muscle	3.8	71		-	0.34	1.84	0.63	0.025	-	-	-	-	-	-
Northern Alberta (Nestling)	1972	Brain	4.9	83		0.20	ND	0.25	ND	0.040	ND	0.010	ND	-	-	-
		Liver	8.4	74		0.76	ND	0.54	ND	0.090	0.010	ND	0.24[a]	-	-	-
		Breast muscle	4.4	77		0.33	ND	0.59	ND	0.040	ND	0.010	0.23[a]	-	-	-
		Fat	70.7	25		-	0.020	40.5	0.030	1.84	0.84	0.010	13.70[a]	-	0.090	-
Northern Alberta (Nestling)	1973	Brain	3.3	87		-	0.005	2.26	0.005	0.060	0.010	0.010	1.76	-	ND	-
		Liver	1.3	78		0.87[b]	0.005	3.46	ND	0.070	0.020	0.010	1.74	-	ND	-
Yukon Territory population:																
Porcupine River	1969	Egg condition not recorded	6.5	82	Mean	0.39	0.063	36.2	0.044	1.22	0.16	-	7.30[a]	-	0.188	-
					#det/N	3/3	2/3	3/3	3/3	3/3	3/3		3/3		3/3	
					min	0.34	0.0005	13.3	0.019	0.36	0.087		1.07		0.060	
					max	0.45	5.05	194.8	0.24	8.00	0.43		68.1		0.551	
Porcupine River	1972	Addled eggs	7.2	80	Mean	0.27	0.15	24.3	0.010	0.39	0.16	0.016	14.4[a]	-	0.115	-
					#det/N	3/3	3/3	3/3	2/3	3/3	3/3	3/3	3/3		3/3	
					min	0.26	0.10	17.9	0.0005	0.23	0.11	0.010	11.7		0.090	
					max	0.29	0.33	35.3	0.050	0.83	0.25	0.020	20.4		0.190	
Porcupine River	1973	Dehydrated egg	35.6	22		1.30	0.798	89.1	7.18	2.98	0.46	0.019	35.1[a]	-	0.080	-
		Addled eggs	8.7	78	Mean	0.30	0.19	21.7	0.92	1.38	0.16	0.066	8.74[a]	-	0.065	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min	0.22	0.042	16.3	0.19	0.54	0.070	0.057	8.30		0.060	
					max	0.40	0.87	28.9	4.45	3.51	0.35	0.076	9.21		0.070	
Peele River	1978	Infertile egg	8.8	74		-	0.040	12.8	0.14	0.12	0.51	0.11	4.54	0.060	0.030	0.48

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Yukon Territory	1980	Fresh eggs	4.9	80	Mean #det/N min max	-	0.0097 1/2 0.0005 0.190	23.6 2/2 18.1 26.3	0.035 2/2 0.010 0.120	0.466 2/2 0.31 0.700	0.364 2/2 0.25 0.53	0.103 2/2 0.030 0.0302	3.98 2/2 3.13 3.13	0.085 2/2 0.080 0.90	0.035 2/2 0.030 0.040	0.490 2/2 0.480 0.500
		Non-viable	8.4	76	Mean #det/N min max	-	0.042 3/4 0.0005 0.600	24.5 4/4 22.3 29.1	0.123 4/4 0.050 0.270	1.070 4/4 0.900 2.450	0.739 4/4 0.40 1.53	0.083 4/4 0.050 0.120	10.00 4/4 5.36 30.70	0.174 4/4 0.100 0.180	0.108 4/4 0.030 0.360	0.276 4/4 0.210 0.350
Porcupine River	1981	Fresh egg	4.3	82		0.35	0.010	4.0	0.020	0.30	0.040	0.022	3.48	0.040	0.090	0.080
		Addled eggs	5.3	81	Mean #det/N min max	0.24 2/2 0.19 0.31	0.010 2/2 0.010 0.010	5.25 2/2 4.80 5.74	0.032 2/2 0.020 0.050	0.13 2/2 0.12 0.14	0.065 2/2 0.060 0.070	0.032 2/2 0.015 0.070	3.44 2/2 2.95 4.01	0.049 2/2 0.040 0.060	0.092 2/2 0.070 0.12	0.053 2/2 0.100 0.280
Mackenzie River population:																
N. Mackenzie R.	1971	Addled egg	6.0	80	ND	0.090	ND	0.090	ND	ND	ND	ND	0.150[a]	-	ND	-
