Peregrine Falcon Surveys Along The Mackenzie River, Northwest Territories, Canada

Suzanne Carrière and Steven Matthews

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ABSTRACT

Peregrine falcons (*Falco peregrinus*) breed in the Northwest Territories (NWT), particularly in areas where cliffs and bluffs occur. Large declines in peregrine falcon numbers and extirpation from a substantial part of the historical distribution occurred from the 1940s until well into the 1970s. Recovery of peregrine falcon populations in North America began after the reduced use of dichlorodiphenyltrichloroethane (DDT). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) re-assessed peregrine falcon *anatum* from Endangered in 1978 and 1992, to Threatened in 2000, and then as Special Concern (*anatum / tundrius* complex) in 2007.

Every five years, from 1970 onward, as part of a national program across Canada, the Canadian Wildlife Service (CWS) then the Government of the Northwest Territories (GNWT) have surveyed peregrine falcons along the Mackenzie River by helicopter and boat. This report presents results from the latest survey in 2010, and trend analyses on nesting behaviour, including productivity and phenology, of peregrine falcons from 1970 to 2010.

In 2010, 73% of nest locations were on rocky or grassy cliffs, 14% were on old stick nests on cliffs, and 13% of nests were on “atypical” substrates such as on the ground along the eroding mud banks of the Mackenzie River or other streams and ponds. No pair was found nesting on trees. Ground nesters can be difficult to survey by helicopter, so results from both helicopter and boat survey methods have been merged every survey year. The total number of productive sites observed along the Mackenzie River reached a new record of 81 in 2010.

New sites were discovered opportunistically during surveys, so the total number of occupied sites in the study area has increased every survey. From 1980 to 2010, the average nearest-neighbor distance between occupied nests declined linearly by -0.23 km/yr (-2.3 km per decade). From 1970 to 2010, the average nesting success was 61%, average brood size was 2.4 young per productive site and average productivity was 1.4 young per occupied site. There were no temporal trends in occupancy of previously known sites.

Advancements of phenological events due to climate change have been demonstrated in many bird species, but less often for raptors. Hatching usually occurs later in northern latitudes than in more southern ones. Hatching dates for peregrine falcons along the Mackenzie River advanced by -1.5 to -3.6 days per decade from 1985 to 2010, depending on latitude. Advancing hatch dates may benefit peregrine falcons by lengthening the rearing period for young so they may learn how to catch difficult prey before making the migration south.

Northern peregrine falcons migrate to countries still using DDT, and new contaminants may affect them in the future. We intend to continue the five-year survey to track further changes, phenology and population numbers.

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INTRODUCTION

Peregrine falcons (*Falco peregrinus*) breed in most of the Northwest Territories (NWT) and Nunavut, particularly in areas where cliffs and bluffs occur. The exact historical distribution of peregrine falcons in the NWT, and for most of North America, has never been fully documented (White et al. 2002).

Large declines in peregrine falcon numbers and extirpation from a substantial part of historical distribution occurred from the 1940s until well into the 1970s (Hickey, J.J. 1969, Cade et al. 1997, White et al. 2002). By 1970, only nine occupied sites could be found along the Mackenzie River study area (Rowell et al. 2003). The cause of the decline was contamination by pesticides such as dichlorodiphenyltrichloroethane (DDT) and other persistent organochlorine compounds causing egg shell thinning, incubation failure, or mortality (Cade et al. 1988, Vorkamp et al. 2009).

Recovery of peregrine falcon populations in North America was initiated after the reduced use of DDT, including a complete ban in Canada in 1969, the United States in 1972, and in many other areas in the following years (Dunlap 1982, Curtis and Lines 2000). Recovery was helped by reintroduction of captive-raised young, especially in southern Canada and the United States (Cade et al. 1988). Reintroduced chicks were selected from the few regions where differences in prey base and wintering range resulted in less of the bioaccumulation that caused egg shell thinning and hence an increased survival of young through the 1960s and 1970s (Cade et al. 1988, Tordoff and Redig 2001).

Two subspecies of peregrine falcons were historically recognized in the NWT: the *anatum* subspecies mostly bred south of the treeline and the *tundrius* subspecies bred on the tundra (White et al. 2002). A third sub-species, *pealei*, occurs in Canada, but not in the NWT, nesting on the islands off the coast of British Columbia. New genetic studies (Brown et al. 2007) using samples taken before the declines have demonstrated that the *anatum* and *tundrius* subspecies were genetically indistinguishable from each other. Brown et al. (2007) only measured slight genetic differences between *anatum* and *tundrius* from recent samples, possibly due to the introduction of new genetic material from introduced birds in the southern portion of the *anatum* range.

By 1978 and again in 1992, the Committee on Endangered Species in Canada (COSEWIC) had assessed the peregrine falcon as Endangered (*anatum* subspecies), Threatened (*tundrius* subspecies), and Rare (*pealei* subspecies) (Martin 1978, COSEWIC 2001). By 2000, the recovery of the peregrine falcon was considered advanced enough for COSEWIC to re-assess the status of the *anatum* sub-species as Threatened (Jonhstone 1999). The anatum subspecies of peregrine falcon was listed as Threatened under the federal *Species at Risk Act* (SARA) in 2004 (Species at Risk Public Registry 2004). Then in 2007, COSEWIC re-assessed peregrine falcon as Special Concern for the *anatum / tundrius* complex (COSEWIC 2007) which was listed under SARA in July 2012 (Species at Risk Public Registry 2012).

Every five years from 1970 onward, a national survey of peregrine falcons is coordinated in selected study areas in all jurisdictions in Canada (Rowell et al. 2003). The main study area in the NWT included in this national survey is along the Mackenzie River. Other surveys on raptors, including peregrine falcons, have been conducted in the NWT. See Carrière et al. (2003) for a summary of historical surveys of nesting peregrine falcon in the NWT. The present file report presents results from surveys conducted in the Mackenzie River study area.

The purposes of this report are to:

(1) Present the results of a peregrine falcon survey conducted in 2010 by the Government of the Northwest Territories (GNWT) along the Mackenzie River,

(2) Present trend analysis of results from the surveys conducted every five years from 1970 to 2010,

(3) Evaluate the recovery of peregrine falcons along the Mackenzie River in the NWT,

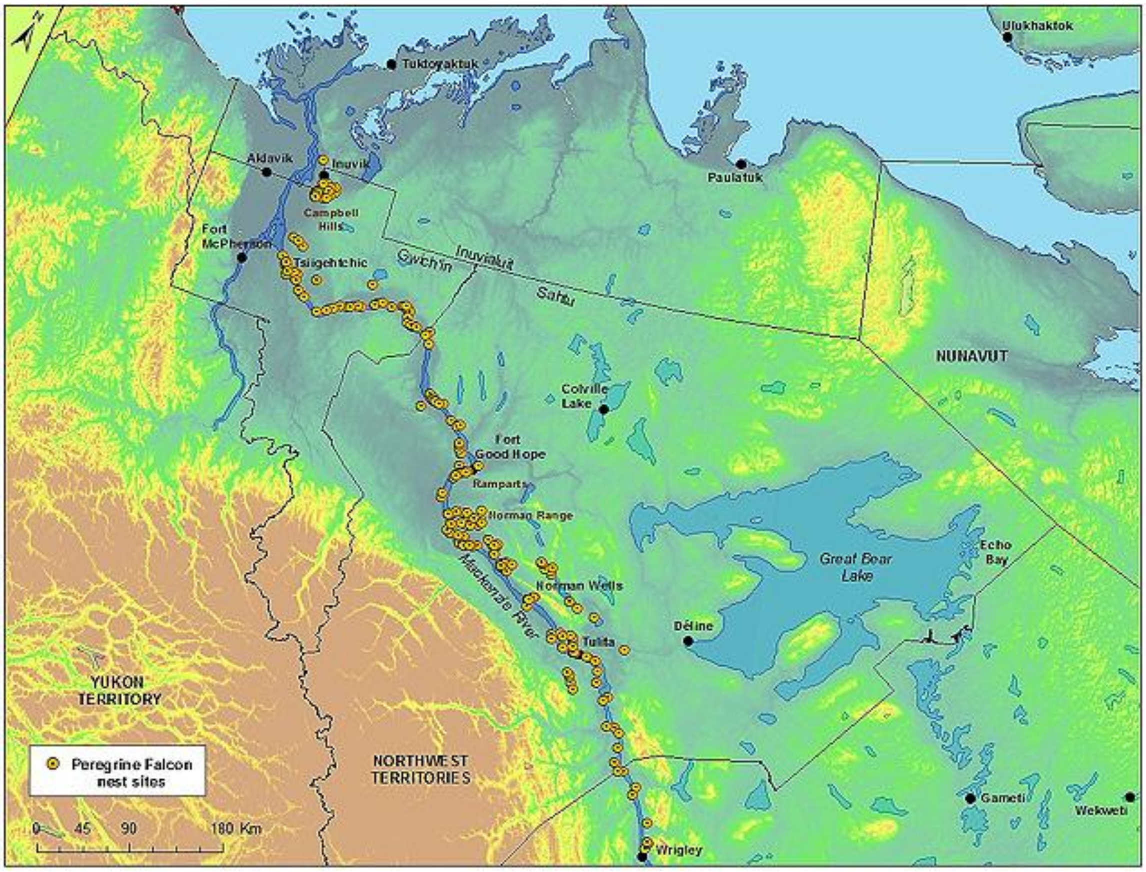
(4) Evaluate future monitoring needs, and

(5) Assess possible future management actions.

Study Area and Methods

<u>Survey by helicopter in 2010</u>

The Mackenzie River study area, as surveyed by helicopter, included river cut-banks, rock outcrops, hills and mountain ranges within about 50 km on either side of the river from north of Wrigley to near Inuvik, NWT. The south to north linear distance of the Mackenzie River study area was about 800 km. In 2010, a Bell 206 Jet Ranger was used, with one pilot having mountain flight experience, one navigator-observer sitting in the front seat and one recorder-observer sitting in the back seat. An additional observer can be positioned in the back seat, if fuel and weight allow, but no additional observer was present during the 2010 helicopter survey.



