

Long-term Trends of Persistent Organochlorine Pollutants, Occupancy and Reproductive Success in Peregrine Falcons (*Falco peregrinus tundrius*) Breeding near Rankin Inlet, Nunavut, Canada

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ABSTRACT. The historical decline of the peregrine falcon (*Falco peregrinus*) in North America was attributed mainly to reproductive failure associated with persistent organochlorine pollutants, in particular DDT (dichloro-diphenyl-trichloroethane). It is generally assumed that declining trends in pesticide loads will be accompanied by a corresponding increase in reproduction. In this study, we concurrently measured occupancy, reproductive performance, and pesticide loads of breeding-aged adults on territory near Rankin Inlet, Nunavut, from 1982 to 2009. Our findings indicate that reproductive success of peregrine falcons in our study population declined despite concomitant reductions in pesticide loads, and that on average, approximately three fewer territories were occupied annually from 2002 to 2009 than were occupied from 1982 to 1989. In addition, the average number of young to reach banding age annually from 2002 to 2009 was approximately half the number banded annually from 1982 to 1989. These results indicate that in recent years fewer pairs have attempted to breed; in addition, those that did breed successfully raised fewer young to banding age. In general, the pesticides examined in this study cannot mechanistically explain either the reduction in occupancy or the decline in reproductive performance. We suggest that the proximate effects of local weather patterns—ultimately associated, either directly or indirectly, with overall climate change—have the greatest potential to explain the altered demographic features of the Rankin Inlet population.

Key words: peregrine, *Falco peregrinus*, Arctic, Nunavut, organochlorine, productivity, occupancy, weather, temperature, precipitation, climate change

RÉSUMÉ. Le déclin historique du faucon pèlerin (*Falco peregrinus*) en Amérique du Nord a été principalement attribué à un échec de reproduction surtout attribuable aux polluants organochlorés persistants, en particulier le D.D.T. (dichlorodiphényltrichloréthane). L'on présume généralement que la tendance à la baisse caractérisant l'utilisation des pesticides sera accompagnée d'une augmentation correspondante de reproduction. Dans le cadre de cette étude, nous avons mesuré, simultanément, l'occupation, le rendement reproducteur et les charges de pesticides des adultes en âge de reproduction sur un territoire situé près de Rankin Inlet, au Nunavut, de 1982 à 2009. Nos constatations indiquent que le succès de reproduction des faucons pèlerins faisant l'objet de la population à l'étude a décliné malgré les réductions concomitantes de charges de pesticides et que, en moyenne, environ trois territoires de moins étaient occupés annuellement de 2002 à 2009 que ce n'était le cas de 1982 à 1989. De plus, le nombre moyen de jeunes qui réussissait à atteindre l'âge du baguage annuellement de 2002 à 2009 était d'environ la moitié du nombre d'oiseaux bagués annuellement de 1982 à 1989. Ces résultats indiquent qu'au cours des dernières années, moins de paires ont tenté de se reproduire. Par ailleurs, parmi les oiseaux qui réussissaient à se reproduire, ils parvenaient à élever un moins grand nombre de jeunes atteignant l'âge du baguage. De manière générale, les pesticides examinés dans le cadre de cette étude ne peuvent pas expliquer, de manière mécaniste, la réduction de l'occupation de même que le déclin du rendement reproducteur. Nous suggérons donc que les effets immédiats de la situation météorologique — liés, au bout du compte, directement ou indirectement, au changement climatique général — présentent la meilleure manière d'expliquer les caractéristiques démographiques altérées de la population de Rankin Inlet.

Mots clés : faucon pèlerin, *Falco peregrinus*, Arctique, Nunavut, organochloré, productivité, occupation, temps, température, précipitation, changement climatique