N. Mackenzie R.	1973	Non-viable eggs	6.2	80	Mean #det/N min max	0.070 5/6 0.0005 0.430	0.030 5/6 0.0005 0.260	7.80 6/6 0.35 19.0	0.0119 6/6 0.005 0.190	0.462 6/6 0.060 1.190	0.072 6/6 0.040 0.090	0.015 6/6 0.010 0.030	4.69[a] 6/6 0.240 10.7	-	0.014 5/6 0.0005 0.05	-
N. Mackenzie R.	1974	Addled eggs	7.2	76	Mean #det/N min max	0.29 2/2 0.090 0.94	0.10 2/2 0.007 1.43	14.8 2/2 11.6 18.9	0.17 2/2 0.15 0.19	1.08 2/2 0.45 2.60	0.47 2/2 0.15 1.50	0.059 2/2 0.0095 0.36	10.0 2/2 4.74 21.3	-	ND	0.68 2/2 0.67 0.68
S. Mackenzie R.	1975	Fresh egg	4.3	79		0.30	0.18	12.2	0.076	0.81	0.45	0.057	14.4	0.14	-	0.320
Mackenzie River	1976	Fresh eggs	2.7	83	Mean #det/N min max	0.34 2/2 0.29 0.40	0.12 2/2 0.11 0.13	7.44 2/2 6.24 8.87	0.12 2/2 0.038 0.38	0.76 2/2 0.69 0.84	0.42 2/2 0.38 0.47	0.066 2/2 0.057 0.076	13.9 2/2 13.8 14.0	0.144 2/2 0.144 0.144	-	0.229 2/2 0.210 0.250
		Addled egg	5.9	80		0.20	0.070	4.47	0.27	0.28	0.080	0.057	5.33	0.14	-	0.120
N. Mackenzie R.	1977	Fresh egg	3.6	70		-	-	11.3	0.076	1.05	2.10	0.15	5.29	-	0.050	0.230
N. Mackenzie R.	1980	Infertile egg	5.6	81		-	0.12	5.39	0.190	0.060	0.080	0.030	4.02	0.060	0.050	0.120

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
N. Mackenzie R.	1981	Fresh eggs	4.6	83	Mean	0.34	0.020	13.6	0.035	0.16	0.25	0.062	6.20	0.14	0.10	0.157
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2
					min	0.21	0.020	12.5	0.020	0.070	0.11	0.037	3.37	0.10	0.040	0.130
					max	0.54	0.020	14.9	0.060	0.35	0.57	0.10	11.4	0.20	0.25	0.190
Mackenzie R. (Nestling)	1969	Brain	10.7	78		-	0.032	6.51	0.014	0.086	0.021	-	-	-	-	-
		Liver	-	76		0.44	-	-	-	-	-	-	-	-	-	-
		Whole body	1.1	78		-	0.008	0.97	0.002	0.008	0.002	-	-	-	-	-
Tundrius Peregrine Falcon population:																
Thelon River	1966	Egg condition not recorded	4.8	83	Mean	0.41	0.15	1.18	0.26	0.50	-	-	11.04[a]	-	-	-
					#det/N	6/6	6/6	6/6	6/6	6/6			6/6			
					min	0.31	0.001	0.058	0.037	0.011			10.1			
					max	0.53	1.23	4.45	1.63	1.76			14.5			
Thelon River	1967	Egg condition not recorded	5.9	81	Mean	-	0.12	0.32	0.094	0.008	0.0069	-	-	-	-	-
					#det/N		3/3	3/3	3/3	3/3	2/2					
					min		0.042	0.054	0.019	0.0005	0.0005					
					max		0.64	4.82	0.88	0.50	0.13					
Thelon River	1968	Addled eggs	9.8	75	Mean	0.35	1.89	18.8	1.60	0.71	0.20	-	24.4[a]	-	-	-
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3		3/3			
					min	0.23	1.18	13.5	0.97	0.51	0.16		14.7			
					max	0.57	3.84	23.7	3.05	1.36	0.26		42.9			
		Fresh eggs	6.8	79	Mean	0.199	0.319	3.24	0.372	0.196	0.059	-	6.52[a]	-	-	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4		4/4			
					min	0.010	0.091	0.275	0.050	0.007	0.009		1.39			
					max	0.67	1.19	9.53	1.34	1.42	0.66		26.2			
Thelon River	1969	Addled eggs	5.8	77	Mean	0.36	0.29	32.5	0.14	1.42	0.37	-	4.29[a]	-	0.289	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4		4/4		4/4	
