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BLUE JAY

C. Stuart Houston banding two nestling Golden Eagles in 1992 on the relatively shallow slopes of the South Saskatchewan River. Ample prey includes two jackrabbits, antelope parts, and a crow. Photo credit: David G. Miller.

INTRODUCTION TO THE SPECIAL ISSUE ON GOLDEN EAGLE DISTRIBUTION IN CANADA

Dear Nature Saskatchewan members,

We hope you enjoy this 75th Anniversary Special Issue of the *Blue Jay*. When this Golden Eagle submission first arrived, we weren't sure how we'd make it fit in a regular issue. However, we decided it would be a lasting tribute to C. Stuart Houston's long-time commitment to bird banding and data collection if the paper was published as a standalone issue during our 75th anniversary celebrations.

Thank you to Joe Schmutz and the other authors for completing and submitting the paper for our members' interest.

Golden Eagles (*Aquila chrysaetos*) are most common in remote landscapes in at least five of Canada's 10 provinces and in three territories. They have been studied since 1958, primarily via leg banding and associated data on habitat use, reproduction and migration. Our most comprehensive data subset is from SW Saskatchewan and less so SE Alberta. There they nest in river-bisected prairie habitats where the major land use includes cattle grazing and crop commodities for export.

In this manuscript, the authors interpret the long-term trends and provide broad and interdisciplinary interpretations by incorporating new insights from eagles studied in other areas, and by reflecting on the combined local challenges of sustainability, climate change and biodiversity losses in the prairie region. These data are presented for the first time in the biological literature.

Eagles nested progressively earlier in Saskatchewan. Nesting success (66 per cent) and brood size (1.55 at three-to-nine weeks) was consistent over 43 years. The 341 prey items of 38 species included terrestrial and aquatic herbivores, omnivores and carnivores, from small ducklings to Great-horned Owls (*Bubo virginianus*) and young ungulates (*Antilocapra americana*, *Odocoileus* sp.). The eagles partially shifted prey taken according to prey abundance. White-tailed Jackrabbits (*Lepus townsendi*) were used throughout but in gradually declining numbers, consistent with a gradual rabbit decline in Alberta and Saskatchewan.

Virtually all of Canada's Golden Eagles migrate and hence the authors also explore threats encountered on migration. A feature of the north-to-south Golden Eagle migration is the use of three previously reported and partially disjunct migration corridors in western North America. These data have added a fourth, central Great Plains, corridor. Based on 27 band recoveries in the United States and one GPS-monitored eagle, southern Alberta and Saskatchewan eagles winter from North Dakota to Texas. In contrast to large numbers of eagles counted in the western mountains and desert-shrub regions, the Great Plains population may be small and feed on Black-tailed Prairie Dogs (*Cynomys ludovicianus*) in winter in addition to jackrabbits.

Despite apparent stability in breeding density and reproduction among prairie-nesting eagles, conservation concerns include population declines based on survival-rate modelling, declines in counts of migrants in the western USA, and a long-term decline in eastern Canada. In prairie Canada, jackrabbits are declining as are Black-tailed Prairie Dogs in the southern Great Plains. Biodiversity declines are substantial in prairie Canada and these could impact our thus far resilient eagle population.

The authors provide a new synthesis as a potential guide for conservation action by governments, conservationists and the rural and urban peoples themselves, jointly. This is to ensure that the eagles are included in future strategies and that these strategies extend beyond the species level to the ecosystem and even global conservation level. The authors begin this synthesis with a heuristic framework provided by a complexity theorist (Mace) and blend it with pertinent actions arising from the Conference of Parties of the UN Kunming-Montreal Biodiversity Convention.

ON THE FRONT COVER

A juvenile Golden Eagle photographed along the South Saskatchewan River, about 30 kilometres downstream from Medicine Hat.

Photo credit: Gordon Court.

ON THE BACK COVER

A Golden Eagle at its nest, located along a small tributary of the Peace River in Wood Buffalo National Park, Alberta. Many of the Peregrine Falcon eyries in the park and on the Canadian Shield country north of Lake Athabasca are located on old Golden Eagle nests.

Photo credit: Gordon Court.

BLUE JAY

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DISTRIBUTION, ECOLOGY AND CONSERVATION OF GOLDEN EAGLES (*AQUILA CHRYSAETOS*) IN CANADA

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Data from the Canadian Wildlife Service's Bird Banding Office show more than 1,000 Golden Eagles (*Aquila chrysaetos*) banded in Canada since 1958, and ongoing. The majority were banded by Richard W. Fyfe (RWF) and associates in Alberta and throughout Canada, and by C. Stuart Houston (CSH) in southwestern Saskatchewan. Little of this information is currently available in the biological literature.

We use banding, field observations and related data to describe the eagles' ecological characteristics, including 'regular' and 'scattered' nesting, prey use and trends, migration routes, winter distribution and survival. For a conservation perspective, we examine interdisciplinary analyses toward broad-based sustainability (e.g., regenerative grass- or crop-based agriculture, remote landscapes, resilience).

While the core of our presentation is about their banding data, both RWF and CSH have also made major contributions in conservation biology and management. RWF first taught elementary school in Canada's North before joining the Canadian Wildlife Service as a research scientist. In the 1960s, wildlife management was largely about species that were hunted. As a falconer, RWF's personal mission was to broaden management to include raptors. He and his colleagues responded to the organochlorine pesticide challenge and had Canada become a participant in the successful international effort to recover the Peregrine Falcon (*Falco peregrinus*) via captive breeding and re-introduction.[1] RWF banded his first Golden Eagle in 1967, as part of an investigation to document the pesticide load among raptors generally.[2,3]

C. Stuart Houston maintained a personal chin-lift exercise regimen that built upper body strength for climbing cliffs and trees. In his later years, he relied on younger helpers to do some of the climbing for him. Here he is banding two Golden Eagles in the South Saskatchewan River valley. Photo credit: Hans S. Dommasch.

Richard W. Fyfe (1932-2017) is out flying his captive-reared Peregrine Falcon "Lady" on ducks in 2007, east of his home in Fort Saskatchewan, AB. Falconry was slow to become enabled by legislation in Alberta. Richard, Mike Person, and John Campbell Sr. were instrumental in legalizing the craft. Thus, alongside their considerable contribution to captive breeding and restocking southern Canadian peregrine populations, these men also pioneered sustainable hunting in the province. Photo credit: Gordon S. Court.

CSH described his and his wife Mary's bird banding as a hobby, alongside his career in medical imaging. Besides reporting on banding locations, recoveries and productivity of nesting pairs, CSH also documented novel trends. He documented many historical basic ecology and conservation contributions made by prairie residents. Together with Mary, CSH produced monographs describing Arctic explorers for which he was awarded an honorary doctorate in history. Combined, Stuart and Mary Houston banded 151,888 birds of 217 species in 75 and 63 years respectively.[4] The Houstons involved many volunteer cliff/tree climbers and visitors in their banding of eagles and other birds and thus had an enormous impact on many young people who became conservation professionals or avocational naturalists. CSH and RWF have shown that significant contributions can come equally from pursuits directed by a person's profession or the free rein and inspiration of hobbyists.

Extending the original research approaches by CSH and RWF, we employed primarily a naturalist inquiry in our analysis.[5,6] We let observations and data trends (e.g., internal consistency) guide the questions explored in greater detail within the context of relevant literature (e.g., external consistency). We did not invite mathematical expertise to help extend the concepts and conclusions that our raw data, descriptive statistics and related literature can reveal on their own.

We agree with Thomson[7] that models are becoming unduly fashionable and are in danger of becoming the primary narrative in wildlife management. This caution is expressed tersely by her as "All models are wrong but many are useful." Similarly, Chapman et al.[8] caution that there are many data disparities that are shrouded in history and in gathering new data even today. They suggest that "The realization that more data or better models will never fully solve systemic bias does not mean there are no solutions. It means there are no shortcuts — no getting around the need for local engagement, context-specific knowledge, and case-by-case considerations when using data."

New questions emerge from our ecologically broad, literature-integrated and sustainability-oriented analyses. These might benefit from targeted follow-up. This can include trends in prey populations (ground squirrels, hares and waterfowl), the roles of their synchronicity or a-synchronicity, landscape changes throughout the eagle's annual range, and an influence of climate on the behaviour of soils, weather and people's livelihoods.

The Canadian Prairies have faced and continue to face fundamental social and ecological change. The prairie ecosystem lies within the rain shadow of the Rocky Mountains and experiences an arid, subarctic climate. Plant productivity is highly seasonal and native prairie species cope via dormancy, hibernation/torpor and migration. Indigenous peoples tended toward nomadism and avoided the arid prairie core, or Palliser Triangle.[9] They conducted their food harvest and traditions primarily around the perimeter of the prairie core, retreating into the mixed-wood forest for winter.[10]

The Bison (*Bison bison*) of the western plains had been annihilated around 1880 followed by a loss of large predators, the Plains Grizzly and Prairie Wolf.[11] The loss of bison carcasses, kills by large predators and natural mortality, led to reduced scavenging opportunities for eagles, at least until cattle and road kills became available.[11] Settlement brought incompatible European agriculture and institutions, causing losses (e.g., grasslands, wetlands) and loss of quality of life to both the Indigenous[12] and settler communities.[13]

Given that virtually all Canadian eagles migrate considerable distances within Canada and southward, habitat loss, mortality from collisions with vehicles, buildings and increasingly wind turbines can influence survival.[14-16] Although adjustments via natural selection can affect some evolutionary adaptation remarkable quickly (e.g., learning to avoid wind turbine rotors), such adaptations are dependent on chance mutations.[17,18] The eagles' historic ecological makeup will continue to influence their character (e.g., traditional migration routes, risky scavenging) and their conservation needs today. While a widespread livestock industry coupled with road kills and hunted carcasses provide renewed opportunities for the former scavenging of bison remains, it can also lead to persecution by humans, road mortality at road kills, lead poisoning from hunter kills and disease.[11,14] Where does the eagle's ability to adapt to changing environments start and stop?

Throughout history, people have held a fascination for eagles and this can aid needed engagement. A positive connection by people was evident when reporting dead eagles to the bird banding offices in Canada and the United States, or by finders who responded to the bander's questionnaires or telephone calls for more information. An engaged citizenry can be a powerful asset toward the biodiversity-saving mission and the transformation called for in our current crisis.[19] As steps are taken to halt and also adapt to climate change, and to reverse biodiversity declines, the eagles' ecological requirements as top predators may serve as a guide for shaping a broader sustainability-oriented trajectory.

Study area

The Golden Eagles primarily chose river valleys for nesting in Alberta and Saskatchewan, including the Oldman, Bow, Red Deer and South Saskatchewan rivers, and Swift Current Creek. These rivers are located in the Mixed Grass, Moist Mixed Grass and Fescue prairie, with Brown, Dark Brown and Black Chernozemic soils.[20]

The South Saskatchewan River, where CSH carried out banding and recorded field observations, flows through the northern portion of the Mixed Grass Prairie. Annual precipitation in the Mixed Grass Prairie was 300-500 mm/year and mean monthly temperatures were -13°C in January and 19°C in July. Under modest precipitation, surface water is scarce and 90 per cent of rural residents obtain water from groundwater wells. Of 35 large reservoirs in Alberta and

Saskatchewan, 21 supply water for irrigation. Historically and still today, wetland drainage allows water to leave the ecosystem quickly. In contrast, besides the large irrigation reservoirs, thousands of little reservoirs hold water for stock and local water supply.[21] These long-standing water modification practices have altered the character of the prairie ecosystem, including standing and flowing water, precipitation patterns and groundwater supplies.[22] This widely recognized ecosystem-level change is coupled with altered grazing, fire and climatic regimes, habitat conversion for municipal and agricultural development, and the use of pesticides. It prompts the question of which new stable and possibly resilient state the prairie ecosystem can reach on its own or with attempts at human intervention?

Dominant grasses include wheat (*Agropyron* spp.), spear (*Stipa* sp.) and blue grama (*Buteloua gracilis*) grasses, associated with snowberry (*Symphoricarpos albus*), wolf willow (*Eleagnus commutata*) and aspen groves (*Populus tremuloides*).[20] Much native vegetation has been lost, whereby Saskatchewan has the highest proportion of cultivated acreage in Canada at 144,000 km^2 with Alberta at 95,000 km^2.[21] In Saskatchewan, grassland habitat had been reduced to 17 per cent by 1990, 14 per cent by 2015 and continues to be lost. [23,24] Saskatchewan's arid Mixed Grass Ecoregion, which comprises 37 per cent of prairie, has the highest proportion of native, mixed and hay grasslands remaining at 40 per cent.[25]

Human-population density in Saskatchewan's Mixed Grass Prairie was approximately 40 persons/100 km^2. Dryland wheat was the most common crop in the region and beef cattle the most common livestock. Landholdings ranged from 4 to >8 km^2/farm or ranch where as much as 10 per cent of cropped area was under irrigation. Grasshoppers were a major crop pest at densities of 20-40/m^2 in high years.[20] Yet, grasshoppers also provide food for wildlife and in turn predispose wildlife to pesticides when sprayed in fields.

For describing local conditions, we used Fung et al.[20] and for regional the Commission for Environmental Cooperation.[26] The characteristics employed by the Commission in delineating ecologically distinct regions include geological, landform, soil, vegetative, climatic, wildlife, water and human factors.

Methods

We obtained banding and recovery data from the Bird Banding Office of the Canadian Wildlife Service, Environment and Climate Change Canada. At banding, 96 per cent of eagles were nestlings. The 32 individual banders in Canada, banded between one and 335 eagles each. The three co-authors accounted for the majority of banding with CSH at 36 per cent, RWF at 28 per cent and Dan Zazelenchuk (DZ) at 20 per cent. These data were for the years 1958 to 2017. To maximize our sample of migrants recovered in the United States we requested recent recoveries bringing that sample from 17 to 27 recoveries.

Locating nests was more opportunistic than systematic. Transportation was via four-wheel drive vehicles, hiking, canoe and later aerial reconnaissance. Nests were found or confirmed by re-visiting known nests and exploring areas *en route* and nearby, and by adopting a detailed search when eagles were noted in a new area. Local residents proved helpful and some local naturalists undertook their own nest searching and reporting to CSH (Sig Jordheim, pers. comm.). RWF, Harry Armbruster, Ursula Banasch and their assistants banded eagles from 1967 to 1980 in southern Alberta and recorded basic ecological data. Field data beyond banding (nest success, fate of eggs or un-banded young and prey), were not available to us after RWF's retirement.

CSH visited his first eagle nest in southwest Saskatchewan in 1959, began banding in 1960, and recorded prey in 1967. In addition to recording date and location, CSH recorded nest substrate and nest success, including causes of failure and behaviour of eagles. To reduce over-representing of slow-to-decay species, he distinguished 'fresh' prey with consumable flesh still present from inedible bones, skin or feathers. He recorded prey in nests to species where possible. Pellets were not analyzed.

Nest locations by RWF and CSH were recorded via legal land descriptions, Mercator units or latitude and longitude. In the early years, these locations were derived from 1:250 000 topographic maps and later via geo-positioning technology. The 10-minute latitude

The age of nestling Golden Eagles and other birds is often judged by plumage development. Judging from the absence of feathers on head, this nestling may be around four weeks old. Photo credit: Josef K. Schmutz.

by longitude blocks used by the Bird Banding Office were available for all banded eagles and we used the centre of these blocks for plotting locations.

CSH typically made one trip, and sometimes more trips, to the study area for banding. Collaborating naturalists reported their findings to him such that as many as four observations per year were accumulated on some nests. Observations on nest establishment through incubation were rare. A nest was considered occupied if new, unbleached nest material was shaped into a nest cup, and held eggs or young, or had one or more eagles in attendance.

In Saskatchewan, banding age was three-to-nine weeks (average four weeks) based on 25 cases when age was described based on plumage development. The two 9-week-old nestlings had already left the nest. In an Idaho study, plumage appeared completed at eight weeks and young fledged at 9.1 weeks on average.[27] When at least one nestling survived to banding age, nesting was considered successful.