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INTRODUCTION

Widespread decline of the peregrine falcon (*Falco peregrinus*) in North America was attributed to reproductive failure (Peakall, 1976; Cade et al., 1988) associated with the ubiquitous use of persistent organochlorine pollutants, in particular DDT (dichloro-diphenyl-trichloroethane) (Hickey, 1969; Fyfe et al., 1976; Cade et al., 1988, Ratcliffe, 1993; Cade and Burnham, 2003). Despite bans on the use of DDT imposed in Canada in 1969 and in the United States in 1972 (Kiff, 1988), the peregrine falcon of continental North America (*F. p. anatum*) was extirpated over its range east of the Rocky Mountains and south of the boreal forest by 1975 (Fyfe et al., 1976). However, the species has shown considerable recovery over the last two decades (Ambrose et al., 1988; Cade and Burnham, 2003; Rowell et al., 2003; Banasch and Holroyd, 2004), in part due to the release of captive-bred birds. In 2006, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) downgraded the threat level for the continental subspecies *F. p. anatum* from "Threatened" to "Special Concern" (COSEWIC, 2006), and the peregrine falcon, *F. peregrinus*, was removed from the United States (U.S.) list of endangered animals in 1999.

The strong recovery of peregrine falcon populations in North America is assumed to have been fueled by two main factors: captive breeding with re-introduction and, just as important, a decline in persistent organochlorine residues in peregrine falcons and their prey species. Remarkably, there exist relatively few studies of the toxicological status of

North American peregrine populations during this recovery era. Court (1993) assessed the toxicology of peregrine falcons (*F. p. anatum*) breeding in Alberta, Canada, between 1968 and 1992, while Court et al. (1990) and Johnstone et al. (1996) reported on the toxicology of the Rankin Inlet population from 1982 to 1986 and 1990 to 1994, respectively. Jarman et al. (1994) reported on organochlorine compounds in the plasma of peregrine falcons nesting in Greenland. More recently, Henny et al. (1996, 2009) reported on trends of organochlorine contaminant levels in migrant peregrine falcons captured on Padre Island, Texas, and Vorkamp et al. (2009) summarized long-term trends in residues found in nesting birds in Greenland.

The present study has two primary objectives. The first was to summarize the changes in blood plasma concentration of dichloro-diphenyl-dichloro-ethylene (DDE), a metabolite of DDT; polychlorinated biphenyls (PCBs); and dieldrin in adult peregrine falcons captured on territory at Rankin Inlet from 1982 to 2006. The second was to report on annual occupancy and nestling productivity of these birds from 1982 to 2009. We also present trends in average summer temperature and patterns of precipitation experienced at Rankin Inlet over the same period.

Study Area

The study population of peregrine falcons is encompassed within a 455 km² study area (Fig. 1) near the hamlet of Rankin Inlet, Nunavut, Canada. At peak density, breeding peregrine falcons at Rankin Inlet included 29