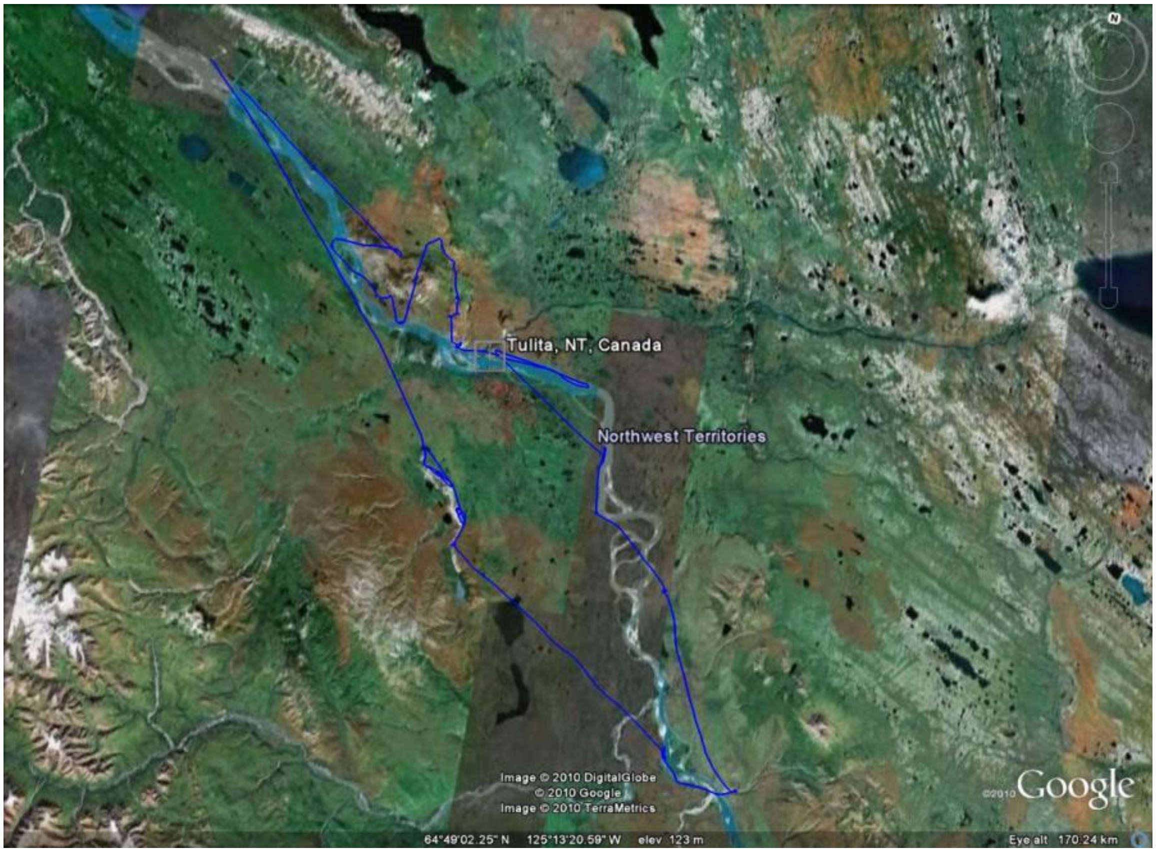
Map 1: Peregrine falcon nesting sites examined in 2010 in the Mackenzie River study area.

Typically, peregrine falcon pairs will return to the same nesting territory (i.e. site) used in previous seasons (e.g. White et al. 2002, Carrière et al. 2003, Ritchie and Shook 2011). Nesting sites may include a principle nesting location (e.g. a small bare ledge on the cliff), and one or many alternative nesting locations. Each spring, the arriving pair will select a specific location for nesting (a bare ledge, or even a stick nest built on a cliff by another species of raptor) and use that site for that year. The alternative locations within the nesting territory may be used for perching, hunting, or resting. In subsequent years, the alternative locations may be used for nesting.

Before a survey, the crew obtained topographic maps (1:250,000 and 1:50,000) with all known peregrine falcons sites, including detailed geo-referenced information on all alternative locations within each site or territory. The crew also obtained, if available, sets of photographs for nesting locations to help locate them while in flight. In 2010, two hand-held Global Positioning Systems (GPS) were used to locate known nesting sites, and to record the coordinates of new sites. Newer GPS units that can display 1:50,000 topographic maps with waypoints provide the best system for quickly locating and recording nest sites. The onboard GPS can also be used. The crew member sitting at the front assumed the primary responsibility for navigation, giving verbal directions to the pilot to the next known site. Approach was done at a reduced speed, about 20 m above the potential location of the nest, parallel to the cliff or bank face. Actual position of the helicopter was determined by wind, cliff topography and other factors. The pilot looked ahead and was often the first member to locate an adult bird. Adult perching locations, description of past nest location, fresh white wash (feces), and a visual search of the cliff or bank helped observers to successfully locate young. Young were aged and counted, and the aircraft quickly left the area.

In 2010, the survey was usually performed in five sections, from south to north, one day per section. Flight lines and number of peregrine falcon nest sites from the 2010 survey are provided in Maps 1-6. The helicopter survey crew was Steven Matthews and Suzanne Carrière (Appendix 1).

Tulita Sector



Map 2: Tulita sector.

The Tulita sector included nest sites along the Mackenzie River from the Saline River to about 35 km north of Tulita. In this sector, sites were right on the river banks, with some additional sites along the cut banks of glacio-fluvial material (photo 1) of smaller rivers and streams emptying into the Mackenzie River.

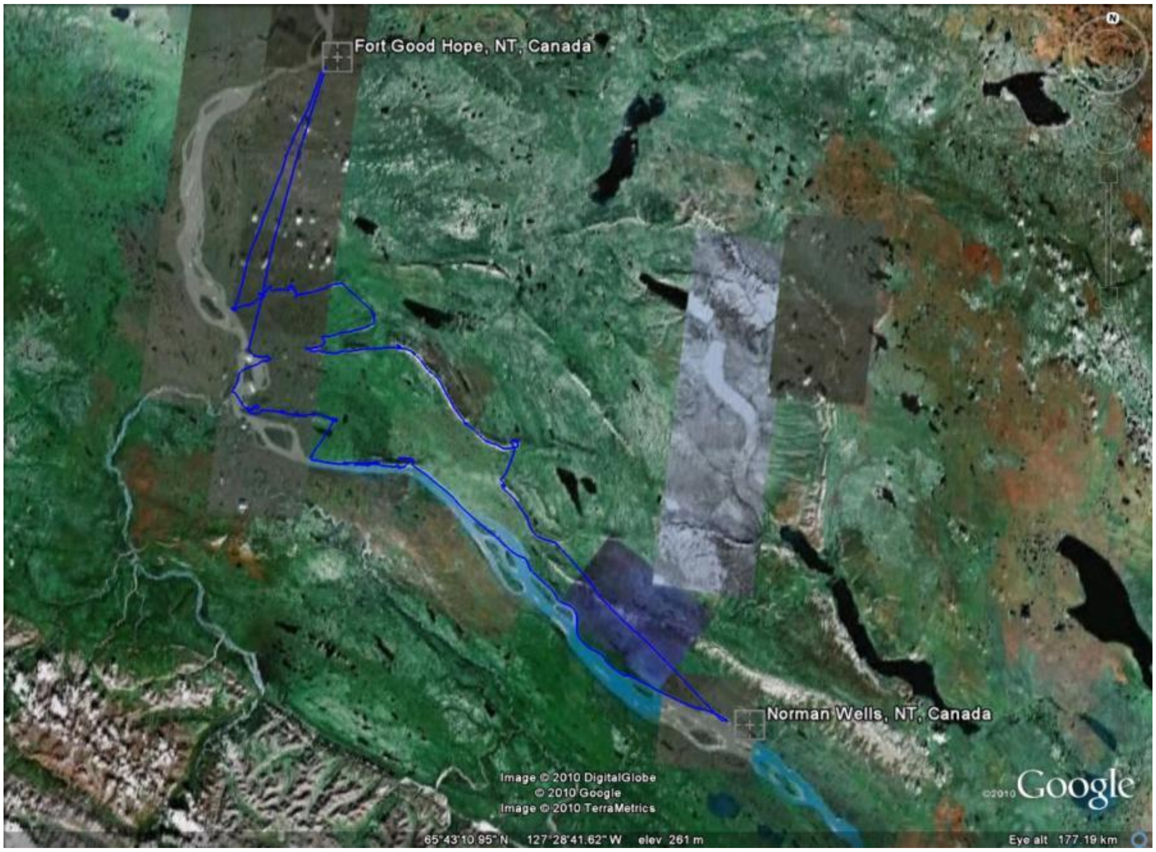
Sites on Mackay Range, on the southern edge of the Norman Range, and on the entire Bear Rock formation were surveyed. Dolomite and limestone ridges, including pack breccias of Bear Rock (Hamilton and Ford 2002), offered ledges for nesting in those areas (Ecosystem Classification Group 2007).

Portions of ecoregions surveyed in the Tulita sector include, from south to north, the Taiga Cordillera’s Central Mackenzie Plains (LSb) and Mackenzie Foothills (LSbs)

(Ecosystem Classification Group 2010) and the Taiga Plains North Mackenzie Plains (LS) (Ecosystem Classification Group 2007).

Photo 1. Nesting location on eroding glacio-fluvial material.

Norman Wells Sector



Map 3: Norman Wells sector.

The Norman Wells sector included sites west of the Norman Range, north of Oscar Creek Gap, in the Franklin Mountains and Carcajou Ridge, with additional sites along river banks east and north of Sans Sault Rapids. Portions of ecoregions surveyed in the Norman Wells sector include, from south to north, Taiga Plains North Mackenzie Plains (LS) and Norman Range (LS) (Ecosystem Classification Group 2007). Some ridges and cliffs were 100-200 m tall; all were of dolomites and limestone of Cambrian-Devonian age (Ecosystem Classification Group 2007).

Photo 2. Ridge in the Norman Wells sector.

Fort Good Hope Sector

Map 4: Fort Good Hope sector.

The Fort Good Hope sector included sites along Bosworth Creek and Lennie Lake, sites along Norman Range not surveyed the previous day, then all sites on the Ramparts, on Fossil Lake, and along the Mackenzie River and smaller incoming streams and rivers to Grand View. Portions of ecoregions surveyed in the Fort Good Hope sector include, from south to north, Taiga Plains North Mackenzie Plains (LS) and the Norman Range (LS) (Ecosystem Classification Group 2007). Cliffs in this sector were formed where Devonian limestone have been eroded by the Mackenzie River (Ramparts: photo 3) and large glacial melt water streams (e.g. Fossil Lake).

Photo 3: South-west aspect face on river-left at the Ramparts, just south of Fort Good Hope. View from helicopter.

Tsiigehtchic Sector

Map 5: Tsiigehtchic sector.

The Tsiigehtchic sector included sites that are mostly directly along the banks of the Mackenzie River from Grand View to Tsiigehtchic, with some additional sites on small rivers merging with the Mackenzie, then north to sites along the Rengleng River to the Campbell Hills. A portion of only one ecoregion was surveyed in the Tsiigehtchic sector: Taiga Plains Arctic Red Plains (HS). Nesting locations are mostly formed by the eroding forces of the Mackenzie River (photo 4) or other smaller streams on glacio-fluvial deposits, where some shelves made of stronger material, vegetation, or simply holes in the crumpling deposits were used by breeding pairs.

Photo 4. Typical river bank formation in Tsiigehtchic sector.

Campbell Hills Sector

Map 6: Campbell Hills sector.

The Campbell Hills sector included sites along Campbell Lake, Dolomite Lake and on the Campbell Hills proper. A portion of only one ecoregion was surveyed in the Campbell Hills sector: Taiga Plains Campbell Hills (HS) (Ecosystem Classification Group 2007). Cliffs (photo 5) are found along fractured Devonian limestone and dolomite (Ecosystem Classification Group 2007).

Photo 5 Typical formation in Campbell Hills.

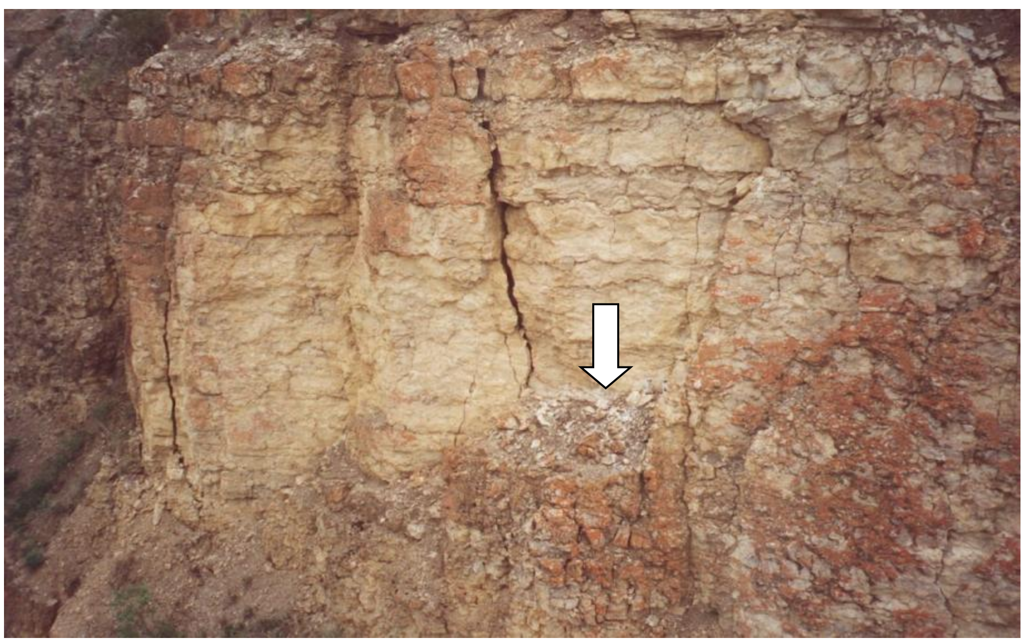


Photo 6 Peregrine falcon nest location with two young, on a ledge.