					min	0.24	0.054	9.98	0.074	0.39	0.23		1.29		0.127	
					max	0.48	1.03	94.5	0.42	2.62	0.60		19.5		0.646	
Thelon River	1972	Fresh egg	8.8	79		0.50	0.020	8.20	0.090	0.36	0.24	0.010	7.77[a]	-	0.080	-
Bathurst Inlet	1973	Addled eggs	24.4	45	Mean	0.20	0.20	17.1	0.72	1.42	0.27	0.14	14.67[a]	-	0.053	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2		2/2	
					min	0.13	0.070	5.74	0.68	0.47	0.080	0.076	5.81		0.020	
					max	0.30	0.55	51.0	0.76	4.27	0.92	0.27	37.0		0.140	

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs*	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Bathurst Inlet	1975	Addled eggs	6.9	80	Mean	0.17	0.073	12.2	0.049	0.54	0.45	0.039	10.4	-	-	0.269
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3			3/3
					min	0.090	0.060	9.56	0.040	0.37	0.18	0.030	8.95			0.130
					max	0.26	0.11	13.9	0.060	0.78	1.57	0.050	13.2			0.440
Wager Bay	1976	Non-viable eggs	13.6	69	Mean	0.243	0.064	9.20	0.195	0.452	0.476	0.036	14.50	0.031	-	0.0043
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3		1/3
					min	0.13	0.007	2.81	0.038	0.14	0.13	0.0095	3.07	0.009		0.0005
					max	0.37	0.27	17.2	0.57	1.30	3.76	0.13	80.7	0.090		0.330
Northwest Territories	1980	Fresh eggs	6.7	80	Mean	-	0.021	7.48	0.0196	0.52	0.36	0.056	6.81	0.13	0.084	0.161
					#det/N		5/5	5/5	4/5	5/5	5/5	5/5	5/5	5/5	5/5	5/5
					min		0.0005	4.30	0.0005	0.12	0.14	0.020	3.07	0.060	0.020	0.10
					max		0.16	12.4	0.230	1.97	1.73	0.35	14.9	0.20	0.34	0.29
		Addled egg	7.1	81		-	0.020	5.66	0.130	0.70	2.07	0.030	6.12	0.17	0.12	0.210
Thelon River	1981	Fresh eggs	7.4	79	Mean	0.18	0.20	10.6	0.088	0.87	0.24	0.060	10.5	0.15	0.046	0.171
					#det/N	4/4	4/4	4/4	3/3	4/4	4/4	4/4	5/5	4/4	4/4	4/4
					min	0.11	0.020	4.95	0.030	0.36	0.15	0.018	6.75	0.11	0.010	0.10
					max	0.42	0.45	18.5	0.15	2.89	0.51	0.17	13.7	0.21	0.37	0.38
		Addled egg	7.4	78		0.42	0.12	9.71	0.17	0.58	0.25	0.028	14.3	0.19	0.13	0.64
Rankin Inlet	1982	Fresh eggs	5.4	79	Mean	0.17	0.053	5.76	0.059	0.52	0.67	0.038	15.9	0.24	0.11	0.238
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min	0.10	0.020	5.05	0.020	0.32	0.39	0.026	11.8	0.23	0.050	0.14
					max	0.28	0.37	6.30	0.15	0.88	1.54	0.059	22.3	0.25	0.32	0.33
Baffin Island	1969	Addled egg	7.3	74		0.42	ND	12.7	ND	0.52	0.060	0.003	12.4*	-	ND	ND
Thelon River (Adult female)	1966	Brain	5.3	73.2		-	0.124	1.68	0.001	0.364	-	-	-	-	-	-
		Breast muscle	3.7	86.1		-	0.077	2.90	.321	0.287	-	-	-	-	-	-
		Subcut fat	42.3	50.0		-	25.3	183.0	23.9	39.8	-	-	-	-	-	-
		Liver	4.4	75.3		-	0.297	9.64	0.564	1.43	-	-	-	-	-	-
		Body muscle	2.5	82.1		-	2.52	45.9	3.67	2.50	-	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs°	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Bathurst Inlet, NWT (Nestlings)	1969	Brain	5.2	85	Mean	-	0.014	0.929	0.0075	0.052	0.040	-	0.335[a]	-	ND	-