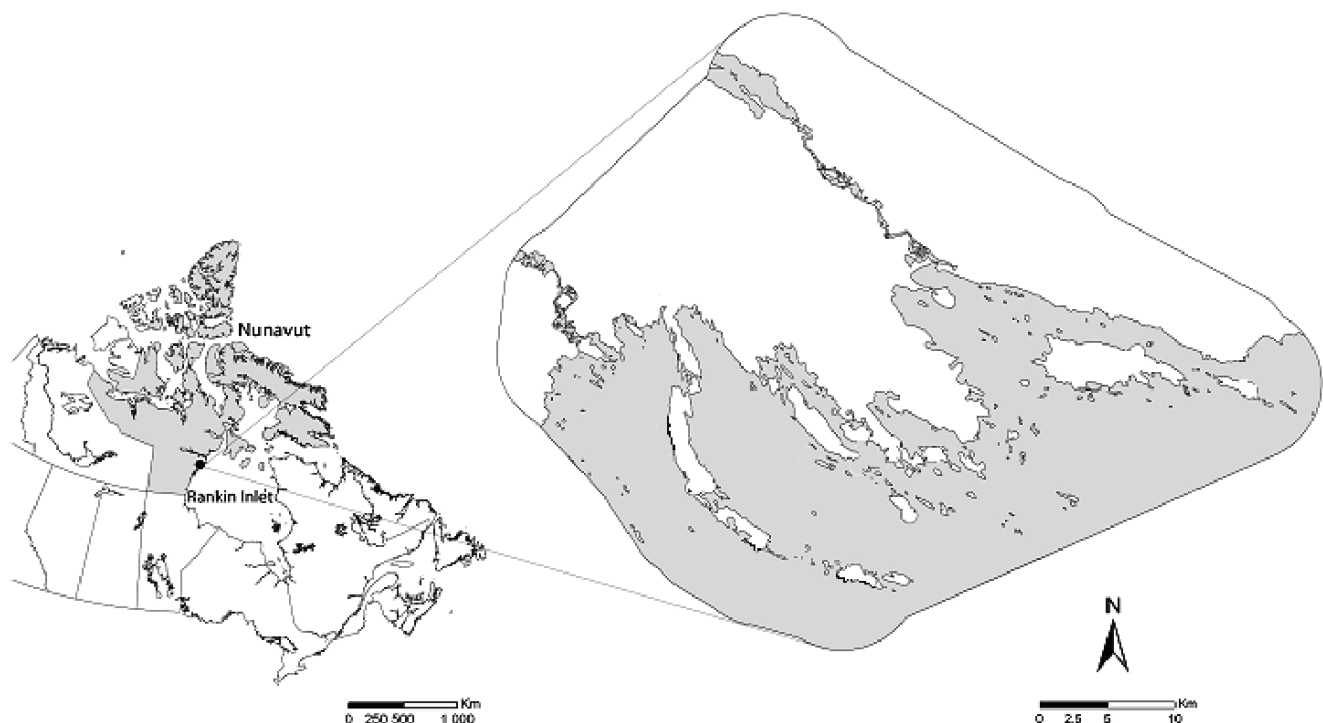


FIG. 1. Map of Canada showing the location of the Rankin Inlet, Nunavut, study area (enlarged in inset).

territorial pairs, or one pair per 15 square km, which is the highest density recorded for the species in the tundra biome and among the highest in the world. Though Rankin Inlet (62°49' N 92°05' W) is a relatively southern location for peregrine falcons in the Canadian Arctic, environmental conditions are as severe as, or more severe than, any encountered in the range of the species. Passerines and small mammals comprise the bulk of the diet, and lemming consumption increases significantly during peak abundance (Court et al., 1988a, b; Bradley and Oliphant, 1991). Terminology used in describing nesting activities of peregrine falcons and a general description of vegetation, climate, and geology of the study area are reported elsewhere (Court, 1986; Court et al., 1988a, b, 1989).

METHODS

Occupancy and Reproductive Success

Accurate determination of site occupancy each breeding season was impossible to achieve with a single, short-term survey, particularly if the survey was conducted later in the breeding season (e.g., at a period of time typically associated with brooding or chick rearing). For this reason, from 1982 to 2008, a full census of the entire study area was conducted a minimum of twice annually. Beginning in May of each year, as peregrine falcons arrived from their wintering grounds, territories were surveyed by snow machine to determine the presence or absence of territorial, breeding-aged adults. All unoccupied sites were checked until occupancy by peregrine falcons was confirmed, or until the breeding season was sufficiently advanced to conclude that the site was vacant.

In cases where sites were occupied by individuals previously fitted with unique alphanumeric color-coded leg bands, bands were read using a Questar Field Model telescope. If territories were occupied by unmarked individuals, effort was made to trap and mark these birds with an alphanumeric color band on one leg and a U.S. Fish and Wildlife band on the other. In addition, we measured unflattened wing chord, body weight, tail length, and tarsus width and length for each bird and recorded sharpness of keel, a subjective measure of body condition.

After breakup of the sea ice, territories were surveyed by boat to determine occupancy and reproduction at each site; inland sites were accessed by all-terrain vehicle for the same purpose. During summer, banded adult peregrine falcons were identified either by trapping or visually by telescope. Unmarked individuals were trapped and banded when possible. Once nestlings reached a minimum of 20 days of age (approximately July 25), they too were banded with an alphanumeric color band on one leg and a U.S. Fish and Wildlife band on the other. Only young that survived beyond 20 days and were banded were included in the annual nestling census. Of the 36 known territories distributed throughout the study area, 22 were surveyed annually

from 1982 to 2009. To ensure that data were not biased by inconsistent survey effort, our estimates of site occupancy and productivity were calculated using only the 22 sites surveyed annually in both spring and summer. The years 2000 and 2001 are excluded from this analysis because in 2000 surveys were conducted only in summer, and in 2001 no survey was conducted at all.