Survey by boat in 2010

The Mackenzie River was travelled from Wrigley to Inuvik in a 28-foot scow with a 25hp outboard motor from 15 July to 1 August 2010. The survey in 2010 was conducted by Keith Hodson with research assistants Heather Hodson, John Campbell, Wayne Sager and Betty Sager. The boat crew searched all known and potential nesting sites along the river, looking for whitewash excrement at perching sites, prey remains, egg shells, and the presence of actual birds. Sites accessible from the river were climbed and young were banded with United States Fish and Wildlife (USFW) issued lock-on aluminum bands (GNWT banding permit 10540).

Survey types

The helicopter surveys were not considered a complete inventory of the entire study area as they do not cover all potential habitats where peregrine falcons can nest. Each helicopter survey concentrated on visiting sites that were known to have been used by a pair in the past. This information was obtained from previous helicopter surveys, from previous boat surveys or from incidental observations by the general public or industry. New sites were found during each helicopter survey, but these were found opportunistically with no systematic endeavour to survey all potential habitats in the study area.

The boat surveys might be considered a more complete inventory of all peregrine falcons nesting along the actual banks of the Mackenzie River, as the boat crew conducted complete boat passes along each shore on the way down then up river. New sites are found when nesting adults, young or feces (white wash) are seen from the boat.

Nesting terminology

We followed terminology defined in the NWT System of Raptor Data Collection (Shank 1997 *updated in* Peck et al. 2012) as used for other surveys in Canada (Rowell et al. 2003) and the United States (Ritchie et al. 1998). Terms are as follow:

- *Site:* cliff, structure or place where peregrine falcon can lay eggs and raise young. These are further classified as '*known site'* known to have been used in at least one previous survey and '*new site'* found to be used during a survey but not known to have been used in previous surveys.

- O*ccupied site*: a site where a single or pair of adults were observed having territorial behaviour during nesting season, in our case during the survey, or where eggs or young were observed.

- *Productive site*: a site where at least one or more young peregrine falcons were observed during the survey and were assumed to have fledged (i.e. all productive sites are occupied).

- *Nesting success*: the proportion of occupied sites that were productive (i.e. raised at least one young).

- *Brood size*: the number of young per productive site.

- *Productivity*: the number of young produced per occupied site.

Age of young was determined by comparing observed chicks with a set of photographs of young of known age class (Canadian Wildlife Service - Wainwright Station: Age Guide for Young Peregrine Falcons; see Clum et al. (1996)). This method yields approximate age classes that are about ± 2 days. We estimated hatch date by subtracting the lower limit of observed age class for a brood to the date the nest was observed (e.g. date observed: 15 July (199 Julian); minimum age estimated: 24 days; hatch date = 175). Julian date 182 is 1 July.

Gender of young for each nest visited by the boat crew in 2010 was determined by overall size and feet size. Female peregrine falcons are larger and require larger band size.

Trend Analyses of 1970-2010 Surveys

We analyzed temporal trends in occupancy, number of productive sites, and productivity using linear regressions. We arcsine-transformed occupancy and productivity ratios prior to analysis (Sokal and Rohlf 1981). We looked for annual differences in brood size using Kruskal-Wallis one-way analyses of variances (Daniel 1978). We compared sex ratio in broods with an expected median of 50% (1 female:1 male) using Wilcoxon one-sampled signed rank test (Daniel 1978). We analyzed temporal trends in hatch dates with latitude as a co-variable. Average nearest neighbour distances were calculated using ESRI™ Average Nearest Neighbour tool, in the Analyzing Patterns - Spatial Statistics Tools package (also termed “mean inter-nest distance”, see Ratcliffe 1980). We used the same tool to determine if distribution patterns of occupied nests each survey year were random (ratio of observed nearest neighbour distances to expected random = 1), dispersed (positive ratio) or clustered (negative ratio). Statistical significance for each ratio per year was measured by Z score in the ESRI tool. All other statistical analyses were conducted using SigmaPlot 12™. We tested for normality in data using Shapiro-Wilk test (Sokal and Rohlf 1981). All data, except brood size, met normality assumption (Shapiro-Wilk test in SigmaPlot 12™). We considered differences and trends significant when $P \leq 0.05$.

RESULTS

2010 Survey Results

A total of 207 sites were surveyed in 2010 (Table 1) along the Mackenzie River. These included 20 new sites not observed in previous surveys. All sites that have been occupied at least once by peregrine falcons were surveyed, even if the site was destroyed, modified or occupied by other species in the past. New sites were generally alternative nesting locations of a previously known territory for one pair that now were occupied by two pairs, or new nesting locations in territories inside the study area.

Table 1. Peregrine falcon sites surveyed, and found occupied and productive along the Mackenzie River, 1970-2010. See footnotes for source information.

Parameters	1970 [a]	1975 [a]	1980 [a]	1985 [b]	1990 [c]	1995 [d]	2000 [e]	2005 [f]	2010 [f]
Number of Peregrine Falcon sites surveyed									
Observed sites known in previous years				61	107	117	118	135	187
New sites observed				17	7	11	4	20	20
Total sites observed	22	49	44	78	114	128	128	155	207
Occupied sites									
Number of occupied known sites [1]				28	81	72	76	92	121
Number of occupied sites	9	24	20	45	88	83	80	112	141
Occupancy									
Proportion of known sites				0.46	0.76	0.62	0.64	0.68	0.65
Proportion of all sites	0.41	0.49	0.45	0.58	0.77	0.65	0.63	0.72	0.68
Productive sites									
Number of productive known sites [2]				19	63	47	33	60	63
Number of productive sites	2	16	*10*	36	70	58	37	76	81
Nesting success									
Proportion of total occupied sites that were productive	0.22	0.67	0.50	0.80	0.80	0.70	0.46	0.68	0.57

Data stored in the NWT/NU *Raptors database in* Environment and Natural Resources. 2011. NWT Wildlife Management Information System. Government of the NWT, Yellowknife, NT. Project 152 – NWT/NU - Raptor Nests 1928 to present.
a Data published by Bromley and Matthews in Cade *et al.* 1988.
b Data published in Holroyd and Banasch (1996) and Murphy (1990).
c Data published in Holroyd and Banasch (1996) with additional parameters from ENR NWT/NU Raptors database.
d Data published in Banasch and Holroyd (2004) with additional parameters from ENR NWT/NU Raptors database.
e Data published in Rowell et al. (2003) with additional parameters from ENR NWT/NU Raptors database.
f Unpublished data (2005 and 2010).
[1] Occupied sites = sites with either pairs, single adult, young, or eggs present.
[2] Productive sites = sites with young present.

Detection rates

We used results from the 2005 and 2010 surveys to examine differences in detection rates and in coverage between survey types.

Forty-one sites were observed by helicopter in either 2005 or 2010 and then observed by boat (Table 2), an average of 7.9 days later (range: 1 to 13 days later). No sites were observed by boat before the helicopter observed them. Detection rates of productive nests by helicopter were estimated using the boat crew results, as the latter can hear defensive birds and invest more time searching for productive sites than the helicopter crew. Of the 41 sites observed by both surveys and found to be productive according to the boat survey, 81-83% of these were recorded as productive by the helicopter survey in 2010 and 2005, respectively (Table 2). Of those nests detected by the boat but missed by the helicopter crew, most (6/9, for year 2005 and 2010) were located along mud or clay banks, where falcons nested deep in the banks, hidden from view and were thus hard to find (see section on nest sites descriptions).

Table 2: Helicopter detection rates of peregrine falcon productive sites

Helicopter Detection Rates			
	Number of nests observed as productive by		
Year	**Helicopter then Boat [1]**	**Boat only [2]**	**Detection rates**
2005	15	3	83%
2010	26	6	81%

[1]Number of sites observed as productive (with at least one young) from both the helicopter then from the boat 1-13 days later
[2]Number of productive nests missed by the helicopter, seen by the boat only.

The helicopter surveys covered more sites than the boat surveys. For example, in 2010, the helicopter crew surveyed a total of 109 sites, whereas the boat crew surveyed 74 sites.

Every survey year, results from both helicopter and boat surveys were merged for analysis. Merging data from both surveys provided a more complete picture of the peregrine falcon population along the Mackenzie River as one method led to high coverage of study area (helicopter) and the second method to best detection rates (boat).

Nest sites description in 2010

About 76% of nest site locations (Figure 1) observed in 2010 were on cliffs 15-50 m high. Most (73%) nests were located on either a rocky or grassy ledge (e.g. photo 6), but some nests (13%) were found on the ground (e.g. photo 1) along eroding banks of the Mackenzie River or other streams and ponds. About 14% of locations were borrowed stick nests from rough-legged hawks, golden eagles, or ravens on cliffs. No nests were found on trees in 2010, or in any other survey year. Most nest sites, 63%, (Figure 2) faced south, south-east or south-west, a few (15%) faced east, and some (9%) faced north or northwest.

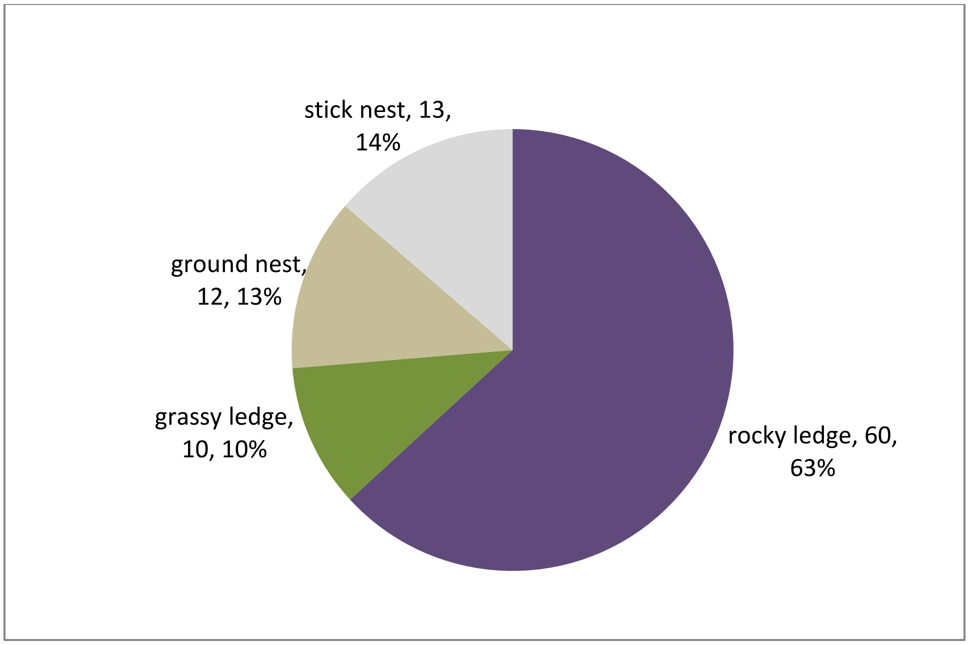


Figure 1: Nest site types used by peregrine falcons along the Mackenzie River, 2010. Shown are number of nests for which nest type descriptions were available and percentages.