					#det/N		3/3	3/3	3/3	3/3	3/3		3/3			
					min		0.006	0.127	0.005	0.016	0.021		0.076			
					max		0.032	6.51	0.014	0.100	0.096		1.40			
		Liver	-	75	Mean	0.320	-	-	-	-	-	-	-	-	-	-
					#det/N	3/3										
					min	0.160										
					max	0.469										
		Leg muscle	1.5	80	Mean	-	0.0054	0.494	0.0018	0.019	0.0054	-	0.061[a]	-	ND	-
					#det/N		3/3	3/3	3/3	3/3	3/3		3/3			
					min		0.004	0.175	0.001	0.008	0.002		0.037			
					max		0.008	0.974	0.003	0.053	0.011		0.108			
		Fat	62.0	34		-	0.22	18.0	0.13	0.84	0.53	-	3.15[a]	-	0.248	-
Coral Harbour (Nestlings)	1974	Brain	4.2	87	Mean	0.039	0.005	1.36	0.010	0.15	0.069	0.005	2.07	-	ND	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.030	0.005	1.33	0.010	0.13	0.060	0.005	1.95			
					max	0.050	0.005	1.39	0.010	0.17	0.080	0.005	2.19			
		Liver	2.6	77	Mean	0.48	0.0016	9.54	0.007	0.92	0.55	0.020	6.96	-	ND	-
					#det/N	2/2	2/2	2/2	2/2	2/2	2/2	2/2	2/2			
					min	0.41	0.0005	7.0	0.005	0.59	0.29	0.020	5.14			
					max	0.56	0.005	13.0	0.010	1.42	1.06	0.020	9.43			
Rankin Inlet (Adult male)	1981	Brain	7.0	79		0.35	0.050	13.9	0.25	2.03	2.08	0.10	59.0	1.10	37.0	0.48
		Liver	2.9	73		1.85	0.35	84.2	0.090	2.97	2.98	0.17	208.0	1.41	132.0	3.08
		Breast muscle	1.0	74		0.80	0.17	47.1	0.070	1.39	1.43	0.083	111.0	0.74	68.4	1.96

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Keewatin (Adults)	1966	Brain	4.5	81	Mean	-	0.009	0.43	0.008	0.10	-	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		0.001	0.36	0.001	0.068						
					max		0.077	0.51	0.058	0.15						
		Liver	2.7	71	Mean	-	0.17	1.57	0.100	0.46	-	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		0.116	0.67	0.010	0.17						
					max		0.245	3.71	0.995	1.28						
		Breast muscle	4.8	75	Mean	-	0.078	2.83	0.39	0.75	-	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		0.010	2.08	0.31	0.45						
					max		0.60	3.85	0.49	1.26						
		Fat	65.8	28.4	Mean	-	4.77	71.2	6.32	16.15	-	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		1.13	66.4	1.7	12.3						
					max		20.1	76.3	23.5	21.2						
		Whole body	4.9	75	Mean	-	0.443	4.46	0.216	1.12	-	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		0.374	3.63	0.210	0.714						
					max		0.525	5.47	0.222	1.76						
		Ovaries	7.3	78.1		-	0.786	9.83	0.872	1.37	-	-	-	-	-	-
							1/1	1/1	1/1	1/1						
Northern Quebec population:																
Ungava Bay	1967	Egg condition not recorded	5.0	79	Mean	-	0.49	9.74	0.61	0.81	ND	-	-	-	-	-
					#det/N		10/10	10/10	10/10	10/10						
					min		0.23	4.63	0.18	0.27						
					max		1.05	27.0	1.59	1.91						
Ungava Bay	1975	Addled eggs	6.8	81	Mean	0.29	0.24	11.8	0.093	0.99	0.21	0.033	13.6	-	-	-
					#det/N	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4			