For a regional population estimate across landscapes, we analyzed Golden Eagle observations in a survey of tree and cliff-nesting raptors in the entire grassland and bordering parkland ecoregions of southeastern Alberta, in 1982, 1987 and 1992.[28-30] An outline of the survey area in relation to grassland and aspen parkland ecoregions is shown in Schmutz 1984.[28] Motorcycles were used for on/off-road transportation in searching the 78-82 randomly selected 41 km^2 study plots located between High River, AB and the Alberta/Saskatchewan boundary, and Hanna and the Alberta/Montana border. Most nests in cliffs and trees could be inspected by climbing, given the prevailing modest tree height in this arid environment.

On 17 August 2014, a single hatch-year Golden Eagle was fitted with a 22 g solar Argos GPS transmitter backpack (Microwave Telemetry, Inc., Columbia, Maryland) with a cross-chest Teflon ribbon harness. The fledged eagle was captured after it gorged on a duck provided by a parent. Unable to fly well due to a full crop, it was easily caught with a large fish net. The transmitter relocation program was set for up to 15 GPS locations per day.

Results and discussion

Our analysis is based on 859 eagles banded in Canada for the period 1958-2017. The Bird Banding Office received 164 encounters, 74 per cent from Canada, 13 per cent from the United States and 13 per cent from Mexico. Encounter details for 159 eagles show 26 (16 per cent) reported by the bander, 91 (58 per cent) by the person finding the eagle and 42 (26 per cent) by a wildlife officer.

Nesting distribution and habitat occupancy in Canada

At a continental scale, the habitat occupancy by Golden Eagles is reminiscent of a habitat generalist, in keeping with the species' circumpolar distribution.[31] Occupied nests were in Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nunavut, Northwest Territories and the Yukon. British Columbia was notably absent even though Golden Eagles nest there.[32] Also, the province's interior serves as a significant migration corridor based on recent studies (see Migration). Diverse nesting habitats included the Arctic and Taiga, Western Mountains, Great Plains and Boreal Shield (Figure 1).

It is noteworthy that in a 2011-2016 study of satellite-monitored migrants, the eagles' summer residency included 22 locations in Alaska where they were also tagged as migrants.[51] Of the remaining 42 tagged eagles, 21 per cent resided in northwestern Canada in summer, near Ivvavik National Park, and near Tuktut Nogait National Park (see Breeding Densities), when they were tagged as migrants or wintering eagles more than 1,300 km farther south. This suggests continuing occupancy of areas in the Yukon and Northwest Territories similar to the scatter of banding sites (Figure 1) from three to 30 years later. One additional GPS-monitored eagle each was located in Banff National Park and near Mount Cartmel southeast of Dease Lake, BC.[51] This suggests a degree of stability in distribution in northwestern Canada.

Golden Eagle nest sites appear associated with rivers and coastal areas.[31] However, this association is likely via a preference for steeply eroded ground or rock instead of aquatic habitat *per se*. Tree nests and those in mountains away from water (e.g., north-central British Columbia[32]) suggest that nest elevation may be the primary factor, possibly for nest protection, ease of access in flight or both. Golden Eagles used nest platforms attached to poles[34] and a hunter's tree-platform in southern Saskatchewan, indicating flexibility in choosing nest substrates.

Golden Eagles apparently selected remote habitats within various ecozones, being far more common in the less populated western Canada (Figure 1) and western United States than east. Also, remoteness was evident by low human density generally in extreme south-eastern Alberta and in north-central British Columbia. Finally, in areas with moderate population density in southern Alberta and south-western Saskatchewan, eagles occupied pockets of remote landscapes such as eroded river valleys or extensive badlands where roads and human presence were scarce. Such sparsely populated and low-traffic regions can be an asset for the conservation of disturbance-prone eagles. CSH's field notes describe cases where adults remained on the nest until climbing began. Yet, in most cases eagles were not seen or were soaring at a distance, illustrating their sensitivity to human presence.

Remoteness along the southern Alberta and southwest Saskatchewan prairie rivers can be attributed to the soil landscape. Regosolic soils or badland habitat, prevailed in the deeply incised rivers with steep slopes and persistent erosion.[35,36] Regosolic soils are unsuitable for annual crop production (soil capability rating = 6).[20] The only exception to a Regosolic river border was Brown Chernozemic soil that extended up to the river without badlands on a 5 km stretch along the South Saskatchewan River and 15 km along Swift Current Creek.[36]

In the vicinity of seven successful nests in 2002, the difference in elevation between the river and the maximum height of adjacent upland using Google Earth Pro LLC, ranged from 45 m in Swift Current Creek to 135 m in the Saskatchewan River valley (mean = 83 m). One outlying nest, visited in 2002 but rarely in other years, was in the Frenchman River Valley with a 96 m difference in elevation.

While eagles may choose to nest below maximum height, the deep incisions in the landscape predispose the region to extensive grazing and not annual crops. Rare human presence minimizes disturbance. Perhaps the greatest risk to eagles arises from municipal development as river valleys invite home construction for the spectacular view the valleys can provide (Richard Douslin, pers. comm.).

A band of grassland lies beyond the Regosolic soils along the rivers. Still farther from rivers was cropland on Chernozemic soils. The width of the grassland belt ranged from 5-55 km.[20]

Even when the bands of eroded grasslands tended to be relatively small in comparison to the mountains of northern British Columbia, remoteness was achieved via few roads in rough terrain. This suggests a potential for eagle conservation (see Table 11, Resilience). Eagles appear to tolerate a degree human activity, just not in close proximity to their nests.

Remote landscapes are occupied by eagles also in the southern Great Plains in Winter, suggesting an importance year-round.[37] When landscapes need protection (e.g., vulnerable Regosolic soils), conservation actions can be inadvertently undermined. Examples include well-intended but perverse government policies (e.g., Wheat Board quotas[38]), vision-drift and closure of long-standing and successful programs (e.g., Prairie Farm Rehabilitation Administration PFRA[39,40]), or degrading soil quality enabled by insurance.[41]

Where eagles place their nests also reveals habitat choices. In southern Saskatchewan, nests were primarily on ledges of steeply eroded slopes or sedimentary-earth cliffs. Rappelling with the use of ropes was necessary to reach nests safely. Nesting success was identical between tree or cliff nests (Table 1).

TABLE 1. Types of nest substrates used by Golden Eagles in southern Saskatchewan, and those successful in raising at least one young to three-to-nine weeks.

SUBSTRATE	NESTS	SUCCESSFUL NO.	SUCCESSFUL %
Cliff	226	172	76
Hillside	3	3	100
Tree	37	28	76

Breeding densities

A species' density can reflect population health and trends can inform conservation. Kochert et al.[42] make a distinction between regions where Golden Eagles nest 'regularly' dense or widely 'scattered.' To maximize sample size, most studies logically focus on areas where a species is common. Boundaries are then drawn around such non-random study areas. This largely unavoidable data disparity[8] that can be more or less accommodated via qualitative expert interpretation.[7]

For eagles, another significant source of error can be simply not finding some nests. Even aerial surveys can be challenging in the narrow canyons bordering Alberta and Saskatchewan rivers.[a] Some eagles quietly withdraw from the nesting area on seeing a human

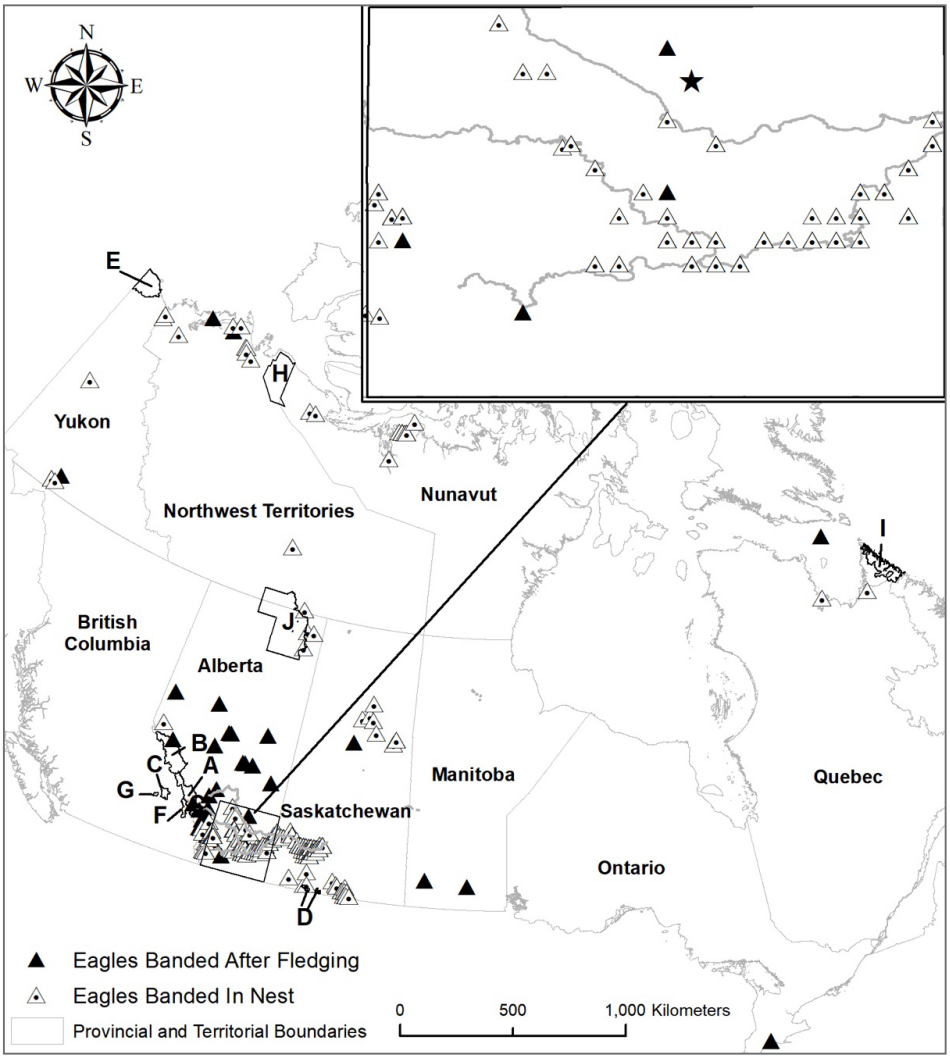

FIGURE 1. Locations in Canada where Golden Eagles had been banded as nestlings or older. The locations of monitored National Parks are also shown: A = Banff, B = Jasper, C = Glacier, D = Grasslands, E = Ivvavik, F = Kootenay, G = Mount Revelstoke, H = Tuktut Nogait, I = Torngat Mountains & Kuurujuaq and J = Wood Buffalo. The inset expands banding locations and the Red Deer-, Bow- and South Saskatchewan rivers in Alberta.

a. To estimate the error in finding nests in the Alberta raptor survey (see Estimates of Population Size), we selected 12 of the 78 study plots 'blindly' and once searched traded parts of the plots to be repeated by a different observer. We abandoned this approach after two plots for time constraints. Nine of the ten nests on two plots were noted on the first count, yielding 90 per cent accuracy.

approach. This makes those nests difficult to find, unlike most other raptors who subtly or vigorously defend a nest and thereby advertise its presence. It is conceivable that persecution of eagles in the past has provided selection pressure favouring a shy behavioural type. Persecution may have been from eagle feathers used in Indigenous traditional ceremonies, a perceived competition from eagles taking young ungulates (RL Collingwood pers. comm. 16 December 2020) or for protection of livestock.

While RWF and CSH knew that river valleys held Golden Eagles, their search also extended along and beyond the rivers to find nests of Ferruginous Hawks (*Buteo regalis*),[43] Swainson's Hawks (*B. swainsonii; Schmutz et al. 2001*)[44] and Prairie Falcons (*Falco mexicanus*).[3] This expanded search confirmed the eagles' preference for remote badland or grassland.

The number of nests found by CSH increased over the years and reached high levels especially in the 1990s, when DZ used an aircraft to monitor the South Saskatchewan River area for nests (Figure 2). During the 1990s and beyond, few new nesting areas were discovered and numbers stabilized. CSH presumes, given land access, landowner participation and coverage of old and new areas, that the proportion of nests found may represent three-quarters of the actual population.

Nesting densities along the South Saskatchewan River were high. For this analysis, we chose the high-density years of 2000-2002 and a section of the river including the southwestern portion of Diefenbaker Lake where eagles were regularly found. During 2000-2002, an additional six, four and four pairs (nine per cent) nested away from the river. Occupied river length from easternmost nests to west were 85 km for 10 pairs in 2000, 143 km for 15 pairs in 2001 and 175 km for 11 pairs in 2002. The average inter-nest distance along the river was 12 km (range 4-36 km). We assumed that this distance to nearest neighbour, or one-half of the distance each east and west, approximated home range. We also assumed that this 6-km distance extends north and south forming a band of river and adjacent habitat 12 km wide. Dividing the area of this band by the number of nests in each of the three years yielded 102, 114 and 191 km^2 per pair, (Figure 3), for an average of 134 km^2 per pair.

Considering density by river length alone without the band-of-home-range assumption, yielded 8.5 km/pair in 2000, 9.5 km/pair in 2001 and 15.9 km/pair in 2002. These South Saskatchewan River lengths/pair are similar to lengths in the Firth and Hornaday rivers in the Yukon, of 9-15 km/pair.[45]

To explore what might be the Golden Eagle's characteristic dispersion pattern across different landscapes and study procedures, we plotted estimates of previously reported breeding densities (Figure 3).[32,42,46] Figure 3 also includes home ranges of 17 radio-marked pairs of eagles studied in the Snake River Birds of Prey National Conservation Area. These yielded a remarkably small home range of 1.9 km^2 but also up to 83.3 km^2, with an average of 25.3 km^2 (Figure 3).[42] If, in a daring approximation, one were to take 134 km^2 as the average density per pair in the South Saskatchewan River valley, and one took 25.3 km^2 as an average home range, it would suggest that breeding pairs of eagles occupy roughly one-fifth of available space in the river valley.

An independent examination of km^2

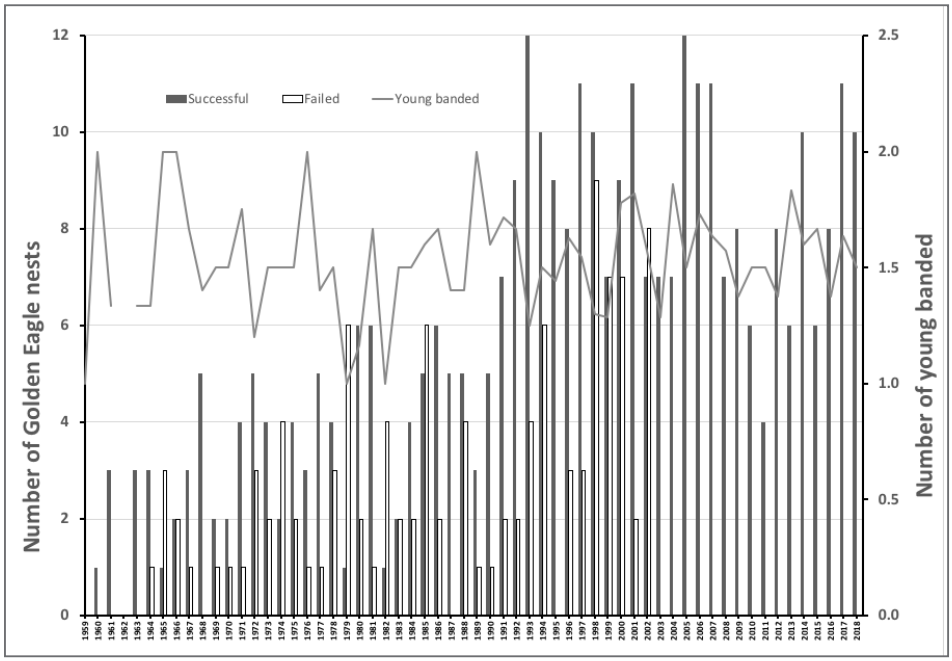

FIGURE 2. Number of occupied Golden Eagle nests found in southwestern Saskatchewan, showing the proportion successful in raising at least one young to banding age (three-to-nine weeks) 1960-2002, and the average number of young banded in 1960-2018.