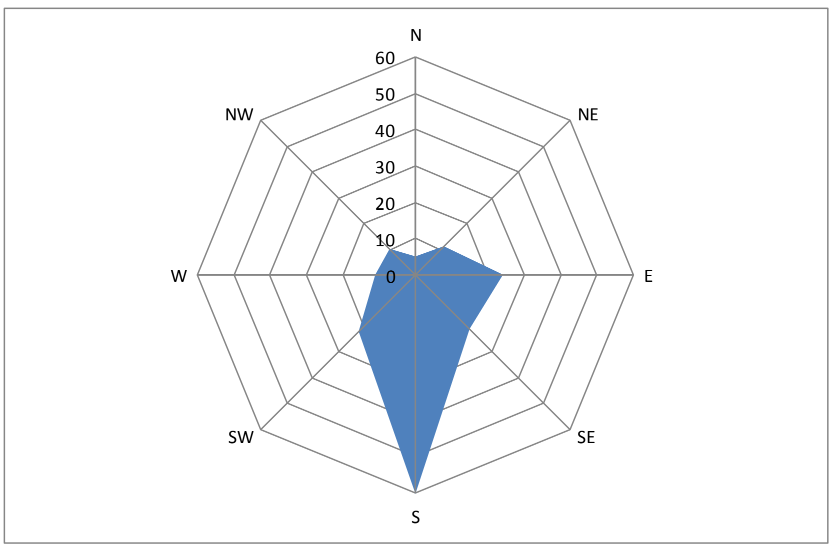


Figure 2: Orientation (aspect) of nest locations along the Mackenzie River, 2010. Shown are number of nest locations (Data in Appendix 2).

Sex ratio of young in 2010

The boat crew visited 27 nests in 2010 when they recorded the gender of 71 young banded. Overall, 50% of young were females (median; CI 95%= 33% to 67% females per brood). Of these 27 nests, five were entirely female, and four entirely male.

The sex ratio was not significantly different than 1:1 (Wilcoxon signed-rank test; Z = -0.55; P = 0.60; n = 71 young).

Change in Average Nearest-neighbour Distances from 1970 to 2010

Occupied peregrine falcon nests (nine) were dispersed with an average of 44.8 km between nearest neighbours in 1970 (Figure 3, Table 3). By 1975, the distribution was somewhat random (Table 3). The nearest neighbour distance declined to 16.9 km. From 1980 to 2010, the average nearest-neighbour distance declined linearly by -0.23 km/yr (-2.3 km per decade: y=-0.227x + 460.9; r^2=0.8798, P=0.002; Figure 3) to the shortest mean distance recorded of 4.3 km in 2010.

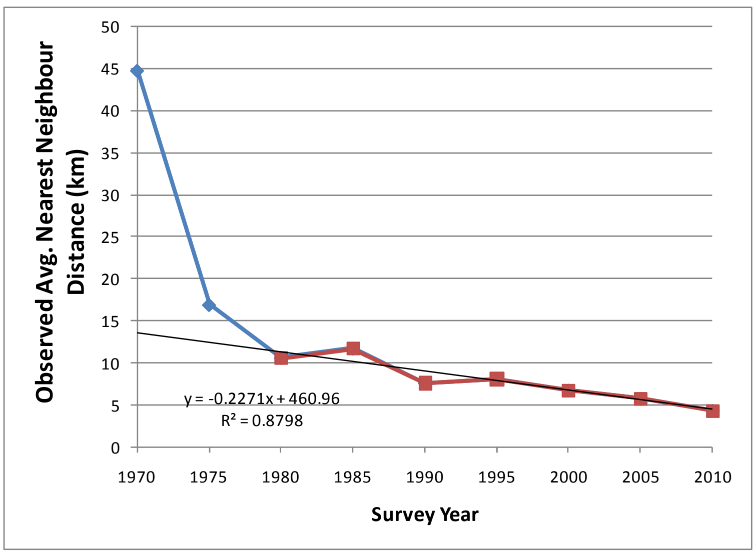


Figure 3: Observed average nearest neighbour distance (km) between occupied peregrine falcon nests, 1970-2010. Linear regression analysis was done for survey years 1980 to 2010 only (red markers).

Table 3: Average nearest neighbour distance and distribution pattern analysis of occupied peregrine falcon nests on the Mackenzie River, 1970-2010.

	Avg. Nearest Neighbour Distance (km)						
Year	**Observed**	**Expected** [1]	**Ratio** [2]	**Z Score**	**p-value**	**Pattern**	**N**
1970	44.8	19.7	2.27	7.28	**	dispersed	9
1975	16.9	20.1	0.84	-1.51	0.13	random	24
1980	10.6	23.4	0.45	-4.66	**	clustered	20
1985	11.7	16.9	0.70	-3.88	**	clustered	45
1990	7.6	13.8	0.55	-7.13	**	clustered	68
1995	8.1	14.1	0.57	-6.41	**	clustered	61
2000	6.7	12.2	0.55	-7.63	**	clustered	79
2005	5.7	11.2	0.50	-9.92	**	clustered	110
2010	4.3	10.3	0.42	-12.87	**	clustered	136

[1] for random distribution.

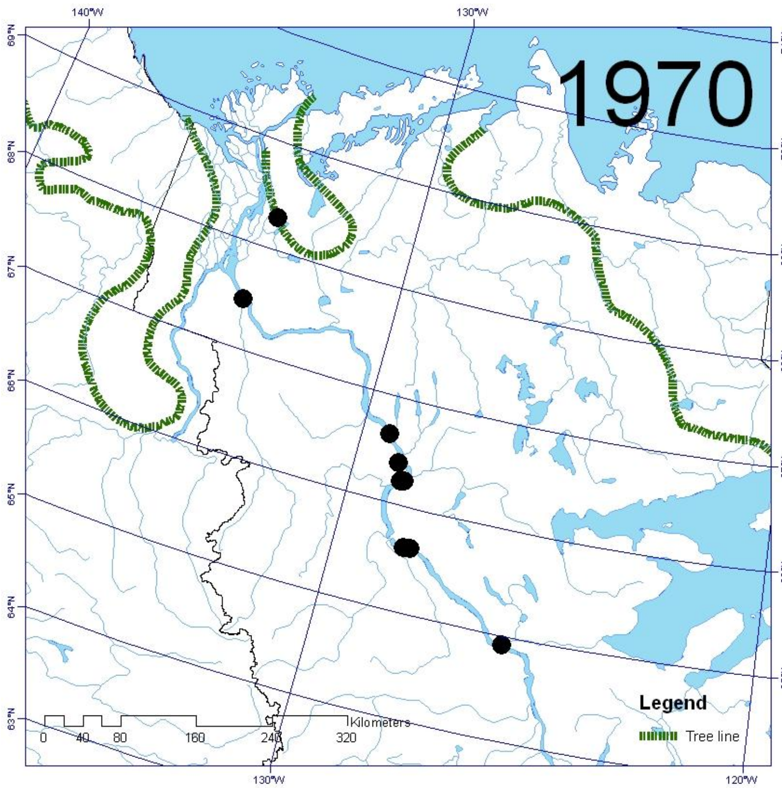
[2] Observed / Expected; Ratio near 1 = random distribution pattern

** p-value less than 0.01

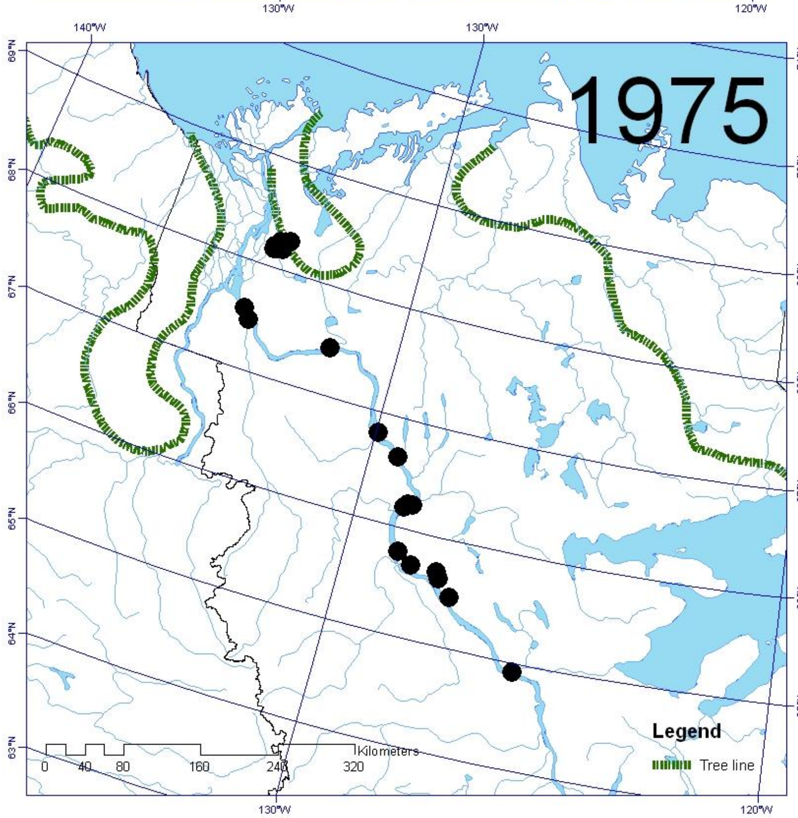
A visual representation of the spatial distribution of occupied peregrine falcon nests in the study area for 1970-2010 is given in Figure 4.

Figure 4.

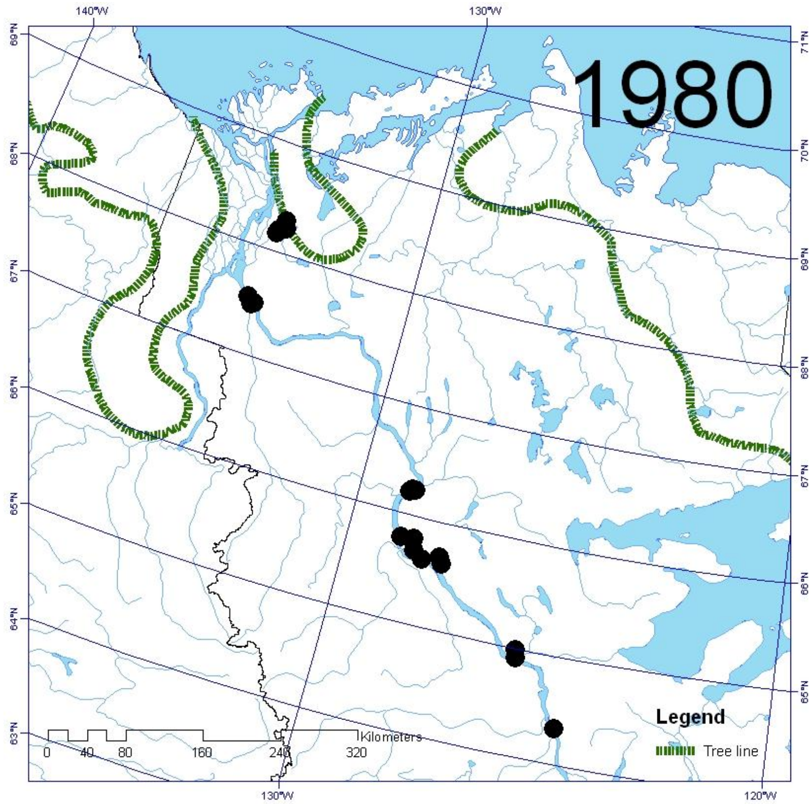
(a)