Organochlorine Residues

We used single-factor ANOVA and Tukey post-hoc tests in the statistical package R to undertake multiple comparisons of means to compare occupancy and total number of young produced, as well as reproductive success across three distinct periods of time (1982–89, 1990–99, and 2002–09), which allowed us to approximate decadal trends. Productivity (the number of young per territorial pair per year) is an alternative measure of reproductive success that takes into account the number of breeding pairs present on a territory in a given year, regardless of whether the breeding attempt was successful. We therefore calculated productivity in an effort to ensure that changes in the number of young were not related simply to changes in the number of pairs that attempted to breed in any given year.

Between 1982 and 2005, 54 adult male and 93 adult female peregrine falcons were captured; approximately 2 ml whole blood was collected from the ulnar vein of each bird using a 23-gauge needle and a 3 cc syringe. Some individuals were trapped in multiple years, resulting in a total of 197 blood samples, 61 for males and 136 for females, each of which was considered to be an independent observation. Samples were stored in heparin and centrifuged to separate red cells from plasma. Samples were sealed and stored frozen at 0°F (-17°C) until analysis. All toxicological analyses for samples collected for the periods 1982–86 and 1990–96 were conducted at the Health of Animals Laboratory, Food Animal Chemical Residues Section, Agriculture and Agri-Food Canada, in Saskatoon. Preparation of samples, initial assay, and confirmatory gas chromatography-mass spectrometry analyses followed the methods of Won and Turle (1987) and Burse et al. (1983), as used by Court et al. (1990). The quality assurance program run by the Health of Animals Laboratory permitted comparisons between samples collected from 1991 to 1994 (Johnstone et al., 1996) and earlier samples collected by Court et al. (1990). Pesticide reference standards used for quantification were validated according to the Health of Animals Laboratory QA protocol. All remaining samples were analyzed commercially, using U.S. Environmental Protection Agency (EPA) Method 8081b (U.S.-EPA, 2007a).

Samples were extracted as reported above; however, cleanup of the extracts was performed using a 12 g Florisil column. The cleanup extract was analyzed using high-resolution gas chromatography/electron capture detection. Two columns were used: a 30 m × 0.25 mm I.D. DB-5 and a 30 m × 0.25 mm I.D. DB-1701. We used hydrogen carrier gas to elicit maximum peak resolution, and performed

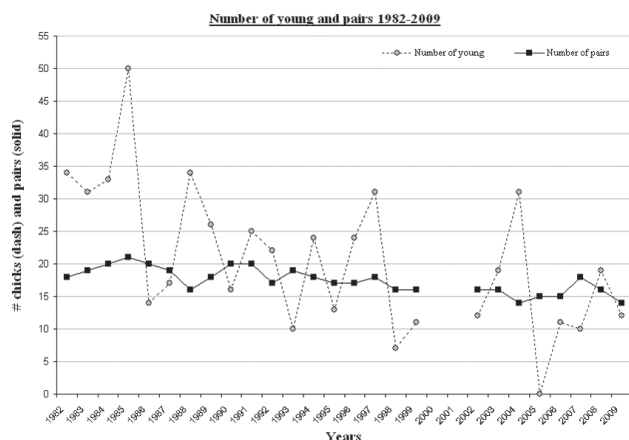


FIG. 2. Long-term trends in annual number of territorial pairs and number of young to reach banding age each year for 22 sites in the Rankin Inlet study area monitored from 1982 to 2009.

dual column confirmation by comparing responses for the two different columns. Analyses for PCBs were performed using Aroclor matching (Method 8082A, U.S.-EPA, 2007b). For biological samples, it is generally recognized that this procedure will return higher detection rates than congener-specific analyses (Burse et al., 1990).

Data were log-transformed (zero values were set to 0.0005 mg/kg, the stated minimum detection limit) and are reported as geometric mean mg/kg wet weight. We used single-factor ANOVA and Tukey post-hoc tests in the statistical package R to undertake multiple comparisons of means in order to compare blood plasma residues (4,4'-DDE, Σ PCB, and dieldrin) across three distinct periods of time (1982–86, 1990–98, and 2004–06).

Weather

We used Environment Canada weather data collected at the Rankin Inlet airport to calculate average summer temperature ($^{\circ}$ C), total summer precipitation (mm), and monthly precipitation for June through August for 1982–2009. We used proc AUTOREG in SAS v. 9 (SAS Institute, 2004) to regress average summer temperature and total precipitation on time, correcting for temporal auto-correlation (and thus dependence) among the residuals (autoregressive error regression). In addition, we calculated the deviation in monthly precipitation from the long-term mean for each month from 1982 to 2009.