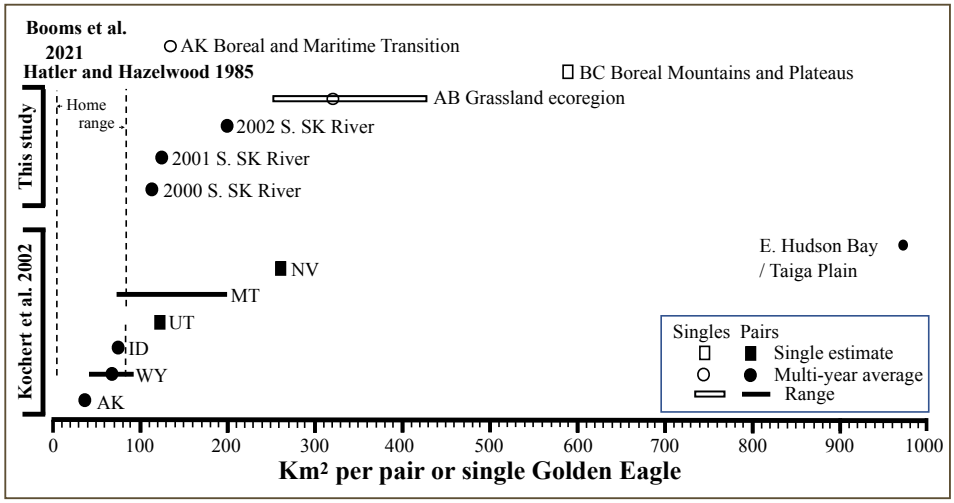

FIGURE 3. Counts of nesting pairs or single Golden Eagles in four provinces and six U.S. states. Counts include two approaches, studies in selected high density nesting areas and observations of widely scattered eagles counted as part of general wildlife surveys or studies designed specifically to include a scattered dispersion.

per breeding pair was provided Newton who plotted breeding density of 21 species of raptors from 53 studies against female body weight.[47] The plot resembled an allometric relationship where similar increments along one scale, body size, yield increasingly large increments along the other scale, km^2 per pair. This relationship is well known as a trend for large species to breed at lower densities.

Newton's plot included eight species of eagles and ten study areas of Golden Eagles.[47] He concluded that most species of eagles use 30-190 km^2/pair. This range is virtually identical to the range 30-200 km^2/pair when the Nevada study is considered a single outlier to the eight study areas cluster (Figure 3).[42] The home ranges calculated for the South Saskatchewan River densities of 102-191 km^2/pair also fall into the 30-200 km^2 range.

Combining all three types of evidence, i) densities on study areas, ii) home ranges of marked eagles and iii) using Newton's cross-species comparison, we propose that densities up to 200 km^2/pair be considered "regular" nesting densities, and areas larger than 200 km^2 be considered "scattered." [42] Even in the regular nesting, one can assume that the eagles do not use all space equally. In the scattered nesting, the space between pairs is so large that one or more pairs could fill the vacant space.

Eagle nests recorded as part of surveys for Mountain Goats (*Oreamnos americanus*) in northern British Columbia's wildlife management zones[32] serve as an example of scattered nesting. Golden Eagles were recorded via helicopter in the pre-defined river or watershed survey boundaries (Table 2). The results of 581 km^2/eagle places this mountain and plateau population in the scattered nesting category, assuming the eagles were breeding.

A combination of ground and aerial surveys of whole national parks in western and northwestern Canada showed Golden Eagle presence in one grassland park (907 km^2/pair) and three mountain parks (1,276-1,403 km^2/pair). Eagles were apparently not present in one mountain, one inter-mountain and one boreal forest park (Table 3). Unless there are nests in trees in these parks, the low density of 1,276-1,430 km^2/pair is similar to scattered nesting in the Hudson Bay region. Most Canadian-parks estimates are low and fall outside of the 1,000-km x-axis in Figure 3.

TABLE 2. Golden Eagles recorded as part of a survey for Mountain Goats and other wildlife in 13 wildlife management zones in the Skeena Mountains and Spatsizi Plateau of northern British Columbia.[32] The survey was conducted by helicopter from 10-16 July 1985 and yielded nine single and two pairs for a total of 13 eagles.

WILDLIFE ZONE	KM^2	EAGLES
Kitchener, Tatlatui & Thutade	1600	7
Terraze, Edozadelly, Brothers & Rognaas	1750	0
Caribou Mts. & Marion	1800	0
Mt. Cartmel & Mt. Brock	650	3
Mt. Edziza & Raspberry Pass	1750	3
TOTAL	7550	13
	km^2/eagle	581

TABLE 3. Golden Eagles in selected Canadian national parks based on park surveys/reports. Density is recorded as linear km/nest along rivers or by park size in km^2.

LOCATION (FIGURE 1)	PARK	PROV. TERR.	YEAR	NESTS	DENSITY	LANDSCAPE	REFERENCE
A & B	Banff & Jasper	AB	1975–1980	14	1,276 km2/pair	Eastern Rocky Mountains	142
C	Glacier	BC	1981–1983	0		Columbia Mountains	143
D	Grasslands	SK		1	907 km2/pair	Mixed Grassland	G.L. Holroyd pers. comm. 28 March 2021
E	Ivvavik	YT	2010	9	9 km/pair	Taiga - Firth River	144
F	Kootenay	BC	1981	1	1,406 km2/pair	Western Rocky Mountains	145
G	Mount Revelstoke	BC	1981-1983	0		Columbia Mountains	143
H	Tuktut Nogait	YT	2010	12	15 km of river / pair	Taiga - Hornaday River	146
H	Tuktut Nogait	YT	2015	15	12 km of river / pair	Taiga - Hornaday River	45
I	Torngat Mountains- & Kuurujuag National Parks	NF	1987–1988	≥3	184 km / pair or single	Arctic Mountains	147
J	Wood Buffalo	AB/NT	2010 & 2016	0		Boreal Plain lowland	G.L. Holroyd pers. comm. 28 March 2021

Estimates of population size

A prairie regional population estimate in Alberta covered 78-82 41-km^2 study plots in 1982, 1987 and 1992 (Table 4). The intensive area coverage and a search image that included ground, cliffs, shrubs, trees and human-made structures yielded 32 individual Golden Eagles. These were rare in comparison to 1,073 nests of Ferruginous, Red-tailed (*B. jamaicensis*) and Swainson's Hawks over three years. On two plots, eagles were present in all three years and on one plot for two years. Because eagles were rare, shy and often encountered away from nest sites, we used individual sightings instead of nests in the population estimate. The survey yielded two Golden Eagle nests in three years, not including three nests encountered outside of study plots. The low number of eagles on plots made double counting of an individual unlikely. We assumed conservatively that a sighting less than 1.6 km apart was of the same eagle.

The population estimate yielded a summer population of 249 Golden Eagles in southeastern Alberta. The 95 per cent confidence interval was 0-614 (Table 4). Considering the eagle-occupied study plots alone, densities ranged from 70-211 km^2 per eagle (not per pair) over the three survey years, with an average 105 km^2.

Booms *et al.*[46] used an innovative approach to estimate population size in a known high-density nesting area in Alaska. They minimized the researcher-imposed boundary bias by GPS marking 91 eagles that moved on to the area in spring. They tracked those eagles letting the eagles set area boundaries based on where they settled for the summer. They then used Bayesian framework to integrate confounding study parameters such as viewshed proportions and detectability. The results yielded an estimate of 1,204 Golden Eagles in 150,325 km^2, or one eagle per 125 km^2 (Figure 3). The Alaska estimate is similar in density to our prairie estimate and both are objective estimates. To our knowledge, they are studies least encumbered by investigator-chosen study area bias outlined above.

Scattered nesting and scarcity

The 249-eagle estimate was for the prairie ecoregion in southeastern Alberta, but most nests were in riverine habitats which occurred only on five of the 78-82 study plots. This illustrates how sparse (approximately two per cent) the suitably incised river nesting habitat was in the entire grassland survey region.

For a comparison to the 249-eagle estimate that could include non-breeders, RWF and associates banded eagles at 20 nests along rivers in the year of highest banding effort 1976. Twenty nests, or 40 individuals, comprise 16 per cent of the estimated prairie population. Given banding effort and the inclusive length of all prairie river valleys, the 249-eagle estimate seems realistic. Scarcity of eagles in this prairie region may not in and of itself be a conservation concern given this species' propensity for specific-habitat and 'scattered' nesting.

For an example of scarcity, a pair of Golden Eagles nested in 1988-90 in a 10 km^2 area 55 km SSE of Hanna, Alberta. In this area, a study of Ferruginous Hawks yielded more than 1,600 nests over three decades.[30] Most of this region appeared

Golden Eagles and Ferruginous Hawks build and use similar types of nests in similar settings. Both species occupy remote landscapes, such as local yet extensive badlands shown here, where roads and human presence are scarce. Photo credit: Josef K. Schmutz.

TABLE 4. An estimate of the total number of Golden Eagles in the prairie ecoregions of southeastern Alberta. Complete counts were conducted on randomly selected 41-km^2 study plots in a 74,686-77,301 km^2 survey area south of the parkland and east of the foothills ecoregions. The 80 plots comprised 4.3 per cent of the entire survey area.[148]

YEAR	NO. OF PLOTS	SURVEY AREA (KM^2)	EAGLES COUNTED	MEAN EAGLES PER PLOT	STANDARD DEVIATION	ESTIMATED POPULATION SIZE	95% CONFIDENCE INTERVALS	AREA (KM^2)PER SINGLE EAGLE)
1982	80	74 686	11	0.138	0.470			
1987	78	74 686	13	0.167	0.692			
1992	82	77 301	8	0.098	0.433			
Av.	80	75 558	32	0.133	0.540	249	0—614	308 (range 246—420)

suitably remote for eagles and was located only 20 km east of an existing breeding population in the Red Deer River valley.

The pair of eagles failed to raise young in three years. There was no evidence of eggs laid in 1988, two unhatched eggs with two eagles attending in 1989, and one nestling close to fledging fell from its small tree nest in 1990. It was trampled by range cattle crowding under the lone nest tree for shade.

Scarcity was apparently not a recent phenomenon. Two local history books for the south Hanna region report numerous wildlife from 1913-1950s.[48,49] There was repeated mention of abundant White-tailed Jackrabbits (*Lepus townsendii*). Yet, there was only one mention of an eagle nesting on the ground in an eroded coulee. This area was used by ground-nesting Ferruginous Hawks after 1975 and presumably also earlier judging from old nests. Melanistic Ferruginous Hawks could be misidentified as eagles. This suggest that breeding eagles were rare or absent already at the time of settlement beginning in 1908.

Some apparently non-nesting eagles use this south Hanna area. Of 2,542 sightings of raptors away from nests, two Golden Eagles were possible migrants in February, three of uncertain status in April, and six presumably different individuals observed many days apart during the breeding season. Some eagles may use this grassland region in winter but overall, its use by eagles appears rare.

For a rare-use example, one relocation of the GPS-monitored Lundbreck eagle (see A Great Plains Migration Corridor) was only 11 km from the three nests described above. In addition to roaming non-nesting eagles, some pairs winter in the grassland region of Saskatchewan and occasionally return to the river habitat and briefly attend to nests. These may be year-round residents (Lynn Grant pers. comm. 26 November 2023) with larger home ranges in winter.[50] Two of 31 GPS-monitored eagles, whose summer residence was in northwestern Canada or Alaska, wintered in or near Banff National Park and in the Peace River district.[51]

Taken together, the eagles' strong association with remote habitats confirm the conclusion that remote landscapes are important for their conservation. Whether remoteness is important year-round or primarily during the breeding season is less clear (see Winter Dispersion). Furthermore, whether remoteness is important per se, possibly via reduced disturbance, or whether remoteness negates mortality factors such as electrocution or collision with towers and vehicles also needs further consideration (see Mortality).

While Golden Eagles can exhibit moderate and even high nesting densities in selected habitats, such as along rivers, the species also exhibits a characteristic type of "scattered" nesting. This prairie cottonwood tree (*Populus deltoides*) supported a Golden Eagle nest, containing two young and jackrabbit prey in the remote rangeland of extreme southeastern Alberta during the 1987 survey. Photo credit: Josef K. Schmutz.

Nesting

The earliest nest sighting of Golden Eagles in Saskatchewan was on 31 March 2002 of an eagle on an already completed nest. The eagle was in low posture as though shaping a nest cup, laying or incubating. Additional observations were of eagles in an incubation posture in early April (1982, 1985, 1993, 2002). Members of this Saskatchewan and possibly whole-prairie breeding population likely arrive in early March, for the timing of breeding to be so far advanced in early April.

Golden Eagles were encountered on a road survey on the Alberta prairie and foothill regions when the surveys began in early March.[52] A peak in the number of eagles occurred during the week of 21-27 March. However, judging from eagle behaviour, these were moving rapidly and possibly migrants of the northerly breeding populations in Canada and Alaska (see Abundance on Migration). An estimated 75 per cent of migrants that arrive in the lower USA come from Canada, 25 per cent from Alaska.[46]

Band recoveries suggest that the eagles tended to return to near their natal area for breeding. While Golden Eagles are considered of breeding age only at four years, they tend to explore potential breeding areas before four years.[42] Thirty-one eagles had been banded in prairie Canada and were recovered in their third year of life (ASY) during the breeding or post-fledging season March through August. Of six banded in Alberta, three were recovered in Alberta, two in Saskatchewan and one in Wyoming. Of 25 banded in Saskatchewan, 24 were recovered in Saskatchewan and one in Alberta.

A plot of CSH's banding dates suggests that the timing of reproduction has shifted progressively earlier in Spring (Figure 4). The trendline suggests a change of 20 days earlier from the early 1960s to early 2000s, or 0.5 days/yr. We do not believe that this earlier trend reflects purely earlier banding.

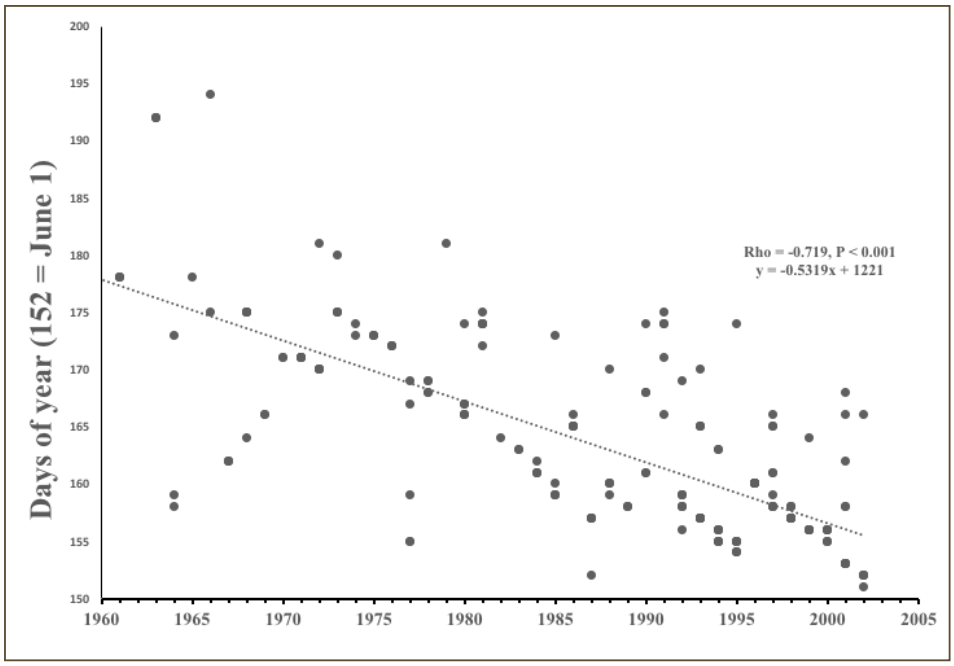

FIGURE 4. Dates when Golden Eagles were banded in southwestern Saskatchewan.