1970
Legend
Tree line
Kilometers
0
40
80
160
240
320
140°W
130°W
120°W
63°N
64°N
65°N
66°N
67°N
68°N
69°N
70°N
71°N

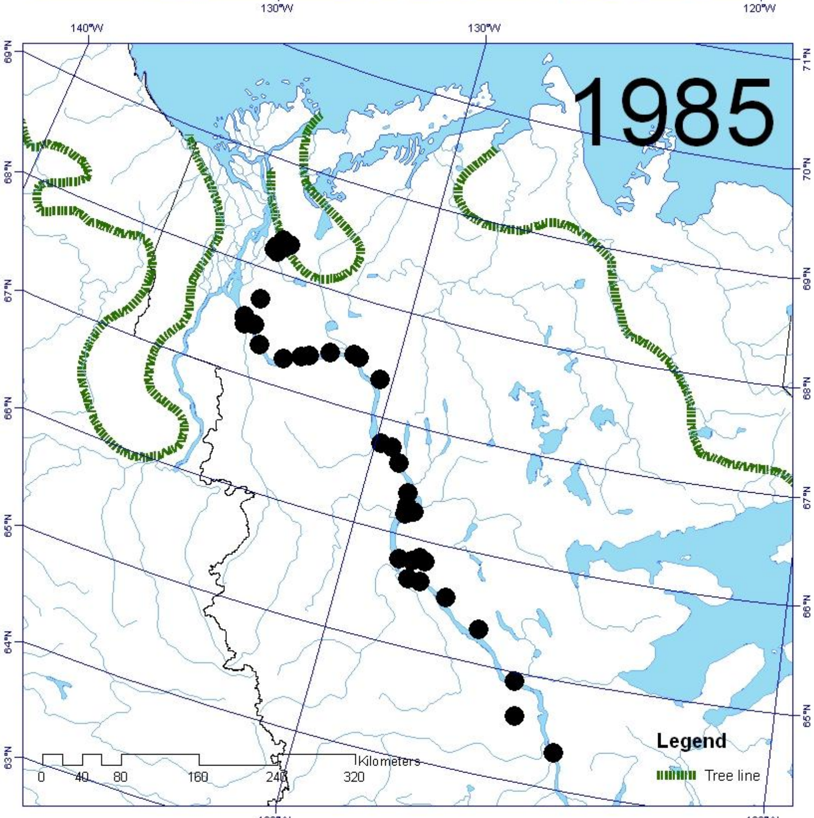
(b)


1975
Legend
Tree line
Kilometers
0
40
80
160
240
320
140°W
130°W
120°W
63°N
64°N
65°N
66°N
67°N
68°N
69°N
70°N
71°N

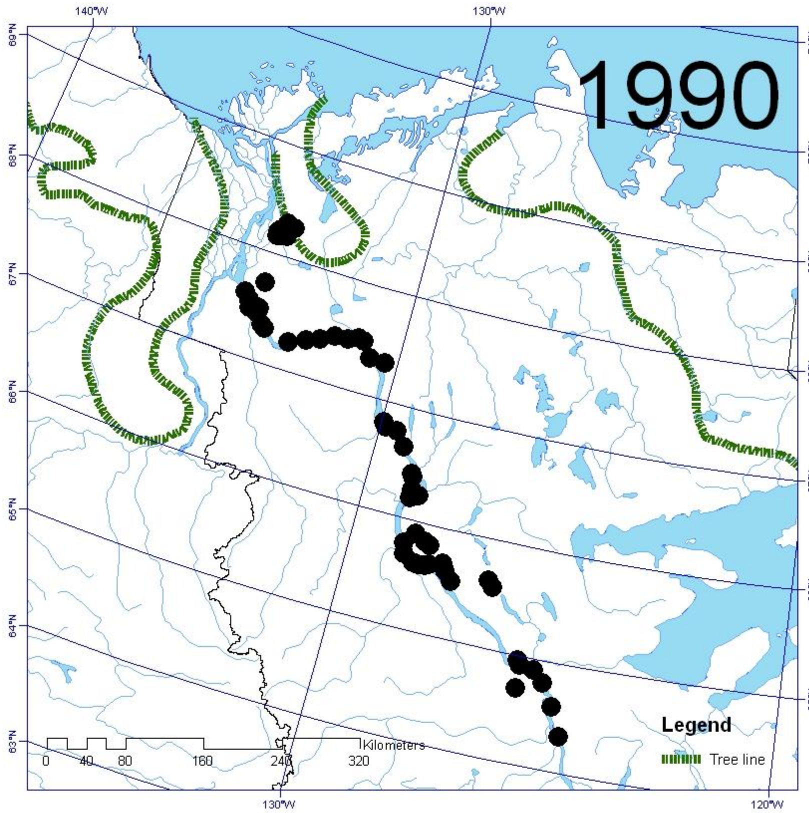
(c)


1980
140°W
130°W
120°W
Legend
Tree line
Kilometers
0
40
80
160
240
320

(d)


1985
140°W
130°W
120°W
Legend
Tree line
Kilometers
0
40
80
160
240
320

(e)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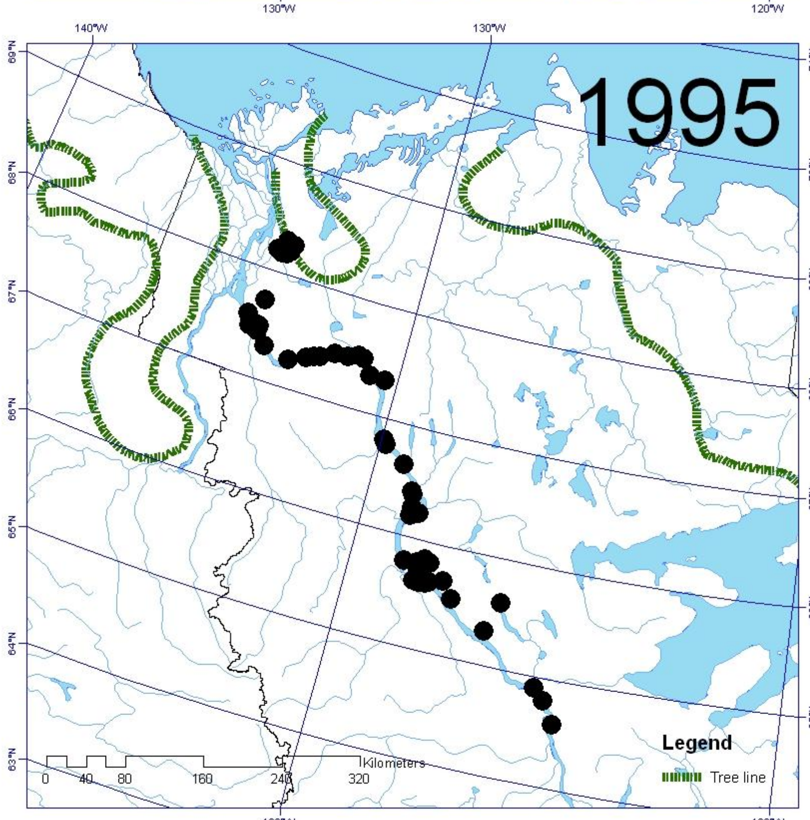
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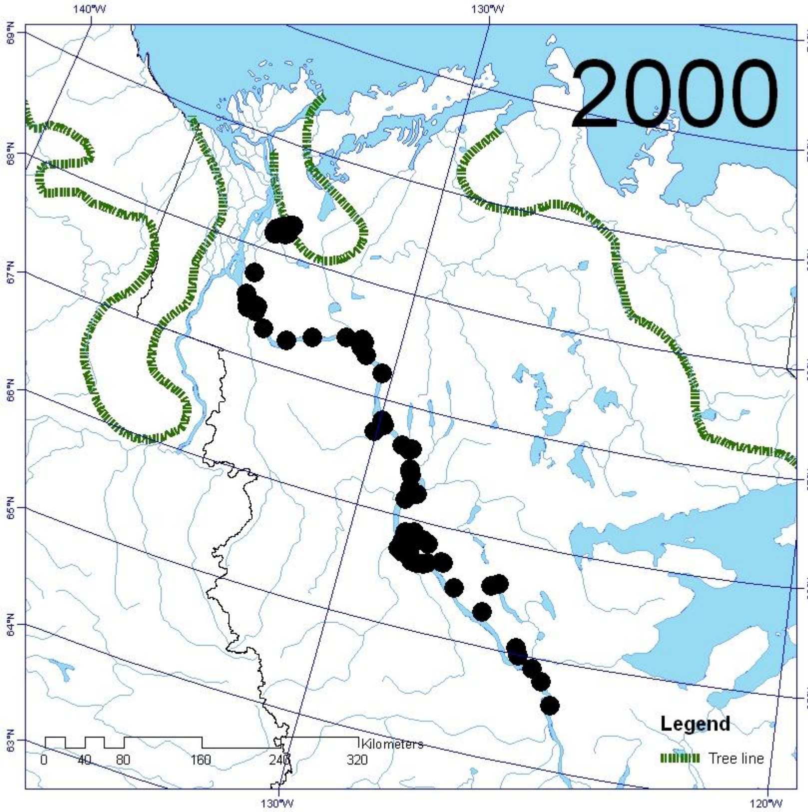
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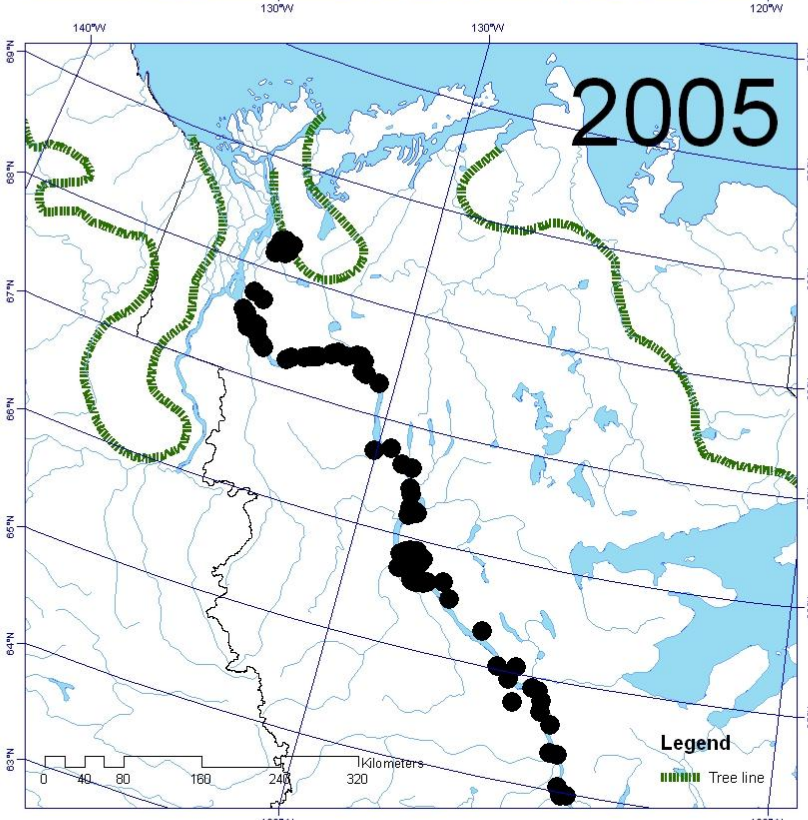
2005
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(i)