					min	0.15	0.098	4.32	0.076	0.41	0.13	0.019	6.51			
					max	0.71	0.49	19.6	0.11	1.86	0.31	0.057	38.5			

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Ungava Bay	1984	Fresh eggs	4.7	79	Mean	-	0.056	4.26	0.0036	0.31	0.33	0.025	3.48	0.12	0.015	0.133
					#det/N		4/4	4/4	2/4	4/4	4/4	4/4	4/4	4/4	3/4	4/4
					min		0.019	1.61	0.0005	0.14	0.15	0.016	1.61	0.050	0.0005	0.045
					max		0.32	13.8	0.028	0.52	1.34	0.046	5.63	0.20	0.034	0.232
		Addled eggs	6.3	76	Mean	-	ND	5.48	0.027	0.52	0.46	0.051	31.9	0.19	0.015	0.181
					#det/N			3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min			5.20	0.025	0.50	0.45	0.049	31.5	0.18	0.014	0.171
					max			5.62	0.029	0.54	0.48	0.053	32.2	0.20	0.106	0.189
Ungava Bay	1986	Fresh eggs	6.7	75	Mean	-	0.041	8.64	0.022	1.44	0.54	0.075	16.8	0.26	0.044	0.339
					#det/N		3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3	3/3
					min		0.030	7.43	0.006	0.84	0.31	0.054	14.1	0.22	0.014	0.079
					max		0.057	10.6	0.066	2.61	0.94	0.11	21.3	0.31	0.088	1.120
Ungava Bay (Biopsies from breeding females)	1967	Fat	94	-	Mean	-	6.08	284.6	16.2	8.60	ND	-	-	-	-	-
					#det/N		8/8	8/8	8/8	8/8						
					min		0.66	193.1	4.31	2.41						
					max		27.3	552.0	35.8	72.4						
British Columbian population:																
Langara Island	1965	Fresh eggs	8.0	78	Mean	1.01	0.33	5.41	0.41	0.075	ND	-	25.6[a]	-	-	-
					#det/N	2/2	2/2	2/2	2/2	2/2			2/2			
					min	0.85	0.25	4.02	0.31	0.067			22.6			
					max	1.21	0.42	7.28	0.56	0.083			28.9			
Langara Island	1967	Fresh eggs	5.1	82	Mean	-	0.14	2.31	0.19	0.067	ND	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2						
					min		0.037	2.24	0.054	0.057						
					max		0.53	2.39	0.68	0.079						
Langara Island	1969	Fresh egg	4.3	84		0.68	ND	10.9	0.036	0.064	0.022	-	4.38[a]	-	0.127	-
		Addled eggs	6.7	79	Mean	0.57	0.0072	19.0	0.16	0.094	0.029	-	5.20[a]	-	0.254	-
					#det/N	3/3	2/3	3/3	3/3	3/3	3/3		3/3		3/3	
					min	0.44	0.0005	15.0	0.087	0.044	0.017		4.67		0.178	
					max	0.76	0.037	25.7	0.24	0.16	0.049		5.51		0.421	
Langara Island	1970	Egg condition not recorded	7.5	78	Mean	0.45	0.0082	4.09	0.063	0.081	ND	0.016	2.135[a]	-	ND	-
					#det/N	2/2	1/2	2/2	2/2	2/2		2/2	2/2			
					min	0.040	0.0005	0.57	0.046	0.055		0.008	0.150			
					max	5.00	0.135	29.3	0.086	0.12		0.030	30.4			
Langara Island	1971	Fresh egg	4.8	85		0.91	ND	11.5	ND	0.010	0.030	0.11	10.2[a]	-	0.120	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs[a]	Oxy	B-HCH	Mirex
Species: PEREGRINE FALCON (*Falco peregrinus*)																
Langara Island	1972	Addled egg	11.1	78		0.70	ND	24.0	0.020	0.040	0.010	0.23	35.5[a]	-	0.510	-
Langara Island	1986	Nonviable eggs	5.2	83	Mean	-	0.010	5.84	0.012	0.027	0.040	0.14	8.55	0.15	0.47	0.062