The banding excursions were timed to maximize the number nestlings three-to-nine weeks old, based on the previous year's age spread.

With a gradual change in climate, Spring arrives earlier in Canada,[53] particularly in the North. Losses to birds from climate change can be via reduced food availability, due to a mismatch in the timing of reproduction between eagles and prey, or mismatch of emergence from hibernation and arrival of migrants.[54] Over the past 25 years, Golden Eagles arrived in their Arctic breeding grounds 0.5 days earlier per year on average, identical to the Saskatchewan trend.[55] Judging from the stable occupancy of nests visited over time and no apparent decline in brood size (Figure 2), the prairie-nesting eagles seem to have adapted to an earlier spring.

The strength of a nest's substrate can influence success. Eagles build bulky nests of thick sagebrush sticks and sod with little weaving for stability possible. The sagebrush stems resist decay especially in this arid environment and are simply added year after year. This, combined with the use of sod, makes for bulky nests prone to separating from the earthen cliffs. They are also unstable in trees (see Scattered Nesting and Scarcity). These nest losses, combined with slumping of soil above nests cause nesting failures on a regular basis especially after a rain (Table 5). Nest success was equal between cliff and tree nests (e.g., Table 1).

A reliance by eagles on the relatively rare river bank habitat (two per cent in Alberta) could limit their distribution on the northern Great Plains. Yet, even with a significant increase of trees in the expanding parkland habitat throughout the 1900s, eagles have not substantially expanded their range away from the so-called badlands habitats.[56-58] In contrast, Ferruginous Hawks, which have nesting requirements similar to eagles, have been able to make use of trees. Stick nests of other hawks or corvids often served as a base for the hawks to add to.[59]

TABLE 5. Categories of success or failure in 338 nests of the Saskatchewan Golden Eagle population monitored by CSH 1960-2002.

Nests	Number	%
Traditional nest not used or cause of failure unknown	69	20
Eggs failed to hatch	9	3
Nest fell from tree	2	1
Nest destroyed by slumping	9	3
No young present	37	11
Dead young present	5	1
Young banded (3 - 9 wks)	205	61
Outcome unknown	2	1

Reproduction

Clutch size was observed in 22 eagle nests over the 43 years in Saskatchewan and ranged from 1-3 eggs, with an average of 1.79. Average clutch size in 332 clutches from studies in the western United States was 1.99.[42]

The eagles' ability to raise at least one young to banding age (three-to-nine weeks) was remarkably stable. When we compared percent success per year as above or below the 43-year mean of 66 per cent for periods 1960-1974, 1975-1988 and 1989-2002, there was no significant difference $x^2 = 0.842$, df = 2. P = 0.656).

Brood size at banding was 1.53 for the 43 years of CSH and 1.56 for 16 years of DZ, for an overall 1.55 for the 59 years combined (Figure 2). In CSH's study, 105 pairs raised one young, 107 pairs two young and three pairs three young. In five mid-continent study areas, brood size was virtually identical at 1.56 per successful pair.[42] Considering brood size above vs. below the overall mean in 1960-1974, 1975-1988 and 1989-2002, also yielded no significant difference ($x^2 = 1.773$, df = 2, P = 0.4121). Brood size was 12 per cent lower[42] among northern populations, presumably reflecting the added energy demand of migration.

This broadly positive scenario, combined with consistent reports of dispersion and western abundance, suggests a relatively healthy eagle population, remarkably so in the face of stark biodiversity declines in the eagles' prairie ecosystem. The eagles' steady reproductive success differed from other local raptors whose success varied greatly. For example, success among Ferruginous Hawks correlated with local abundance of ground squirrels.[60] Ground squirrels were also important prey for eagles but the eagles apparently could switch prey compensating for ground squirrel declines (see Food). The eagles' ability to maintain stable nest success and brood sizes over the long term, are consistent with a k-reproductive strategy in the r- and k-selection continuum[61] and may be linked to successful feeding adaptations.

Similar to the potential data disparities described above for nesting

densities, unintended sampling disparities could apply to data on eagle nest success. In long-term studies, nests are re-visited annually and the chance of finding them is high, even if a pair needs to build a new nest nearby. First-time nests have a higher chance of being missed, unless a rigorous and complete nest-search method is employed which is rare and difficult in the eagles' rugged landscapes. If first nests, are those of young or otherwise less successful pairs, this could lead to an overestimate of reproductive success in a population. This disparity, if it exists is likely to apply to most if not all studies and thus should not seriously compromise our ability to compare reproductive success among populations.

Prey in Saskatchewan

Based on prey remains that are fresh (judged 0-2 days), southern Saskatchewan eagles captured, scavenged or took from other raptors a total of 35 species of prey (Table 6). Prey in four orders of vertebrates, included eight fish, one reptile, 19 bird, and seven mammal species. On 13 per cent of 145 visits to nests, there was no prey.

Using prey remains, pellets and time-lapse cameras in Montana, investigators recorded 38 species over two years.[62] Interestingly, the smallest (snakes and ground squirrels) and largest prey (jackrabbits) were underestimated based on prey or pellet analyses. Using cameras at nests yielded twice as many items as prey or pellets. Comparisons of prey used by eagles feeding on different prey assemblages should be done with caution.

In CSH's study, three main prey groups, water birds, ground squirrels and jackrabbits, each comprised more than 15 per cent by items. Plotting their prevalence in eagle nests in successive four-year intervals from 1967-2002 shows substantial shifts in prey use over time (Figure 5). Ground squirrels and water birds displayed changes resembling peaks and troughs, corresponding to a dry period favoring ground squirrels and a wet period favoring waterfowl. Jackrabbits displayed more modest

TABLE 6. Prey items found in nests of Golden Eagles in southwestern Saskatchewan, between 1 June and 7 July 1969-2002. These 340 "fresh" prey items included still consumable flesh. An additional 44 prey items were old and of these 29 (66 per cent) were rabbits. Items were identified to the lowest possible taxonomic level. Items that were either small or otherwise recognized as young were recorded as juveniles, and adult or near-adult size items were recorded as adults.
Capital letters indicate: A = aquatic, C = carnivore, H = herbivore, O = omnivore, T = terrestrial.

MAMMALS	CONSUMER CATEGORY	TOTAL ITEMS (JUVENILE)	PER CENT
Richardson's ground squirrel (*Urocitellus richardsonii*)	HT	54	16
Nuttall's Cottontail (*Sylvilagus nuttallii*)	HT	9	3
White-tailed Jackrabbit	HT	102(3)	30
Muskrat (*Ondatra zibethicus*)	HA	2	<1
Long-tailed Weasel (*Mustela frenata*)	CT	1	<1
Weasel sp.	CT	1	<1
Pronghorn (*Antilocapra americana*)	HT	5	1
Deer sp.	HT	1	<1
Ungulate sp.	HT	2	<1
		Subtotal 177	52
BIRDS			
Horned Grebe (*Podiceps auritus*)	CA	1	<1
Grebe spp.	CA	5	1
Canada Goose (*Branta canadensis*)	HT	10(10)	3
Mallard (*Anas platyrhynchos*)	OA	52(1)	15
Northern Pintail (*Anas acuta*)	OA	1	<1
Gadwall (*Anas strepera*)	OA	4	1
American Wigeon (*Anas americana*)	OA	3	1
Shoveler (*Anas clypeata*)	OA	3	1
Blue-winged Teal (*Anas discors*)	OA	4	1
Lesser Scaup (*Aythya affinis*)	OA	4	1
Duck spp.	OA	29(2)	9
Sharp-tailed Grouse (*Tympanuchus phasianellus*)	OT	8	2
Gray Partridge (*Perdix perdix*)	OT	4	1
Coot (*Fulica americana*)	OA	6	2
Ring-billed Gull (*Larus delawarensis*)	CT	1	<1
Common Tern (*Sterna hirundo*)	CA	1	<1
Golden Eagle (Nestling)	NA	1(1)	<1
Burrowing Owl (*Athene cunicularia*)	CT	1	<1
Black-billed Magpie (*Pica pica*)	OT	4(2)	1
American Crow (*Corvus brachyrhynchos*)	OT	4	1
Western Meadowlark (*Sturnella neglecta*)	CT	1	<1
		Subtotal 147	43
REPTILES			
Gopher Snake (*Pituophis catenifer*)	CT	1	<1
		Subtotal 1	<1
FISHES			
Whitefish (*Coregonus clupeaformis*)	CA	2	1
Cisco (*Coregonus artedi*)	CA	1	<1
Shorthead Redhorse (*Moxostoma macrolepidotum*)	OA	1	<1
Sucker (*Catostomus* spp.)	OA	3	1
Burbot (*Lota lota*)	CA	1	<1
Goldeye (*Hiodon alosoides*)	CA	1	<1
Walleye or Sauger (*Sander* sp.)	CA	1	<1
Perch (*Perca flavescens*)	CA	1	<1
Fish spp.		4	1
		Subtotal 15	4

changes, possibly cycles, and a significant decline overall.

Water bird prevalence in nests changed from a moderate level in the late 1960s, declined in the 1970s and 1980s, and then returned to a high level in the 1990s (Figure 5). Mallards were the most common waterfowl at 15 per cent. Mallards per visit was weakly correlated with aerial counts of breeding Mallards throughout the North America-wide central flyway ($r_s = 0.262$, $P = 0.074$.)[63] These results indicate that even in the arid margin the central flyway's waterfowl breeding region, Mallards increased along with a large regional increase. The eagles were able to respond to this increase in keeping with their flexible and opportunistic nature as predators. Eagles are sometimes observed near waterbodies where waterfowl congregate in fall and winter (JKS pers. obs.) when waterfowl may represent an important food source.

Richardson's Ground Squirrel prey exhibited a peak 1979-1990, returning to near pre-1979 levels thereafter (Figure 5). This rise in ground squirrel prey coincided with a similar 1975-1988 peak based on burrow counts on the Hanna study area, and throughout southeastern Alberta between 1982 and 1987 judging from on poison use.[64] Furthermore, the numbers of ground squirrels in nests of Ferruginous Hawks, was positively correlated between the Hanna, Alberta, and southwestern Saskatchewan study areas from 1983-2006.[60]

Changes in food availability

The 1979-1990 regional peak in Richardson's Ground Squirrels was linked in timing to the El-Niño-related North American drought.[65] Ground squirrels favour grassland vegetation that is short and sparse, including overgrazed areas. Squirrels increased after a loss of the tall desert-shrub cover.[60,66-68] It is not clear whether the apparent preference for short rangeland vegetation operates by affecting crypticity and predator avoidance, the higher nitrogen content of new grass shoots in continuously grazed range; or insulation, soil temperature and energy demand during hibernation.[69,70]

Taken together, these studies suggest that while local conditions can affect ground squirrel abundance, regional climate can also be a factor. Climate change could affect this hibernating species which contributes to soil aeration, provides burrows for other animals to use, influences range condition via complementary grazing and is prey to a host of other prairie animals.

Jackrabbit prey declined, as indicated by the trendline, from 0.9 to 0.4 jackrabbits per visit (Figure 5). This decline in jackrabbits was mirrored near Hanna, Alberta, also in the Mixed Grassland Ecoregion 200 km WNW of CSH's study area. In 28 years of the Hanna study, from 1975-2012, 55 jackrabbits were found in 3,952 visits to nests of Ferruginous and Swainson's Hawks. As with eagles, the number of jackrabbits per visit declined (Spearman rho = -0.415, P = 0.034). Similarly, night-light transects in 1975-1977 yielded 7.3, 35.2 and 56.3 jackrabbits/100 km. Night-lighting was abandoned in the 1980s as jackrabbits became scarce in nests and sightings in the field.

The correspondence between prey use by the eagles (Figure 5) and various other measures of prey abundances provide a level of independent verification that the eagles responded to actual changes on the land. These other measures include: i) regional waterfowl counts; ii) direct (burrow counts) and indirect measures (poison use) of ground squirrel abundance, iii) a similarity in the pattern between the eagle's prey use (ground squirrels and jackrabbits) and that of Ferruginous Hawks in Alberta, iv) the timing of a periodic drought, and v) historic and regional evidence of changes from the literature (jackrabbits). Combined, these lines of evidence suggest that the changes in eagle prey reflect the respective changes in prey availability in the ecoregion.

Golden Eagles in other regions also took a variety of prey.[33,42] Our results differ from Kochert et al.[42] who report 80-90 per cent mammalian prey in 24 studies. In southwestern Saskatchewan mammals comprised only 52 per cent when birds were preyed upon at 43 per cent. In the western United States, the authors concluded that the use of >20 per cent waterfowl was an indication of a shortage of the eagles' main leporid prey.

A series of events, attributed to a warming climate and invasive species, led to declines in reproduction by the eagles.[66] Increased frequency and extent of wildfires reduced the rabbits' (*Lepus californicus, Sylvilagus nuttallii*) desert-shrub habitat, leading to a greater use of waterfowl prey and reduced reproductive success. Nestling mortality was most severe when Rock Pigeons (*Columba livia*) were frequent, which

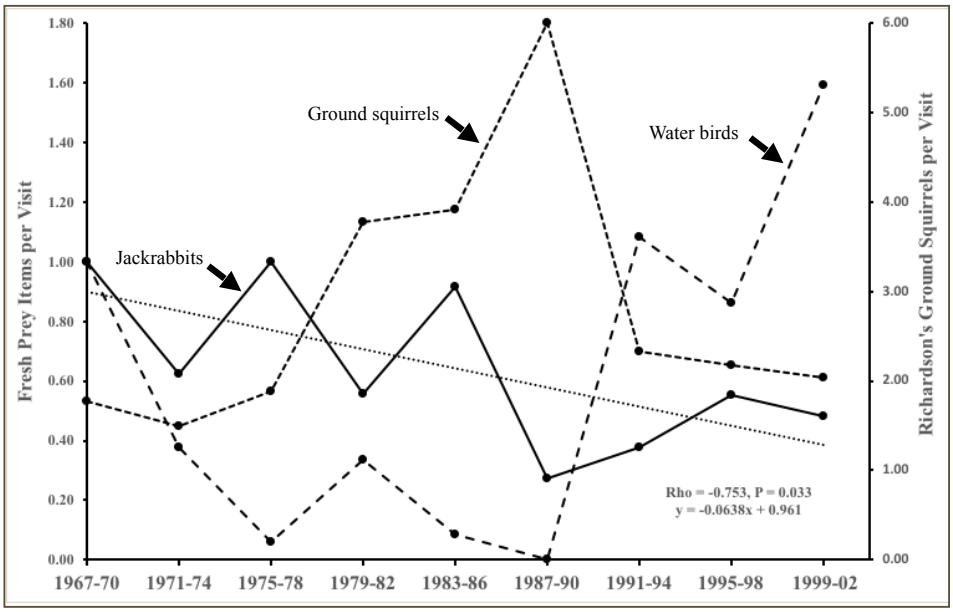

FIGURE 5. Changes in three prey groups taken by Golden Eagles along the South Saskatchewan River. Prey data are grouped in four-year intervals spanning a total of 35 years. The trendline captures the overall decline among rabbits and is defined by Rho.

when carrying *Trichomonas gallinae* caused nestling mortality. In a southern Great Plains study, GPS-monitored nestlings and fledglings suffered increased mortality from Mexican chicken bug (*Haematosiphon inodorus*) parasitism and the apparent expansion of the bug northward was attributed to climate change.[152]

In our study, in contrast, jackrabbit declines were gradual. The rise in water birds in 1967-70 and again 1991-2002 though substantial, was short-lived as was the rise in ground squirrels in 1979-1990. The eagles apparently responded opportunistically to these changes in prey availability and no corresponding change in reproductive success was evident.