RESULTS

Occupancy and Reproductive Success

On average, 17.42 ± 1.96 of the 22 sites that received consistent survey effort from 1982 to 2009 were occupied annually by a breeding-aged pair of peregrine falcons and produced an average of 20.27 ± 11.55 young annually,

TABLE 1. Summary data (mean \pm SD) for annual occupancy at 22 sites monitored for territorial adults, total production (number of young banded each year), and productivity (number of young per occupied territory) of peregrine falcons breeding near Rankin Inlet, Nunavut, from 1982 to 2009.

	Occupancy	Production	Productivity
Mean \pm SD			
1982–2009	17.42 ± 1.96	20.27 ± 11.55	1.15 ± 0.62
1982–89	$18.88 \pm 1.55^{ab*}$	29.88 ± 11.23^a	1.59 ± 0.58^a
1990–99	17.80 ± 1.48^{abc}	17.40 ± 9.26^b	0.97 ± 0.51^b
2002–09	15.50 ± 1.31^c	14.25 ± 9.00^{bc}	0.94 ± 0.64^{bc}
Range			
1982–89	16 – 21	14 – 50	0.7 – 2.38
1990–99	16 – 20	2 – 31	0.8 – 1.74
2002–09	14 – 18	0 – 31	0.0 – 2.21

* Means in the same column that share a superscript letter are not significantly different.

resulting in an average of 1.15 ± 0.62 nestlings per occupied territory per year (Fig. 2, Table 1). The range of natural variation across all years was 14–21 for occupancy, 0–50 for total production, and 0.0–2.38 for productivity (Fig. 2, Table 1).

Multiple comparisons of occupancy and total production among time periods indicated a significant decline in both the number of territorial pairs ($p < 0.001$) and the number of young produced ($p < 0.01$). There was no difference ($p = 0.28$) in the number of occupied territories between the 1980s (mean = 18.88 ± 1.55) and the 1990s (mean = 17.80 ± 1.48). However, fewer territories were occupied in the 2000s (mean = 15.50 ± 1.31) than in the 1980s (mean = 18.88 ± 1.55 , $p < 0.001$) and the 1990s (mean = 17.80 ± 1.48 , $p < 0.01$).

For total production, a comparison among time periods indicates there was no difference ($p = 0.77$) between the 1990s (mean = 17.40 ± 9.26) and the 2000s (mean = 14.25 ± 9.00). However, a significant decline is evident in comparisons between the 1980s (mean = 29.88 ± 11.23) and both the 1990s (mean = 17.40 ± 9.26 , $p < 0.05$) and the 2000s (mean = 14.25 ± 9.00 , $p = 0.10$).

Despite our correction for the number of territories occupied each year, the decline in reproductive success as estimated by productivity remained consistent with the decline observed for total production. We found no difference ($p = 0.99$) between estimates of productivity observed in the 2000s (mean = 0.94 ± 0.64) and those observed in the 1990s (mean = 0.97 ± 0.51). Nevertheless, significant declines in productivity were apparent when we compared the 1980s (mean = 1.59 ± 0.58) to the 1990s (mean = 0.97 ± 0.51 , $p < 0.10$) and the 2000s (mean = 0.94 ± 0.64 , $p < 0.10$).

Organochlorine Residues

Results for both sexes combined (Table 2) indicate that plasma DDE levels in adult peregrine falcons breeding in Rankin Inlet were significantly higher in the 1980s

TABLE 2. DDE (geometric mean and maximum levels) in blood plasma of adult peregrine falcons captured on territory in Rankin Inlet, Nunavut, 1982–2006.

Time Period	Both Sexes			Females			Males		
	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N
1982–86	0.76 ^{a*}	8.19	75	0.70 ^a	6.56	55	0.93 ^a	8.19	20
1990–98	0.27 ^b	4.45	97	0.31 ^b	4.45	66	0.18 ^b	1.95	31
2004–06	0.12 ^{bc}	5.40	25	0.23 ^{ab}	5.40	16	0.05 ^{bc}	0.33	9

* Means in the same column that share a superscript letter are not significantly different.