					#det/N		4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
					min		0.007	5.26	0.005	0.023	0.037	0.074	7.97	0.13	0.42	0.049
					max		0.015	6.57	0.030	0.036	0.043	0.19	9.80	0.17	0.56	0.077
Langara Island (Adult)	1966	Brain	0.9	93		-	0.101	0.250	0.172	0.009	ND	-	-	-	-	-
		Breast muscle	2.4	88		-	0.34	1.65	0.31	0.033	ND	-	-	-	-	-
Langara Island (Nestlings)	1969	Brain	3.1	87	Mean	-	0.005	2.16	0.006	0.0039	ND	-	0.494[a]	-	0.045	-
					#det/N		2/2	2/2	2/2	2/2			2/2		2/2	
					min		0.005	1.83	0.003	0.003			0.405		0.044	
					max		0.005	2.55	0.010	0.005			0.602		0.046	
		Liver	1.8	76	Mean	-	0.007	4.99	0.006	0.019	0.007	-	0.321[a]	-	0.100	-
					#det/N		2/2	2/2	2/2	2/2	2/2		2/2		2/2	
					min		0.005	4.83	0.005	0.014	0.006		0.088		0.096	
					max		0.009	5.16	0.008	0.025	0.008		1.17		0.105	
		Breast muscle	1.6	78	Mean	-	0.008	2.47	0.006	0.004	ND	-	0.387[a]	-	0.035	-
					#det/N		2/2	2/2	2/2	2/2			1/1		2/2	
					min		0.006	1.95	0.003	0.002					0.026	
					max		0.010	3.12	0.014	0.008					0.047	
		Whole sample	3.9	79		-	ND	19.1	0.056	0.091	0.036	-	3.24[a]	-	0.337	-
Langara Island (Nestlings)	1971	Brain	6.0	85		0.14	ND	0.53	ND	ND	ND	ND	0.450[a]	-	ND	-
		Liver	6.0	75		0.61	ND	0.94	ND	0.010	ND	0.020	0.810[a]	-	ND	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: TURKEY VULTURE (*Cathartes aura*)																
Ontario (Adult)	1970	Liver	-	-	Mean #det/N min max	30.81 3/3 12.1 60.4	-	-	-	-	-	-	-	-	-	-
		Breast muscle	-	-	Mean #det/N min max	17.39 2/2 16.0 18.9	-	-	-	-	-	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: COMMON BARN OWL (*Tyto alba*)																
British Columbia	1984-85	Liver	3.7	67.5	Mean #det/N min max	0.128 8/8 0.029 0.884	0.0118 7/8 0.0005 0.050	0.553 8/8 0.20 4.29	0.0056 6/8 0.0005 0.020	0.326 8/8 0.0005 0.140	0.0365 8/8 0.010 0.080	-	0.482 8/8 0.09 3.52	-	ND	0.0041 5/8 0.0005 0.06

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: LONG-EARED OWL (*Aslo otus*)																
Saskatchewan	1967	Fresh eggs	3.7	83.6	Mean #det/N min max	-	0.004 2/2 0.004 0.004	0.135 2/2 0.193 0.486	0.0045 2/2 0.004 0.005	0.0089 1/2 0.0005 0.159	0.0115 2/2 0.012 0.011	-	-	-	-	-
Saskatchewan	1968	Fresh egg	-	80	Mean #det/N min max	0.043 2/2 0.041 0.046	-	-	-	-	-	-	-	-	-	-
Saskatchewan	1968	Fresh egg	5.0	83.3		0.025	0.045	3.06	0.053	0.022	ND	-	-	-	-	-
Saskatchewan	1969	Addled egg	5.3	79.1	Mean #det/N min max	-	0.0006 1/3 0.0005 0.001	0.404 3/3 0.078 1.86	0.003 2/3 0.0005 0.014	0.0168 3/3 0.007 0.034	0.009 3/3 0.005 0.018	-	0.063[a] 3/3 0.013 0.348	-	ND	-
		Fresh egg	4.0	80.7		-	0.004	1.46	ND	0.013	0.011	-	0.046[a]	-	ND	-
Saskatchewan	1967	Brain	4.8	86.7		-	0.004	0.145	0.007	0.022	ND	-	-	-	-	-
		Breast muscle	5.6	78.9		-	0.035	0.244	0.030	0.042	0.032	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: SHORT-EARED OWL (*Asio flammeus*)																