Instead of climate-influenced fluctuations in abundance that may recur as shown by Saskatchewan waterfowl and ground squirrels, jackrabbits showed a long-term decline. This may constitute a serious conservation concern. Intermountain Black-tailed Jackrabbits (*Lepus californicus*), while exhibiting pronounced cycles unlike the modest cycles by white-tailed on the Great Plains, also showed a decline from a high in 1971, lasting to at least 1994.[71]

In the 1930s, Jackrabbits were abundant in southern Alberta where they were shot for human consumption.[49] In the 1940s and 1950s, rabbits were killed in large numbers in southern Saskatchewan. In winter, vehicles loaded with frozen rabbits were delivered as food to fur farms.[72] The apparent jackrabbit decline may present a challenge for eagle conservation.

Based on museum specimen and literature, Brown et al.[73] found evidence of White-tailed Jackrabbit declines as early as the late 1800s, and particularly widespread and continuing since the 1950s. They found little or no evidence for road kills, recreational hunting, disease and parasites as universal, range-wide causes of the decline or extirpation. Instead, they concluded that habitat alterations and climate change were major factors. Rabbit control programs and increased predator populations exerted only a regional or periodic influence. A risk for White-tailed Jackrabbits arises from loss of camouflage and increased predation in areas with reduced snow cover.[74] While jackrabbits in the northern portion of their range including Canada are less likely to be affected by reduced winter camouflage, this could impact our migrant eagles during winter.

While jackrabbits have suffered from diseases, its influence has been local or regional.[73] For example, a new variant of rabbit hemorrhagic disease virus Type 2 appears to affect all leporids with outbreaks thus far west of the Rocky Mountains in California and British Columbia.[75] Currently, the only known mortalities attributed to Type 2 have been among feral European rabbits in Edmonton and Taber, Alberta.[76]

Interestingly, jackrabbits are common in suburban habitats of both Saskatoon, Saskatchewan (L. Piecowye pers. comm. 3 April 2022) and Calgary, Alberta (R. Knopff pers. comm. 23 January 2022). It is conceivable that reduced predation and/or the planting of ornamental shrubs in suburbs encourages rabbit immigration and population stability.

Two Golden Eagle nestlings are in a 1985 nest in Alberta's Dinosaur Provincial Park. The nest ledge is facing east and has an overhang, providing shade and minimizing heat stress. Prey remains include the rear portion of a jackrabbit and the front portion of a Richardson's Ground Squirrel. Photo credit: Josef K. Schmutz.

Food-web dynamics

Trophic pyramids can help reveal the role a consumer plays within a food web.[77] We plotted the various functional categories in the eagles' trophic pyramid, herbivore, omnivore or carnivore, showing terrestrial and aquatic separately. We compared the shape of such a pyramid with ecologically similar Ferruginous Hawks that were also studied by CSH over nearly the same period from 1969-2005 in an overlapping but also larger study area in southwestern Saskatchewan. The shapes of the two pyramids are different (Figure 6). While Ferruginous Hawks preyed on Richardson's Ground Squirrels almost exclusively, the eagles also used ground squirrels but relied more on jackrabbits. Eagles, unlike Ferruginous Hawks, took more ducks and a broad range of carnivores including fishes. Our pyramid of numbers is furthermore unusual whereby it includes herbivores that even as fawns are larger in size than most carnivores taken (e.g., weasels, fishes). The eagles' dietary flexibility is noteworthy (Table 6) and could possibly

This winter-pelage White-tailed Jackrabbit was photographed in central Alberta in 1986. The species has faced long-term declines in prairie Canada and throughout the Great Plains. This is a conservation concern for eagles and many other prairie species. Photo credit: Daniel W. Wood.

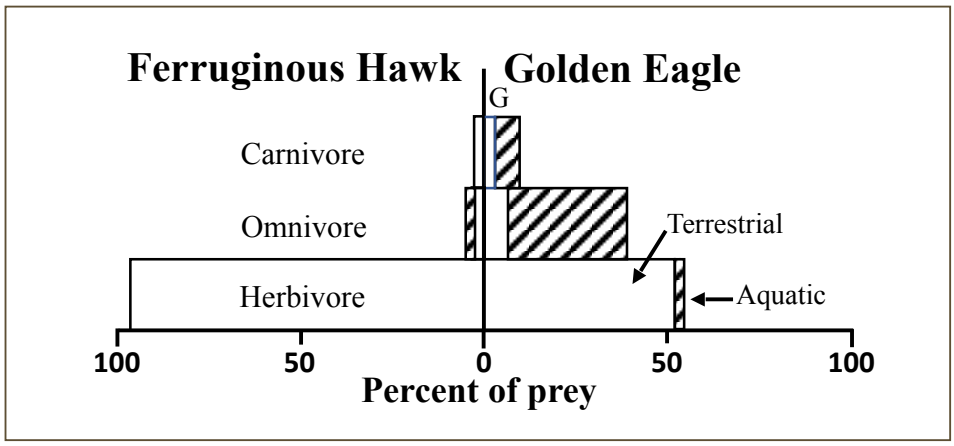

FIGURE 6. Comparison of prey recorded in nests of Ferruginous Hawks (1969-2005) and Golden Eagles. Aquatic includes fishes and waterfowl. G indicates old remains of a Great Horned Owl.

facilitate the species persistence under altered lands use, ecological and climatic conditions.

Fishes were available because the eagles' nesting area included the upstream portion of the 225 km-long Lake Diefenbaker. The lake was created via Gardiner Dam in 1959 for irrigation and hydropower, before CSH's study began. The lake includes a fish farm and is attractive also to human fishers. Water birds are available in the region despite extensive wetland drainage in the past and ongoing.[78] Water bird numbers can be high in this kettle-moraine, post-glacial landscape, especially when wet climatic periods create ecologically productive prairie ponds.

Our estimated food niche breadth[79] of southwestern Saskatchewan eagles was 5.99. This estimate was exceeded by only two species of 35 diurnal raptors studied in the Americas and Europe, the Peregrine Falcon and Cooper's Hawk (*Accipiter cooperii*).[79] Niche breadth for Golden Eagles in northern Utah was 1.89 with a more recent estimate of 3.81.[71] For the Eastern Imperial Eagle (*Aquila heliaca*) and Booted Eagle (*Hieraaetus pennatus*) of southern Spain, it was 2.08 and 3.99, respectively. Over all the 35 raptors, niche-breadths ranged 1.15-12.18.

Golden Eagle food webs would show a remarkable diversity of linkages, including the ability to take prey larger than themselves, including antelope calves and deer fawns. While Golden Eagles scavenge road- or other kills, their hunting behaviour is also directed at live ungulates. An immature Golden Eagle was observed diving repeatedly into tall grass where a pronghorn calf was hidden, while the doe charged the diving eagle.[80] The calf then rose and stood close to the doe until the eagle eventually left the area.

In the Spatsizi Plateau of north-central British Columbia,[81] Tahltan and Euro-Canadian outfitting guides observed eagles taking Stone Sheep lambs (*Ovis dalli stonei) and* Mountain Goat kids (RL Collingwood pers. comm. 16 December 2020). Observations included eagles taking adult-size Mountain Goats. A guide also observed from afar an eagle striking a large Woodland Caribou (*Rangifer tarandus caribou)* calf three times in October. When RLC followed by air the small herd pursued by the eagle, the eagle struck again. The calf was able to right itself again, blood visible from the air. The caribou had crossed a mountain ridge then and disappeared from sight in forest. In an aerial conflict, over food or simply space in northern British Columbia, RLC observed from a blind a Golden Eagle strike a Bald Eagle (*Haliaeetus leucocephalus*) that was then unable to fly due to a broken wing (RL Collingwood pers. comm. 16 December 2020).

These observed predation events and others[42] coupled with many studies of food habits during the nesting period, confirm the eagles' ability to take a great variety of prey. This versatility may have contributed to the eagles' ability to maintain stable populations in prairie Canada while other raptors fluctuated or declined. This versatility may present an opportunity for conservation into the future. On a cautionary note, food habits of eagles outside of the nesting season

are vastly understudied.

A literature review confirms the existence of trophic cascades and explores "top-down" and "bottom-up" models of community organization.[82] In their natural flood-induced experiment the authors confirm top-down regulation by predators on prey, evident when prey species expanded population size many times in the absence of their predators.

Given their prowess as predators, the Golden Eagles also have the potential to affect ecological communities by a partial removal of other predators in the food web. Based on observations and band recoveries, adult eagles spend six months in the study regions, and fledglings three months. While the number of terrestrial predators as prey was small, this can be significant when magnified over a Spring to Fall. All mid-size terrestrial predators combined found by CSH (1967-2002) and DZ (2003-2018), included: nine bullsnakes, one Double-crested Cormorant (*Phalacrocorax auratus*), two Great-horned Owls (*Bubo virginianus*), two Burrowing Owls (*Athene cunicularia)*, two Common Raven (*Corvus corax*), 12 magpies, 10 crows, and three Long-Tailed Weasels, for a total of 41 predators/omnivores. There were no young coyotes or foxes in either study although both exist in the area.

Dispersion in Eastern Canada

Given that Golden Eagles are widely distributed in Canada, are there noteworthy regional differences. For 1958 to 2017, we received 164 eagle banding and recovery locations that were either banded or recovered in Canada, or both. They reflect broadly N-S movements regardless of banding region east to west. However, this continent-level pattern obscures important detail in the eagles' regional movements.

From a western-region perspective some Golden Eagles "leap-frog," where northern, Alaskan eagles fly over and farther south than southern eagles. Of 11 eagles banded in Alaska, the recoveries were: Yukon (1), British Columbia (3), Alberta (2) and Mexico (3). Of 98 eagles banded in Canada, 79 where recovered in Canada, 19 in the contiguous United States and none in Mexico. Of 57 eagles banded in the contiguous United States, 39 were recovered in Canada and 18 in Mexico. This contiguous United States sample had mixed origins with 70 per cent livetrapped, some of which may have been raised in Alaska or northern Canada and caught in the United States on migration. GPS monitoring suggests that 24 per cent of migrants arriving in the United States originate from Alaska and 76 per cent from northern Canada.[46]

Historically, Golden Eagles bred in the northeastern United States and eastern Canada.[83]

Holroyd, for example, reported sightings of nine Golden Eagles in eastern Ontario in summer 1968.[151] Currently, Golden Eagles have been extirpated in the eastern United States, 187 breeding pairs have been documented throughout eastern Canada in 2013, and a simple extrapolation suggests a total population of eastern eagles at 1236 nesting pairs.[86] Of these, 66 per cent may nest in northern Quebec and 27 per cent in Labrador.[86]

While Golden Eagles are considered endangered in Ontario,[83] they can be remarkably common when presumed northern migrants pass migration observatories. At Hawk Cliff Hawk Watch, at Lake Erie near Port Stanley, Ontario, two hatch-year Golden Eagles had been banded in 1978 and 1990 (Figure 1). Observers recorded a total of 2,650 Golden Eagles at 0.27 eagles/hr. from September through December 2000-2022 (https://hawkcount.org/siteinfo.php?tab=inv_t&rsite=392&dyearsel=1999).

Eagle numbers differed over three periods 2000-2003, 2004-2016 and 2017-2022, with 271 (0.21/hr.), 1999 (0.30/hr.) and 380 (0.22/hr), respectively. Passing Hawk Cliff Hawk Watch may have been influenced by a geographic funnel created by Lake Ontario and Lake Huron. The substantial increase in eagles from 2004-2016 may be related to an increase in Snow Goose (*Anser caerulescens)* populations (https://www.canada.ca/en/environment-climate-change/services/migratory-game-bird-hunting/consultation-process-regulations/report-series/population-status-2021.html) nesting in the eastern Arctic and Subarctic. Although the rise in goose numbers began slightly earlier than the rise in eagle sightings, the eagle's long generation time may explain a delay in their breeding-population increase. These patterns will benefit from further analysis and confirmation.

One hatch-year Golden Eagle, banded in 1967 in northern Quebec, was re-captured at the Kittatinny Mountains Raptor Banding Station in New Jersey in October. Golden Eagles were rare but regular migrants at this station. In 1975, for example, during 794 person-hours of observations from September through November, only eight eagles were spotted (0.01 eagles/hr).[84]

At a nearby observatory, also on the Kittatinny Ridge in the Appalachian Mountains, Raptors have been monitored for 45 years.[85] Golden Eagles were rare at 0-2 per year for a total of 22. There was no evidence of a decline over 45 years. The large concentration of migrating eagles at the Hawk Cliff Hawk Watch site compared to small numbers in the Appalachian Mountains may reflect the Great Lakes funnel, whereas Appalachian Mountain Ridges allow dispersed movements.

A recent examination of nearly 12,000 current and historic eagle sightings in eastern United States, from Minnesota eastward, suggests that migrant Golden Eagles from Canada are more common and more widely distributed than previously thought.[87] Eagles had been observed in all of the 31 States, and even within states in 61 per cent of 2,045 counties. The counties visited by eagles tended to be more rugged and contained more forest on average. This suggests that remoteness influences eagle dispersion in winter also.

In contrast to eastern Canada, Golden Eagles were very abundant in the Rocky Mountain corridor, with an annual average of 3,897 eagles counted in the Kananaskis Valley of Alberta between 1993-2005.[88] In the western United States, eagles declined significantly in five sites and increased in five. The decline began in the 1990s and included Alberta's Mount Lorette.

A great plains migration corridor

Judging from band recoveries in the nesting areas, on migration and in winter, our prairie-resident Golden Eagles remained on the Great Plains year-round. Even within the Great Plains they occupied the central grasslands selectively, reminiscent of the existence of a grassland ecotype.

Only four Golden Eagles banded in the Northern Forest (Boreal) Ecoregion of Alberta and Saskatchewan had been recovered. Only one was encountered outside of Canada, in north-central Montana, precluding a meaningful comparison of migration patterns between prairie and boreal eagles. Interestingly, none of the prairie-banded eagles were recovered in north-central Montana.

To analyze this year-round Great Plains dispersion, we used only eagles banded in Canada's Prairie-Ecozone and their recoveries. The eagles did not only avoid ecozones outside of the Great Plains, even within there was a tendency to remain near their natal areas toward and in adulthood. Of 100 recoveries, 73 were in prairie Canada and 27 east and south in the central grasslands of the United States. In prairie Canada, there were 22 eagles encountered at four years old or older. It is likely that these eagles had not yet or just begun to migrate. They were recovered on average 81 km (range = 0 - 282 km) from their natal site. In Idaho, distance moved by individuals known to be breeding was 40 km on average (7 - 65 km).[42] Given that banding in Alberta and Saskatchewan took place over 650 km east to west, 81 km suggests significant natal fidelity. Such low dispersal distances are consistent with a prairie subpopulation somewhat genetically separated from other populations.

We use two types of data to explore migration, prairie band recoveries and a single foothills GPS-monitored eagle. 'Prairie banded' includes a 650 km east-to-west region, from Balgonie east of Regina, Saskatchewan (104°W) to Lethbridge, Alberta (113°W). To maximize the recoveries, we requested the recent (2018-2023) United States recoveries from the Banding Office. This increased our United States sample from 17 to 27 recoveries. We left the Canadian banding and recovery locations in Figure 1 to include only 1958-2017.

Despite mailed questionnaires and telephone calls to the 'finder,' there are relatively few cases when band recoveries can accurately describe the date of mortality. We designate any recovery in the United States as a migrant. This leaves many Canadian recoveries undesignated even though some of these may have migrated across the whole banding region, up to 650 km. Information from the finder did provide useful insight on causes of mortality. While band recoveries serve well to ascertain geographical locations, GPS-monitoring yields accurate timing. However, attaching a harness and backpack to a wild bird is not without risks. Hence the risks entailed should match biological or conservation value of the information obtained.

Once in the United States, 21 or 87 per cent of the United States recoveries were east of 104°W, in the North Dakota to Texas portions of the Great Plains. Five recoveries were west of 104°W but these were in extreme northeastern Montana, and presumably *en route* to North Dakota. One recovery in eastern Wyoming was only 30 km west of 104°W, which we consider part of the ND-TX sample (Figure 7).