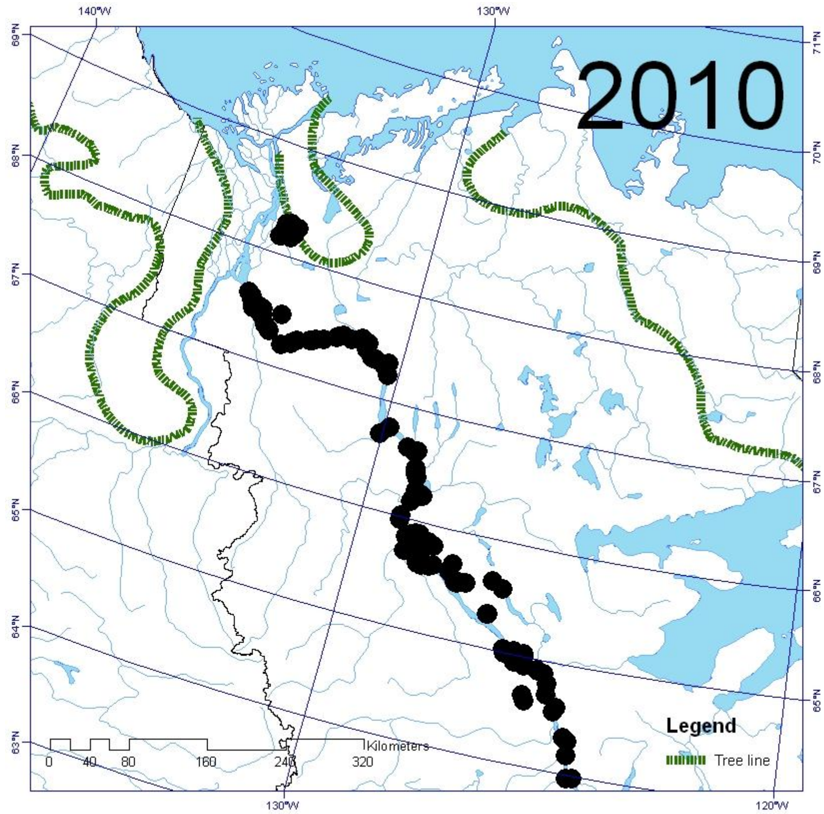


Figure 4: Spatial distribution of occupied peregrine falcon nests along the Mackenzie River, in each survey year (a) 1970, (b) 1975, (c) 1980, (d) 1985, (e) 1990, (f) 1995, (g) 2000, (h) 2005 and (i) 2010. Green lines are the approximation of treeline.

Changes in Occupancy from 1970 to 2010

Occupancy, as measured by the percent of known sites with adults or young, helicopter and boat surveys combined, was 65% in 2010 (Table 1). This is similar to the average occupancy of 63% ± 4% (1 SE) estimated from 1985 to 2010. There was an increase in occupancy of known sites from 1985 to 2010 (linear regression; t = 0.82, P = 0.46). Because new sites were opportunistically discovered every survey, the total number of occupied sites in the study area increased every survey (Figure 5), but not occupancy of previously known sites.

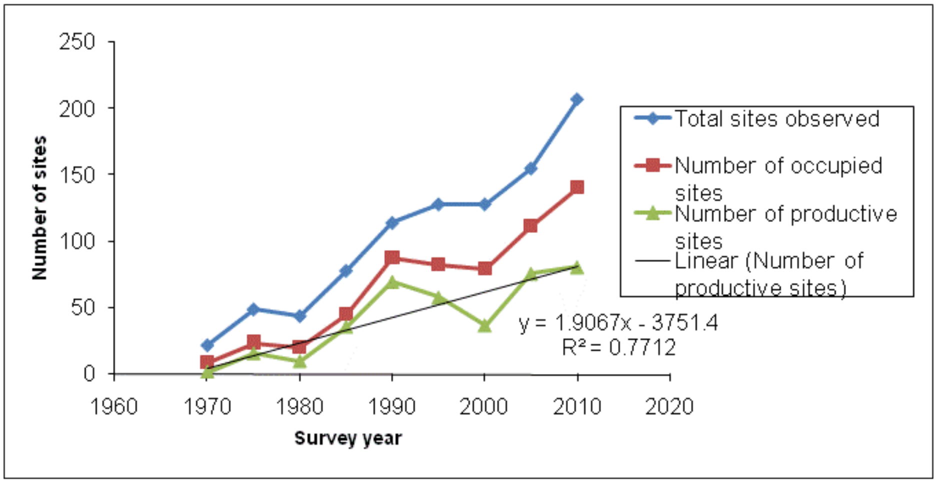


Figure 5: Total number of peregrine falcons nesting sites observed, number of occupied sites (where at least one adult is present), and number of productive sites (where at least one young was observed), along the Mackenzie River, NWT, 1970-2010.

Changes in nesting success from 1970 to 2010

The total number of productive sites observed along the Mackenzie River reached a new record of 81 in 2010 (Table 1, Figure 5). Nesting success as measured by the percent of occupied sites that are productive (with young) was 57% in 2010. The average nesting success for this study area for 1970-2010 was 61% ± 6.2% (1 SE), and ranged from 22% to 80% (Table 1). There was no temporal trend in nesting success from 1970 to 2010 (t=0.76, P=0.47).

Changes in brood size from 1970 to 2010

Brood size (Table 4, Figure 6) as measured by the average number of young per productive site was 2.4 in 2010. The average brood size measured in the study area was 2.4 young (SD=0.8, SE=0.1; 1975-2010). There was no difference in brood size among survey years 1975 to 2010 (H=8.46, P=0.29; Figure 6).

Table 4. Peregrine falcon clutch size and productivity, Mackenzie River, 1970-2010. Source: ENR or as noted.

	1970 [a]	1975 [a]	1980 [a]	1985 [b]	1990 [c]	1995 [d]	2000 [e]	2005 [f]	2010 [f]
Brood size									
Number of young per productive site	3.5	2.36	1.86	2.12	2.59	2.55	2.22	2.47	2.44
Standard deviation		0.75	0.9	0.93	0.92	0.83	0.8	0.78	0.84
Standard error		0.2	0.34	0.18	0.14	0.13	0.13	0.09	0.09
Sample size	2	14	7	28	41	42	36	74	80
Productivity									
Number of young per occupied site	0.8	1.4	0.9	1.7	2.1	1.8	1.0	1.7	1.4
Total number of young produced	7	34	18	76	185	151	82	185	195

Numbers in italic differ from published data due to differences in definitions.
a Data published by Bromley and Matthews in Cade *et al.* 1988.
b Data published in Holroyd and Banasch (1996) and Murphy (1990).
c Data published in Holroyd and Banasch (1996) with additional parameters from ENR NWT/NU Raptors database.
d Data published in Banasch and Holroyd (2004) with additional parameters from ENR NWT/NU Raptors database.
e Data published in Rowell et al. (2003) with additional parameters from ENR NWT/NU Raptors database.
f Unpublished data (2005 and 2010).

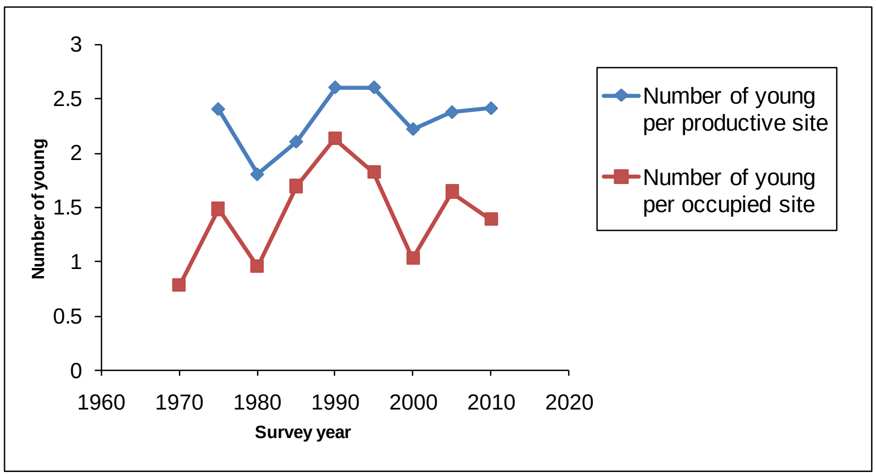


Figure 6: Brood size measured as the average number of young observed per productive sites (where at least one young was observed) and productivity measured as the average number of young per occupied sites (where at least one adult is present) of peregrine falcons along the Mackenzie River, NWT, 1970-2010.

Changes in number of productive sites and productivity from 1970 to 2010

The number of productive sites observed reached a record of 81 in 2010. The number of productive sites significantly increased on the Mackenzie River by 1.9/yr from 1970-2010 (Figure 5: linear regression, t=4.86, P<0.01).

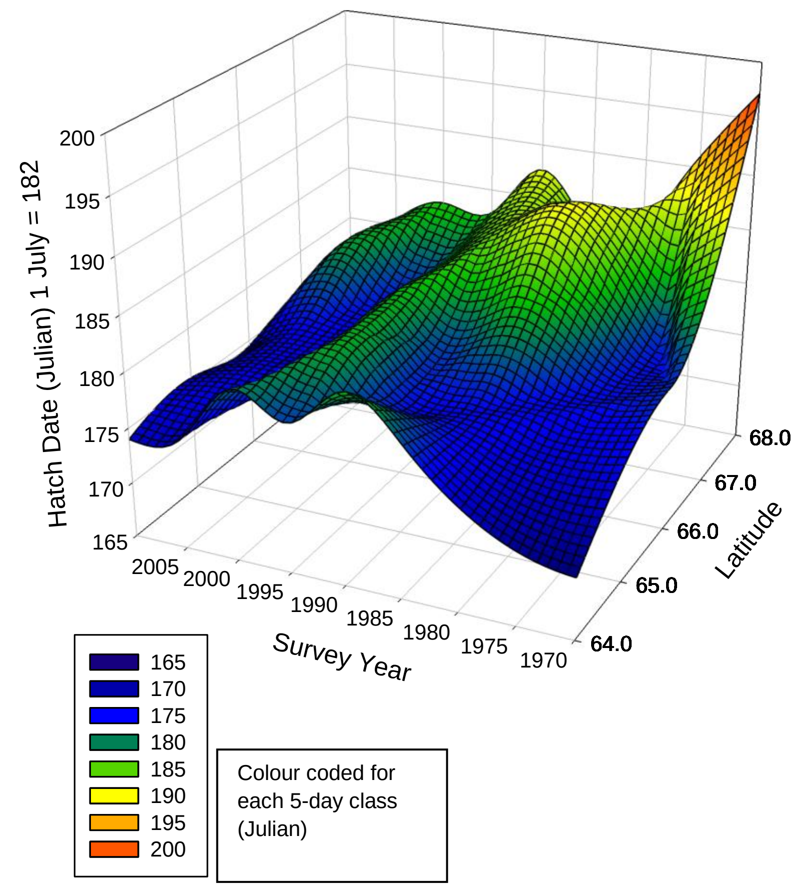
The number of young per occupied nest was 1.4 in 2010 (Table 4, Figure 6). The total number of young observed was 195 (Table 4) in 2010, a record for the study area.

Average productivity in 1970-2010 was 1.4 (range: 0.8-2.1) young per occupied nest. There was no temporal trend in productivity from 1970 to 2010 (linear regression: t=0.86, P=0.42; Figure 5).