TABLE 3. Σ PCB (geometric mean and maximum levels) in blood plasma of adult peregrine falcons captured on territory in Rankin Inlet, Nunavut, 1982–2006.

Time Period	Both Sexes			Females			Males		
	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N
1982–86	0.64 ^{a*}	3.84	70	0.66 ^a	3.84	53	0.58 ^a	2.55	17
1990–98	0.11 ^b	13.86	97	0.40 ^a	13.86	66	0.01 ^b	3.27	31
2004–06	0.32 ^a	3.50	25	0.57 ^a	2.40	16	0.11 ^{ca}	2.80	9

* Means in the same column that share a superscript letter are not significantly different.

TABLE 4. Dieldrin (geometric mean and maximum levels) in blood plasma of adult peregrine falcons captured on territory in Rankin Inlet, Nunavut, 1982–2006.

Time Period	Both Sexes			Females			Males		
	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N	Geometric mean (mg/kg)	Maximum level (mg/kg)	N
1982–86	0.07 ^{a*}	0.30	72	0.07 ^a	0.27	54	0.08 ^a	0.30	18
1990–98	0.0 ^b	0.37	97	0.01 ^b	0.37	66	< 0.01 ^b	0.30	31
2004–06	0.0 ^{bc}	0.10	25	0.01 ^{bc}	0.10	16	< 0.01 ^{bc}	0.08	9

* Means in the same column that share a superscript letter are not significantly different.

(geometric mean = 0.76 mg/kg) than in the 1990s (0.27 mg/kg, $p < 0.001$) and the 2000s (0.12 mg/kg, $p < 0.001$). However, there was no difference in the geometric means for plasma DDE levels recorded in the 1990s and the 2000s ($p = 0.359$).

For adult males, plasma DDE levels were significantly higher in the 1980s (geometric mean = 0.93 mg/kg) than in the 1990s (geometric mean = 0.18 mg/kg, $p < 0.001$) and the 2000s (geometric mean = 0.05 mg/kg, $p < 0.001$). However, there was no difference in the geometric means for plasma DDE levels recorded in the 1990s and 2000s ($p = 0.334$). Females also had a significant decline in plasma DDE levels from the 1980s (geometric mean = 0.70 mg/kg) to the 1990s (geometric mean = 0.31 mg/kg, $p = 0.02$); however, the declines observed in the 2000s were not statistically significant compared to the 1980s ($p = 0.11$) or the 1990s ($p = 0.95$).

For both sexes combined, PCB residues declined significantly from the 1980s (0.64 mg/kg) to the 1990s (0.11 mg/kg, $p < 0.001$; Table 3), but there was no significant difference between the 1980s (0.64 mg/kg) and the 2000s (0.32 mg/kg, $p = 0.39$), or between the 1990s (0.11 mg/kg) and the

2000s (0.32 mg/kg, $p = 0.15$). Taking sex into account, we found that although both sexes experienced reduced Σ PCB burden between the 1980s and 1990s, only males experienced a significant reduction (from 0.58 mg/kg to 0.01 mg/kg, $p < 0.001$), while that in females was not statistically significant (from 0.66 mg/kg to 0.40 mg/kg, $p = 0.24$). Whether considered together or separately, male and female peregrine falcons captured on territory at Rankin Inlet in the 2000s showed higher levels of PCBs (males: 0.11 mg/kg; females: 0.57 mg/kg) than the cohort captured during the 1990s (males: 0.01 mg/kg; females: 0.40 mg/kg).

Appreciable levels of dieldrin were recorded in samples of blood plasma collected from adults of both sexes from 1982 to 1986 (Table 4). The geometric means recorded during this period were 0.07 mg/kg for females and 0.08 mg/kg for males, and maximum levels were 0.27 mg/kg for females and 0.30 mg/kg for males. Although maximum levels recorded in the population in the 1990s remained the same or increased regardless of sex, the geometric means for both sexes declined significantly from those recorded from 1982 to 1986 (Table 4).

The geometric means for both sexes decreased no further in the 2000s from values recorded in the previous time period (1990–98); however, substantial declines were evident in the maximum values recorded in the population. Over the course of the study, maximum dieldrin levels decreased to about one-third of their previous levels in both females (from 0.27 mg/kg in the 1980s to 0.10 mg/kg in the 2000s), and males (from 0.30 mg/kg to 0.08 mg/kg).