An east-then-south 'central Great Plains' migration route was shown by the 27 prairie-banded eagles recovered in the United States (Figure 7). We refer to central Great Plains, as the eagle's wintering area including North Dakota, South Dakota, Nebraska, Kansas, Oklahoma and Texas. This designation differs from the World Wildlife Fund's Central Great Plains which includes only parts of Texas, Oklahoma, Kansas and Nebraska. The scatter of our recoveries resembles a unique region and does not fit well with the polygons in either the CEC Level III Ecoregions, nor the North American Bird Conservation Regions. Our ND-TX or central Great Plains region consists of a long and narrow band primarily of grassland, whereas the western Great Plains, particularly Montana and Wyoming, is dominated by dessert-shrub communities.

We use a 'hockey-stick' metaphor to denote the dispersion of prairie-banded eagles year-round. A hockey-stick also describes the Great Plains Ecoregion, suggesting the eagles' selective occupancy of grasslands summer and winter. We note that the eagles did not fly the shortest distance to their wintering grounds in the ND-TX Great Plains. They flew an additional 200 km east and remained in southern Alberta and Saskatchewan. They then crossed extreme northeastern Montana before they moved southward into North Dakota and some as far as Texas (Figure 7). None of our eagles were recovered in central Montana. Other raptors, Ferruginous Hawks and Prairie Falcons but not Merlins (*Falco columbarius*) also used this east-then-south route.[43,89] Sandhill Cranes (*Antigone canadensis*) arriving from Alaska and Siberia also flew along 104°W when one might expect that the terrain along the nearby Rocky Mountain Front would have provided flight-energy savings.[90,91]

We examined the extreme northeastern Montana recoveries (Figure 7) in greater detail to explore the eagles' east route before heading south, as opposed to straight-line travel from Alberta and Saskatchewan. We first calculated the geographic centres for the banding locations each in Alberta and Saskatchewan. We then plotted straight lines from these banding centres to the calculated ND-TX Great Plains centre which lay in northern Nebraska (Table 7). If the straight lines accurately described flights taken across Montana, then 50 per cent of the Montana recoveries should lie above and 50 per cent below these lines.

Five of the six presumed migration recoveries were above the line connecting the Alberta banding centre with the Nebraska winter centre. This small sample suggests that migrants from Alberta did not fly in the straightest straight line to their wintering grounds ($P < 0.05$) but first east and only then south. The Saskatchewan banding centre was closer to the wintering grounds east

of 104°W. The Saskatchewan results of three recoveries above and three below a straight line (Table 7) suggests that Saskatchewan eagles flew in a direct southeast line to the wintering grounds by simply crossing northeastern Montana to the Dakotas and southward.

Eight eagles reported as freshly killed during the winter months of November through February corroborate the ND-TX Great Plains region as a winter destination for our prairie-banded eagles. Recoveries were in Montana, (1), North Dakota (2), South Dakota (3), Kansas (1) and Texas (1). The mode of this small sample, South Dakota was close to the calculated geographic winter centre in northern Nebraska (Table 7).

Part of CSH's eagle-related correspondences included a Google Earth scan of a GPS-monitored nestling that corroborates near perfectly our prairie-banded results. The eagle was banded in Alberta's Dinosaur Provincial Park north of the banding geometric centre (Table 7) on an unknown date. It stayed in the banding region but also, similar to our Lundbreck eagle, took one lengthy excursion, this one into northeastern Montana instead, and then back to Alberta. The eagle survived at least one winter when it flew across northeastern Montana at a position that placed it north of the line from the Alberta to Nebraska geographic centre (Table 7). The eagle stayed in southwest South Dakota, southeast of the Black Hills. Most of its relocations were in a 30-km diameter area approximately 100 km northeast of the Nebraska recoveries centre. It returned to Alberta and on its second travel to North Dakota, presumably the following year, the transmission ended in northwestern North Dakota.

Why would Alberta- and also some Saskatchewan-banded eagles fly the extra distance to reach the ND-TX Great Plains east of 104°W? It suggests that the grasslands and croplands are somehow important to eagles, and by extension important for the conservation of eagles breeding in Canada. The Montana and Wyoming plains, in contrast, are at higher elevation than North Dakota to Texas. It is conceivable that the lower

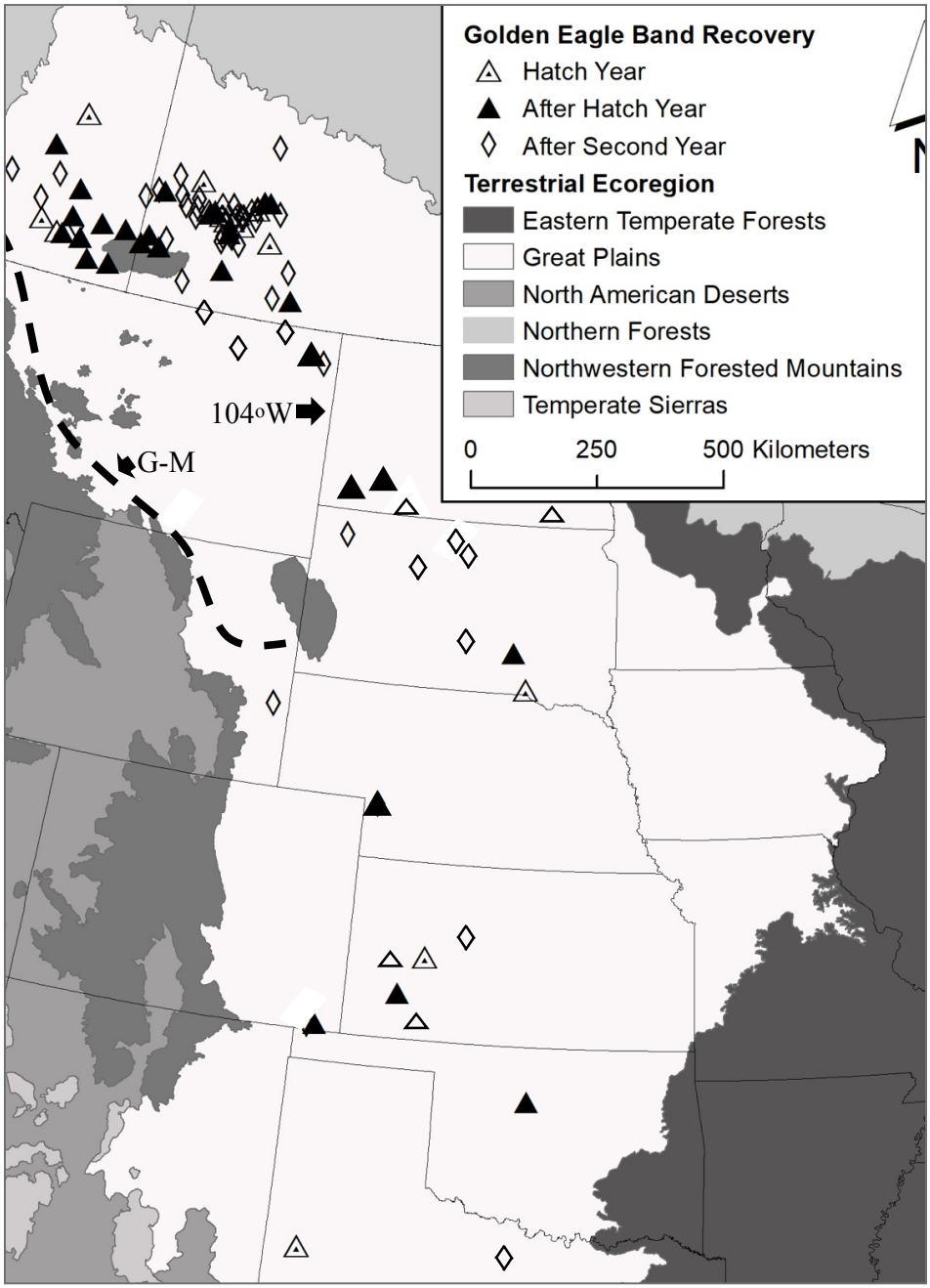

FIGURE 7. Movements of young and adult Golden Eagles based on band recoveries within the North American Great Plains. Data for Canada ranged from 1958-2017, and for the United States 1958-2022. G-M identifies the southward and near-identical northward migration of a satellite-monitored eagle (Figure 8).

TABLE 7. Geographic centres for Golden Eagles banded in southern Alberta (n =231) and southern Saskatchewan (n = 399). The geographic centre of all band recoveries (n = 27) from the United States is in Nebraska. "Above" refers to the proportion of six migration recoveries that were north of the shortest line connecting the banding to recovery geographic centres. P is the random probability in a binomial test.[150]

REGION	LATITUDE	LONGITUDE	TOWN	ABOVE	P
Banding					
S. Alberta	50.32	111.82	Tilley	5/6	0.984
S. Saskatchewan	50.68	107.85	Kyle	3/6	0.656
Recovery					
Central Great Plains	42.72	101.80	Merriman, NE		

elevations may be more favourable for migrants, possibly including cranes, via milder temperatures, wind conditions, prey or other possible factors. Milder temperatures could mean that prairie dogs (see Winter Dispersion) are above ground and available to raptors both later and earlier in the year compared to the higher elevation desert-shrub habitats in Montana and Wyoming.

If a Wyoming Golden Eagle study provides a valid comparison for our postulated lower ND-TX elevation and climate advantage, an eagle-distribution model yielded only 9.4 per cent of predicted contribution for climate and weather.[92] This Wyoming study included data on all available residents and migrants, on all age classes as did ours, but a different mix of characteristics that may pertain only to higher elevation landscapes. Another ND-TX migration advantage maybe reduced competition with year-round residents or migrants wintering in Montana and Wyoming.[14]

In stark contrast to prairie-banded eagles, the GPS-monitored eagle from the foothills near Lundbreck at 114.0°W, moved southeasterly along the Great Plains and Forested Mountain ecotone. There was an 80 km separation between the most westerly prairie-banded eagles near Lethbridge, and the eagle raised in the fescue grasslands of Alberta's foothills. Lundbreck is the most westerly banding location in Figure 1.

In addition to the Lundbreck fledgling, the eastern Rocky Mountain edge or Front is also frequented by eagles from Alaska and northern Canada, the most-used corridor in North America.[88] At the southern, wintering end of the route, the GPS-monitored eagle had stopped near the Wyoming-North Dakota boundary for the winter (Figure 8). There, it could have mixed with our ND-TX Great Plains eagles at the very western edge of their prairie corridor (Figure 7).

A question then is, are prairie-resident eagles spatially and reproductively separate from foothills- and mountain-resident eagles? Furthermore, is the postulated difference merely a difference in their use of geographical space, or does it go deeper to reflect ecological differentiation and population subdivision? This postulated subdivision between prairie and foothills has yet to be confirmed with a larger sample of Alberta-foothills-banded eagles.

A young eagle's annual dispersion

A young eagle was monitored via GPS in 2014-15 and provides an example of Alberta foothill-origin and the Rocky Mountain Front migration route. This Lundbreck, southwest Alberta, fledgling was banded on 29 August 2014. The relocations in late August and September suggest that the young eagle moved little from the nesting area. We received only 34 relocations on the eagle's southward flight in 2014, and 458 in 2015.

Once migration began, the GPS-equipped eagle followed the Rocky Mountain Foothills and moved rapidly (Figures 8 and 9). This is similar to northern migrants moving along the Rocky Mountain Front with "little or no wandering." [42,51]

The GPS-monitored eagle remained over winter in a 7,800-km^2 area of the northwestern Great Plains, southwest of the Black Hills (Figures 8 and 9). Ninety percent of its winter relocations were within the Thunder Basin National Grassland in northeastern Wyoming. This semi-arid region supports recreation and ranching with a mix of federal, state and privately administered land.

Relocations were too few to rule out short excursions (Figure 9). Assuming that the eagle made no distant excursions from late December to mid-February, this winter range of 7,800 km^2 falls on the lower end of 2,200-59,000 km^2.[42] The late summer residency, the rapid southward movement and relatively sedentary winter residency suggests that the young eagle possibly followed one or more of its parents. This may be consistent with our repeated observations in southwestern Alberta of three eagles moving together apparently on migration (DP personal observation). For example, some ungulates learn migration from family or other cohort members, some juvenile birds can follow their fathers and yet others migrate independent of parents.[93-95]

The eagle's northward flight was again rapid but it stopped short of its natal area. The eagle remained in a 120 x 85 km (10,200-km^2) area both south and north of the 49th parallel, including the Blackfeet Indian Reservation in Montana and the Milk River Ridge in southwestern Alberta. This month-long residency was interrupted twice. In mid-April, the eagle moved NW over three days to its Lundbreck natal area, and then returned to the Blackfeet Indian Reservation. In late April it moved along the foothills-parkland and mixed-wood ecoregions north to near Edmonton, Alberta over five days. From the west Edmonton area, it moved southeasterly to return partly along the Red Deer River back to the Blackfeet Indian Reservation. The eagle's last relocation came on 2 May 2015 from 35 km SW of Coutts, Alberta. The fate of eagle and transmitter is unknown.

A pre-planned study used GPS-marked, migrant eagles at least five

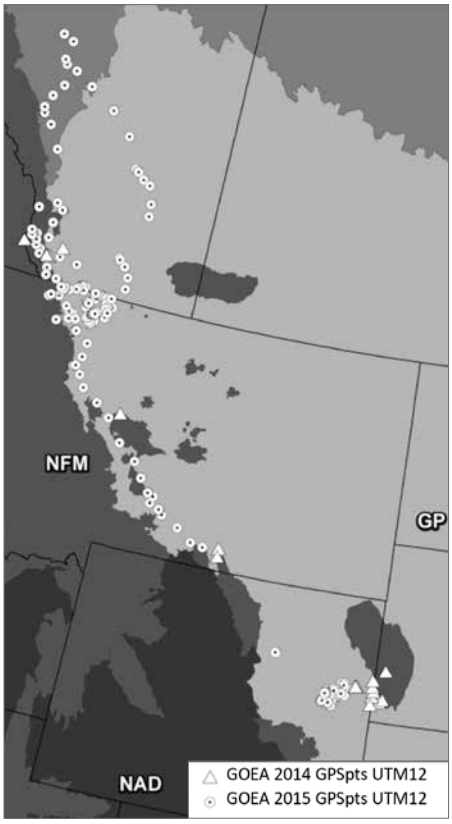

FIGURE 8. Movements by a backpack-transmitter-equipped eagle fledged in the foothills of southwestern Alberta. Relocations (triangles) were in Fall/Winter 2014, and circles in winter/early Summer 2015. GP = Great Plains, NFM = Northern Forested Mountains, NAD = North American Deserts.[26]

years-old trapped in six trapping areas in Montana (5) and Alaska (1).[51] The resulting maps of repeated GPS locations showed a concentrated band of movement, particularly in Alaska and the Yukon. Migrants began to disperse from the dense migration corridor once they reached Wyoming via the Rocky Mountain Front. Parts of this Front route were used by our Lundbreck migrant, consistent with the high migration counts reported for Mount Lorette in Alberta and Bridger Mountains in Montana.[88]

Winter dispersion

A 1986-87 road survey from Saskatoon, Saskatchewan to the Panhandle of Texas on 18-21 December 1986, along roads east or west of 104°W, yielded 68 raptors of 7 species.[96] Golden Eagles were the fourth most common raptor at 0.66 eagles/100 km, beginning in North Dakota for 1,675 km (Figure 10). On reaching northern Colorado, snow cover became scant and flocks of waterfowl were common. The first above-ground Black-tailed Prairie Dogs (*Cynomys ludovicianus*) were at a colony in southeastern Colorado. Like eagles, Rough-legged Hawks (*Buteo lagopus* 1.25/100 km) were seen in all four day-time survey segments within the United States. These results suggest that Golden Eagles, though widespread from North Dakota to north Texas, were not abundant.

Mitchell et al.[37] estimated Golden Eagle densities using a 2,805-km road survey in 2014/2015 and 2015/2016. They extrapolated their counts to a 136,800-km^2 area throughout eastern New Mexico and the panhandles of Texas and Oklahoma, where resident and migrant eagles winter.[31] Their estimated winter density for the region was 0.31/100 km^2.