Saskatchewan	1969	Addled eggs	8.0	78.7	Mean #det/N min max	-	0.0036 4/5 0.0005 0.016	4.175 5/5 2.14 7.62	0.0057 5/5 0.002 0.013	0.122 5/5 0.025 0.945	0.039 5/5 0.016 0.108	-	0.100[a] 5/5 0.029 0.319	-	0.0032 2/5 0.0005 0.066	-
Alberta	1969	Egg condition not recorded	6.7	81		-	0.018	3.63	0.012	0.034	0.028	-	-	-	ND	-
Saskatchewan (Adult)	1967	Gonad	4.1	77.6		-	ND	1.15	0.021	ND	0.131	-	-	-	-	-
		Subsut. fat	81.3	18.7		-	0.007	0.225	0.015	0.029	0.050	-	-	-	-	-
Alberta (Adult)	1968	Liver	-	69.6		3.468 3/3 0.42 11.3	-	-	-	-	-	-	-	-	-	-
British Columbia (Adult)	1968	Breast muscle	4.1	69.3	Mean #det/N min max	-	0.012 2/3 0.0005 0.104	0.221 3/3 0.038 2.69	0.062 3/3 0.020 0.227	0.0135 3/3 0.007 0.032	ND	-	-	-	-	-
		Brain	5.2	78	Mean #det/N min max	-	0.0088 3/3 0.002 0.034	0.060 3/3 0.011 0.426	0.0148 3/3 0.002 0.077	0.0041 3/3 0.001 0.017	ND	-	-	-	-	-

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: GREAT HORNED OWL (*Bubo virginianus*)																
Saskatchewan	1967	Nonviable eggs	8.4	73.4	Mean	-	0.055	1.37	0.063	0.055	0.037	-	-	-	-	-
					#det/N		13/13	13/13	13/13	13/13	10/13					
					min		0.006	0.073	0.011	0.011	0.0005					
					max		0.625	15.3	0.737	0.763	1.83					
		Fresh eggs	5.2	74.9	Mean	-	0.041	1.012	0.054	0.082	0.044	-	-	-	-	-
					#det/N		2/2	2/2	2/2	2/2	2/2					
					min		0.032	0.702	0.047	0.043	0.013					
					max		0.052	1.46	0.063	0.156	0.152					
Saskatchewan	1968	Fresh eggs	5.5	74.1	Mean	0.091	0.048	0.651	0.042	0.107	.326	-	-	-	-	-
					#det/N	3/3	3/3	3/3	3/3	3/3	3/3					
					min	0.073	0.033	0.209	0.032	0.019	0.121					
					max	0.121	0.084	1.29	0.062	0.264	1.88					
Saskatchewan	1968	Addled eggs	11.5	71.7	Mean	0.0139	0.108	3.39	0.101	0.231	0.434	-	-	-	-	-
					#det/N	3/4	4/4	4/4	4/4	4/4	4/4					
					min	0.0005	0.046	0.044	0.044	0.092	0.177					
					max	0.121	0.402	0.368	0.368	0.598	1.48					
NWT, District of Mackenzie	1968	Egg condition not recorded	14.3	68.7		1.94	0.072	1.52	0.043	0.103	0.254	-	-	-	-	-
Ontario	1968	Non-viable egg	5.8	80.5		-	0.120	0.847	0.104	0.217	ND	-	-	-	-	-
Saskatchewan	1969	Fresh egg	6.3	75.3		-	0.925	13.9	0.039	0.115	0.357	-	2.18[a]	-	ND	-
Saskatchewan	1969	Addled eggs	7.2	74	Mean	-	0.0089	4.25	0.0063	0.117	0.114	-	0.520[a]	-	0.0034	-
					#det/N		6/6	6/6	5/6	6/6	6/6		6/6		3/6	
					min		0.006	1.17	0.002	0.053	0.021		0.041		0.0005	
					max		0.023	12.6	0.048	0.214	0.455		1.81		0.032	
Saskatchewan	1970	Addled egg	7.8	76.2		0.07	0.049	16.2	ND	0.239	0.214	0.017	2.41[a]	-	ND	ND
Alberta	1970	Fresh egg	6.9	81.6		-	0.064	0.895	0.066	0.166	0.964	-	-	-	ND	ND
Saskatchewan (Adult)	1967	Ovaries	2.0	78.4		-	0.009	0.387	0.04	0.013	0.014	-	-	-	-	-
		Subcut. fat	71.4	28.1		-	0.153	22.6	0.208	1.09	1.04	-	-	-	-	-