Weather

The average summer temperature measured at Rankin Inlet increased by approximately 1.5°C (slope: 0.065 ± 0.02 SE, $p = 0.008$; $R^2 = 0.23$) from 1982 to 2009 (Fig. 3). Although we found a declining trend (slope = -1.30) in total precipitation for the same period, it was not significantly different from zero ($p = 0.19$). Similarly, deviations calculated for each month from the averages calculated for June (slope = -0.81), July (slope = 0.33), and August (-0.34) from 1982 to 2009 were not significantly different from zero.

DISCUSSION

Pollutant status and reproductive dysfunction in peregrine falcons are well documented both for populations in North America in general (Berger et al., 1970; Peakall and Kiff, 1988; Peakall et al., 1990) and in the Rankin Inlet study area specifically (Court et al., 1990; Johnstone et al., 1996). Of the contaminants measured here, only DDE is known to have been associated with population declines (from eggshell thinning) in North American peregrine falcon populations, and although the effects of dieldrin were reportedly absent in North American peregrine falcons (Risebrough and Peakall, 1988), this contaminant was considered important in the British Isles (Nisbet, 1988). The effects of PCBs on peregrines, if any, remain unknown, but at least it is well established that neither PCBs nor dieldrin contributes to eggshell thinning.

Although this analysis showed that some individuals within the Rankin Inlet population were as contaminated in recent years as their ancestors were more than 25 years ago, overall population-level organochlorine residues in peregrine falcons have shown a significant decline over the last three decades. Furthermore, levels recorded throughout the study period, and in particular those recorded more recently, are significantly below levels (1.8–2.4 ppm in serum) known to cause problems in eggshells (Peakall and Kiff, 1988; Court et al., 1990). We believe that peregrine falcons that breed near Rankin Inlet no longer face a direct threat from the pollutants investigated in this study, and in this regard, there is good reason to be optimistic about the future of peregrine falcons breeding at Rankin Inlet. Similar trends have been noted previously by other authors (Jarman et al., 1994; Henny et al., 1996, 2009; Ambrose et al., 2000; Clark et al., 2009) investigating pollutant levels in peregrine falcons in other jurisdictions, and we

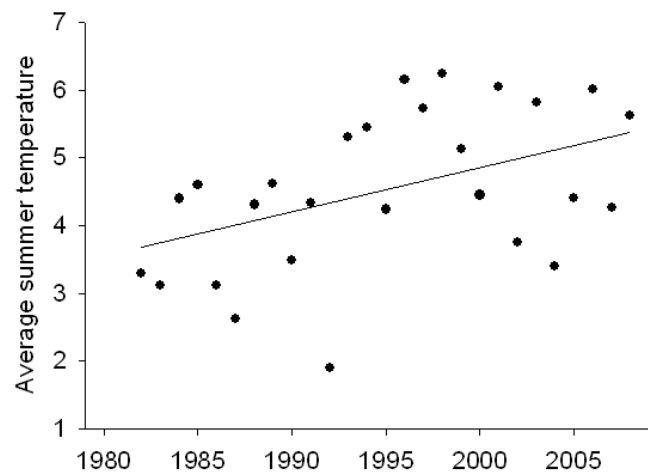


FIG. 3. Average summer temperature (average monthly temperature from June to August, °C) at Rankin Inlet, Nunavut, Canada, from 1982 to 2008. Line represents the estimated linear trend (slope: 0.065 ± 0.02 SE; $p = 0.008$; $R^2 = 0.23$). The regression was performed with proc AUTOREG in SAS v.9 (SAS Institute, 2004), correcting for temporal auto-correlation, and thus dependence, among the residuals (autoregressive error regression).

suggest that this trend most likely applies to other Canadian populations.

It is generally assumed that declining trends in pesticide loads will be accompanied by a corresponding increase in productivity. We therefore measured occupancy, reproductive performance, and pesticide loads concurrently. However, our findings indicated that reproductive success of peregrine falcons in our study population declined despite concomitant reductions in pesticide loads. On average, approximately three fewer territories were occupied annually from 2002 to 2009 than were occupied from 1982 to 1989. The overall decline in reproductive success can likely be explained in part by the presence of fewer pairs attempting to breed each year. However, it is important to note that productivity, which accounts for the number of occupied territories, also declined significantly. Considered together, these results indicate that in recent years fewer pairs have attempted to breed, and in addition, those that were successful in breeding raised fewer young to banding age (≥ 20 days of age). In general, the pesticides examined in this study cannot mechanistically explain either the reduction in occupancy or the decline in reproductive performance.