Our count of raptors on 28 41-km^2 randomly selected study plots in a 25,253 km^2 area of the Texas Panhandle yielded seven Golden Eagles. Extrapolated to the total 1,148-km^2 plots-alone area yielded an eagle density of 0.61/100 km^2. Our higher than the Mitchell et al. density could reflect our smaller survey area and thus a more uniform/desirable eagle habitat, or a reduction of the population over the 30-year period between the two studies. Our Texas study was designed for Ferruginous Hawks and other raptors were recorded for comparison. The 28-plot region was chosen for the high proportion of banded Ferruginous Hawks recovered there. It is likely that Ferruginous Hawks responded to a significant concentration of prairie dogs, as the eagles may have done.

Our seven eagles were on four of 28 plots and in each case associated with prairie dog colonies. An additional eight plots held prairie dogs but no eagles. These results suggest that Golden Eagles, also were not abundant in the panhandle, where 112 Ferruginous Hawks were counted compared to seven Golden Eagles.

Our eagle band recoveries, coupled with counts from the road survey and the Texas Panhandle study plots point to a subdivision in the distribution of wintering eagles compared to the Rocky Mountain Front wintering locations (Figure 10).[51] Our prairie-resident eagles occupied primarily the central ND-TX Great Plains (east of 104°W; Figure 7), while 22 of the satellite-monitored migrants wintered westward in Montana, Wyoming, Colorado and New Mexico (west of 104°W).[51] An additional five tracked eagles wintered in Washington state, one in Arkansas, one in or near Kootenay National Park (e.g., Table 3) and two in the Peace River District of Alberta and British Columbia. These GPS-monitored eagles were all adults. Whether subadults and hatch-year migrants were equally faithful to the concentrated route of adults is unknown, although a separation in routes by age has not been shown for Golden Eagles.

Our study shows a concentrated central Great Plains dispersion including all age groups. Of the 27 eagles recovered in the USA, 78 per cent were in a corridor between 97°W and 104°W. If the five eagles possibly *en route* in extreme northeastern Montana are excluded, it was 95 per cent (Figure 7). This separation in the eagles' distribution was previously unrecognized.

The eagle population using the Rocky Mountain corridor in both Canada and the United States is much larger than the Great Plains population, given the large number of sightings on migration counts.[88] The difference in population size of the eagles may not be due to differences in local breeding densities (e.g., Figure 3) but in the lower amount of remote and suitable breeding habitat in prairie Canada (deeply incised rivers) as compared to montane western Canada or the western United States.

From a continent-wide perspective, there is also an Intermountain and Pacific Coast corridor (Table 8) in addition to the Rocky Mountain Front corridor, and our central Great Plains migration/winter corridor.[31,88] In addition to these four western corridors, there may be a corridor including Tundra and Taiga east of Hudson Bay through the inter-lakes region in southwestern Ontario and the Eastern Temperate Forest into the United States. An Atlantic coast corridor is also plausible.

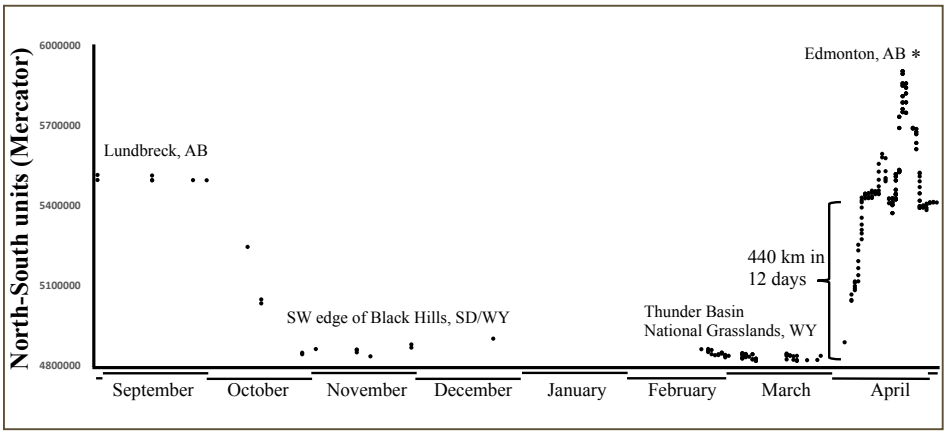

FIGURE 9. Movement by a GPS-monitored Golden Eagle fledged near Lundbreck in the foothills of southwestern Alberta in 2014.

The use of remarkably distinct N-S corridors seems to be a feature of Golden Eagles, unlike some other raptors. The intermountain- and Pacific Coast Corridors are based on migration counts,[88] the summer locations of these migrants have not been reported to our knowledge. While the separation between these corridors is evident, there is also rare interchange. For example, one of the 36 satellite-monitored winter locations, was in eastern Texas.[31]

Bedrosian et al. showed in their Rocky Mountain Front (see their Figure 1), 36 winter locations used by one or more eagles and 31 summer locations.[51] The eagles' migration corridor reached its densest use in southwest Alaska and southern Yukon, where the corridor was only 150 km wide. Metaphorically speaking, their year-round dispersion resembles the number eight, with concentrated movement between two dispersed summer and winter areas.

The term corridor, as used currently in the literature, includes both a narrow movement portion, and a winter-residency portion, i.e. the constriction in metaphorical number eight and the winter spread. Their winter spread is smaller in size than the summer area. Omitting outliers in the winter portion, at least 90 per cent of the Rocky Mountain Front eagles were distributed over a convex polygon of 1.5 million km² of mountain and shrub-steppe habitats.[51] Summer locations (n =31) were primarily in Alaska, the Yukon and Northwest Territories covering 2 million km² of Boreal Mountains and Tundra.

In comparison, our prairie-banded eagles, covered a summer polygon of 0.2 million km² and in winter 0.8 million km², four times larger than the

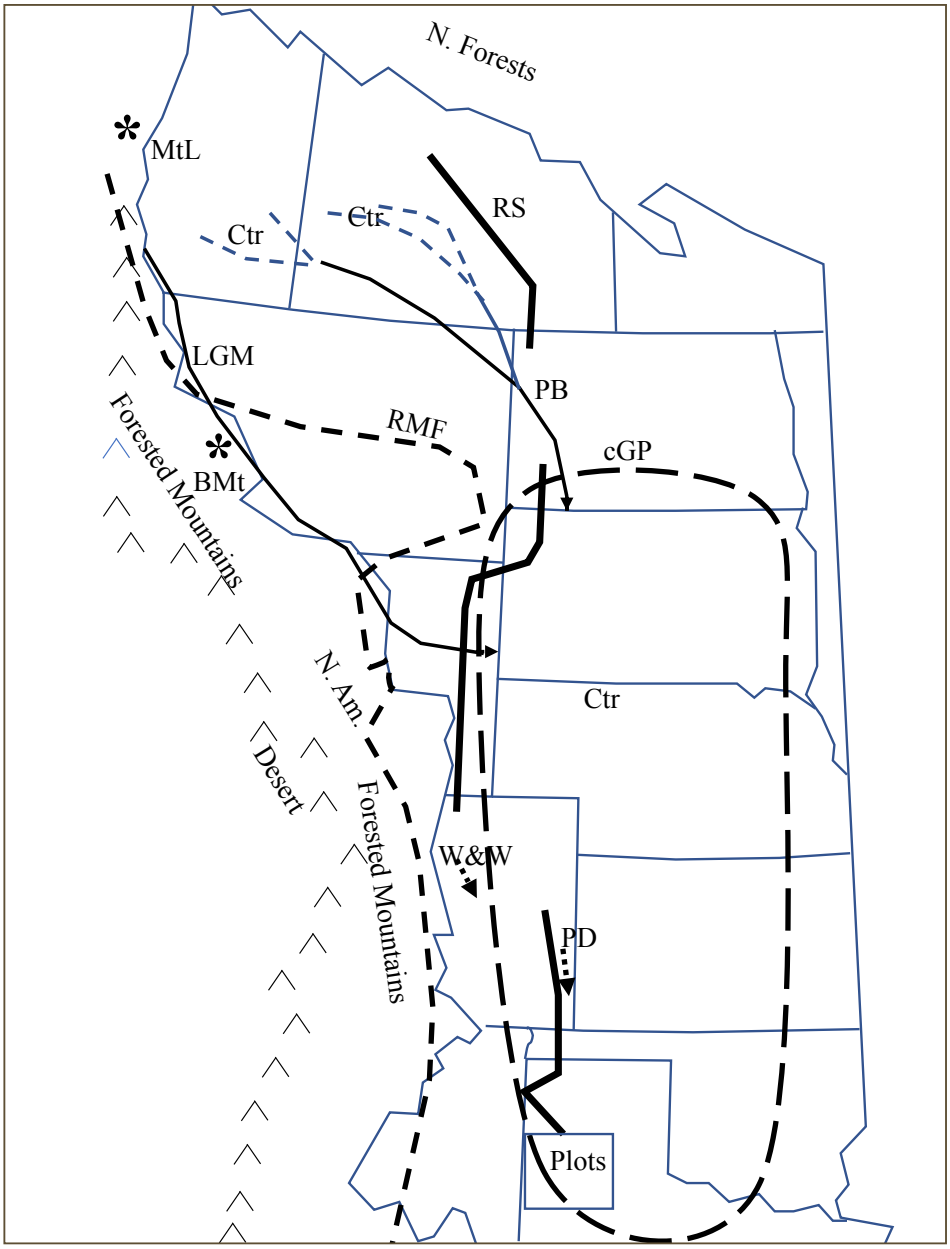

FIGURE 10. A generalized synthesis of Golden Eagle dispersion on the Great Plains and adjacent Northern Forested Mountains and North American Desert (Level II Ecoregions)[26] omitting the most easterly portion of the Temperate Sierras. PB refers to "prairie banded" and shows the migration route from Alberta and Saskatchewan to the N. Dakota – Texas central Great Plains. The dashed convex polygon includes the 21 recoveries from the central Great Plains. Ctr depicts the geographic centre of banding in Alberta and Saskatchewan, and the centre of winter recoveries in Nebraska, near the South Dakota boundary. LGM marks the route of the Lundbreck GPS-monitored eagle to its wintering area near the Black Hills. RS marks the northern of three road-survey segments from Saskatoon to the Texas panhandle (see Winter dispersion), noting the most northern extent where open water and waterfowl were detected (W&W) and where prairie dogs where above ground (PD). The survey ends at the 28 study plots (Plots) in the Texas panhandle. The dashed line marked RMF depicts the easterly boundary of the Rocky-Mountain-Front migrants[51] and the juxtaposition of this Rocky-Mountain-Front corridor from the central Great Plains corridor. MtL and BMt refer to Mt. Lorette and Bridger Mountain bird observatories.

TABLE 8. Four Golden Eagle migration corridors are recognizable in western North America.

	MIGRATION CORRIDORS			
	PACIFIC COAST	INTERMOUNTAIN	NW FORESTED MOUNTAINS & ROCKY MOUNTAIN FRONT	CENTRAL GREAT PLAINS
Winter locations	CA, OR, WA	AZ, ID, NV	WA, MT, WY, CO, NM.	ND. SD, KS, OK, TX
Summer locations			AK, YK & NWT	AB & SK
Migration/Winter counts	[1]Av./yr 4–127 [2]Av./yr. 20 2004–15	Av./yr. 26–254	Av./yr 3897 & 1463	0.66/100 linear km, 0.31 & 0.61/100km²
References	88, 149	88	51, 88	This study, 31, 96

banding area. Conversely, the mountain and shrub-steppe population's winter area was smaller, three-quarters the size of the summer area. Judging from the dispersion of prairie-banded and their winter recoveries, if there is a comparatively narrow movement corridor it may be a short corridor in southern Saskatchewan across the extreme northeastern tip of Montana and into northern North Dakota (Figure 7). An advantage of such relatively small breeding, winter and migration area is that it may be amenable for meaningful conservation.

Mortality

Based on the reports to the banding office there were seven broad mortality categories (Table 9). CSH and RWF had contacted the finder by telephone or sent a questionnaire, asking for additional detail. In 15 of 22 responses an eagle was simply unwell and could be caught. This was often attributed to an injury, but reasons could be many. For example, in five cases of mortality from 29 radio-marked eagles in Montana, two died from lead poisoning.[97]

"Found dead" was the largest category of mortality (Table 9) and may include poisoning. Follow-up to reports showed two dead eagles near a dead coyote apparently poisoned using Carbofuran in 1996. In 2000, one Golden and one Bald Eagle were found near a dead coyote where stomach analysis for the Golden Eagle confirmed Carbofuran. In 2002, a total of eight eagles lay near a coyote that apparently also had been poisoned, for a total of 12 raptors. Fluid and granular Carbofuran were banned in Canada in 1996, yet stockpiled carbofuran was still used for poisoning coyotes contrary to regulation. This illustrates the importance of an informed and compliant citizenry for conservation.[98]

In a sample of satellite-monitored eagles that were recovered and analyzed, 74 per cent of Golden Eagle deaths were associated with human activity, including shooting (30 per cent), collisions (28 per cent), electrocutions (23 per cent) and poisoning (19 per cent).[99] The authors concluded that while the overall breeding population of approximately 31,800 eagles in the contiguous United States has been stable, the current permitted take coupled with mortality may not be sustainable.

In addition to poisoning, 20 Golden Eagles were caught in traps set for furbearers. Some of these could be released again. It appears, therefore, that while the flexible food habits by eagles included scavenging to broaden a food base, it can also be a detriment. Scavenging a strychnine-poisoned ground squirrel was suspected for one dead Golden Eagle yet consumption of a strychnine-poisoned squirrels may not invariably kill an eagle.[100] Whether secondary poisoning causes death depends on the size of a meal taken and how much of the gastro-intestinal tract that contains the poison is eaten. A rare case involved a Golden Eagle that on post-mortem showed a porcupine quill in its liver, yet this quill alone may not have caused its death.

Poisoning and trap mortality, appears as a significant risk factor for Golden Eagles (Table 9).[101] Based on reports from finders, Golden Eagles have a high rate of trap mortality 20/152 = 13 per cent compared to Ferruginous Hawks 0/43,[43] and Swainson's Hawks 4/538 <1 per cent.[44]

These rare Canadian prairie dogs were above-ground in Grasslands National Park, along with a pair of Golden Eagles, on a warm and windy 29 September 2023. Prairie dogs occur throughout the eagles' Great Plains range and attract resident and migrant Golden Eagles in winter. Photo credit: Josef K. Schmutz.

TABLE 9. Known or suspected causes of mortality or injury for 152 Golden Eagles banded in Canada, as reported by the finder.

HOW OBTAINED	NO.	%	SUBCATEGORIES
Band read	7	5	Alive
Caught	22	14	After a known or suspected injury (15), cut bank collapsed during incubation (1), entanglement in barbed wire (1) or fishing gear (1), or for research (4)
Found dead	77	51	Struck tower, windmill or train (6), electrocuted (3), secondary poisoning (3), starvation (3), porcupine quill in liver (1)
Roadkill	2	1	
Shot	8	5	Shot by accident while hunting geese (1)
Struck tower or electrocuted	16	11	Suspected electrocution (7)
Trapping by-catch	20	13	Dead (14) taken into captivity (1) released (5)

Explanations for this disparity could be two-fold. Eagles, unlike Ferruginous and Swainson's hawks, live in forested regions in Canada where trapping may be more common. Alternatively, scavenging may have been a characteristic feeding strategy with adaptive origins. The large eagles are able to defend a carcass with less predation risk to themselves, and may even seek out carcasses for the opportunity to prey on smaller scavengers. Olson and Janelle point to many sources of mortalities and carcasses during the bison era on the Great Plains.[11] When available, the carcasses themselves and the medium-sized scavengers using them may have strengthened the eagles' scavenging habit.