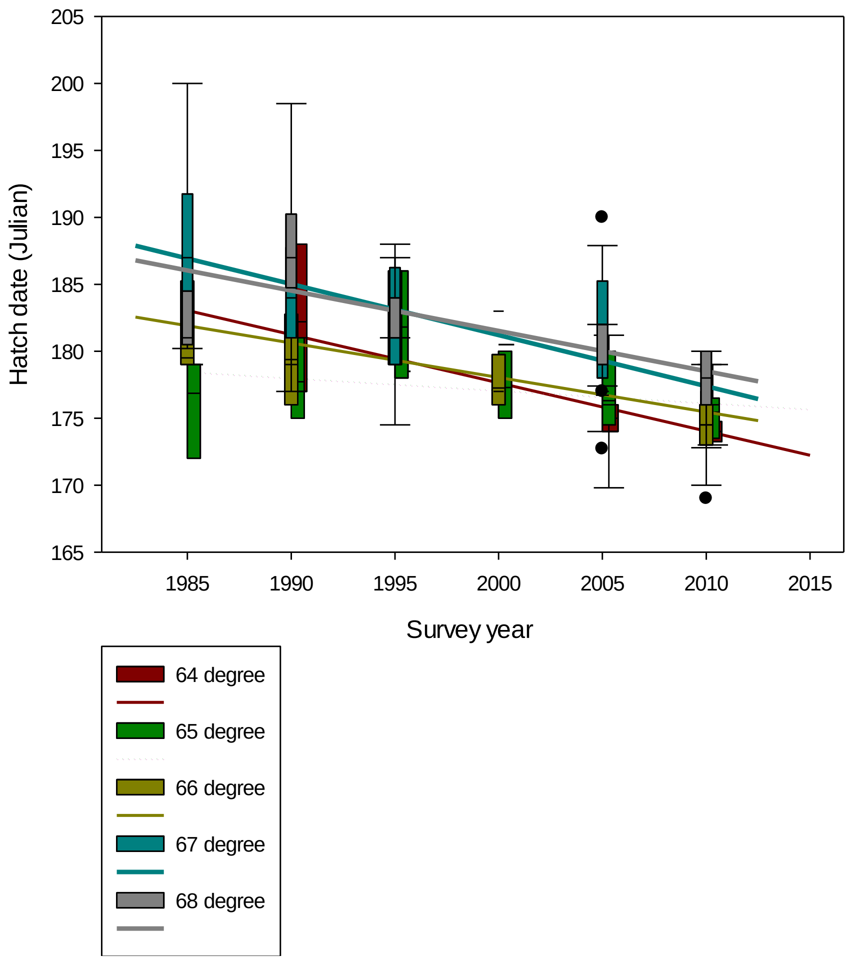
Changes in hatch dates from 1970 to 2010

On the Mackenzie River, peregrine falcon young were hatching later at northern latitudes (Figure 7a, Table 5) than at more southern ones. Also prior to 1990 (Figure 7a, Table 5), hatch date variability was high at high latitudes (Figures 7b). Latitudinal differences in hatch dates lessened in recent years (2000-2010), when variability in hatch dates diminished and most young hatched around June 25 (Julian 176: Figure 3, Table 5).

Figure 7: Latitudinal and temporal trends in hatching date (Julian) of young peregrine falcons nesting along the Mackenzie River, NWT, 1970-2010. Same data on a) mesh 3D graph; b) on box-plots for only 1985-2010 with linear regressions (y = b(0)+b(1)x) of temporal trends in hatch dates per latitude (64° to 68° N). Linear regression for 65 degree was not significant, all others differ from b(1)=0. (Julian; 1 July = 182, 1 July = 183 in 2000).



7a) Mesh 3D graph of latitudinal and temporal trends in hatching dates (Julian) of young peregrine falcons nesting along the Mackenzie River, NWT, 1970-2010.



7b) Box plots with linear regressions for latitudinal and temporal trends in hatching date (Julian) of young peregrine falcons nesting along the Mackenzie River, NWT, 1985-2010.

Table 5. Average hatching dates (Julian) per latitude and survey year of peregrine falcons nesting on the Mackenzie River study area, 1970-2010. Data in italics were omitted during analysis (see Table 5).

Survey	Latitude										
year	63	64	65	66	67	68	69	70	71	Average	n
1970				178						178	1
1975				177	179	191	*177*		*188*	182	8
1980					180	177				179	2
1985		179	177	181	187	182				182	29
1990		182	178	179	185	188	*198*			183	*40*
1995		178	182	182	182	183				182	37
2000		180	177	177	178	183				179	27
2005	*185*	175	176	177	181	181				179	65
2010		174	175	175	176	177				176	45
Average	*185*	177	177	179	181	182	*188*		*188*	180	
n	*3*	21	48	36	89	51	4	0	2	254	

Considering this shift in hatch date variability with latitude, we analyzed for temporal trend in hatch dates for each latitude separately, where sample sizes were sufficient (1985-2010: Figure 6b, Table 5). Both polynomial (Table 5) and linear regressions (Figure 6b, Table 5) were obtained; we selected the simpler but still significant linear regressions from 1985-2010 for further analysis. Hatching dates for peregrine falcons along the Mackenzie River advanced by -0.36 day/yr at latitude 64°, (SE=0.01, t=-3.53, p<0.01), -0.16 day/yr at latitude 66° (SE=0.06, t=-2.52, p=0.02), -0.30 day/yr at latitude 67° (SE=0.06, t=-4.85, p<0.01), -0.31 day/yr at latitude 68° (SE=0.05, t=-6.22, p<0.01). This translates to an advance in hatching of -1.5 to -3.6 days per decade, depending on latitude, or up to six days earlier in 2010 compared to 1985 (Table 6: linear regressions for latitudes 64°, 66°, 67° and 68°). There was no temporal trend in hatch dates at latitude 65° (Table 6).

Table 6. Analysis of temporal trends in hatch date grouped by degree of latitude (64-68°). Coefficients for both polynomial and linear regressions. Significant linear declines are in bold.

Temporal trends of hatch date per latitude

		Polynomial $b(0) + b(1)x + b(2)x^2$				Linear b(0) + b(1)X			Linear regression b(1) analysis			
Latitude	N	b(0)	b(1)	b(2)	R^2	b(0)	*b(1)* [a]	R^2	SE	t	*p*	
64	21	-45843	46.4	-0.01	0.41	899	***-0.36***	0.40	0.01	-3.53	**<0.01**	**
65	48	-67667	68.0	-0.02	0.11	363	*-0.09*	0.04	0.06	-1.47	0.15	
66	36	-50506	51.0	-0.01	0.34	479	***-0.15***	0.16	0.06	-2.52	**0.02**	**
67	89	-42739	43.3	-0.01	0.24	787	***-0.30***	0.22	0.06	-4.85	**<0.01**	**
68	51	-31983	32.5	-8.22	0.47	808	***-0.31***	0.44	0.05	-6.22	**<0.01**	**

**Declines significantly different than slope = 0 are in bold. P<0.05.
[a]Decadal rates of change in hatch date (days per decade) was calculated as *b(1)**10.

DISCUSSION

Survey methods

Survey by helicopter is the preferred method for monitoring raptor populations in remote areas in Canada (Holroyd and Banasch 1996, Rowell et al. 2003) and Alaska (Ritchie and Shook 2011). Boat surveys are also completed along rivers. Many studies combine survey methods to verify accuracy and increase coverage of a large study area (Rowell et al. 2003). The Mackenzie River survey uses merged helicopter-boat data to produce the best estimates possible on productivity of peregrine falcons in this large study area. However, each method has different challenges and advantages. The helicopter survey can investigate sites off the river that are not accessible to a boat crew. Neither survey can be considered a complete inventory of all peregrine falcons nesting in the Mackenzie River study area.

Nesting habits of peregrine falcons along the Mackenzie River

In a study area with discrete topographic features in central west Greenland, Wightman and Fuller (2005) provide insights on habitat features apparently selected by nesting pairs in a northern region. Spacing amongst occupied nesting sites was the most important component in habitat selection for peregrine falcons in Greenland: suitable nesting sites were not occupied in some years due to the proximity of another nesting pair (Wightman and Fuller 2005). They found that distance to the nearest-neighbour averaged 3.3 km (SE=0.2); a longer distance than the nearest-cliff distance (2.2 km; Wightman and Fuller 2005). Nearest-neighbour distances between nesting peregrine falcons in Alaska were 5.8 km, 8.0 km and 9.2 km depending on the study area (Ritchie and Shook 2011), declining by about -0.4 km/yr from 1995-2003. Similarly, along the Mackenzie River, we measured that the mean nearest-neighbour distance had shortened by about -0.2 km/yr, as the number of occupied sites increased from 1970 to 2010, with the distance being 4.3 km in 2010. Mean nearest-neighbour distance for peregrine falcon nests on the Arctic coast in the central barrens (Nunavut) was 8.4 km (Poole and Bromley 1988). At Rankin Inlet, Nunavut, one of the highest density nesting area for peregrine falcon in the world, the mean nearest-neighbour distance was 3.3 km (Court et al. 1988). Potential nesting sites are not distinct entities along the Mackenzie River (cliffs or bluffs form a quasi-continuous potential habitat in most of the study area) thus estimating characteristics of potential nesting sites was not attempted.

In the Mackenzie River study area, most nest sites faced south. This is typical for populations of peregrine falcons nesting in northern latitudes (Court et al. 1988, Poole and Bromley 1988, White et al. 2002, Ritchie and Shook 2011), presumably because a southern orientation provides enough warmth to nestlings to increase their chances of survival during cold periods. A northern orientation and the presence of shade is noted for populations in more southerly regions and in deserts (White et al. 2002).

In our study area, sex ratio of peregrine falcon young was 1:1 in 2010. This was measured late in the hatchling period and may not represent the sex ratio of the clutch during the egg period. Parity sex ratios appear usual in peregrine falcon (Burnham et al. 2003).

Cliffs along coastlines or rivers are the typical nesting habitat for peregrine falcons (White et al. 2002, and ref. therein). In Greenland, Wightman and Fuller (2005) found that five attributes best described sites occupied by peregrine falcons. Occupancy of sites was best predicted by inaccessibility of predators and ledges with bare ground (Wightman and Fuller 2005). Probability of a site being occupied also increased with cliff height and declined with height of terrain opposite the site (falcons preferred open terrain in front the nest) and exposure with less overhead (Wightman and Fuller 2005). These preferred characteristics may be found by nesting peregrine falcons in a surprising array of habitats. In addition, as the best nesting areas are used with increasing falcon populations in North America (White et al. 2002, Hoffman and Smith 2003, COSEWIC 2007), less optimal sites may be used with increasing frequency (Court et al. 1988, Ritchie et al. 2004, Ritchie and Shook 2011). Pairs have successfully nested on pingos, buildings, bridges, quarries, road cuts, nest boxes and on stick nests built by other raptors or ravens (White et al. 2002, Ritchie et al. 1998). In Alaska, peregrine falcon pairs have been observed nesting on very low elevation bluffs along the shore of tundra lakes (Ritchie et al. 2004). Pairs also nest successfully on low elevation rock outcrops and on pit walls at mine sites near Daring Lake and elsewhere on the barren-grounds of the NWT (Steve Matthews unpublished data). This “atypical” use of nesting habitat was observed in the Mackenzie River study area, where in 2010, 13% of pairs nested on the ground or under trees, on crumbling unstable sandstone bluffs, or on till cut-backs along streams, lakes or ponds. Another 13% of pairs used old stick nests on cliffs.

Most of the NWT has not been surveyed for peregrine falcon nests (Carrière et al. 2003, COSEWIC 2007). Based on these varied nesting habitats, peregrine falcons might be successfully but sparingly nesting in large areas of the NWT that were not considered to contain appropriate habitats in the past (White et al. 2002, Ritchie et al. 2004).