Although the mechanism or mechanisms (e.g., disease, predation) associated with the reported declines are unclear, the proximate effects of local weather patterns—ultimately associated, either directly or indirectly, with overall climate change—may be noteworthy in regard to explaining the altered demographic features evident in the Rankin Inlet population. We suggest that this factor is particularly important given the documented rise in average summer temperature recorded in Rankin Inlet over the course of this study. Although the patterns in precipitation examined here indicate that there was no significant change in either the amount of rain and snow or the manner in which total



FIG. 4. A soaked adult female peregrine falcon breeding near Rankin Inlet, Nunavut, stands beside a clutch of almost entirely submerged eggs.

precipitation was distributed through the summer months from 1982 to 2009, it is interesting to note that the slope calculated for average summer precipitation was negative, as were slopes for the deviations in June and August precipitation each year relative to mean June and August precipitation for all years of the study. Conversely, a positive slope was calculated for the deviation in July precipitation each year relative to mean July precipitation for all years of the study. It is thus feasible that in recent years both June and August may have become drier, while July may have become wetter. Increased precipitation in the month of July, even if associated with reduced precipitation in June and August, could easily result in widespread loss of broods, as nestlings typically hatch around July 11 and remain particularly vulnerable to the direct effects of cold and wet conditions until at least 21 days of age. Recently, motion-sensitive cameras deployed in our study area have documented several cases of nest flooding (e.g., Fig. 4) and shown that otherwise healthy broods of young can perish in as few as two hours after direct exposure to cold, wet conditions. In these cases, photographic evidence indicated that weather-killed young were either fed to siblings or consumed or cached by the parents. In other cases where cameras were not present, but the presence of healthy nestlings had been confirmed immediately prior to an extended period of inclement weather, it was not unusual for follow-up monitoring of the same sites soon after the poor-weather period to document a reduction in brood size or a total absence of nestlings. At sites where collection of dead young was possible immediately after extended periods of rainfall, young were often found huddled together, and on occasion, examination of the carcasses revealed that nestlings had died prior to passage of food from the crop into the proventriculus (i.e., they had not starved).

Alternatively, poor weather may indirectly influence annual reproductive success of peregrine falcons in a “bottom-up” manner via availability of food resources. Repeated site visits revealed that in some cases, nestlings that had been initially spared from the direct effects of poor weather

(by either parental care or advanced feather growth) later died as a result of poor body condition. In these instances, we believe that the abundance of prey species (primarily juvenile ground-nesting passerines) was reduced by adverse weather conditions to levels at which adult peregrine falcons were not able to provision young adequately. In recent years, the carcasses of several nestlings that showed poor rates of growth or sudden declines in body weight at some point during rearing were collected, and post-mortem examination clearly indicated that these young had been severely food-limited prior to their deaths. In several cases, all nestlings within a brood experienced significant weight loss (50–160 g each) during periods when the feeding rate decreased from 6–7 prey items per day to 1–2 per day. Brood size was routinely reduced in these cases.

The results reported here emphasize how important it is for wildlife agencies to continue monitoring reproductive success of peregrine falcons and encourage routine residue scans in their tissues to detect any sharp changes in either hatching success or chemical residues over time. In addition, declining levels of organochlorine residues found in peregrine tissue leave little room for complacency. Although there are global initiatives in place to eliminate the manufacture and use of many of the most environmentally damaging compounds, strong lobbies exist that aim to resurrect chemicals like DDT as a short-term measure to control malaria and other insect-borne diseases in developing nations (Raloff, 2000). As virtually all the peregrine falcons from northern Canada overwinter in Mexico, Central America, and South America, any move to resume DDT use on a large scale will be detrimental to these birds.

Finally, it is important to note that our comments with regard to the observed downward trends in occupancy and reproductive success are limited to peregrine falcons breeding at Rankin Inlet. Such trends may exist at broader scales, but larger patterns can be clarified only by incorporating additional, geographically distinct areas into the study.

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