The oldest band-reported eagle was 26 years old (Table 10), compared to 23 years in North America, 12 to 32 in Europe and 46 in captivity.[42] Fifty-nine per cent of banded eagles survived to one year of age, and 32 per cent to presumed first breeding at four years. Based on the United States sample, 70 per cent of eagles survived to one year old, and 90 per cent of adults annually.[99]

Recommendations: sustaining eagles and biodiversity

The eagles' nest success (66 per cent), brood size (1.55 for 59 years), and density (102-191 km^2/pair) suggest stability in the prairie Canada population even if small in size. Yet, it has also been questioned whether the size of the western populations is sustainable.[99] Declines among jackrabbits (see Food) should also be of concern as the eagles' characteristic food source, and, along with prairie dogs,[102] likely an important food year-round. This warrants a concern for the prairie-Canada population, especially considering widespread declines in biodiversity that may yet make themselves felt to eagles.

Raptors that share the eagles' prairie ecosystem have declined, including Burrowing Owls, Swainson's Hawks, Prairie Falcons along with Greater Sage-Grouse (*Centrocercus urophasianus*) and other grassland birds.[103-108] For North American birds overall, a net loss approaching three billion birds, or 29 per cent of 1970 abundance has been reported.[109] An analysis of risk assessment, as assigned by the Committee on the Status of Endangered Wildlife in Canada, has shown that of 369 species examined, only 5.4 per cent improved in their risk status.[110] Past successes show that at least some biodiversity decline is preventable.[111,112]

Biodiversity losses and challenges to ecological, social and economic sustainability are recognised world-wide. In the lead-up to the final agreement of the United Nations 15th Conference of the Parties, urgent calls advocated for transformative engagement in our collective response to the joint crises, biodiversity and sustainability.[19] The COP15 Working Group concluded that the Global Assessment Report of Biodiversity and Ecosystem Services 2019, and "many other scientific documents provide ample evidence that, despite ongoing efforts, biodiversity is deteriorating world-wide at rates unprecedented in human history." Addressing the biodiversity crisis may require unprecedented transformation by a fully engaged citizenry.[19]

We attempt in our analysis a measure of transformative engagement that is rooted in the eagles' ecology but goes beyond a common conservation approach to 'recommend' ecological action. We identified the core food, energy and municipal-related human impacts in the eagles' ecosystem, multiplied by planetary factors such as climate and socioeconomic inertia. We review pertinent literature below to learn from the experiences and insights of others. We have already begun to try and engage diverse stakeholders toward the sustainable actions we outline, and are finding it challenging.

For a conceptual road map, Mace[113] aimed to refocus conservation as a primarily mission-oriented discipline by aligning people's aspirations with nature's capacity. Conservation failures do happen and they can provide important learning opportunities for transformation. Science may be necessary for conservation but is not sufficient (No.19).[19] Success will require the "whole-of-government and whole-of-society" (No.10).[19] Conservation success will benefit from a new brand of conservation professionals who embrace

TABLE 10. Survival schedule for 88 Golden Eagles banded in Canada and recovered in Canada, the United States or Mexico. The age of seven eagles captured alive and released is also shown.

AGE INTERVAL	RE-CAPTURED ALIVE	NUMBER ALIVE AT BEGINNING OF INTERVAL	FRACTION SURVIVING	NUMBER DYING	FRACTION DYING
<1	2	88	1.00	36	0.41
1	1	52	0.59	10	0.11
2	2	42	0.48	9	0.10
3		33	0.38	5	0.06
4		28	0.32	7	0.08
5	1	21	0.24	4	0.05
6		17	0.19	4	0.05
7		13	0.15	1	0.01
8		12	0.14	3	0.03
9		9	0.10	2	0.02
10	1	7	0.08	2	0.02
11		5	0.06	2	0.02
12		3	0.03	0	0.00
13		3	0.03	2	0.02
					0.00
26		1	0.01	1	0.01

complexity, have transdisciplinary capacities, have an understanding of the role of traditional knowledge, a grasp of democratic principles for governance and have a concern for equity and human rights (No.14, No.22).[19]

Mace[113] describes four periods over 50 years with changing conservation approaches and varying scientific underpinnings: 1960s and 1970s, "Nature for itself" – entailed protecting species, habitats and wilderness in isolation of related contexts; 1980s and 1990s, "Nature despite people" – stressed preventing further extinction, habitat loss, pollution and over overexploitation, by attempting to limit peoples' damaging influence; 2000s, "Nature for people" – stresses adoption of ecosystem approaches, ecosystem services and economic values to be preserved for peoples' benefits; and 2010s, "People and nature" – advocates for more than mere protection by accepting unavoidable environmental change, for fostering ecological and human systems that are adaptable and resilient, and for creative socio-ecological institutions involving interdisciplinarity.[113]

Obura et al.[114] accept that pure protection may play a role but they recognize that it alone is not sufficient. The authors suggest "… locally contextualized solutions for conservation, across intact, shared, and fully altered landscapes." Both Mace[113] and Obura et al.[114] agree that contextualized resilience building is harder to achieve and to measure than simply accounting for areas or species under so-called protection.

In relation to recommendations in Table 11, many promising actions have relevance to eagles. Species-conservation efforts are at their core reliant on data and especially long-term trends. After the death of RWF, a new Government in Canada had closed departmental libraries and programs and some eagle data may have been lost[115,116] potentially influencing the conclusions we reached here. Since that time, many mechanisms for data storage have been created and these deserve to be supported to function beyond the life of a publisher, a library or government program.[117]

Habitat has been and continues to be a cornerstone in conservation. "The Global Deal for Nature" calls are for the conservation of at least 30 per cent of the Earth's surface by 2030.[118] This goal has also been embraced by COP15 (No. 31 Target 3)[19] and could be achieved in the eagles' Mixed-Grass Prairie where 40 per cent grassland remains.[25] However, provincial government priorities are not yet in line with the 30-by-30 goal as Crown-owned grasslands are "are being lost at an alarming rate."[24] Mixed-Grass Prairie in Alberta and Saskatchewan contains deeply incised river valleys and their grassland borders, land well suited for supporting eagles and the wider grassland communities. Mixed-Grass Prairie also supports a ranching economy through state-of-the-art grazing especially with fire as a management tool.[119-121]

TABLE 11. Potential conservation actions are aligned with a framework and headings provided by Mace.[113] Numbers in parentheses correspond to recommendations from the Kunming-Montreal biodiversity framework.[19]

NATURE FOR ITSELF Species	Protect eagles (e.g., Migratory Bird Treaty) with sustainable take (e.g., Indigenous ceremonial, falconry); Raise management status of jackrabbits and prairie dogs in wildlife acts, including monitoring and education; Support archiving and access to conservation-relevant data
NATURE DESPITE PEOPLE Habitat loss	Limit habitat conversion to sites and uses with high and sustainable benefits (e.g., Capability for Agriculture rating 1-3 for crop production, & 4-6 for permanent cover/grazing); Restore degraded land (e.g., Prairie Farm Rehabilitation Administration); Prevent perverse subsidies (e.g., Crop insurance on ill-suited land); Integrate Indigenous Conserved & Protected Areas
Pesticides	Use integrated pest management on an as-needed basis
Eutrophication	Minimize synthetic fertilizer use and runoff (e.g., eutrophication)
NATURE FOR PEOPLE Ecosystem approach (No.20)	Maintain functioning water cycle (e.g., minimize drainage, adapt groundwater discharge to recharge); Strive for permanent cover with native species; Strive for biodiversity (No. 2) and foster community and food-web function
Ecosystem services	Enable wild harvest (e.g., fungi, plants and animals); Address multiple factors of insect declines[125]
PEOPLE AND NATURE Environmental change	Anticipate and adapt to unavoidable change (e.g., shrub/tree encroachment, altered prairie hydrology, 1.5ºC climate change)
Resilience	Adapt land use and municipal developments to soil capability, give soil health highest priority; support sustainability-oriented and harmonious local economies and livelihoods, cooperatives and industry; Encourage complementarity in crops and their rotation, and in grazing; Learn from and adapt to failures.
Socioecological systems	Foster producer-consumer partnerships (No. 6) to enable agricultural adaptation (e.g., farm-to-fork circular food systems); Respect Indigenous and settler sustainable land uses and traditions; Enable outdoor recreation and education (No. 40) for well-being and harvesting of nature's products (No. 9); Build institutional capacity and holistic approaches to foster fair and equitable sharing of benefits from a sustainable development agenda (No. 26)

If there is a direct or opportunity cost to protecting the eagles' landscapes or to amending human uses, would incentives be required? Much conservation planning has focussed on how to provide a public good without free-riders shirking their supporting roles (e.g., biodiversity, greenhouse gases) on how to enable best practices locally (e.g., riparian zones), and how to manage resource commons.[122-124] Instead of repeated subsidies, system-based solutions have the potential to be transformative for the long term and be cost-effective.

A state of the art example of land restoration for sustainability evolved in early-1900s western Canada. Community pastures restored 10,000 km^2 of degraded grassland and improved livelihoods.[13] The commons-style Prairie Farm Rehabilitation Administration (PFRA) was created by Parliament in 1935, for summer grazing of locally owned cattle. PFRA employed professional pasture managers in collaboration with range ecologists on staff. PFRA's Community Pasture program achieved a 2.5:1 benefit-to-cost ratio.[125,126] The pasture program was discontinued via Bill-C38 of the Harper Government in 2012,[116] illustrating the need for whole-government-whole-society participation for sustainability.[19] In their analysis of risks threatening Canadian agriculture and sustainability, LaForge et al. point to the successful institutions in prairie Canada, the Wheat Board and the PFRA.[127] They suggest that such inclusive governance mechanisms be considered going forward as "communities and social networks are important elements of resilience."

The COP15 working group stresses that reversing biodiversity declines is one pillar in concert with other United Nation Sustainable Development Goals.[19] While rangeland grazing is not only possible but required for grassland biodiversity conservation, Health Canada's Food Guide recommends that red meat consumption be decreased. Fully 34 per cent of global greenhouse gas emissions arise from agricultural including transportation, packaging, waste, land use and land conversion.[128] Current red meat production practices are associated with significant greenhouse gas emissions, water withdrawal, acidification, deforestation, eutrophication and waste.[129]

Grazing on Brown and Dark Brown soils enhances biodiversity in north-temperate grasslands, and maintains soils and human livelihoods.[130,131] Rotational grazing on existing arid rangelands retains carbon in soils and provides suitably remote habitats for wildlife minimizing disturbance and other human impacts.[131]

The "backgrounding" and much of the "finishing" beef production stages can happen on range mixed with tame hay production, minimizing involvement of labour- and greenhouse-gas intensive feedlots. An environmental impact can vary 50-fold from high to low depending on specific practices in beef production.[129] The authors suggest that a dietary change holds significant promise for sustainability. Short of abandoning some diets including red meats, however, they suggest that consumers become drivers of sustainability by monitoring their own food-induced impacts and purchase directly from individual producers or producer groups that can offer the lowest-impact beef. Many farm-to-fork producer and consumer linkages exist already in prairie Canada that could be strategically 'scaled-up.'

It is noteworthy that recent calls for achieving biodiversity and sustainability goals increasingly include personal action.[132] Deep and civil-society-driven actions may be one of the pillars in transformation. Godfray writes "History suggests that change in dietary behaviors in response to interventions is slow. But social norms can and do change, and this process can be aided by coordinated efforts of civil society, health organizations and government."[133] Benton et al. join others in calling for a diet shift to include more plant-based foods.[134] While the eagles and grassland ecosystems depend on grazing, a partial or even significant shift away from beef need not be a threat to grassland communities. If a decline in beef production happens at the expense of the high input feedlot production, the grassland ecosystem and ranch livelihoods need not suffer unduly.[130] Kenyon[135] is a rancher and advocate of low impact agriculture and resilience. He suggests a virtual elimination of feedlot production and instead putting cattle "… back out on the land where they belong in order to heal the soil."[135]

A grass-based agroecosystem is one pillar in transforming agriculture, crop-based is another — conservation and resilience from the ground up. Eagles may breed primarily in the grass-based system but use both throughout their annual cycle, as does other wildlife. Regenerative agriculture can also be applied to advantage in annual crop production.[136,137] If the capacity of soils and landscapes to provide ecological goods and services is respected, smaller beneficial habitat patches are provided by conserved field edges, ponds and their borders, poorly drained areas, and slopes.[136,138]

LaForge et al. reiterate that producing "the food that sustains us is one of the most significant human undertakings."[127] So is biodiversity conservation and maintaining ecosystem functions via certification in crop and livestock production, direct producer-consumer participation and many other creative ways to advance sustainability.

The prairie-resident eagles spend approximately seven months of a year in Canada, five months in the United States and some possibly in Mexico. All of the known or suspected mortality factors (Table 9) are a threat to eagles in Canada and the United States. In addition, the World Wildlife Fund estimates that 57.4 million acres had been converted to cropland throughout the Great Plains between 2009 and 2017.[139] In a welcome and inclusive step, the Biden Administration of the United States had committed to protecting 30 per cent of land and water by 2030, as has the Canadian Government. The United States' plan is to include public and private lands in the 30 per cent, to work toward preserving biodiversity and curbing climate change, and do so with a systems perspective to create jobs and

promote environmental justice.[140]

COP15 crystalized coordinated planning world-wide. In Canada, as elsewhere, ours may be an opportune time to re-focus conservation to include the broad forces in the human enterprise that influence the biosphere, ecosystems, landscapes and species. Rarely has the global community examined so seriously the inclusive sustainability elements from cityscapes[141] to landscapes. Crisis can be fruitful in re-focussing practices in a fundamental way. Eagles have inspired humans throughout history and they can help inspire the conservation community in a new path forward.

Conservation implications

We have provided a comprehensive overview of the state of Golden Eagles in Canada, including, we believe, much of the available information on eagles with wide-ranging and pertinent context. We present this in one place for the reader. One of several next steps might be to examine specific elements of our story in greater detail. For example, how does the survival of eagles in the central Great Plains population compare to eagles within other western corridors? What is the role of eagles, as top predators, in shaping or even stabilizing the wildlife community of which they are a part? What are possible future impacts of an altered climate on water-bird prey in an already water stressed ecosystem? How vulnerable are ground squirrels as hibernators to climate change? How is one to understand the long-term declines in rural populations of jackrabbits?

Our conservation recommendations focus primarily on a prairie agroecosystem under stress where we followed the advice to seek locally contextualize solutions (Table 11). Golden Eagles in other parts of Canada will require a different set of conservation considerations, that respond to their respective local contexts. Despite serious historic failures in our relationship with the prairie ecosystem, recent advances in sustainability and an improved human quality of life deserve to be applauded.[72] Yet, new sustainability challenges have also become more complex as they span disciplines, production systems and governance from local to global levels. Implications are that solutions may need to transform to keep pace with these new challenges.

A promising sign is the increasing formation of strategic and cooperative partnerships broad in scope. Examples include the Prairie Farm Rehabilitation Administration in prairie Canada, which, while cancelled, now serves as a model for renewal as a Canadian Farm Resilience Agency proposed by the National Farmers Union of Canada. Other promising visions include the United Nations' call for 30 per cent of habitat protected by 2030. Perhaps most promising of all is a level of engagement by the public confronting tough questions in the popular media. These approaches deserve to be scaled up for the improved health of eagles and the ecosystem they call home.

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C. Stuart Houston inspects a young Golden Eagle at an abandoned farm shelterbelt in the steeply undulating and sparsely populated Beechy Hills Mixed Grass Prairie. Dan Zazelenchuk is supporting the ladder below. Houston recorded the second year of reproductive failure in 2002 after part of the nest slumped away and the pair of eagles was still present, following 16 years of consecutive reproductive success. Photo credit: David G. Miller.

C. Stuart Houston banding two young Golden Eagles in 1992, on a steep cliff along the eastern part of Diefenbaker Lake. Sportfishing boats in background. Photo credit: David G. Miller.

C. Stuart Houston banding a young Golden Eagle in 1992 at a nest on the relatively shallow South Saskatchewan River slopes, well upstream of Diefenbaker Lake. Photo credit: David G. Miller.

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