		Breast muscle	0.9	72.8		-	0.004	0.609	0.013	ND	ND	-	-	-	-	-
		Brain	5.6	81.8		-	0.009	0.212	0.006	0.023	0.010	-	-	-	-	-
Ontario (Adult)	1968	Liver	-	70.0		1.44	-	-	-	-	-	-	-	-	-	-

- indicates that chemical was not included in analysis; ND indicates chemical was included in analysis but not detected; [a] PCBs are presented on the basis of Aroclor 1260, otherwise PCBs are based on a 1:1 mixture of Aroclors 1254:1260; [b] methyl mercury

Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: GREAT HORNED OWL (*Bubo virginianus*)																
Saskatchewan (Nestling)	1969	Brain	4.0	86.3		-	ND	0.039	0.002	0.003	0.006	-	0.012[a]	-	ND	-
New Brunswick (Adult)	1969	Brain	6.2	81.3		-	0.006 2/2 0.003 0.013	0.184 2/2 0.097 0.348	0.0042 2/2 0.002 0.009	0.0028 2/2 0.002 0.004	ND	-	-	-	ND	-
Alberta (Nestling)	1970	Liver	4.0	72.7		-	0.076	0.743	0.084	0.097	0.167	-	-	-	ND	ND

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Location	Year	Tissue	% Fat	% Water		Mercury	DDD	DDE	DDT	Diel	HE	HCB	PCBs	Oxy	B-HCH	Mirex
Species: BURROWING OWL (*Athene cunicularia*)																
Saskatchewan	1968	Fresh egg	17.8	65.6	Mean #det/N min max	0.112	0.006	0.678	0.019	0.420	0.155	-	-	-	-	-
Alberta (Adult)	1968	Brain	6.6	78.3	Mean #det/N min max	-	0.0125 3/3 0.005 0.028	1.078 3/3 0.797 1.95	0.024 3/3 0.017 0.031	0.0192 3/3 0.002 0.272	0.092 3/3 0.014 0.705	-	-	-	-	-
		Liver	-	71.3	Mean #det/N min max	1.775 3/3 0.729 1.23	-	-	-	-	-	-	-	-	-	-

- indicates that chemical was not included in analysis; ND indicates chemical was included in analysis but not detected; [a] PCBs are presented on the basis of Aroclor 1260, otherwise PCBs are based on a 1:1 mixture of Aroclors 1254:1260; [b] methyl mercury

APPENDIX B

CHEMICAL NAMES OF ORGANOCHLORINES DISCUSSED IN THIS REPORT:

DDT	1,1,1-trichloro-2,2-bis(p-chlorophneyl)ethane
DDD	1,1-dichloro-2,2-bis(p-chloropheny)ethane
DDT	1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Heptachlor epoxide	1,4,5,6,7,8,8a-hexachloro-2,3-epoxy-3a,4,7,7a-tetrahydro-4,7-methanoindane
Mirex	Dodecachlorooctahydro-1,3,4-metheno-1H-cyclo-buta [cd]pentalene
Oxychlordane	1-exo-2-endo-4,5,6,7,8,8a-octachloro-2,3-exo-epoxy-2,3,3a,4,7,7a-hexahydro-4,7-methanoindane
Chlordane	1,2,4,5,6,7,8,8-octachloro-3a,4,7,7a-tetrahydro-4,7-methanoindane (cis and trans isomers)
Nonachlor	1,2,3,4,5,6,7,8,8-nonachloro-3a,4,7,7a-tetrahydro-4,7-methanoindane (cis and trans isomers)
HCB	Hexachlorobenzene
HCH	1,2,3,4,5,6-hexachlorocyclohexane (alpha, beta and gamma isomers)
Endrin	1,2,3,4,10,10-hexachlorocyclohexane-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethananaphthalene
PCBs	Mixtures of polychlorinated biphenyl differing in the amount of chlorine present.