<u>Recommendation 1:</u> Information on any peregrine falcon adult and any nesting site should be communicated to the Department of Environment and Natural Resources (ENR) along with information on habitat, behaviour, nest content (eggs or young), and

location data. Please note however that intentionally disturbing a peregrine falcon nest contravenes the *NWT Wildlife Act*.

Hatching phenology

Peregrine falcon females lay one to five eggs, laying one egg about every second day (Court 1986), and incubate for 32-33 days (Stepnisky 1998, White et al. 2002). Hatching asynchrony is thought to increase with latitude (White et al. 2002). Female peregrine falcons nesting at Rankin Inlet initiated incubation well before the last egg is laid, resulting in hatching dates slightly more staggered than in falcons nesting in southern areas (Court 1986, see White et al. 2002). Delaying incubation in cold regions may result in mortality of the first eggs laid, and mortality of the last young hatched often results (Court 1986). At Rankin Inlet, Court et al. (1988) found that within-brood variation of hatch dates in peregrine falcon chicks ranged three to five days (about four days).

During our study we dwelt with intrinsic (within-brood) variation by using a visual guide for dating age classes (± 2 days) for entire broods. During calculations we used the lower limit (younger) of any age class, giving the latest hatching date possible for that entire brood. The variation was also early-bound because during a helicopter survey the oldest chick is presumably most visible, so the age class assigned to the entire brood could be that of the older chick, which could be about four days older than the youngest one; (Court et al. 1988). This gives the earliest hatching date possible for that entire brood. So hatch dates as estimated during this survey may contain an intrinsic variation of about two to four days per brood.

A summary of peregrine falcon breeding phenology studies from the 1980-1990s clearly demonstrates that average hatch date will vary by latitude of the breeding range

(White et al. 2002), where in the northern-most regions hatching occurs in mid-July (9-14 July: Thule 76°N; west Greenland 67°N). Along the Arctic coast in the central barrens (68°N), peregrine falcons hatched around 14 July (Poole and Bromley 1988; Figure 1). In the mid-continental areas hatching occurs from mid-April to mid-June: 15 April (Seattle 47°N), 10 May (Puget Sound 49°N) and 11 June (southern Alberta 52-3°N). At latitudes somewhat south of the Mackenzie River study area, hatching dates ranged from mid-June to mid-July: 11 June (northern Alberta 59°N), 4 July (south Greenland 60°N) to 9 July (Rankin Inlet 62°N).

The Mackenzie River study area, covering an exceptionally large latitudinal gradient (from 62 to 68°N), offers an opportunity to monitor both temporal and latitudinal differences in hatching dates in nesting peregrine falcons. A temporal trend towards less variability and an earlier hatch of -1.6 to -3.6 days per decade was observed at almost all latitudes. By 2010, hatching occurred around 25 June even for nests at 68°N. On average, hatching occurred in 2010 about one week earlier than in the 1980s. Because of the intrinsic variation discussed above, caution must be used in studying trends in hatching dates in northern-nesting peregrine falcons. However, as our trend directions are consistent among latitudes and the number of nests monitored is large for most survey years (1985-2010), we are confident that these findings reflect an actual change in the hatching phenology of peregrine falcons along the Mackenzie River.

Earlier timing of life events (or phenological advancements) can be predicted from climate change as most life cycle events, especially for organisms living in temperate and Arctic ecosystems (Love et al. 2010), are influenced by climate (Pau et al. 2011). Evidence for earlier timing of life events was found across most species studied, with larger changes in northern species (Root et al. 2003), as rates of temperature change are occurring faster in the North than in other regions (Burrows et al. 2011). There is compelling evidence that a changing climate is affecting phenologies in many species across biomes (Parmesan and Yohe 2003).

There is a strong selection for early breeding in birds nesting in seasonal environments (Rowe et al. 1994, Potti 2009) and a shift to earlier breeding in response to earlier-warmer springs has been clearly demonstrated for other avian species (Crick 2004, Gienapp et al. 2005). However, not all bird species exhibit large changes in phenology in response to climate change (Parmesan and Yohe 2003, Parmesan 2007, Thackeray et al. 2010). Earlier breeding in migratory birds, for example, may be constrained by how early the arrival on the breeding grounds can be achieved (Møller et al. 2008, Goodenough et al. 2011, Gunnarsson and Tómasson 2011). Earlier breeding may also be constrained by heightened competition, predation risks, low genetic plasticity, or factors like sunlight that are not responsive to inter-annual seasonal changes (Both et al. 2009, Moe et al. 2009, Thackeray et al. 2010, Goodenough et al. 2011, Visser et al. 2011). There is also evidence in birds that some populations within a species may have different local adaptations allowing them to respond better to earlier springs than others (Gienapp et al. 2010).

The fitness consequences of breeding phenology shifting in response to climate change are varied in birds but includes reduced young survival resulting from increased mismatch with optimum food availability during subsequent periods important for reproductive success (Visser et al. 2004, Visser and Both 2005, Potti 2009, Both et al. 2009, Thackeray et al. 2010). This mismatch occurs because species that are low in a food-chain have faster rates of change in spring phenological events than higher trophic species, such as most bird species, especially raptors (Both et al. 2009). This mismatch may drive population declines in some migratory bird species (Møller et al. 2008, Saino et al. 2011). Fitness benefits for advancing breeding events, including hatching dates, are not well understood for raptors, but may include more time for parents to raise young and learn how to hunt difficult prey, presumably resulting in better survival of first-year raptors. McIntyre and Collopy (2006) found that golden eagles nesting earlier in Alaska did not migrate south earlier, leaving more time to raise young. In peregrine falcons, a raptor with a varied and difficult to catch prey base (White et al. 2002), lengthening this learning period may be a better strategy to increase survival in young than matching the hatchling period with a peak in any one prey abundance (Olsen and Georges 1993).

The Mackenzie Valley is experiencing rapid warming, including in the spring season (Environment and Natural Resources 2011). There is little information on phenological changes in breeding events for top avian predators, such as raptors. Some evidence points to only weak shifts towards earlier breeding in raptors (Both et al. 2009). Although Arctic species are predicted to be likely to shift their timing of breeding events with changes in spring climate (Pau et al. 2011), no study has examined if this occurs for Arctic or northern-nesting raptors. Average advancement rates of timing of breeding events in birds were measured as -3.7 days per decade, with slightly faster rates in higher latitudes (Parmesan 2007). Advancement rates for secondary consumers average about -2.1 days per decade (Thackeray et al. 2010). Our results of hatching date advancement of -1.6 to -3.6 days per decade for peregrine falcons are comparable with the above rates. They are faster than advancement rates estimated for other raptors (-0.9 days per decades; Both et al. 2009).

Peregrine falcons on the Mackenzie River may have reached a limit in how early they can advance hatching. By 2010, hatch dates were less variable and concentrated around 25 June. This would back cast to an average laying date of 21 May. As surveys are done only every five years, we do not know if this is typical for most years or only for

2010. Also, we do not know if earlier breeding by falcons in our study area is constrained by how early they can advance arrival on the nesting area (Gunnarsson and Tómasson 2011). Published arrival dates for peregrine falcons nesting in the region and further north range from 27 May to 25 June (McGrady et al. 2002). Peregrine falcons were recorded on nesting sites as early as 20 May (average 28 May 1982-1984) at Rankin Inlet, Nunavut, a nesting area on the tundra with a harsher climate than the Mackenzie River (Court et al. 1988). Arrival dates at Rankin Inlet varied with spring weather (Court et al. 1988).

Recommendation 2: Advancement in hatching dates for peregrine falcons could be analyzed at other study sites in the NWT where long-term datasets exist (in barren-grounds and at Tuktut Nogait National Park).

Recommendation 3: Five-year survey of peregrine falcons nesting along the Mackenzie River should be continued to determine if the estimated rates of advancements of hatching dates will continue, or if they may be constrained by arrival dates or other factors.

Recovery of peregrine falcons in the NWT

The surveyed portions of the Mackenzie Valley appeared to have reached a near maximum occupancy for peregrine falcon territorial pairs in the early 1990s. The average productivity (number of young per occupied site) at our study area is 1.4, which is considered high enough to translate into an increasing population in peregrine falcon (Craig et al. 2004). Peregrine falcon populations are increasing in western North America (Hoffman and Smith 2003). The exact origin of most new pairs of peregrine falcons in the Mackenzie River study area is unknown, but we may assume that most are of local or at least northern origin for these following reasons. Re-introduction of peregrine falcons was not done in our area, in fact many birds used for re-introduction elsewhere in western Canada were of northern origin (White et al. 2002, Brown et al. 2007). The fast rate of increase in our peregrine falcon population within our study area has outpaced the rate of re-introductions in North America (Jonhstone 1999, COSEWIC 2001, COSEWIC 2007).

Current threats and future needs

Reduction in organochlorine contaminants is widely considered responsible for the increase in peregrine falcon populations in most regions (Millsap et al. 1998, COSEWIC 2007, Franke et al. 2010, Ritchie and Shook 2011). Large annual variations in reproductive success in northern areas exist mostly due to the effects of harsh local weather, and these may result in population declines over short to medium timeframes (Rowell et al. 2003, Franke et al. 2010). Some areas still harbour prey species with high enough contaminants to prevent the re-establishment of a self-sustaining peregrine falcon population (e.g. Okanagan Valley, B.C.; Elliott et al. 2005). Northern peregrine falcons, including those nesting in the Mackenzie River study area migrate to countries still using DDT (see U.S. Fish and Wildlife Service 2003). In addition, other contaminants, some of them new, are found in peregrine falcon eggs, with concentrations that may possibly impair reproduction (Henny et al. 1998, White et al. 2002, U.S. Fish and Wildlife Service 2003, Chen et al. 2008, Holmstrom et al. 2010).

Disturbance at nest sites may be a concern in areas with a high concentration of human activities. How this translates to change at the population levee is unknown. Regardless, all raptors are protected under the *NWT Wildlife Act*.

Peregrine falcons (*tundrius-anatum*) have been assessed as a species of Special Concern (COSEWIC 2007), listed under the federal *Species at Risk Act* and are scheduled for re-assessment under the *Species at Risk (NWT)* Act by 2017. While a national management plan for the species is required because of the federal listing, the overall management and research needs in Canada are currently undetermined.

Recommendation 4: Five-year survey of peregrine falcons nesting along the Mackenzie River should be continued to track possible changes in productivity and occupancy due to possible new threats.

ACKNOWLEDGMENTS

We would like to acknowledge the help of Keith Hodson, who conducted the boat surveys and banding program with the help of friends over many decades. The survey would not be complete with their help. We thank the Environment and Natural Resources Sahtu Region staff, Sahtu Renewable Resources Board, Gwich'in Renewable Resources Board and community members who help during each survey.

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LITERATURE CITED

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APPENDIX 1. Crews for Peregrine Falcon surveys on the Mackenzie River 1970-2010.

Helicopter Survey crews

Year	Helicopter	Boat
1970	Fyfe, Semeniuk	Hodson
1975	Windsor, Richards	Hodson
1980	Court, Allen	Hodson
1985	Matthews, Bromley, Banacsh	Hodson
1990	Matthews, Wakelyn, Owens	Hodson
1995	Matthews, Wakelyn	Hodson
2000	Matthews, Carriere	Hodson
2005	Matthews, Carriere	Hodson
2010	Matthews, Carriere	Hodson

Boat survey crew included others - names not recorded.

APPENDIX 2. Aspect of nesting locations of peregrine falcons along the Mackenzie River, 1970-2010.

Aspect	Number of sites	Percent
N	5	3%
NE	11	7%
E	24	15%
SE	21	13%
S	60	37%
SW	22	13%
W	11	7%
NW	10	6%
Total	164	100%